

# OFFSHORE WIND POWER PREDICTIONS THROUGH CFD SIMULATION AND THE ACTUATOR DISC MODEL

USER MEETING | JUNE 2011

PRESENTED BY: GIORGIO CRASTO

windsim

# Actuator disc - Content

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## Wake modelling and validation

In WindSim now has two methods to model the wakes:

**Analytical wake models (single and multiple)**

**The actuator disc method**

**(wake-wake, wake-terrain, thermal effects)**

**Grid dependency, stability, turbulence in single wake**

**Offshore wind farm: Horns Rev (new cases)**

# Actuator disc

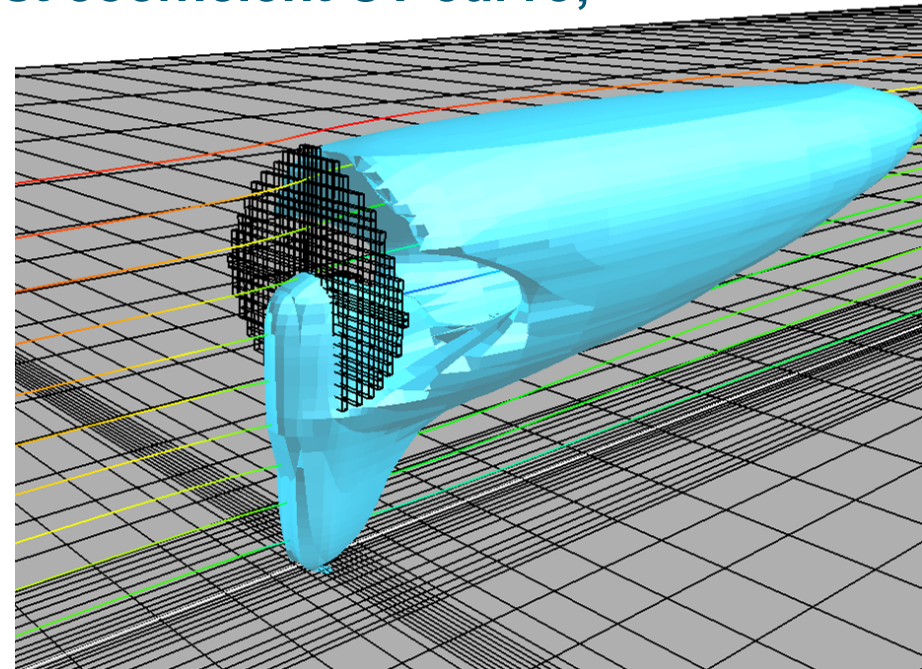
The rotor is modeled by a porous disc providing a resistive force which is calculated from the thrust coefficient CT curve;

**Axial thrust:**

$$T \approx \sum_i t_i = \sum_i \left( C_T \frac{1}{2} \rho u_{\infty i}^2 area_i \right)$$

**Sum of thrusts:**

$$t_i = C_{T,i}(u_{1,i}) \frac{1}{2} \rho \left( \frac{u_{1,i}}{1 - a_i(u_{1,i})} \right)^2 area_i$$



*Perspective view of the actuator disc, streamlines and iso surface of turbulent kinetic energy ( $1,4 \text{ m}^2/\text{s}^2$ ,  $U_e$  10 m/s at 500m a.g.l.).*

# Actuator disc

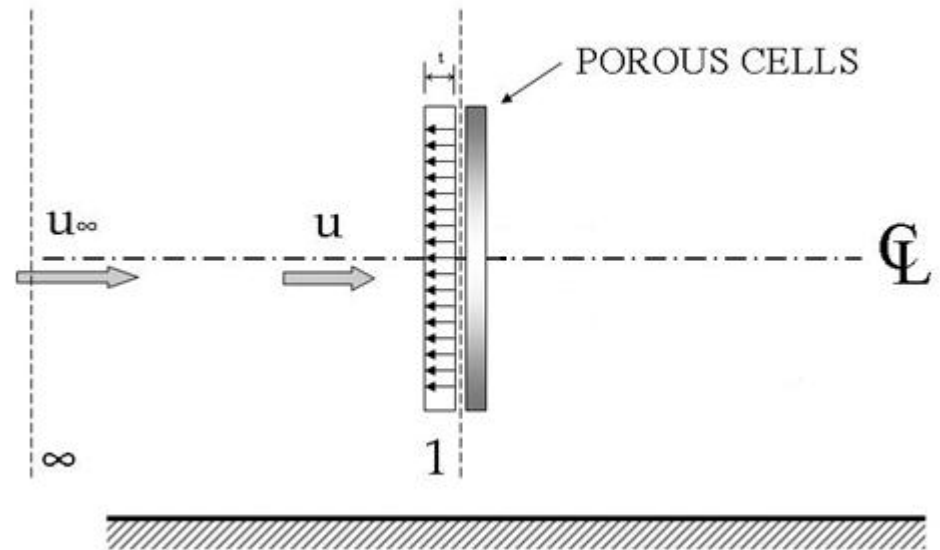
The thrust, momentum sink for the axial flow, is distributed on the swept area (uniform, parabolic or polynomial distribution)

Axial induction factor:

$$a = \frac{u_\infty - u_1}{u_\infty}$$

By definition

$$a = \frac{1}{2} (1 - \sqrt{1 - C_T}) \quad \text{Betz's theory}$$



# Radial variation of actuator disc quantities

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We distributed the axial forces in three different manners:

1. Uniform distribution

$$t = T / A = C_T \frac{1}{2} \rho u_\infty^2$$

2. Parabolic distribution

$$t(\rho) = C_1 + C_2 \rho^2$$

with :  $\int_{A_S} t(\rho) dA = T;$

$$t(R) = 0 Pa$$

3. Polynomial (4<sup>th</sup> order) distribution

$$t(\rho) = C_1 + C_2 \rho^2 + C_3 \rho^4$$

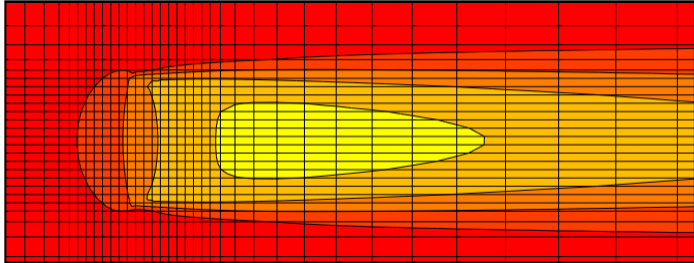
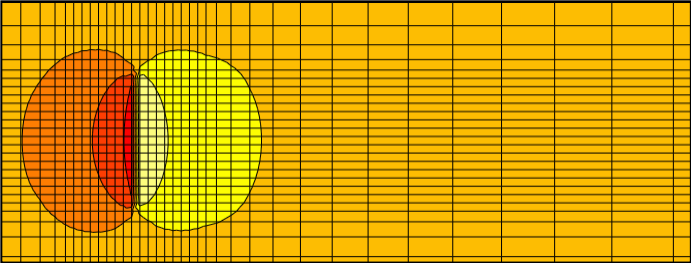
with:  $\int_{A_S} t(\rho) dA = T;$

$$t(R) = 0 Pa;$$

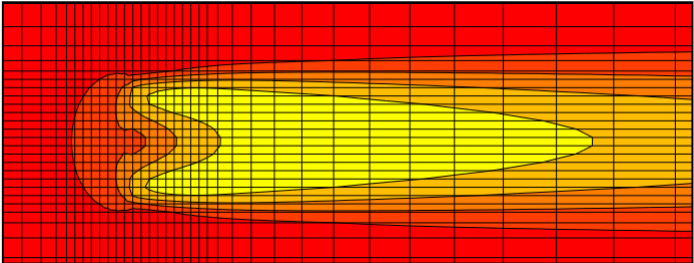
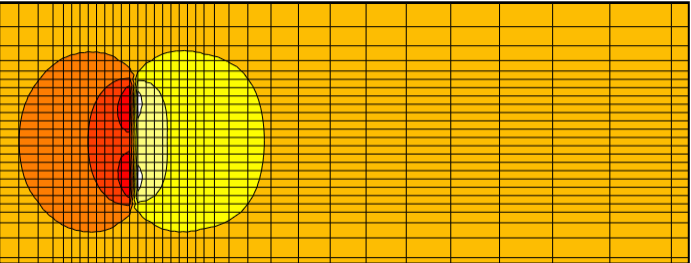
$$t(R/2) = 2t(0)$$

# Radial variation of actuator disc quantities

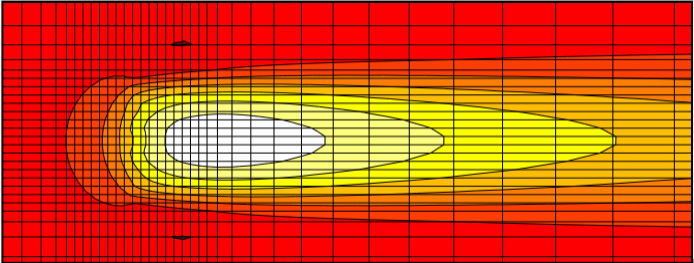
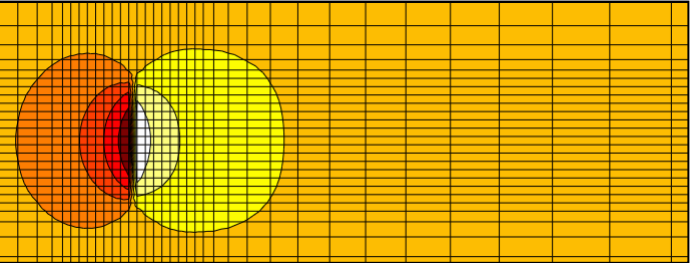
Uniform distribution:



Polynomial (4<sup>th</sup> order) distribution:



Parabolic distribution:

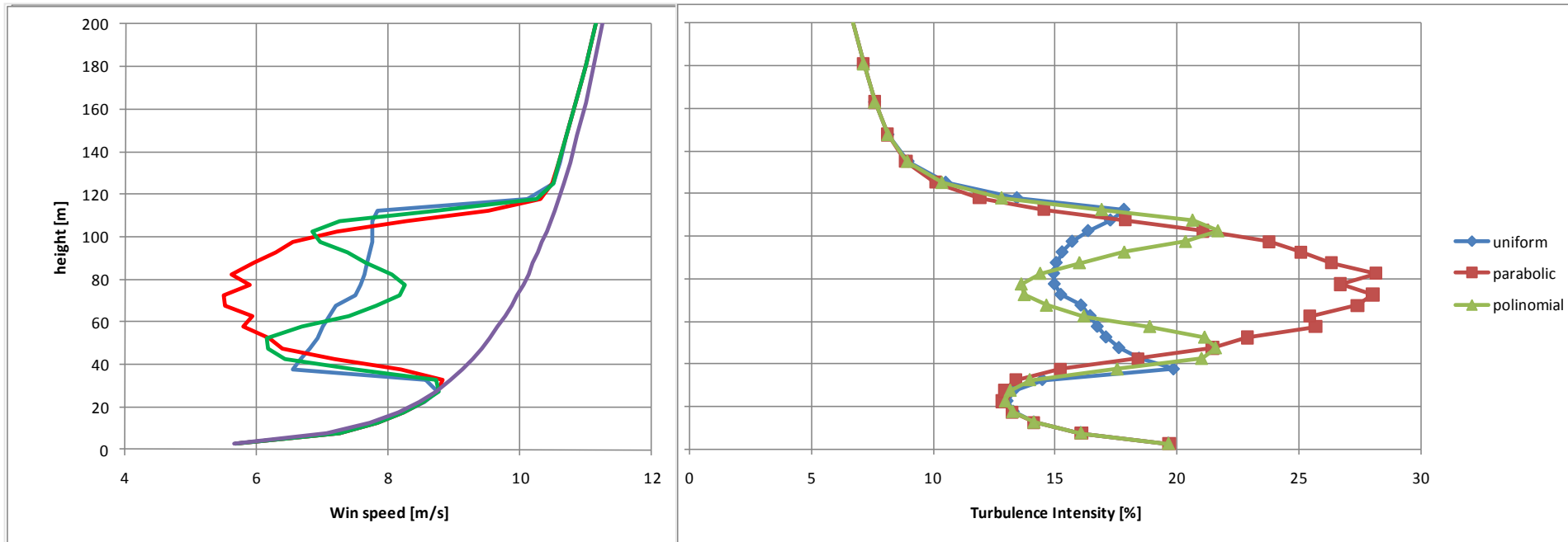


Pressure (-27;35 Pa)

Wind speed (3;11 m/s)

# Radial variation of actuator disc quantities

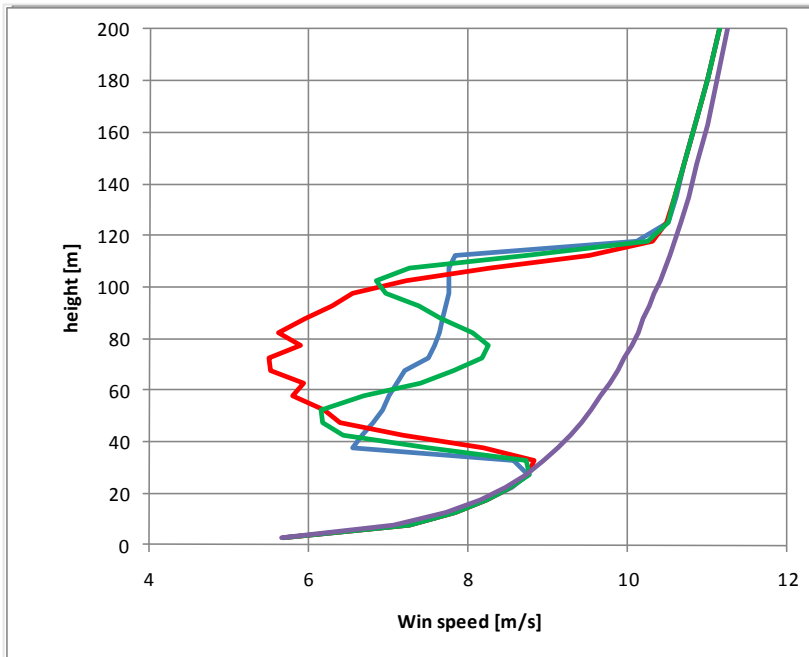
At turbine location:



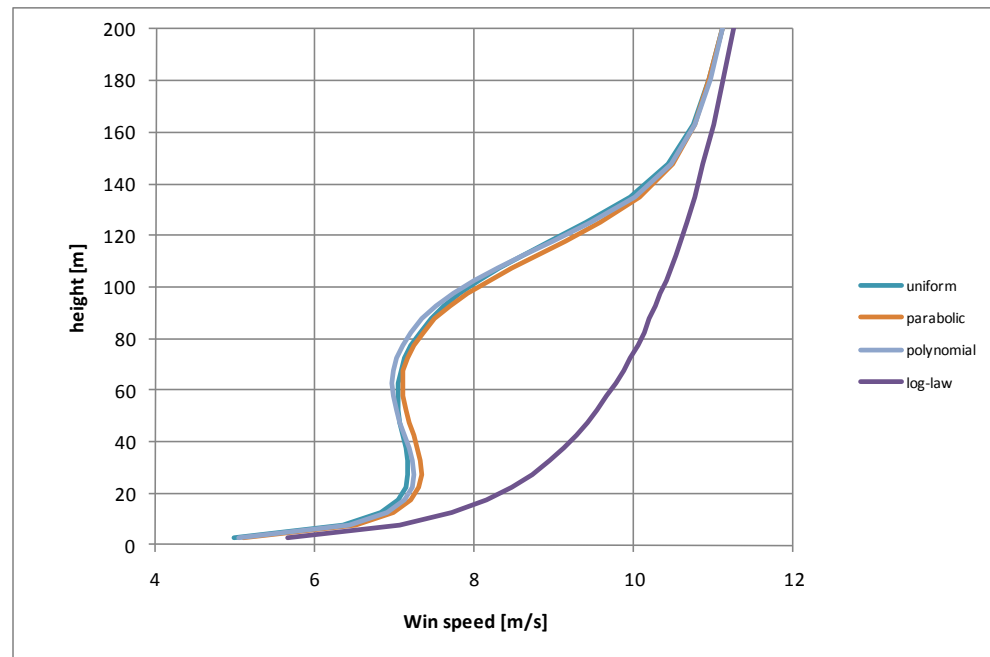
*Vertical profiles of wind speed (m/s) and turbulence intensity (%).*

# Radial variation of actuator disc quantities

At turbine



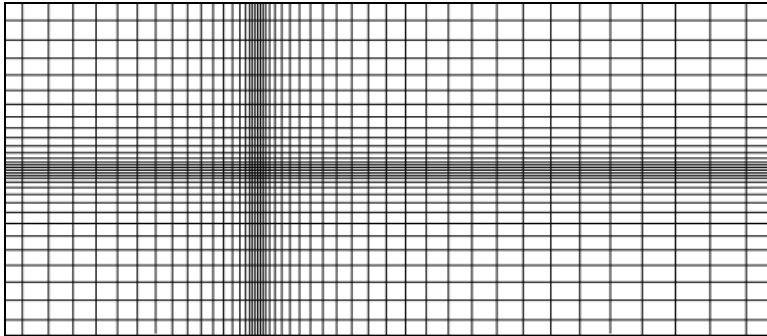
7D downstream



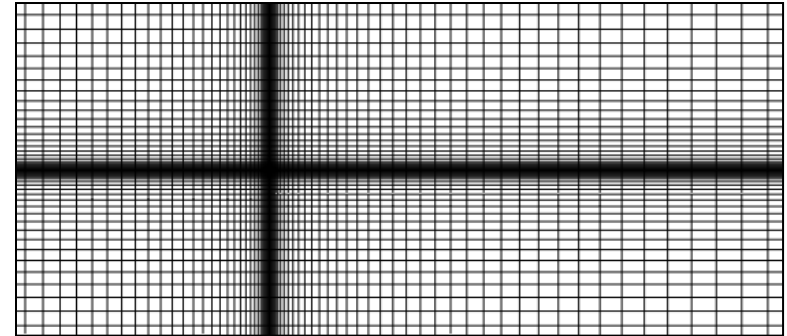
*Vertical profiles of wind speed (m/s) and turbulence intensity (%).*

# Single turbine: grid sensitivity study

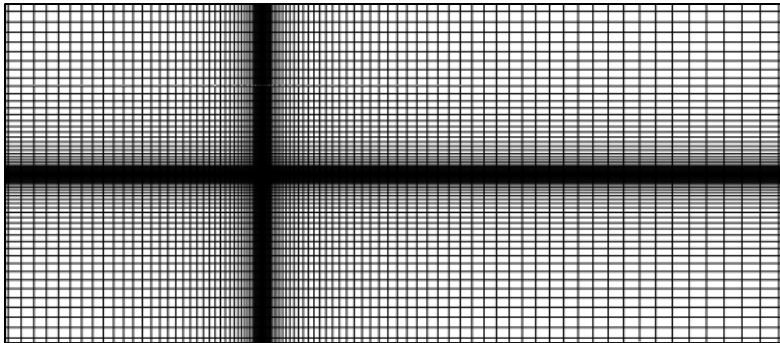
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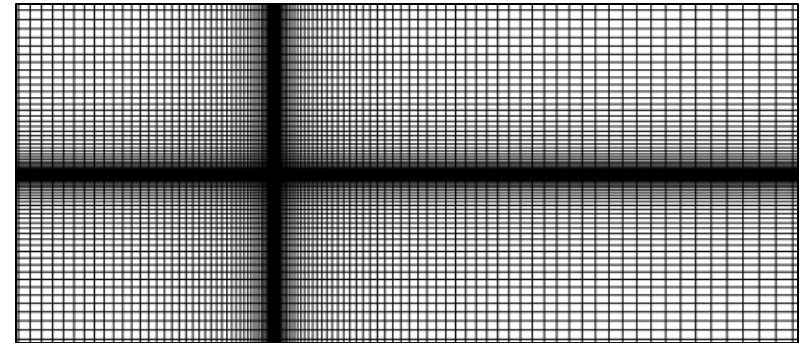
*Resolution 20 meters,  $D/4$*



*Resolution 10 meters,  $D/8$*

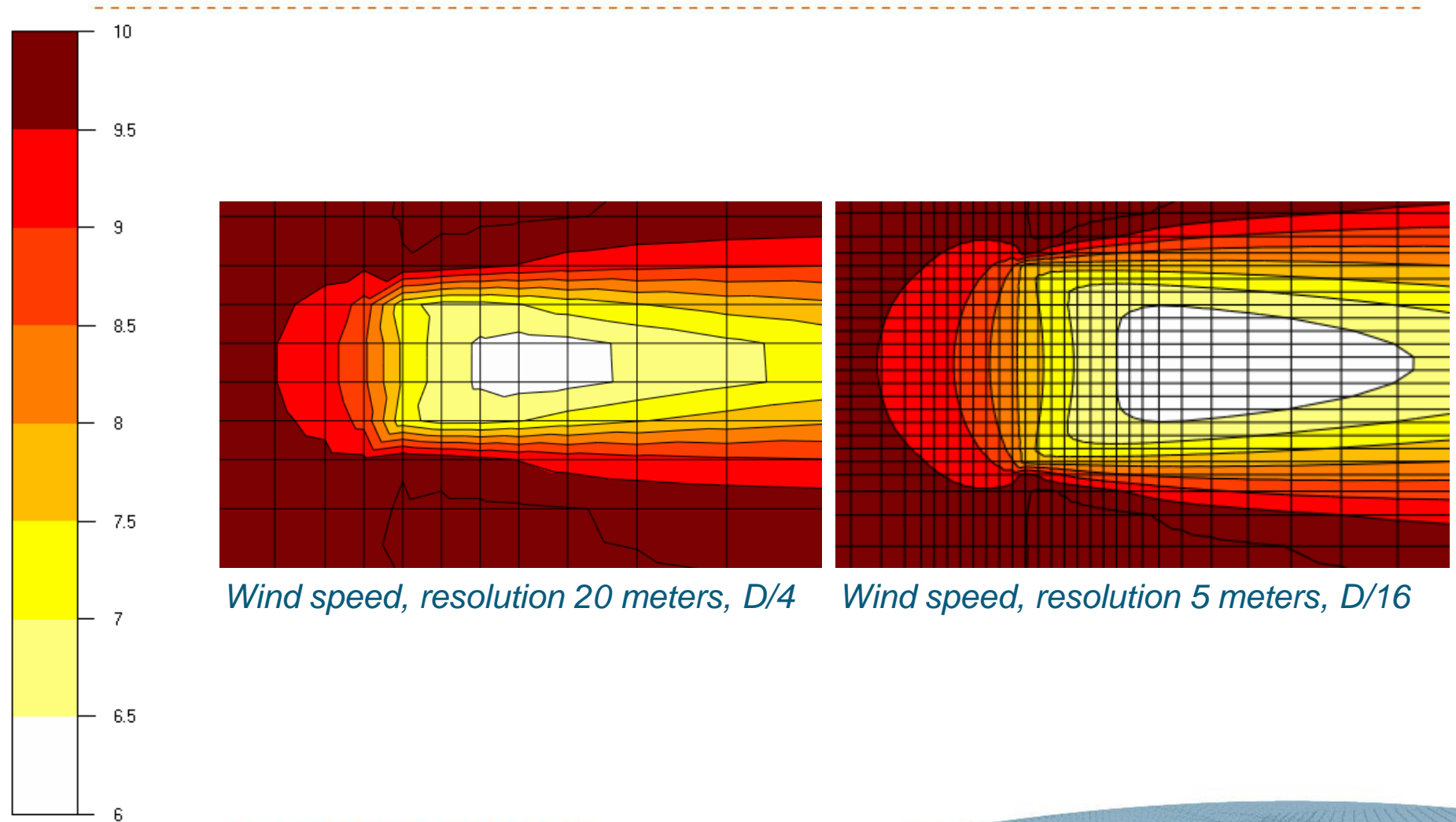


*Resolution 5 meters,  $D/16$*



*Resolution 4 meters,  $D/20$*

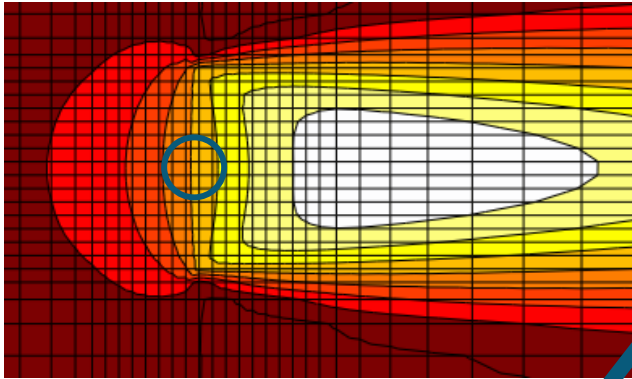
# Single turbine: grid sensitivity study



*Wind speed, resolution 20 meters, D/4*

*Wind speed, resolution 5 meters, D/16*

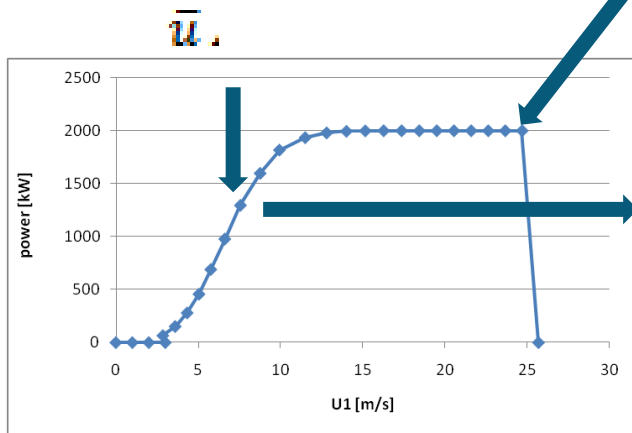
# Power extraction method (energy module)



Wind speed is extracted at the hub

**Power curve corrected** with axial-induction factor and Betz's theory

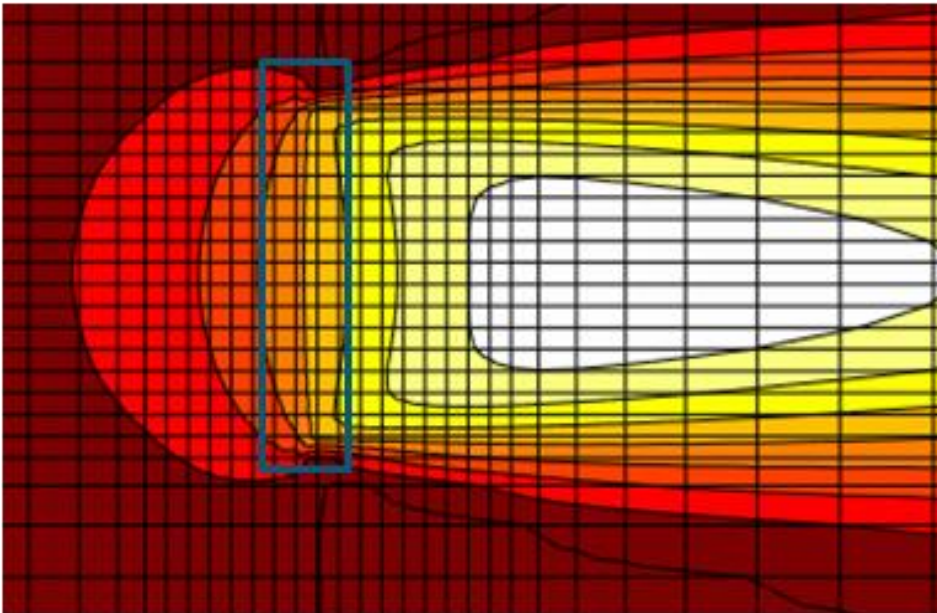
Evaluate the power entering in the corrected power curve



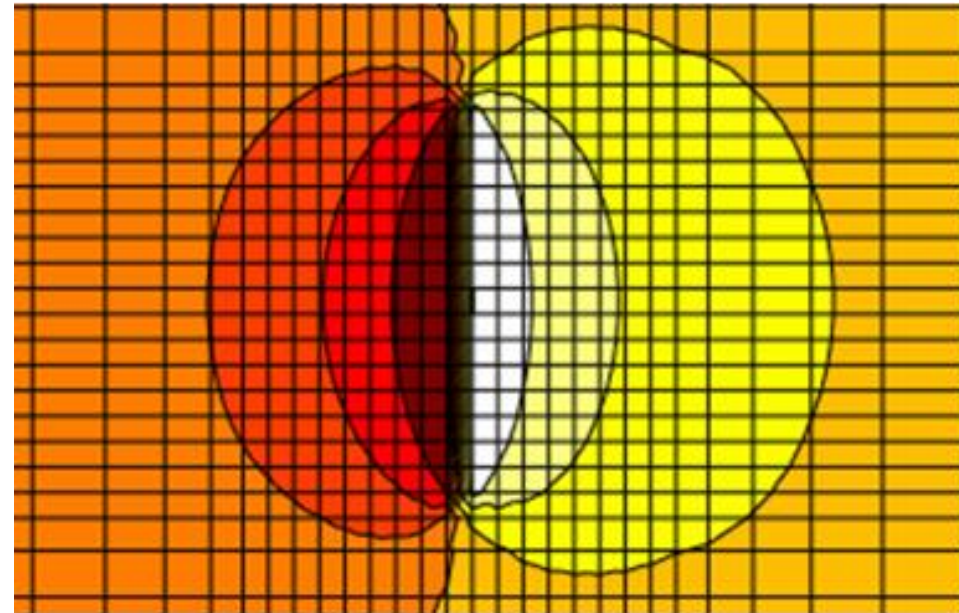
# Power extraction method (external routine)

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Wind speed on a horizontal plane at hub height



Pressure field on a horizontal plane at hub height



The power is finally estimated by performing the integral:  $Power = \int_A u \Delta p dA$

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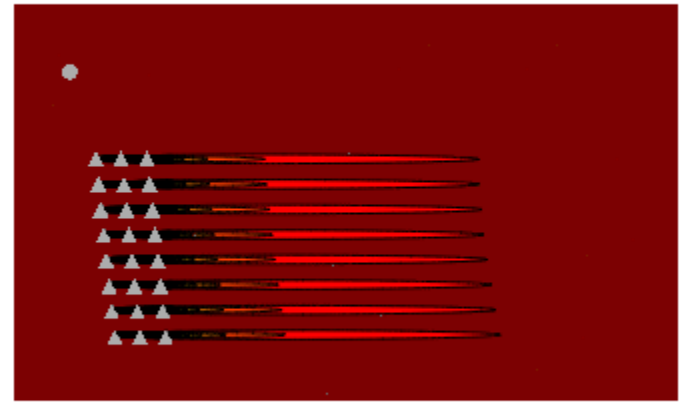
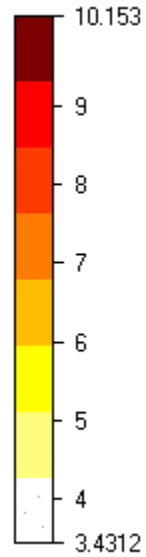
# Offshore wind farm: Horns Rev

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- Horns Rev is an offshore wind farm located 13 km from the Danish coastline consisting of 80 wind turbines (Vestas V80);
- **New simulations** (poster Crasto *et al.*, EWEC2011)
- The extension of the CFD model is 15 km (easting) x 9 km (northing) x 0.8 km, with a the following number of hexahedral cells:  $304 \times 562 \times 29 = 4\,954\,592$
- The horizontal resolution is 8 m (10 rotor diameter subdivisions) for the results presented below. It was not possible to achieve 5 m resolution (16 rotor diameter subdivisions) in the wind farm area and some grid dependency is expected. Vertically the grid is uniform from the lower to the upper tip, from 30 m to 110 m asl, with 8 m resolution. Above the upper tip the grid is vertically expanded.
- Only first three lines of turbines are modeled

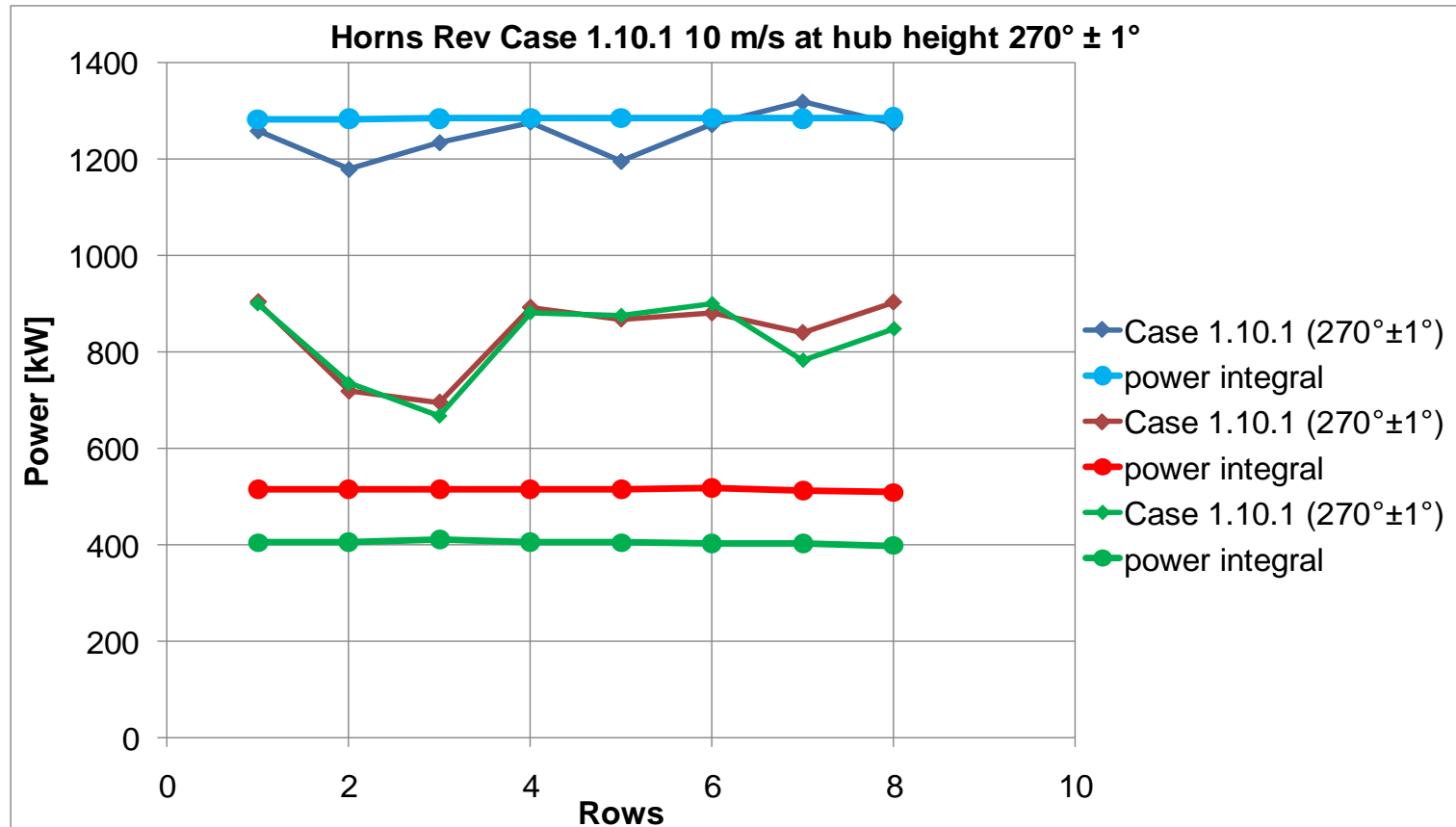
# Offshore wind farm: Horns Rev

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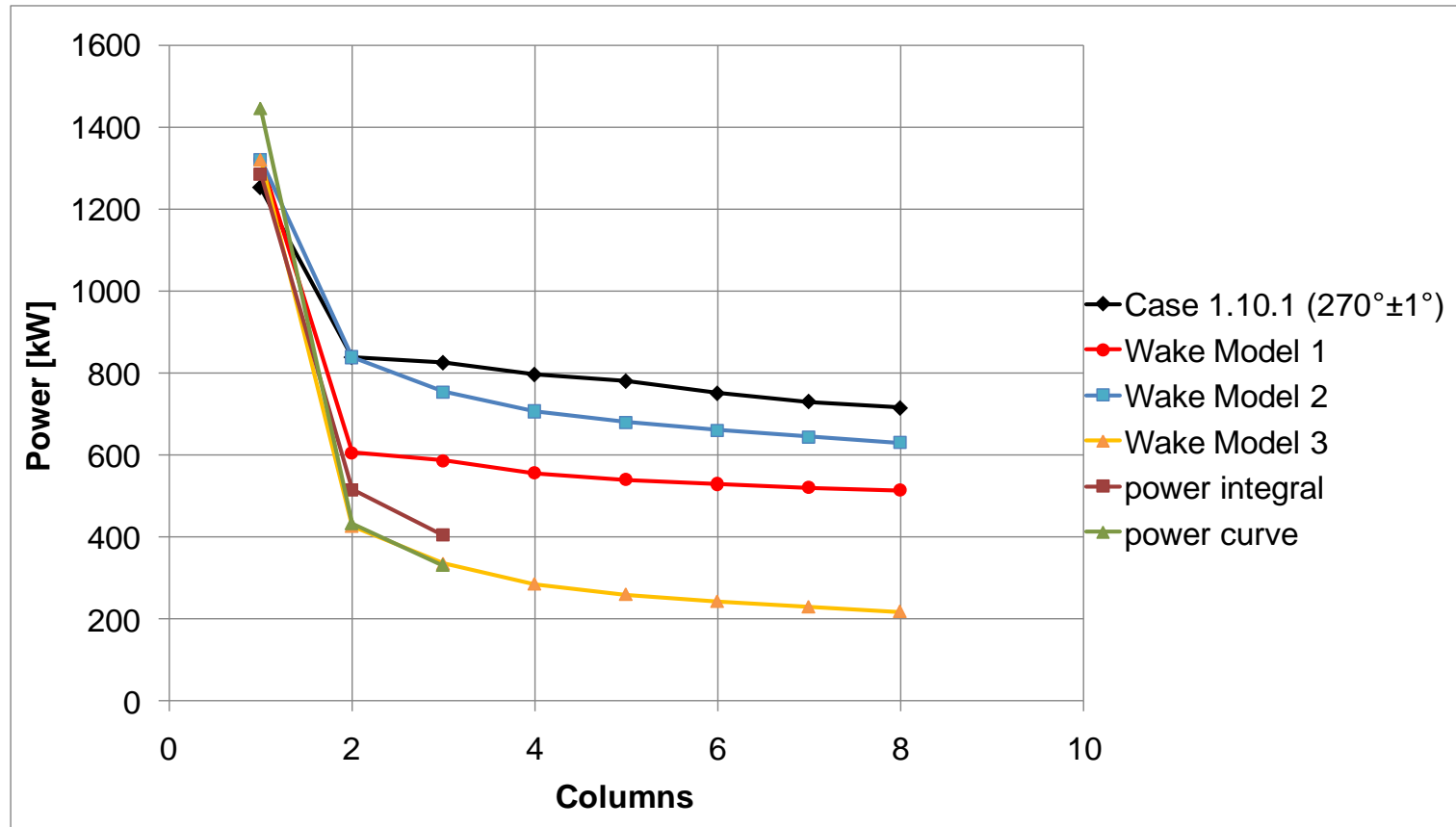
# Power predictions for three cases of west wind

*Horns Rev Case 1.10.1 10 m/s at hub height  $270^\circ \pm 1^\circ$*



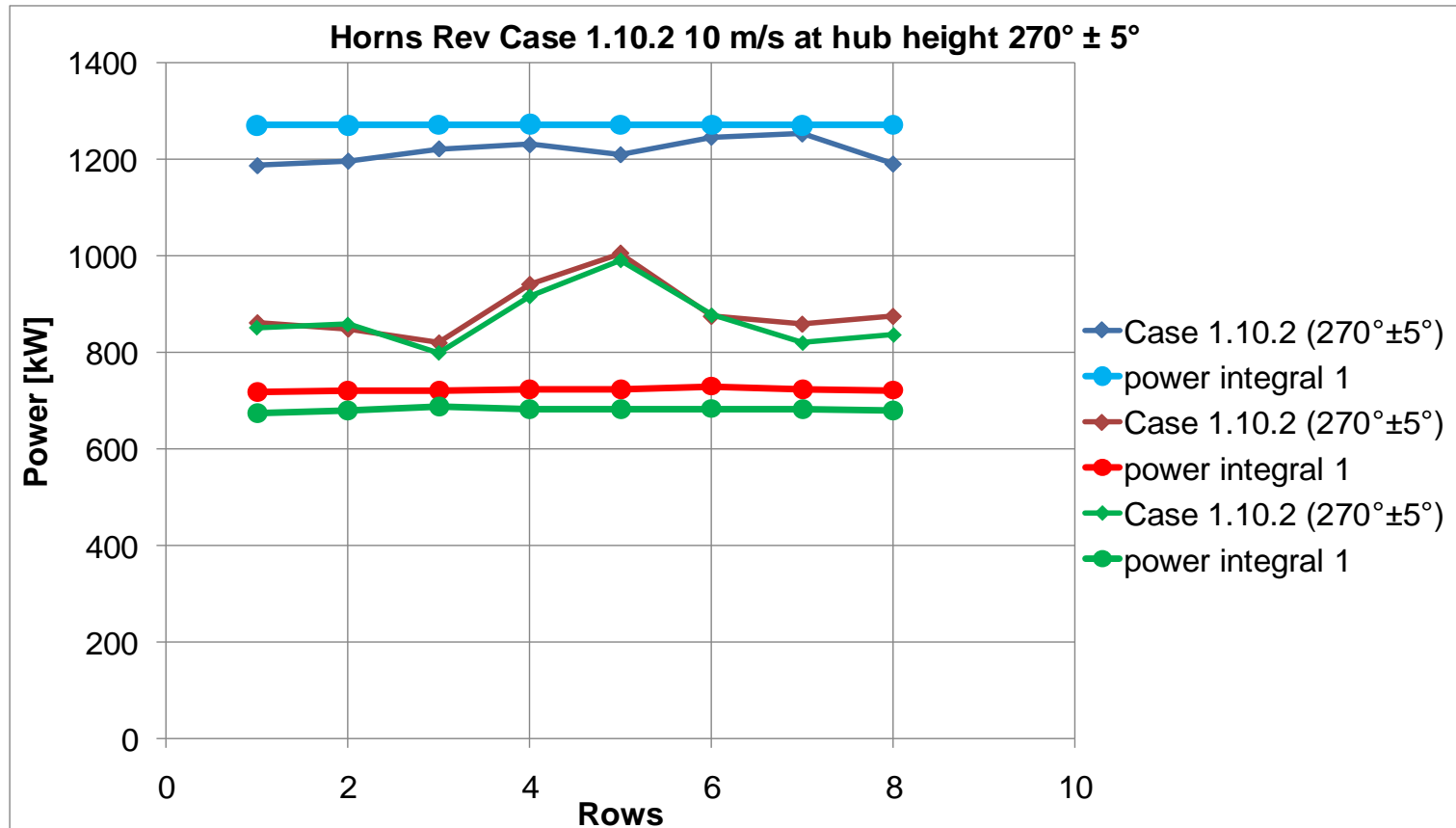
# Power predictions for three cases of west wind

*Horns Rev Case 1.10.1 10 m/s at hub height  $270^\circ \pm 1^\circ$*



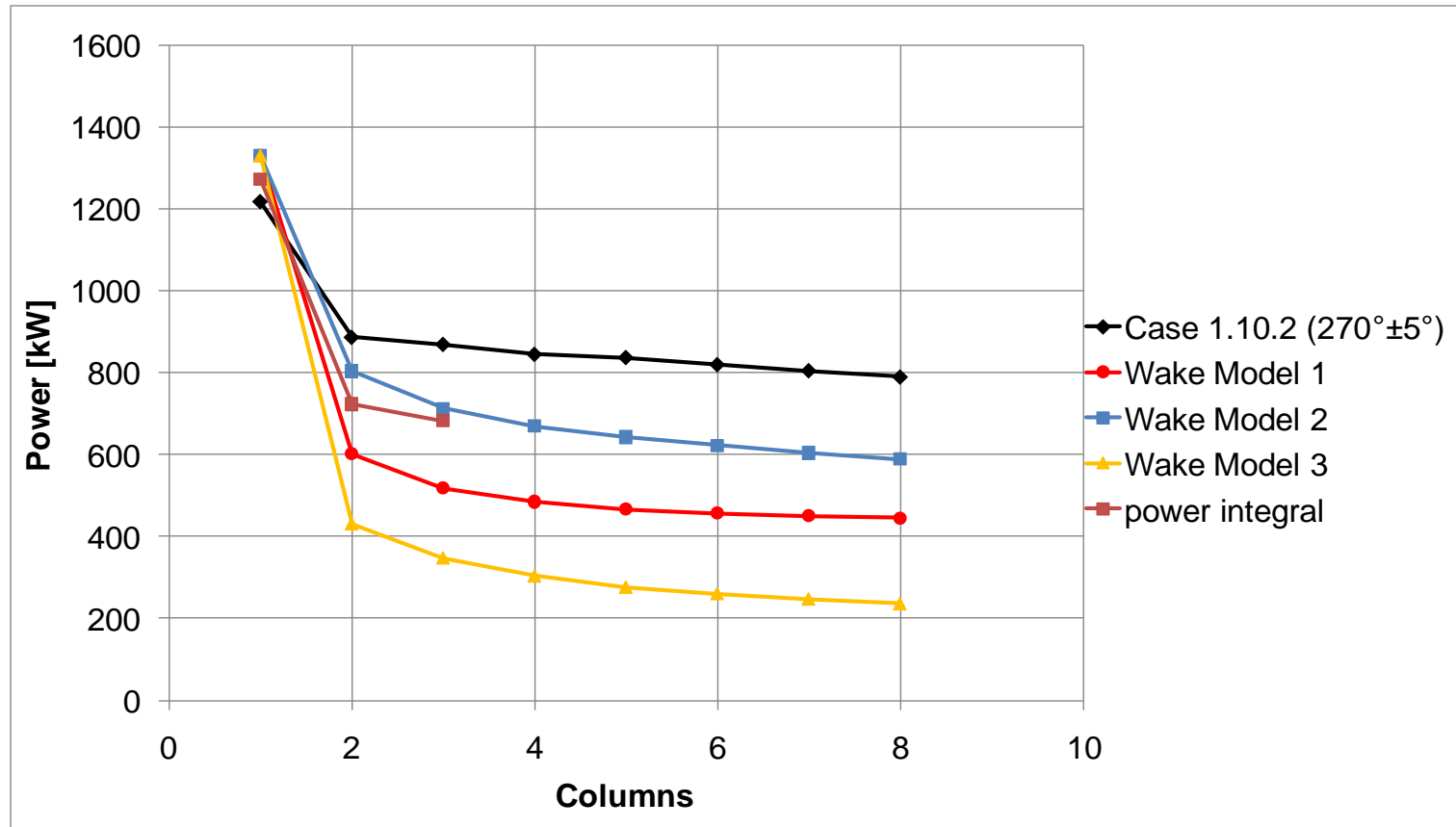
# Power predictions for three cases of west wind

*Horns Rev Case 1.10.2 10 m/s at hub height  $270^\circ \pm 5^\circ$*



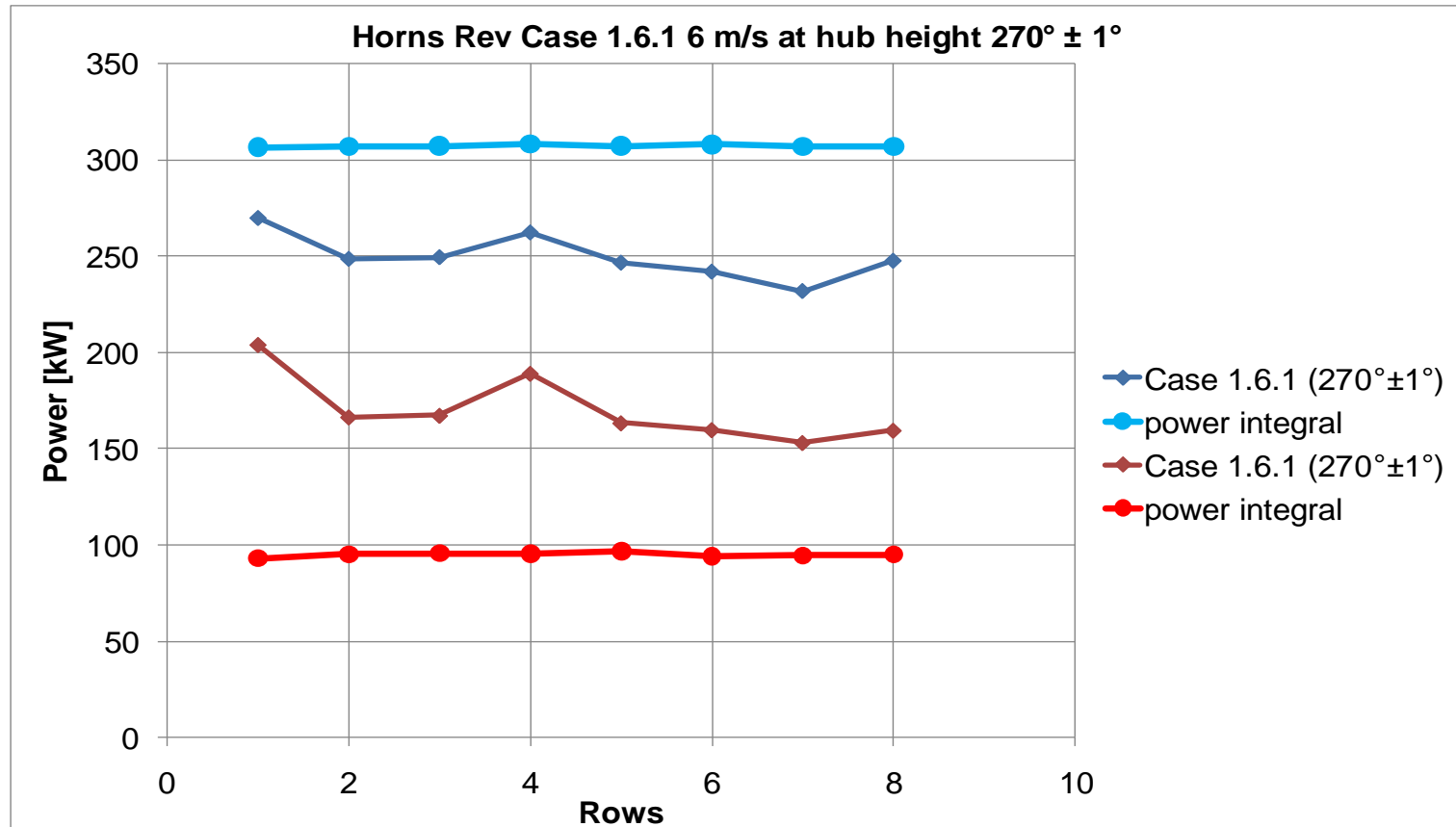
# Power predictions for three cases of west wind

*Horns Rev Case 1.10.2 10 m/s at hub height  $270^\circ \pm 5^\circ$*



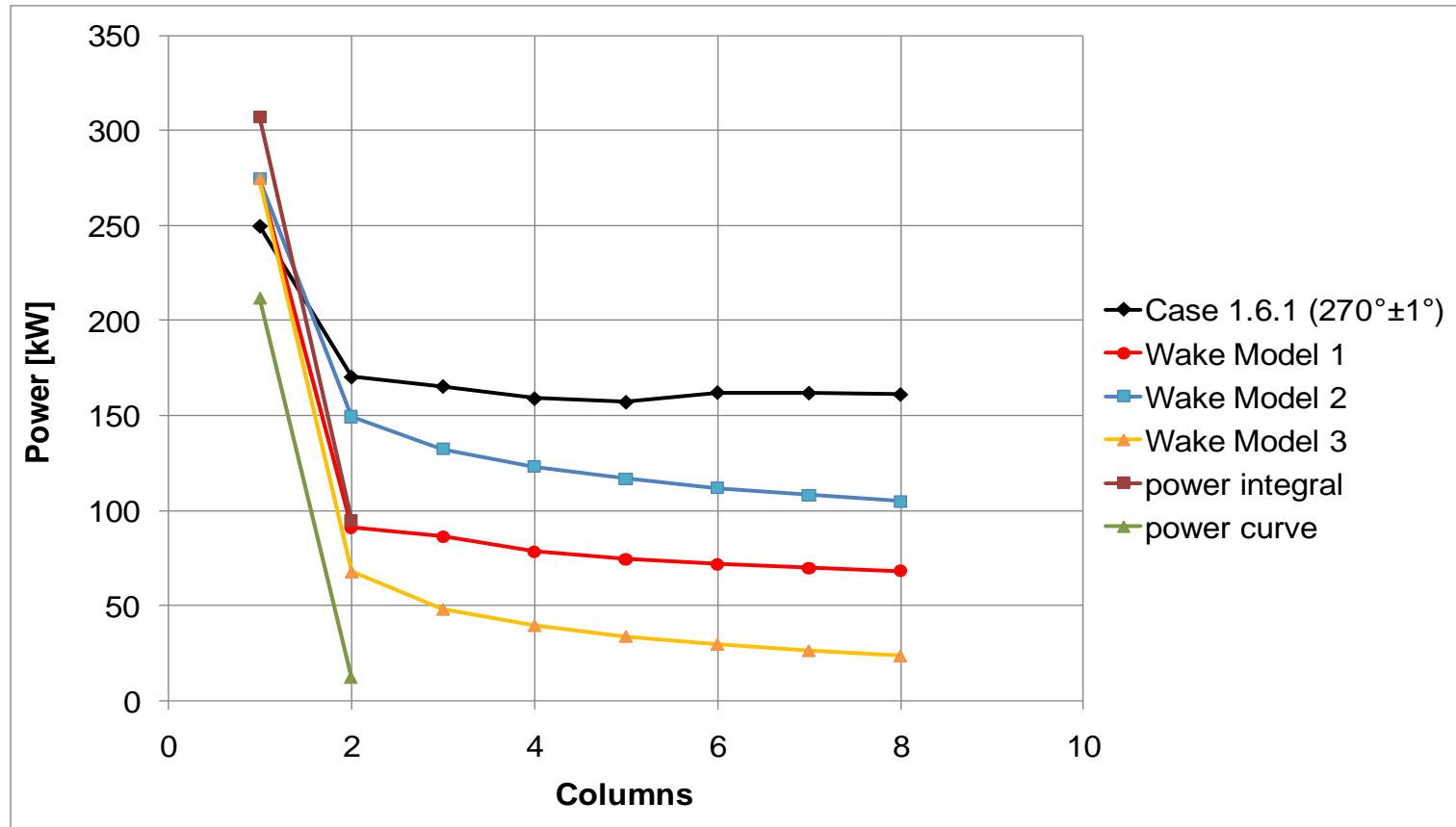
# Power predictions for three cases of west wind

*Horns Rev Case 1.6.1 6 m/s at hub height  $270^\circ \pm 1^\circ$*



# Power predictions for three cases of west wind

*Horns Rev Case 1.6.1 6 m/s at hub height  $270^\circ \pm 1^\circ$*



# Conclusions

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**An actuator disc concept is applied in WindSim 5.0;**

**Three different ways of distributing the pressure drop:**

- *uniform, parabolic and polynomial.*

**Two methods to compute the power:**

1. *extracting a wind speed at the rotor and applying the power curve (corrected with power vs. wind speed at rotor plane);*
2. *computing an integral of the power extracted by the disc;*

**When comparing the results from the actuator disc simulations with the Horns Rev production data at 6 and 10 m/s the power drop from first to second row is predicted within a good approximation.**

**Better predictions of power for higher wind speeds and wider directional sectors. In the cases presented the most performing methodology has resulted the Larsen (1988) model [2].**

# Future steps

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1. Tangential forces (swirling wakes)
2. Different handling of “skewed” cases (not 0, 90, 180, 270 directions)
3. Integral of swept area for power calculation
4.  $C_t$  calculated from a bulk velocity  $\langle u \rangle$ , or  $u$  @ hub height instead of  $u_i$
5. Correction of thrust curve based on velocity profile (equivalent to point 3?)
6. Actuator disc with thermal effects (stable/unstable atmosphere)
7. Improvement of high resolution models of wind farms (unlimited-parallel WindSim) // Computational requirements?
8. is the Betz’s theory for the computation of the axial induction factor good enough?
9. Unsteady simulations (URANS) to account for meandering

# References

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[1] Crasto G., Castellani F., Gravdahl AR, Piccioni E. "OFFSHORE WIND POWER PREDICTION THROUGH CFD SIMULATION AND THE ACTUATOR DISC MODEL" EWEA ANNUAL EVENT, 2011.

[2] LARSEN, C. G. "A SIMPLE WAKE CALCULATION PROCEDURE." RISØ-M-2760, 1988.