Technical University of Denmark

Aeroelastic modelling of vertical axis wind turbines

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Aeroelastic modelling of vertical axis wind turbines

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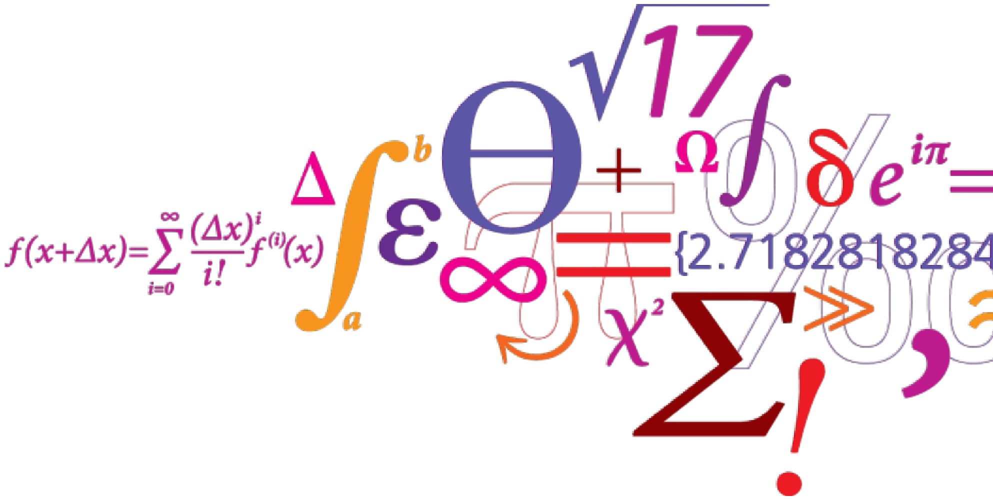


Renewed interest in Vertical Axis Wind Turbines - Most floating MW concepts

Credits Image by Grimshaw & Wind Power Ltd

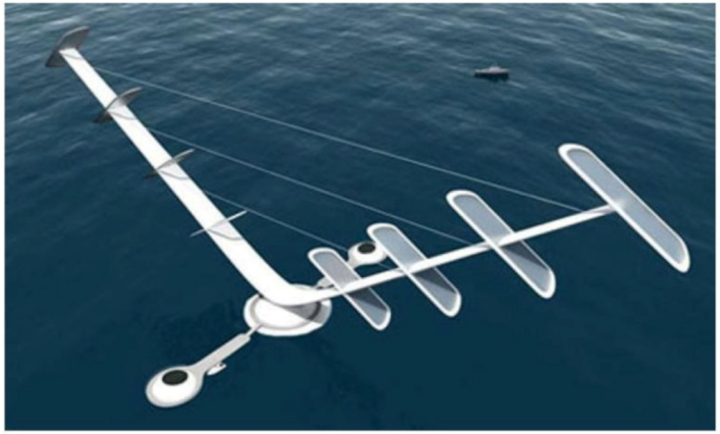
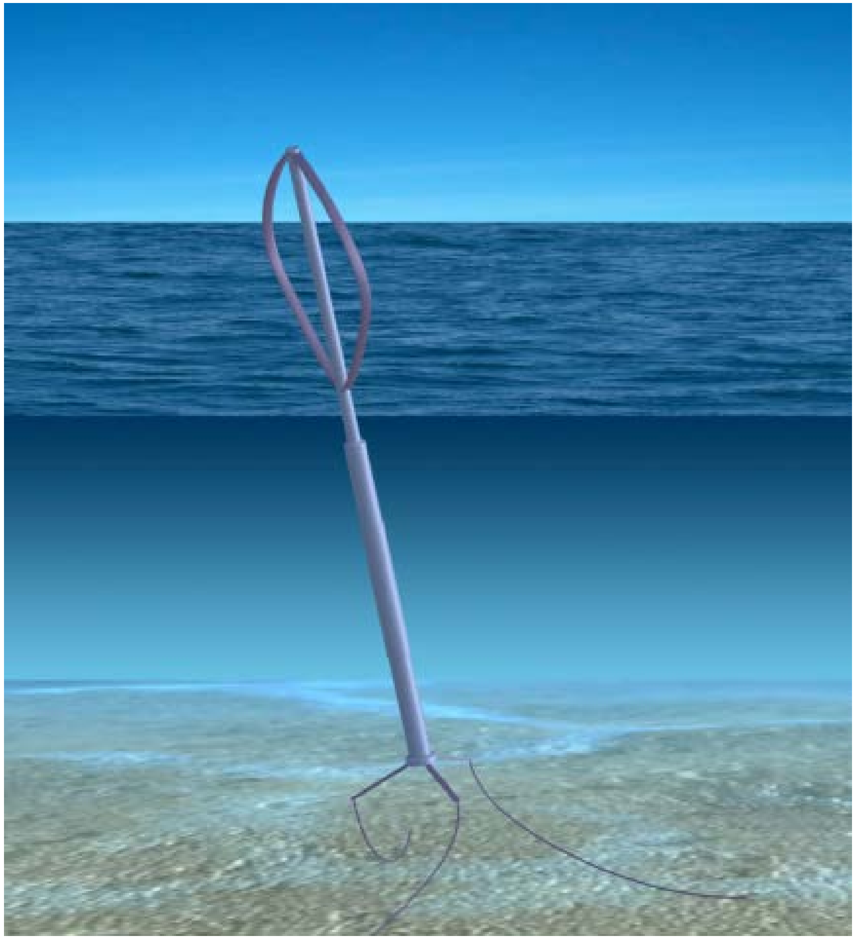


Figure 30. Offshore vertical Aerogenerator concept. Photo: Grimshaw Architects.

DeepWind 5MW design



Small on-shore Vertical Axis Wind Turbines

Windpower tree

http://www.windpower
tree.com/products.htm
l

Quiet revolution

http://windpowerdirectory.net/manufacturers/vaw
t/quiet-revolution-s14.html

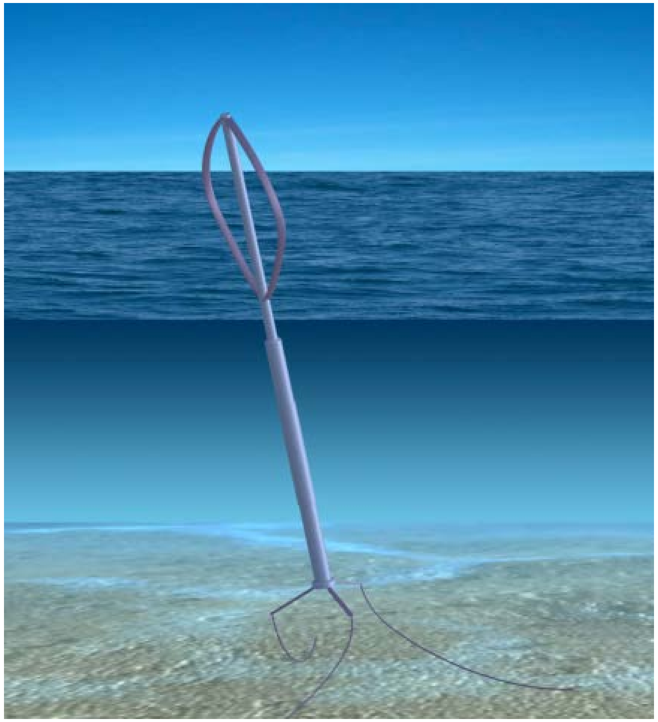
http://windpowerdirectory.net/manu
facturers/vawt/wepower-creating-
and-delivering-clean-energy-
solutions-s41.html

Accurate aerodynamic and aeroelastic design tools are necessary for the design studies of new VAWT concepts

Aeroelastic code HAWC2

– **H**orizontal **A**xis **W**ind Turbine **C**ode

?



HAWC2 – developed from 2003-2006 at DTU Wind (former Risø)

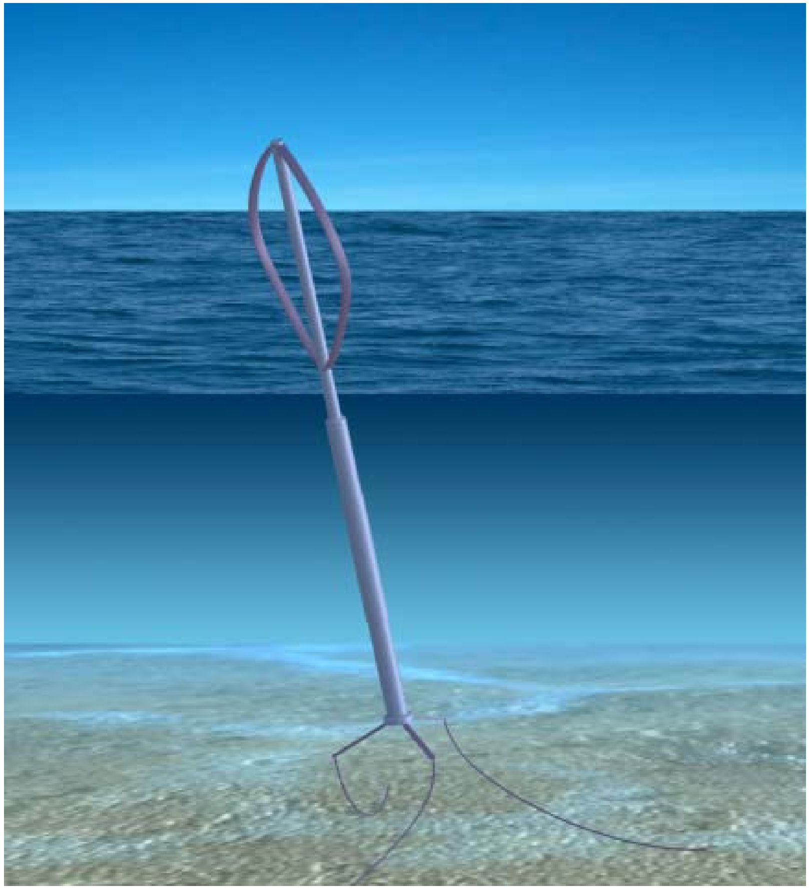
HAWC2

- ❑ Structural core based on a multibody formulation
- ❑Joints modeled by geometric constraints

Use for VAWT´s ?

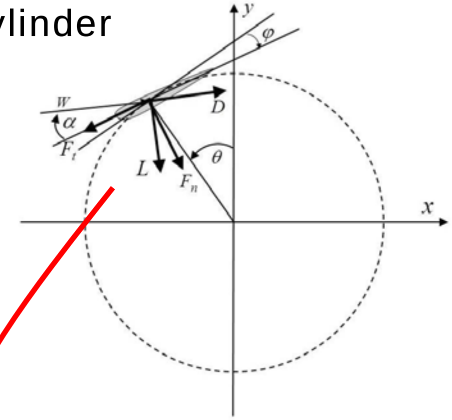
- ➢ **Arbitrary geometry** √
- ➢ **Hydrodynamic loads** √
- ➢ **Wave loads** √
- ➢ **Mooring lines** √
- ➢ **Turbulent inflow model** √
- ➢ **Aerodynamic blade loads** √
- ➢ **Dynamic stall** √

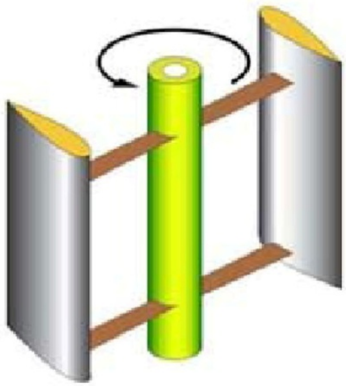
- ➢ **BEM induction model** ÷
- ➢ **Magnus forces on floater** ÷



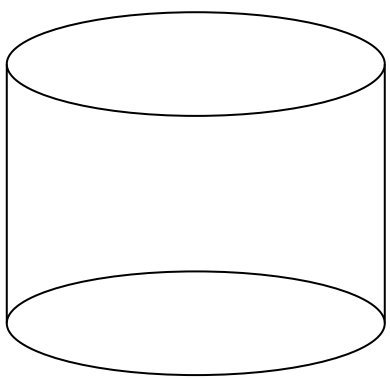
Induction model implemented
The Actuator Cylinder (AC) flow model

- an extension of the **actuator disc AD** concept to an actuator cylinder

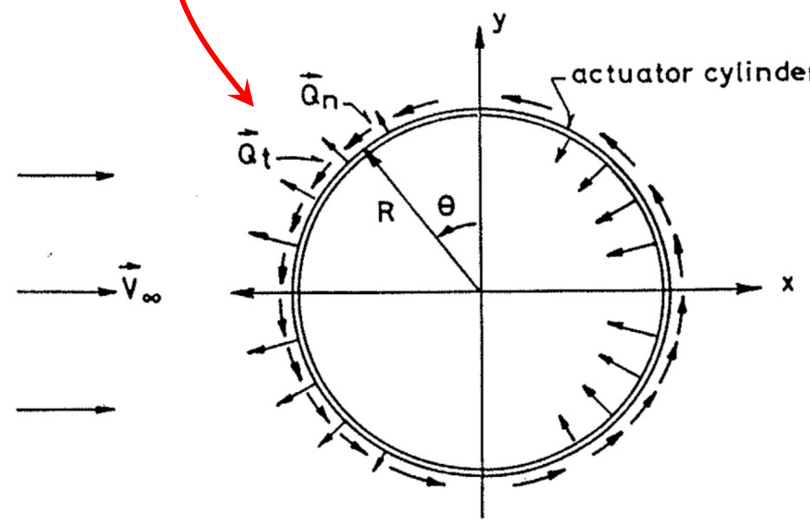




Swept surface a cylinder



Blade forces distributed on the cylinder surface



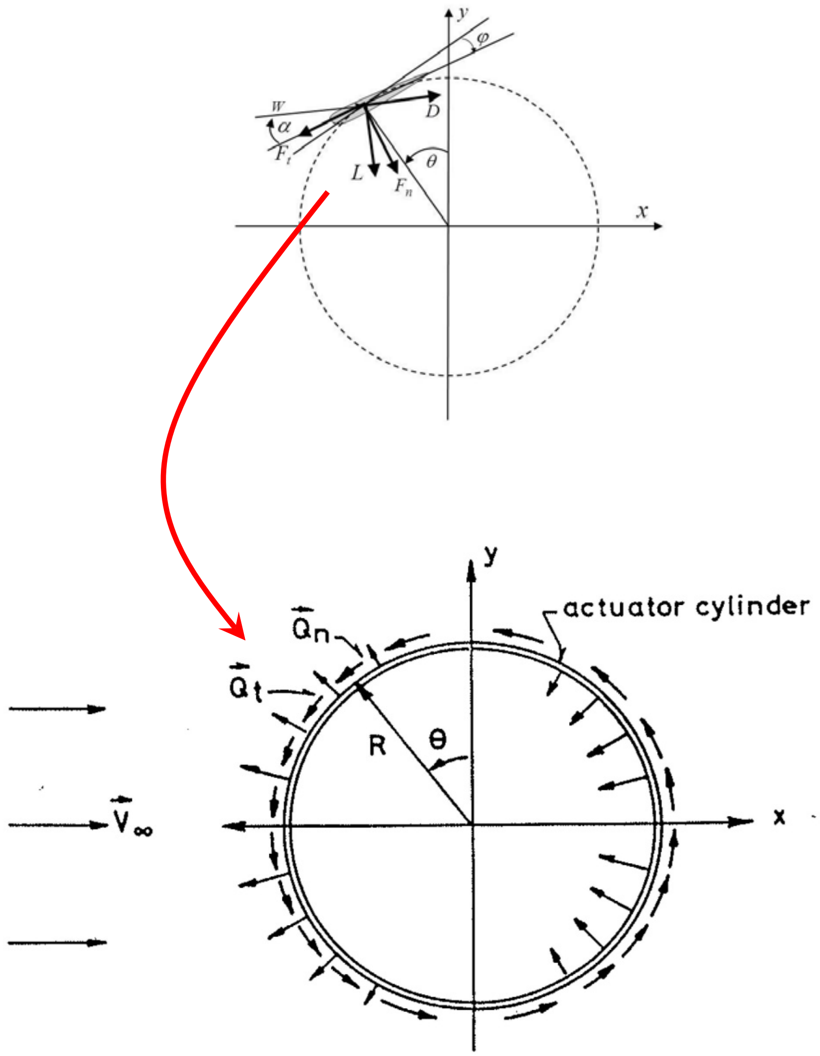
The AC flow model – the loading

Blade forces distributed on the cylinder surface:

$$Q_n(\theta) = B \frac{F_n(\theta)\cos(\varphi) - F_t(\theta)\sin(\varphi)}{2\pi R \rho V_\infty^2}$$

$$Q_t(\theta) = -B \frac{F_t(\theta)\cos(\varphi) + F_n(\varphi)\cos(\varphi)}{2\pi R \rho V_\infty^2}$$

Where $F_n(\theta)$ and $F_t(\theta)$ are the projections of the lift and drag blade forces on a direction normal to chord and tangential to the chord

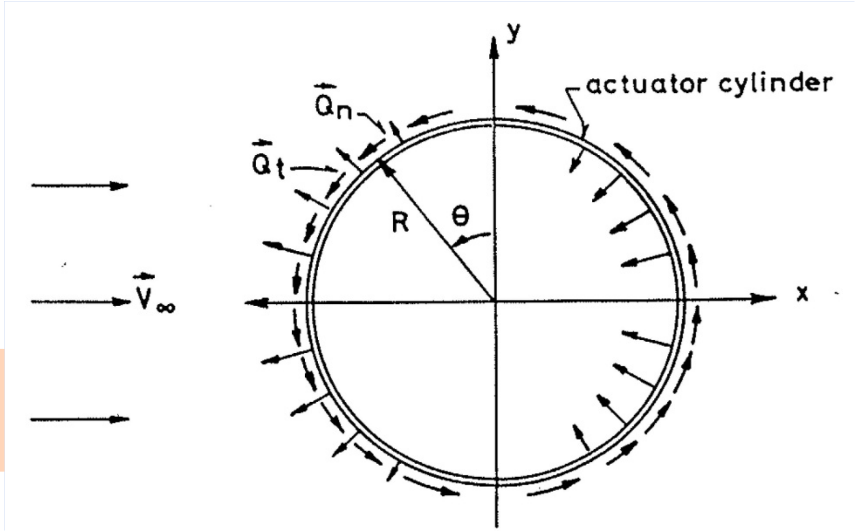


How to compute the flow field for the AC model ?

1) a standard CFD code can be used:

$$Q_n(\theta) = \int_{-\Delta s}^{\Delta s} f_n(\theta)dr$$

$$Q_t(\theta) = \int_{-\Delta s}^{\Delta s} f_t(\theta)dr$$



2) a solution procedure with potentials for low computational demands:

Approach: solution is split into a linear and a non-linear part

Velocity components are written as:

$$v_x = 1 + w_x \quad and \quad v_y = w_y$$

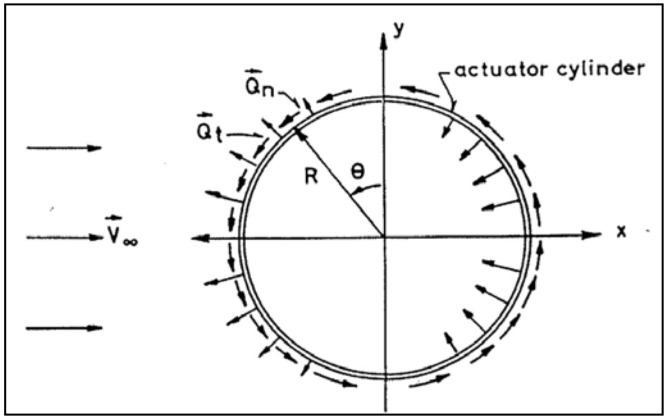
Equations non-dimensionalized with: V_∞, ρ, R

The Linear solution

Assuming the loading is constant within an interval $\Delta\theta$

$$w_x(j) = \frac{1}{2\pi}\sum_{i=1}^{i=N} Q_{n,i}\, R_{w_x}(i,j) - Q^*_{n,j} + Q^*_{n,(N-j)}$$

$$w_y(j) = \frac{1}{2\pi}\sum_{i=1}^{i=N} Q_{n,i}\, R_{w_y}(i,j)$$



The influence coefficients can be computed once for all:

$$R_{w_x}(i,j) = \int_{\theta_i - ½\Delta\theta}^{\theta_i + ½\Delta\theta} \frac{-(x(j)+\sin(\theta))\sin(\theta) + (y(j)-\cos(\theta))\cos(\theta)}{(x(j)+\sin(\theta))^2 + (y(j)-\cos(\theta))^2}\, d\theta$$

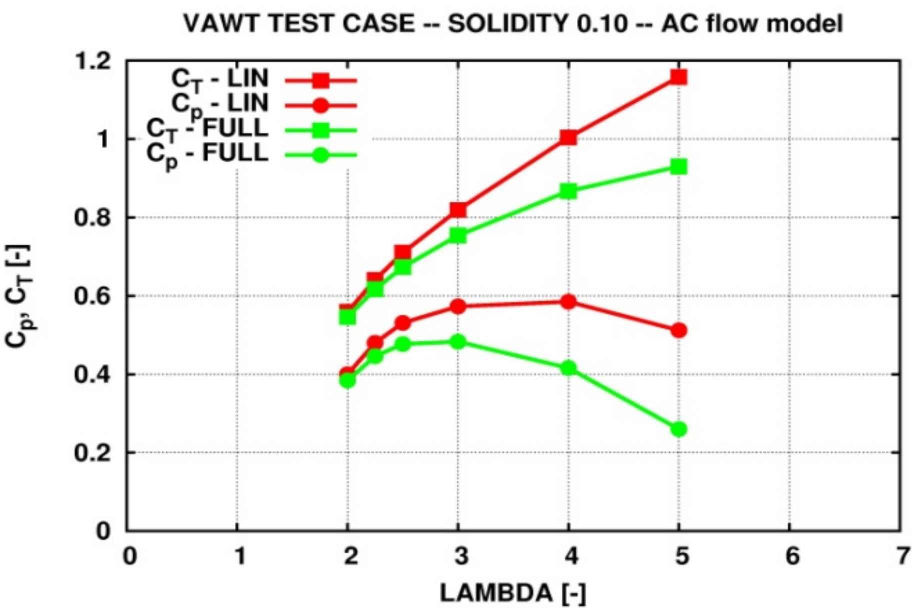
$$R_{w_y}(i,j) = \int_{\theta_i - ½\Delta\theta}^{\theta_i + ½\Delta\theta} \frac{-(x(j)+\sin(\theta))\cos(\theta) - (y(j)-\cos(\theta))\sin(\theta)}{(x(j)+\sin(\theta))^2 + (y(j)-\cos(\theta))^2}\, d\theta$$

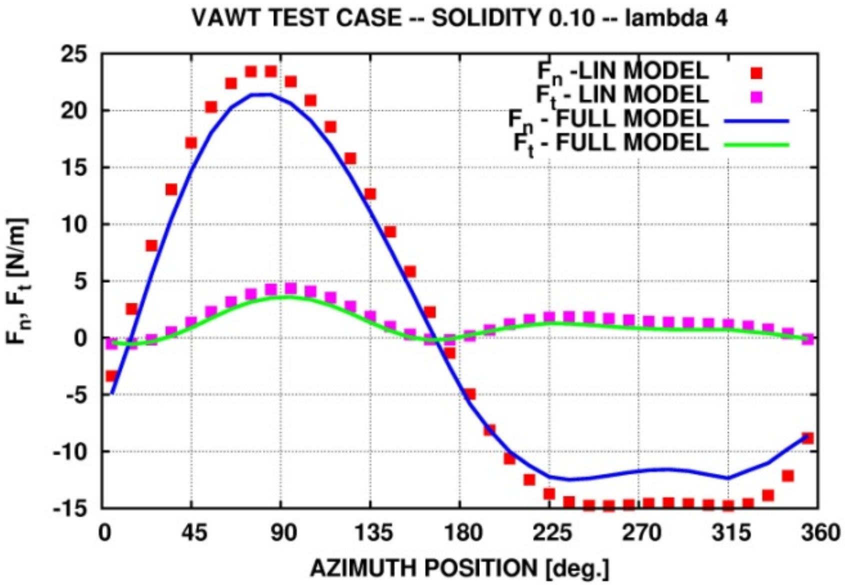
$$x(j) = -\cos(j\Delta\varphi - ½\Delta\varphi) \qquad j = 1,2.....36$$

$$y(j) = \sin(j\Delta\varphi - ½\Delta\varphi) \qquad j = 1,2........36$$

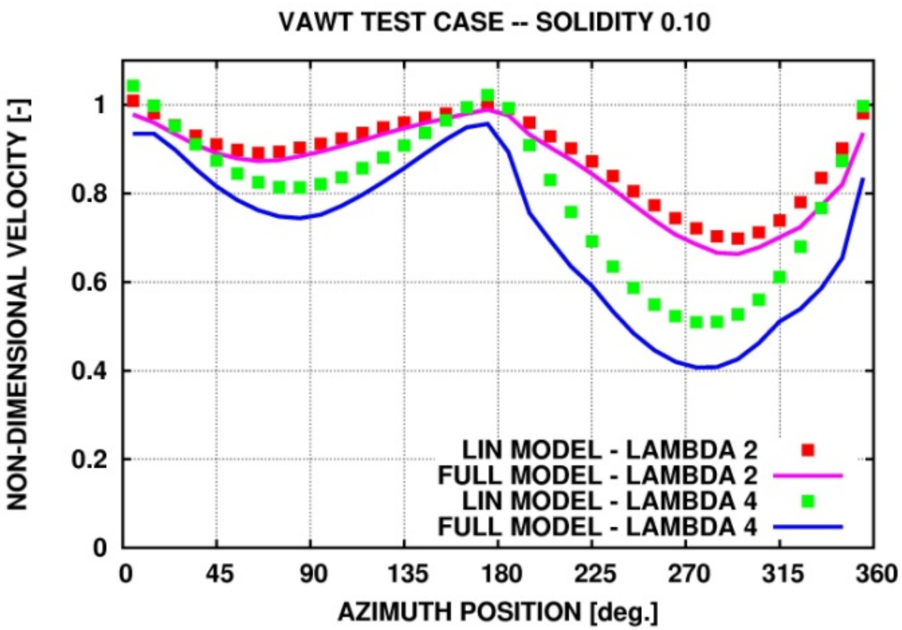
Results

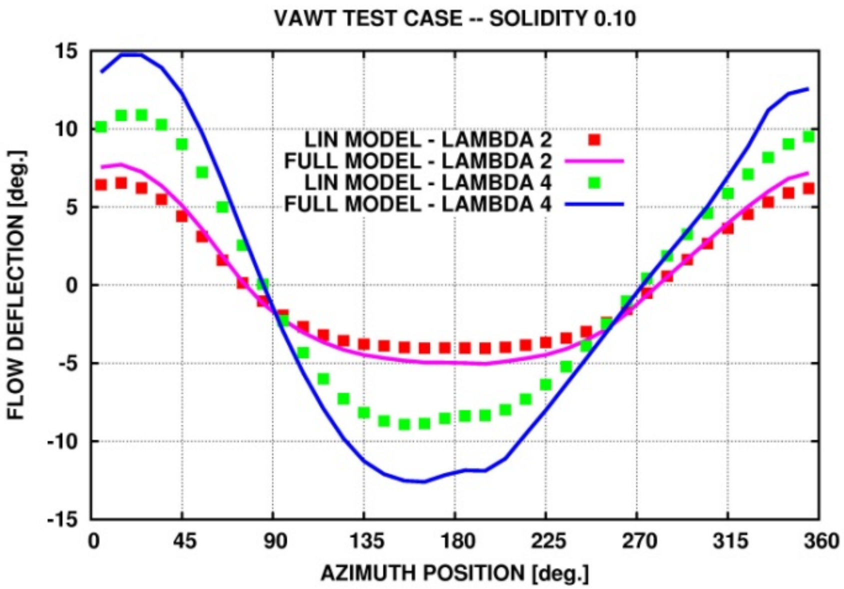
Solidity $\sigma = \frac{Bc}{2R}$

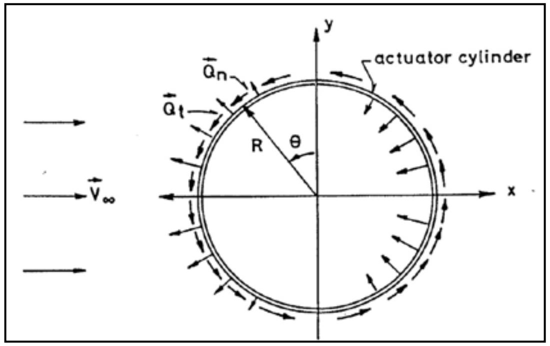




Results – flow







A modified linear AC model

The same method of solution (linear and non-linear part) is used **for the 2D actuator disc**:

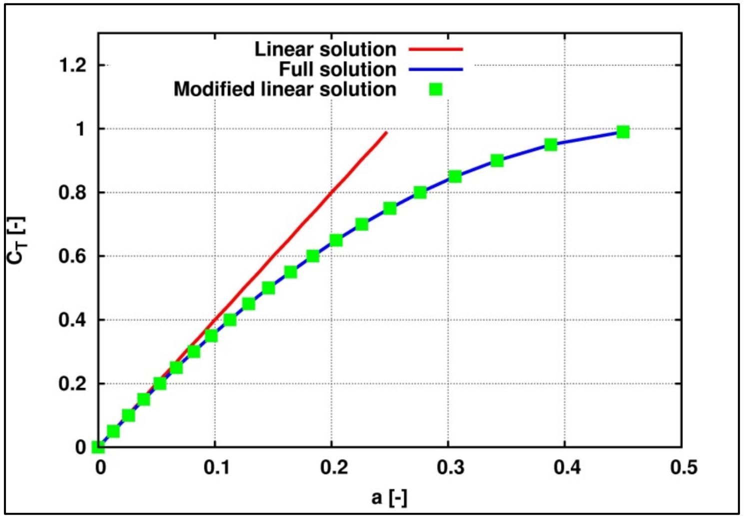
$$v_x = 1 - \frac{\Delta p}{2\pi}\left(arctg\left(\frac{1-y}{x}\right) + arctg\left(\frac{1+y}{x}\right)\right) - \Delta p^*$$

$$v_y = \frac{\Delta p}{4\pi}\ln\left(\frac{x^2 + (y+1)^2}{x^2 + (y-1)^2}\right)$$

$$C_T = 4a_{lin}$$

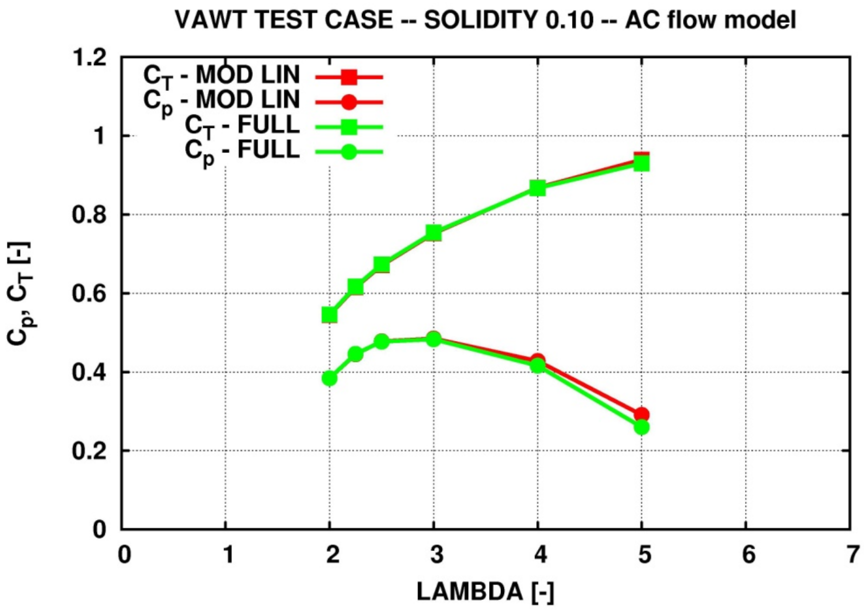
However, from **BEM** theory we have:

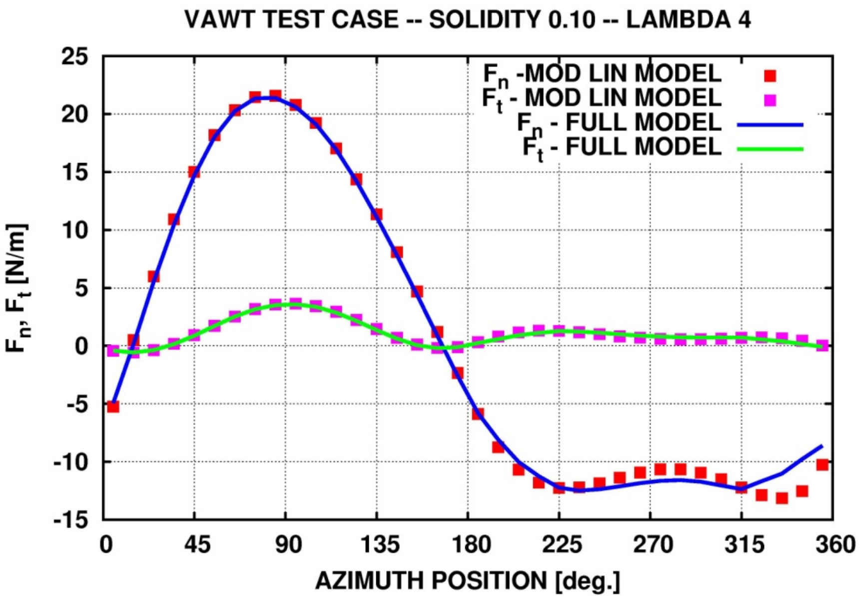
$$C_T = 4a - 4a^2$$



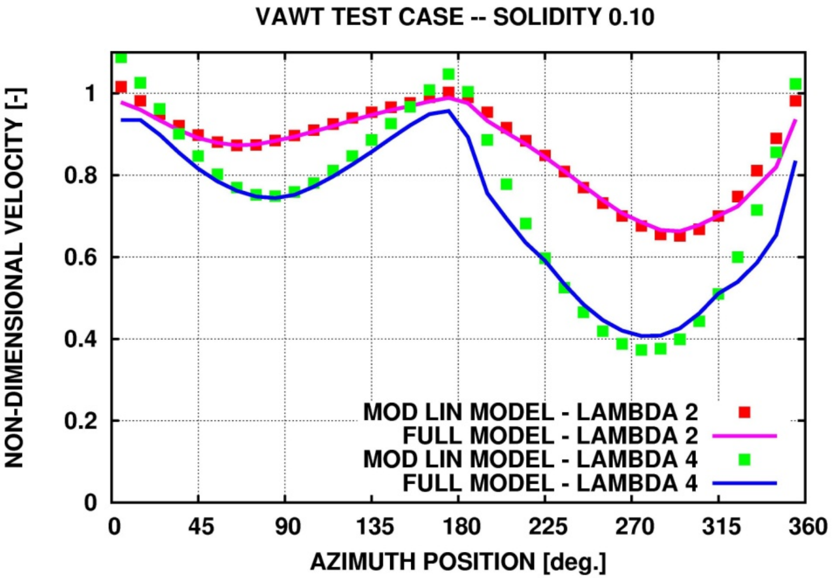
To achieve a modified linear solution we multiply the inductions with the factor $k_a = \frac{1}{1-a}$

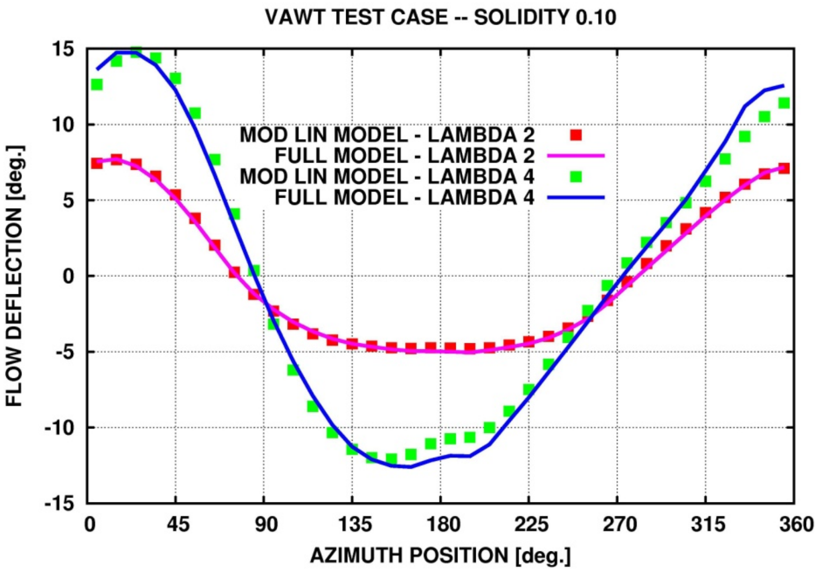
Results – modified linear AC model

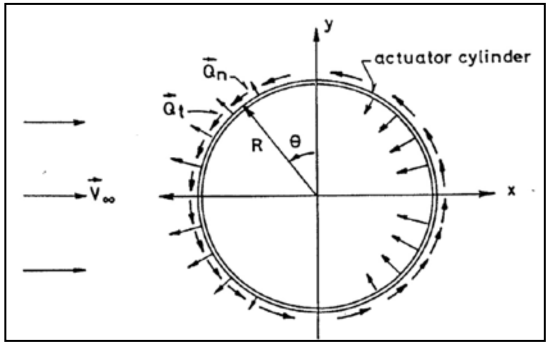




Results – modified linear AC model





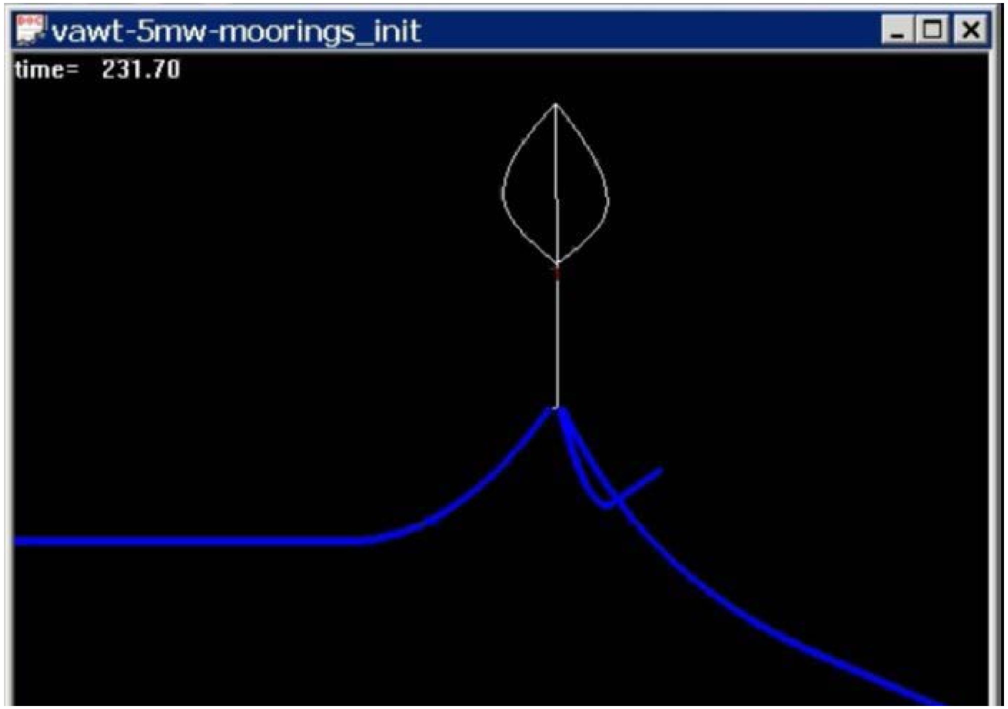


Results

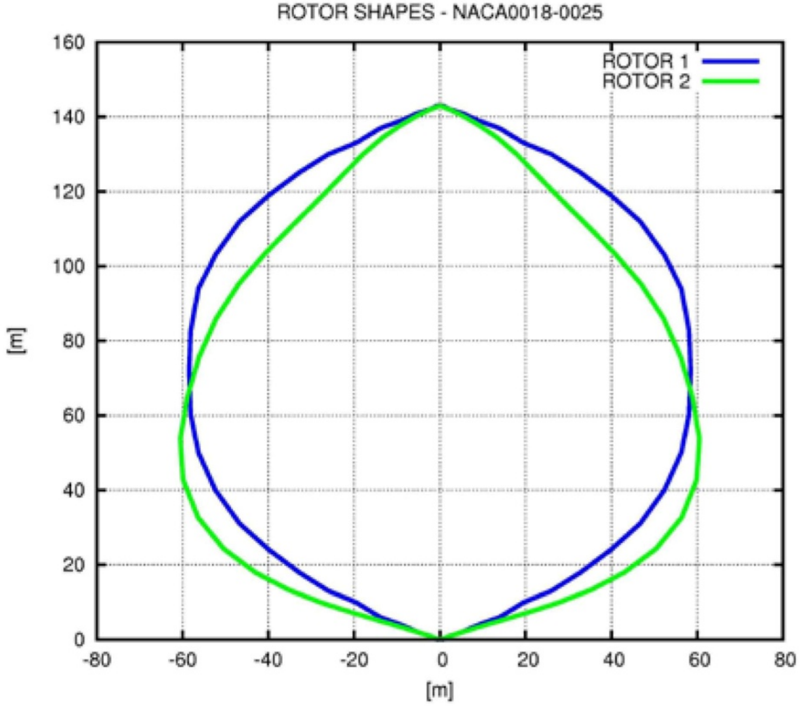
- 5MW DeepWind 2nd design

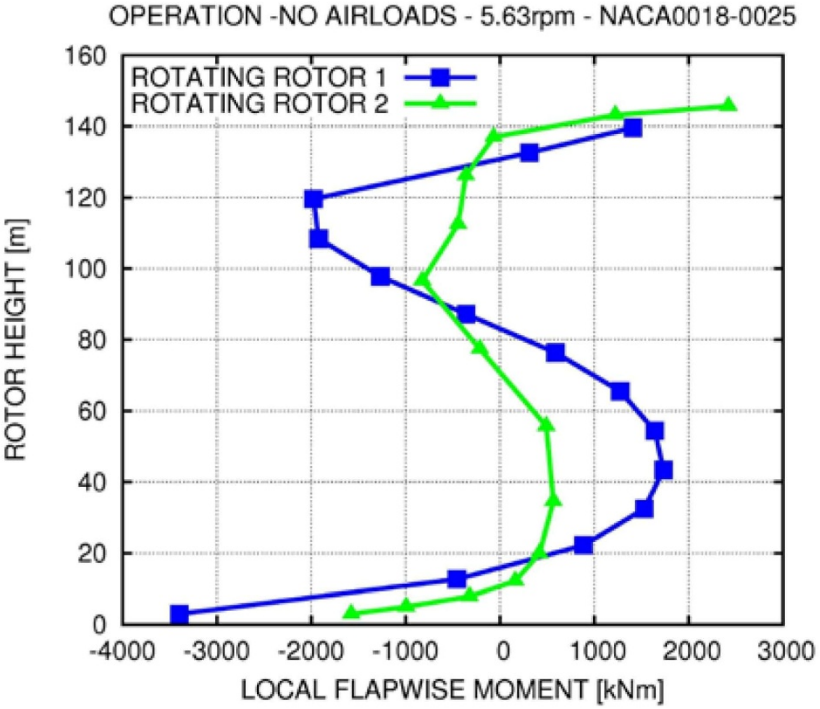
rotor radius	60.51m
blade chord	5.0m
rotor height	143.0m
airfoil	NACA0018
number of blades	2
solidity	0.17
rated power	5000kW
rated speed	5.63rpm
swept area	12318m2

Baseline design



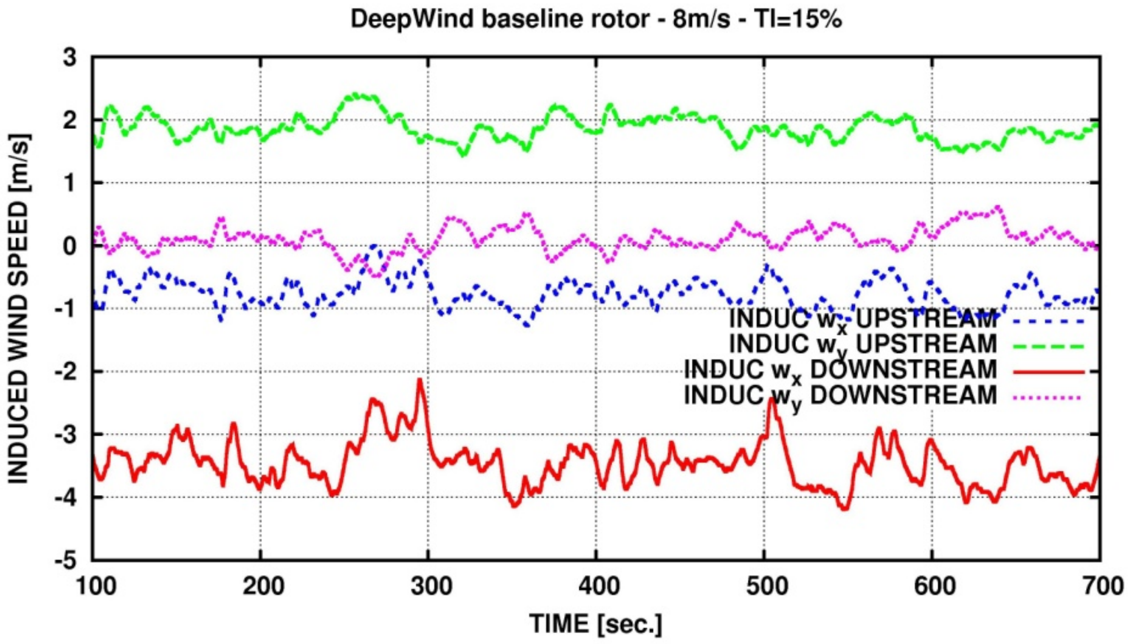
Results –from baseline to 2nd design

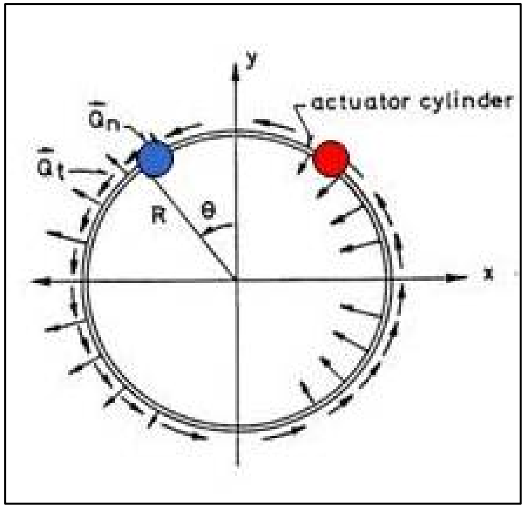




Results

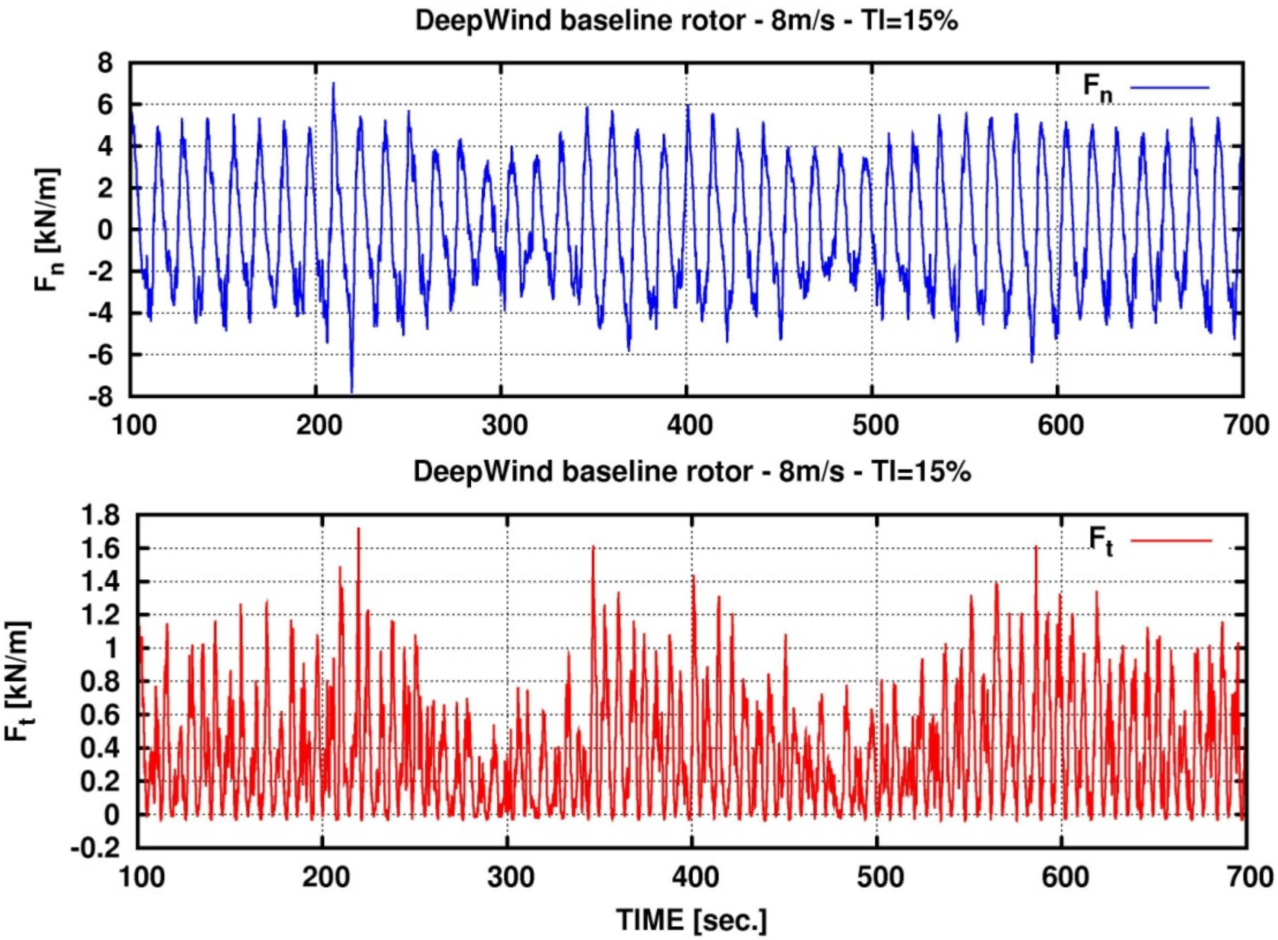
-5MW baseline DeepWind design





Results

-5MW baseline DeepWind design



Conclusions

- The aeroelastic model HAWC2 has been extended to model VAWT´s with the same level of accuracy as HAWT´s

- Experience on aeroelastic modelling of VAWT´s is being build up at the moment

Acknowledgement

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Participants

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TU DELFT(NL)
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DHI(DK)
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MARINTEK(N)
MARIN(NL)
NREL(USA)
STATOIL(N)
VESTAS(DK)
NENUPHAR(F)

Thank you
for your attention