New Rotor Concepts for Future Offshore Wind Farms

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Outline

- Introduction and Motivation
- Purpose of the Work
- Method
  - Rotor concepts studied
  - Hornsrev as reference wind farm
  - Analysis Conditions and Assumptions
- Results
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  - Wind turbine level – With ECN airfoils
  - Wind turbine level overall
  - Wind farm level
  - Wind farm level – Effect of airfoils
- Conclusions and discussions

Introduction and Motivation

Plans to increase the offshore wind capacity enormously: EC 2008, Offshore wind should increase 30-40 times by 2020 and 100 times 2030* (www.ewea.org).

Continuous growth in the sizes of the wind turbines (not necessarily the capacity!)

Vestas V164 8MW prototype

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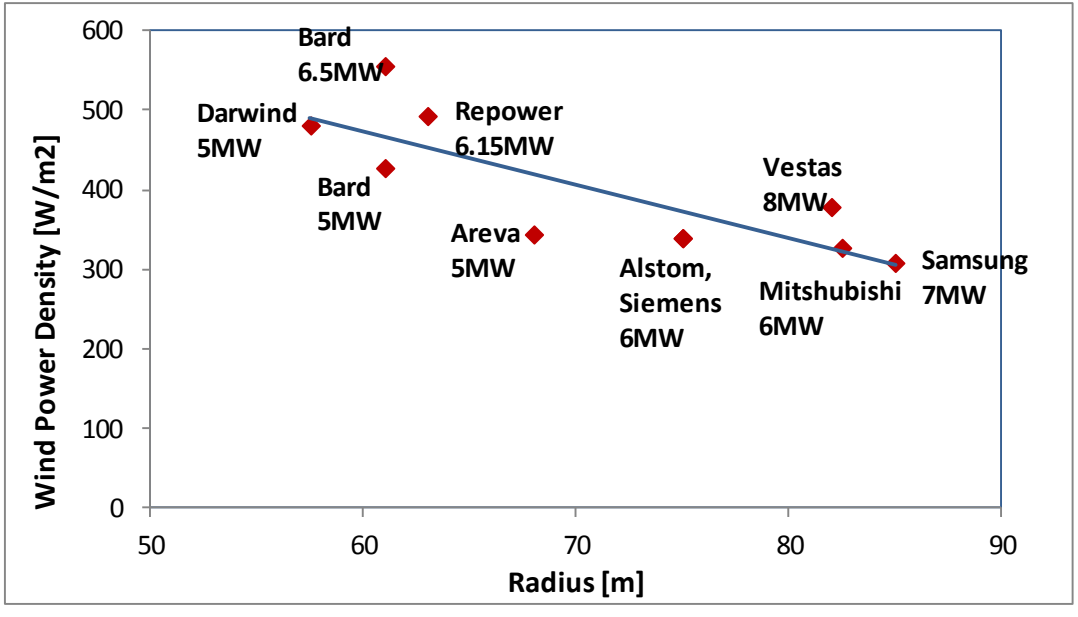
- Continuous growth in the sizes of the wind turbines (not necessarily the capacity!)

Vestas V164 8MW prototype

Image: Courtesy of Official Vestas Linkedin page&Albert Winnemuller

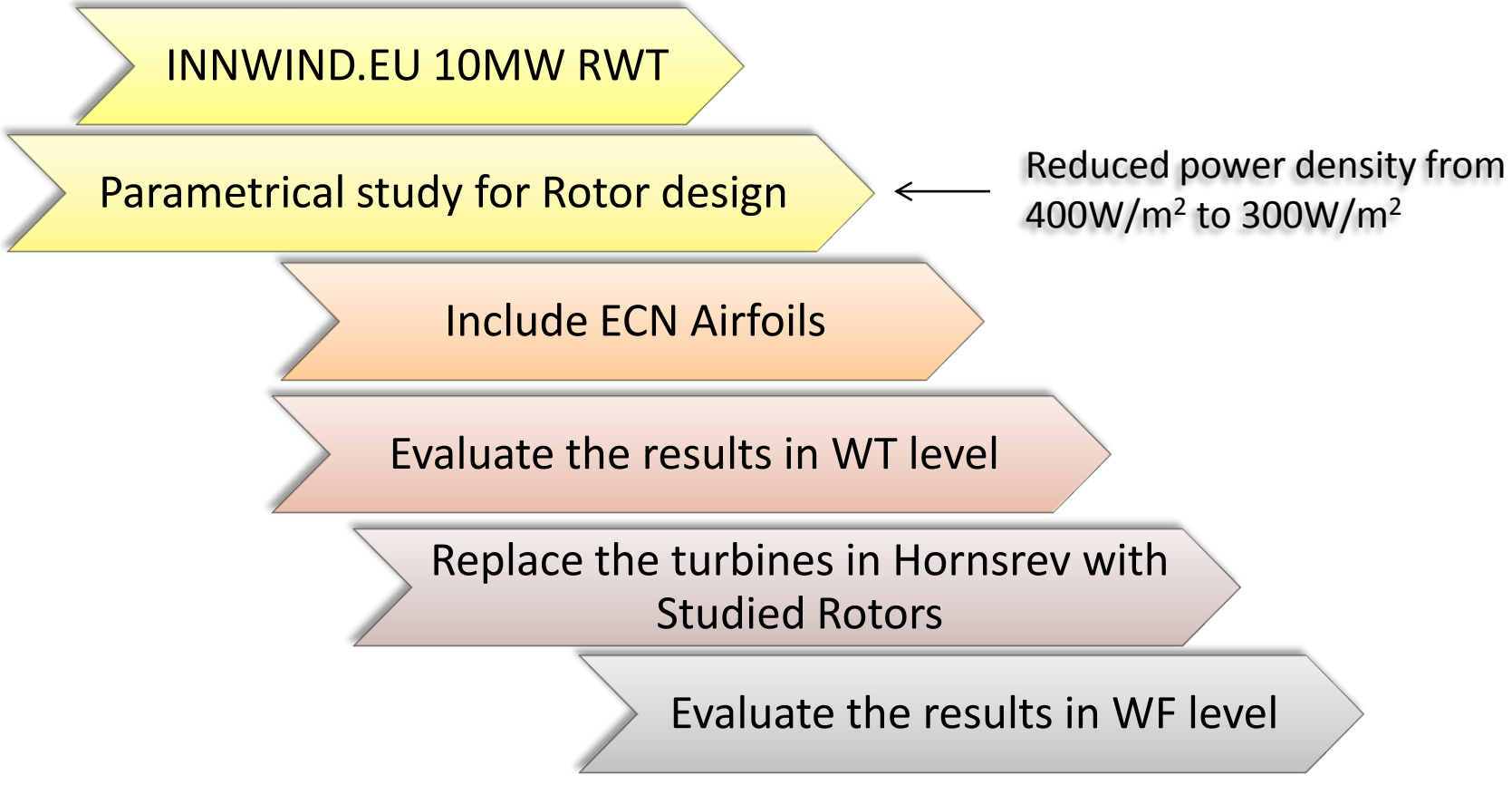
Purpose of the Work

- Reflect the current design trends in rotor design by a parametrical conceptual study
- Evaluate the rotor designs including their performance in Offshore farm environment
- Evaluate ECN's airfoils for chosen concepts in farm operation
- Include as realistic information for a farm operation as possible
- Possibility of bringing a different perspective to rotor designs for farm operations.



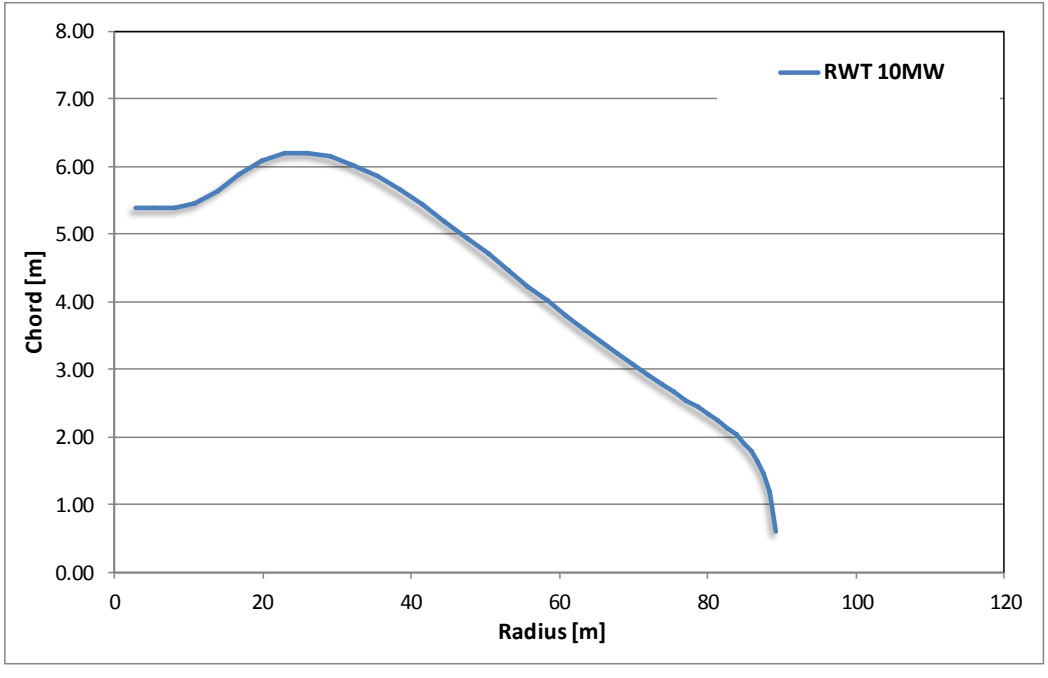
Method

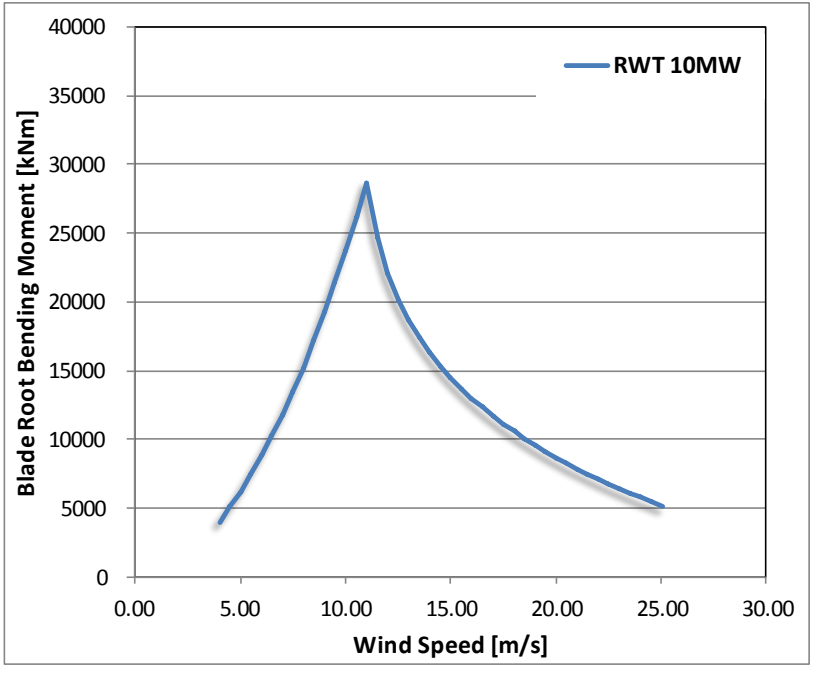
Method


INNWIND.EU 10MW RWT
Parametrical study for Rotor design
Reduced power density from 400W/m² to 300W/m²
Include ECN Airfoils
Evaluate the results in WT level
Replace the turbines in Hornsrev with Studied Rotors
Evaluate the results in WF level

Rotor Concepts and Parameters (1/7)

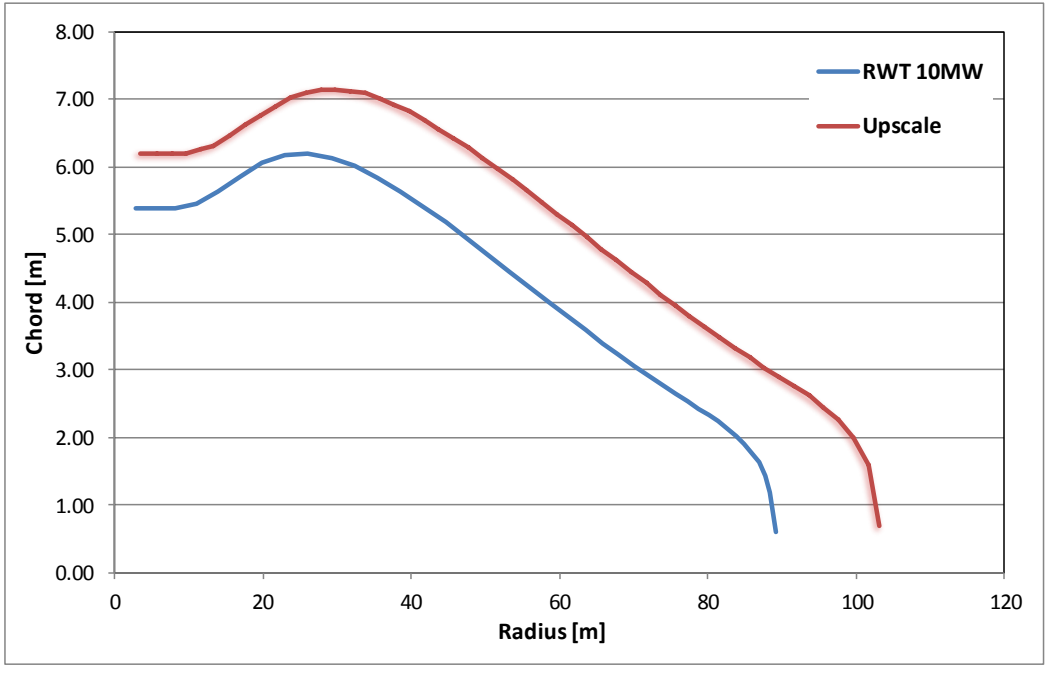
RWT 10MW

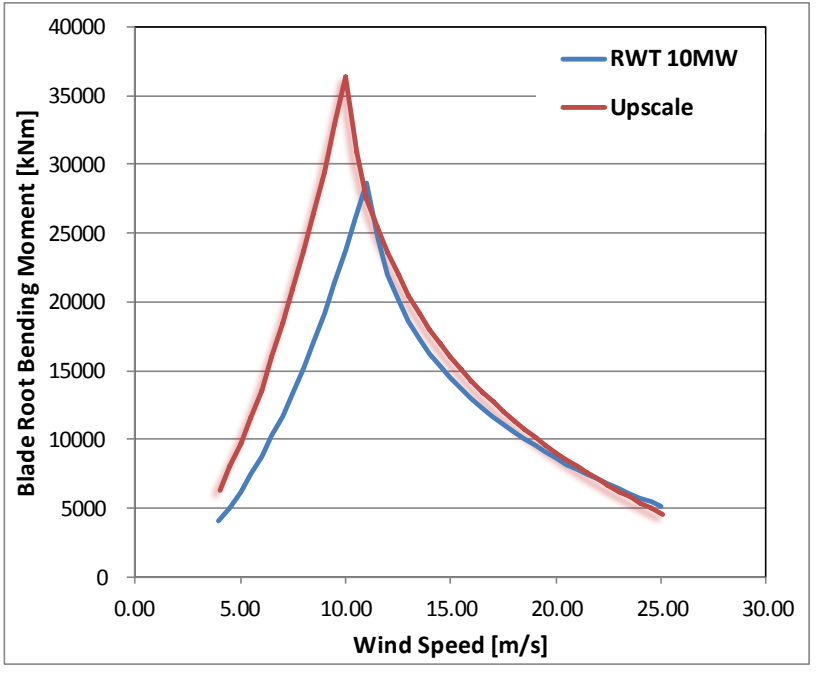




Rotor Concepts and Parameters (2/7)

RWT 10MW → UPSCALE

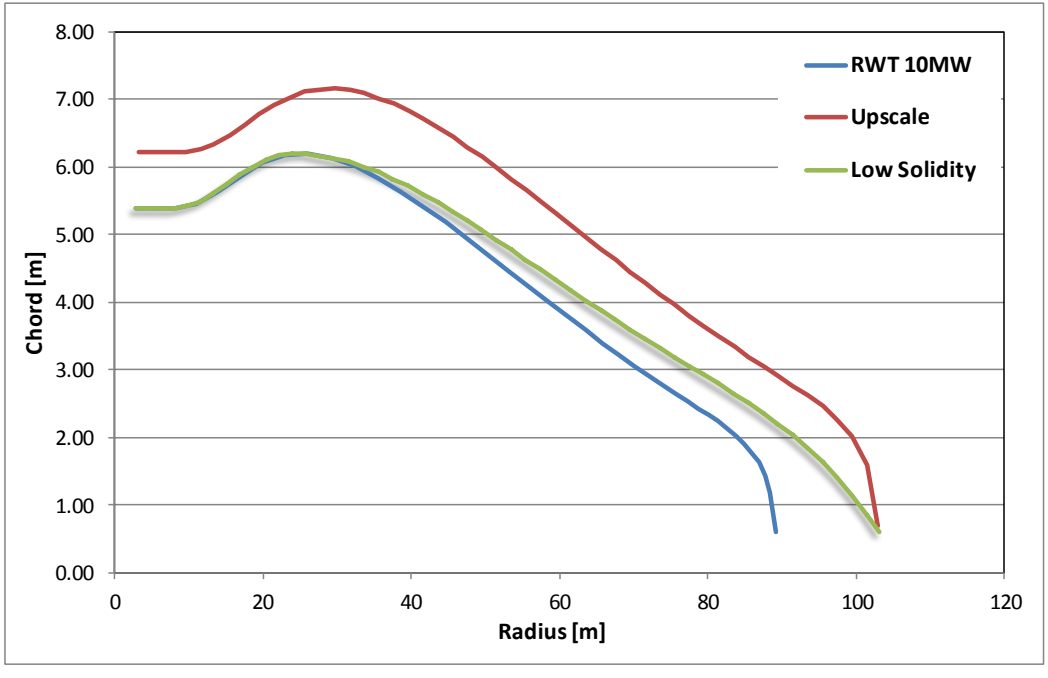


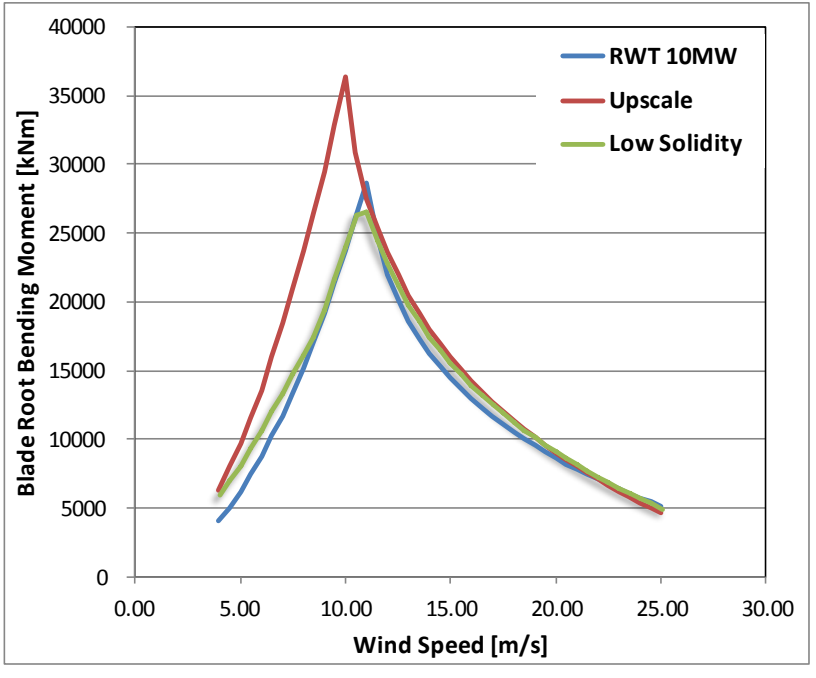


Upscaled by keeping c/r distribution constant for r/R.

Rotor Concepts and Parameters (3/7)

RWT 10MW → UPSCALE → LOW SOLIDITY

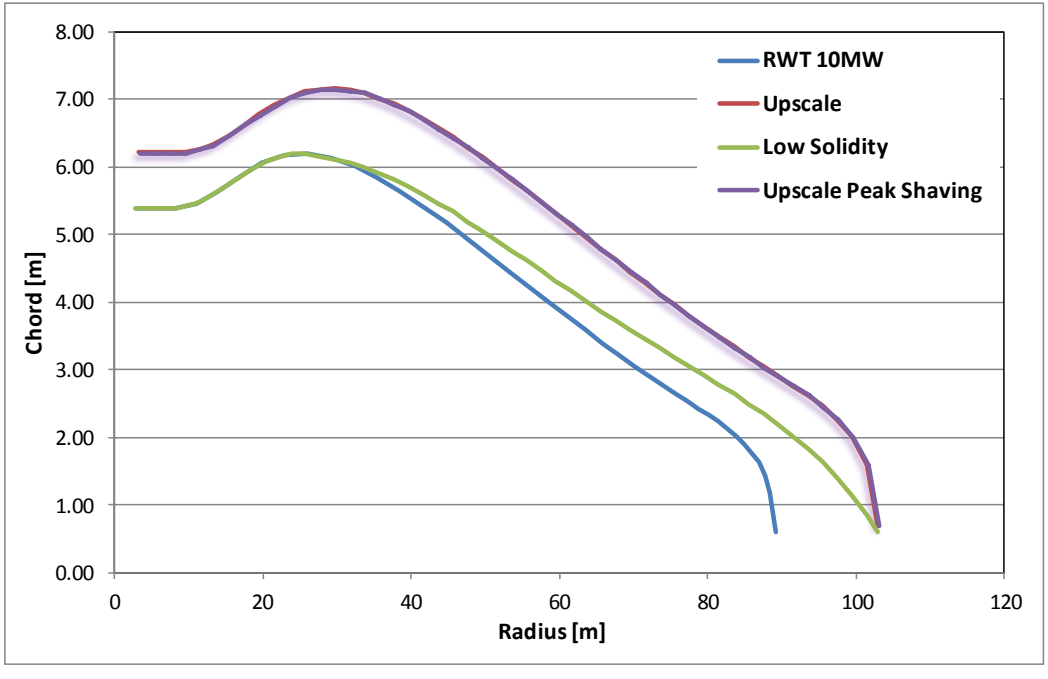


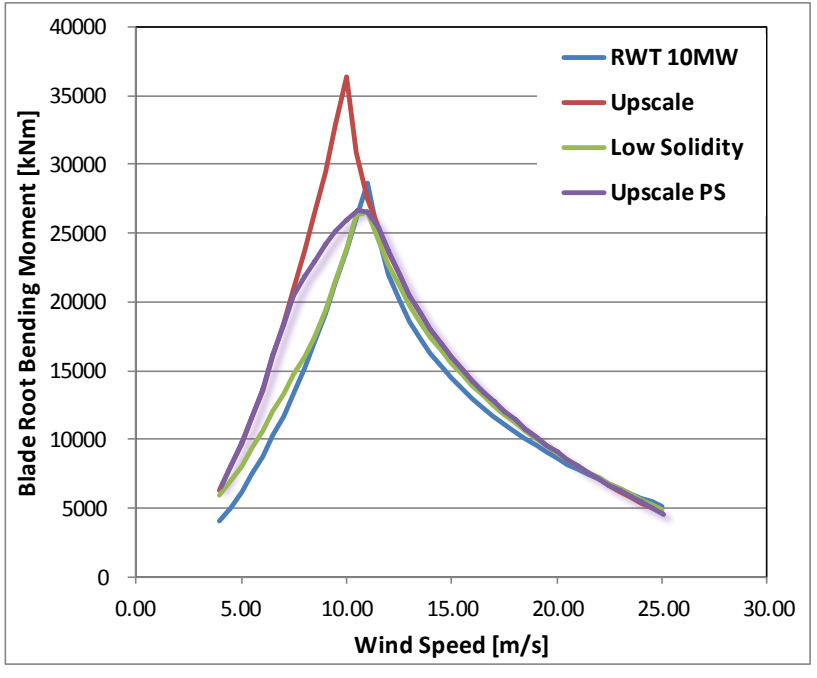


Solidity $\left(\sigma = \frac{Bc}{2\pi r} \right)$ *is decreased by averaging the chord lenght between Upscale and RWT, BRBM is reduced to RWT*

Rotor Concepts and Parameters (4/7)

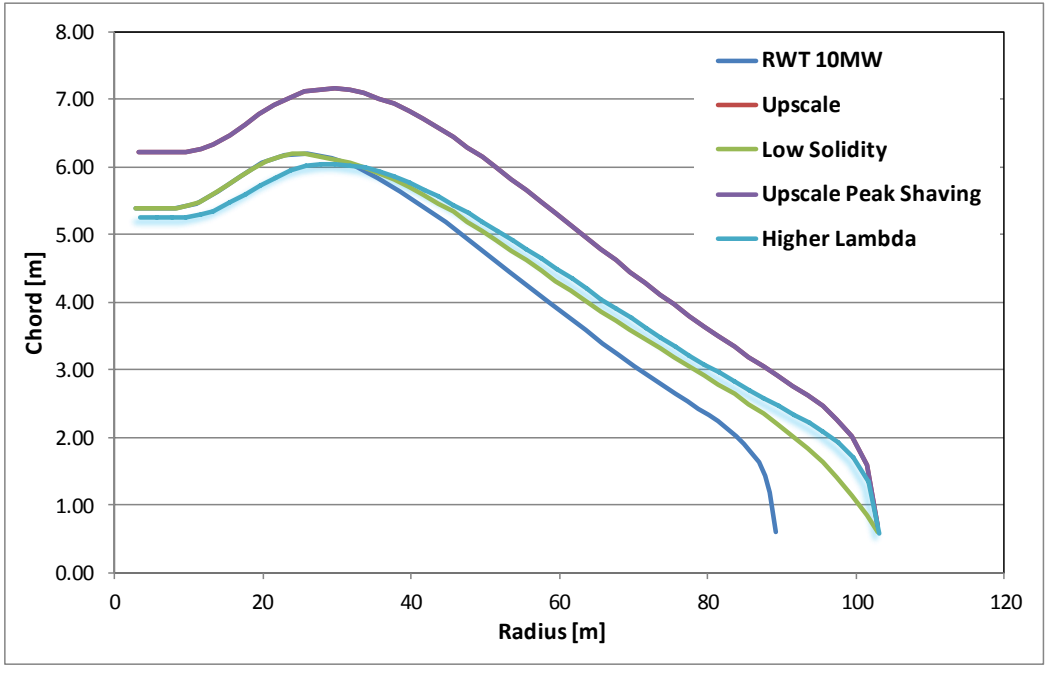
RWT 10MW | UPSCALE | LOW SOLIDITY | UPSCALE PS

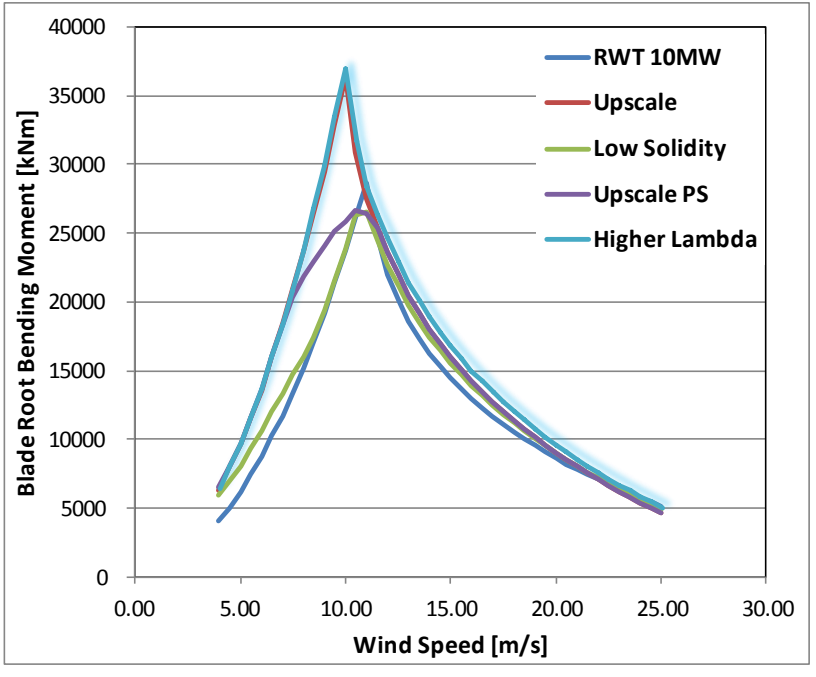




Rotor Concepts and Parameters (5/7)

RWT 10MW → UPSCALE → LOW SOLIDITY → UPSCALE PS → HIGHER LAMBDA

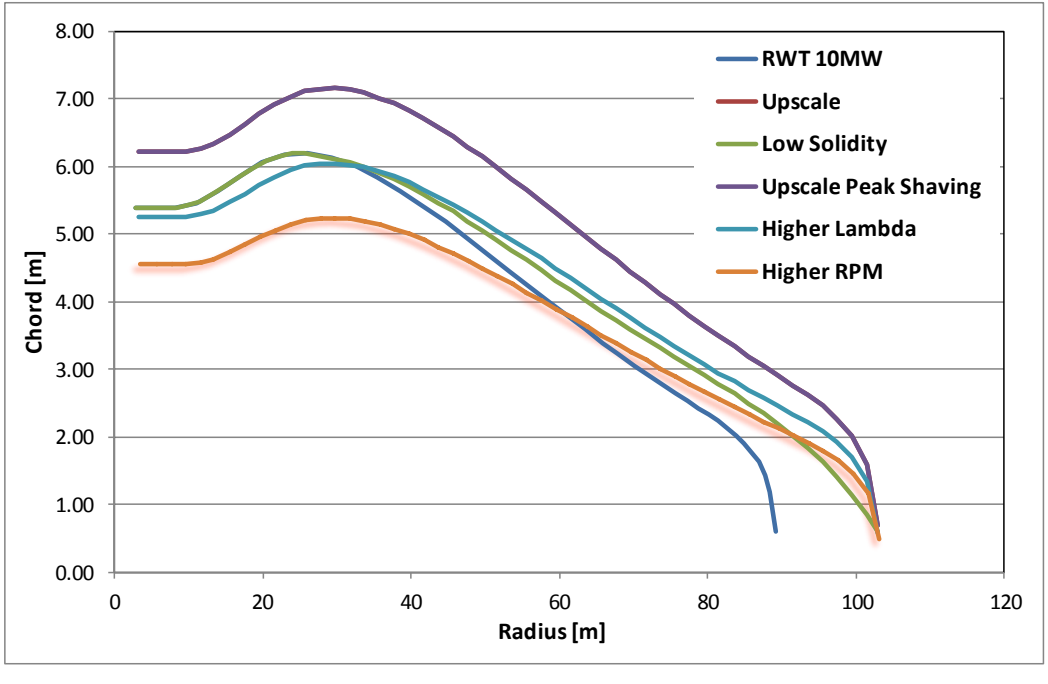


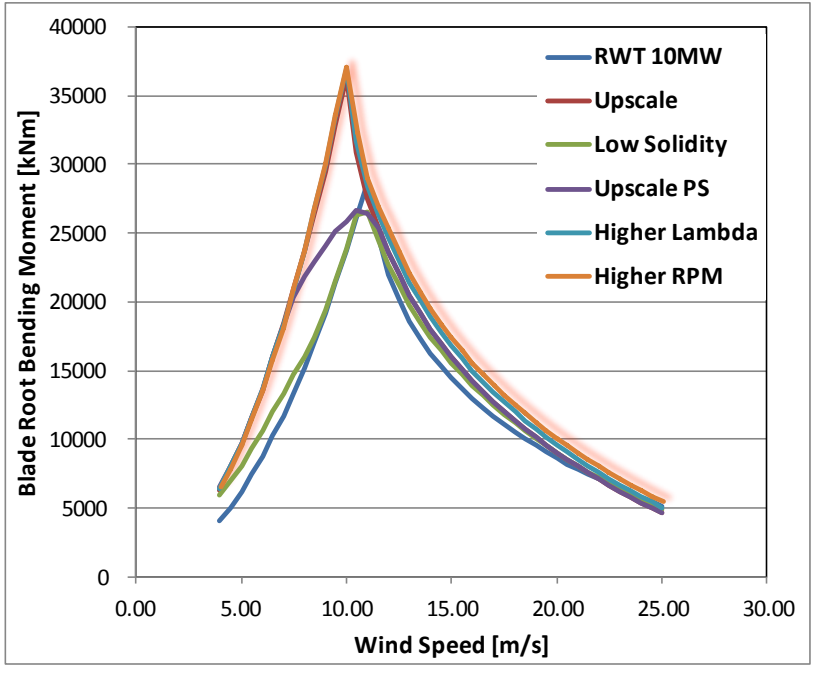


RPM is equal to RWT, lambda is increased to (aerodynamic) optimum lambda.

Rotor Concepts and Parameters (6/7)

RWT 10MW → UPSCALE → LOW SOLIDITY → UPSCALE PS → HIGHER LAMBDA → HIGHER RPM

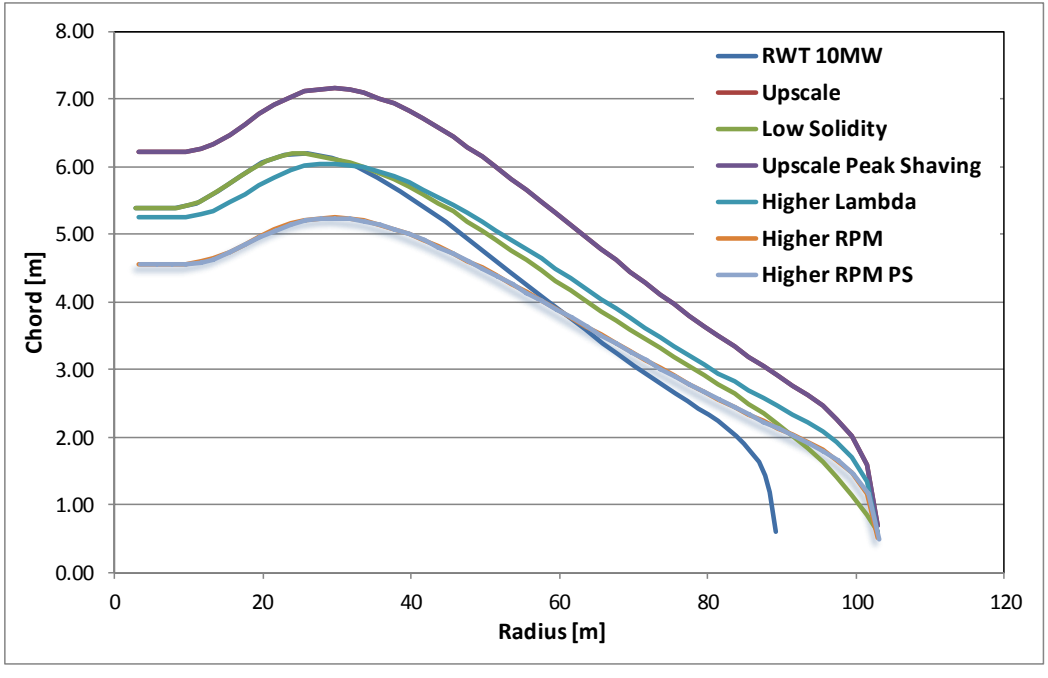


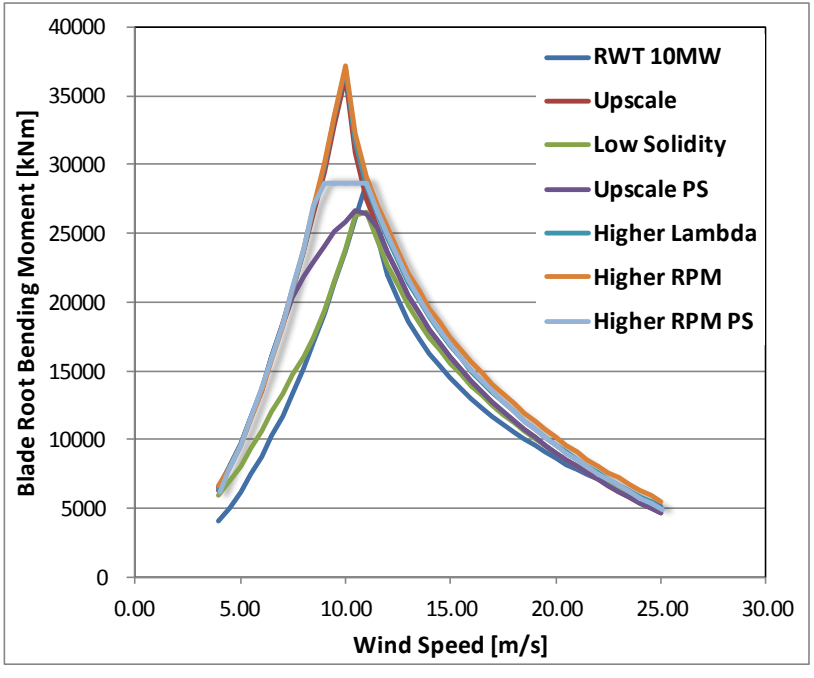


RPM is increased, tip speed is also increased. Chord is reduced proportionally.

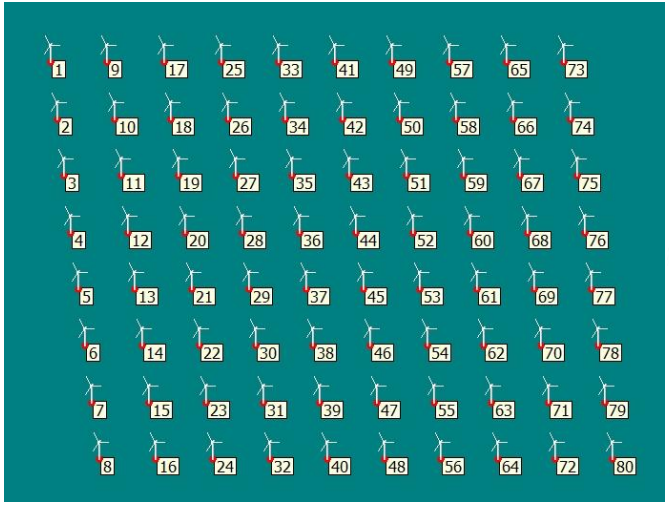
Rotor Concepts and Parameters (7/7)

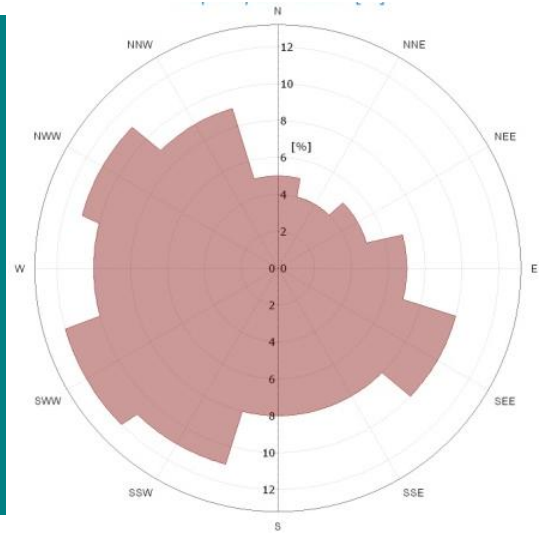
RWT 10MW | UPSCALE | LOW SOLIDITY | UPSCALE PS | HIGHER LAMBDA | HIGHER RPM | HIGHER RPM PS

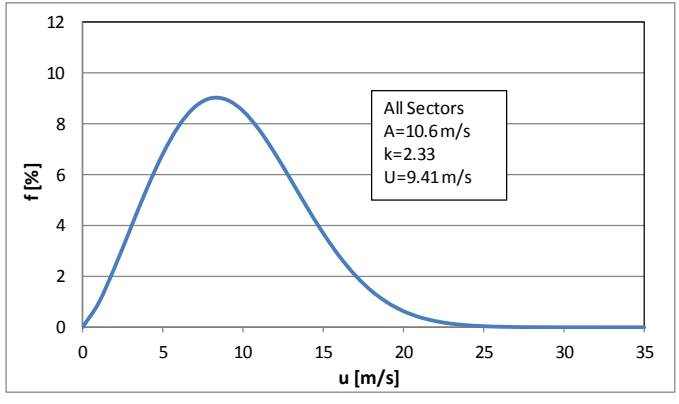


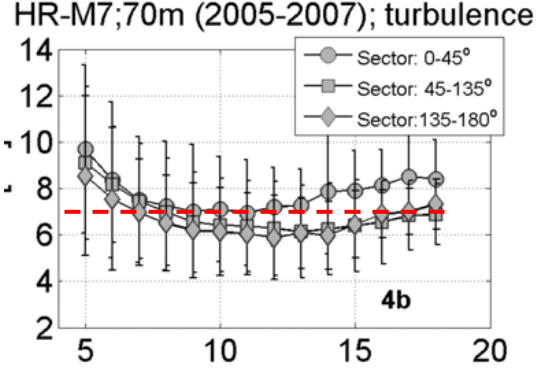


Horns Rev as Reference Wind Farm









- ***Wind data is from 2000.01 to 2003.12. Measured at 62m. Undisturbed. Provided by Kurt Hansen (DTU) on 08.01.2014***

- ***Turbulence intensity graph is taken from*** *'Hansen K. et all "The impact of turbulence intensity and atmospheric stability on power deficits due to wind turbine wakes at Horns Rev wind farm", Wind Energy Special Issue: Upwind, Volume 15, Issue 1, pages 183-196, January 2012'*

Analysis Conditions and Assumptions

Wind Turbine Level Analysis

- Rotor analysis are performed with BOT software
  - *ECN's state-of-the-art BEM based rotor design and optimisation tool*
- Steady state analysis are performed.
- Structural design or analysis are not included.
- All parameters are kept the same for all rotors except the ones that are changed.

Wind Farm Level Analysis

- Farmflow software is used.
  - *Parabolized NS Eqns*
  - *WTs are modelled with actuator disc*
  - *Wake is modelled with free wake method*
  - *Modified k-ε model is implemented.*
- Wind turbine locations are kept as original.
- Wind conditions are assumed to be the same at new hub height (119m).
- Analysis are performed for every 30 degrees of wind direction.
- Turbulence intensity = 0.07

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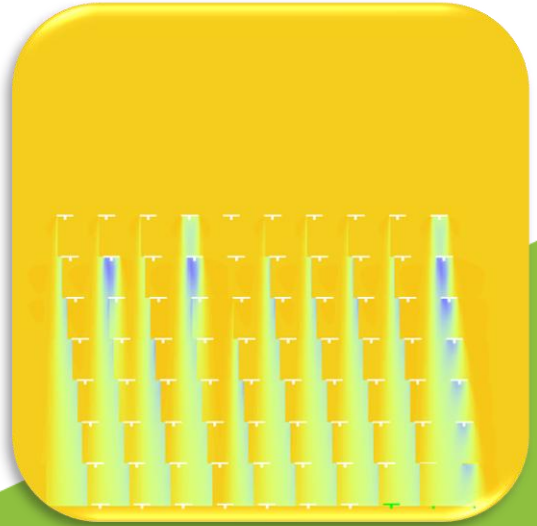
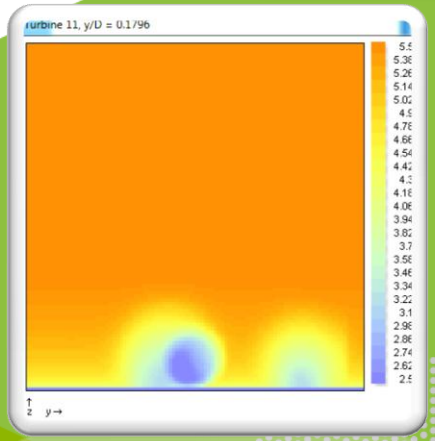
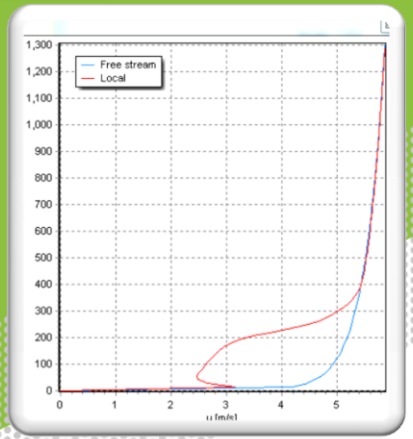
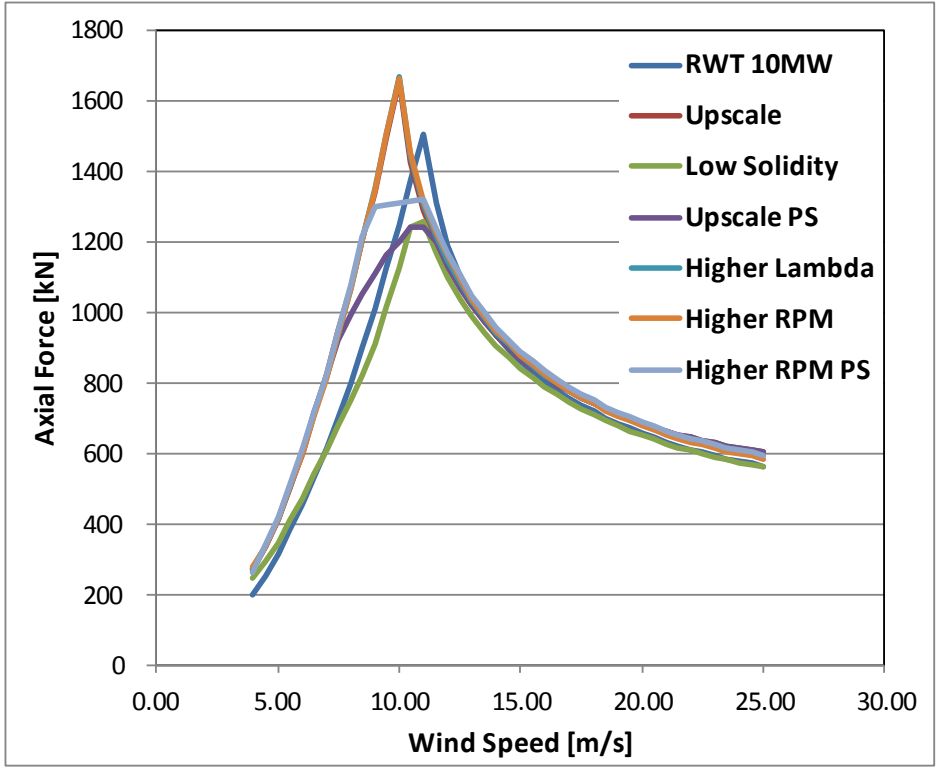
RESULTS

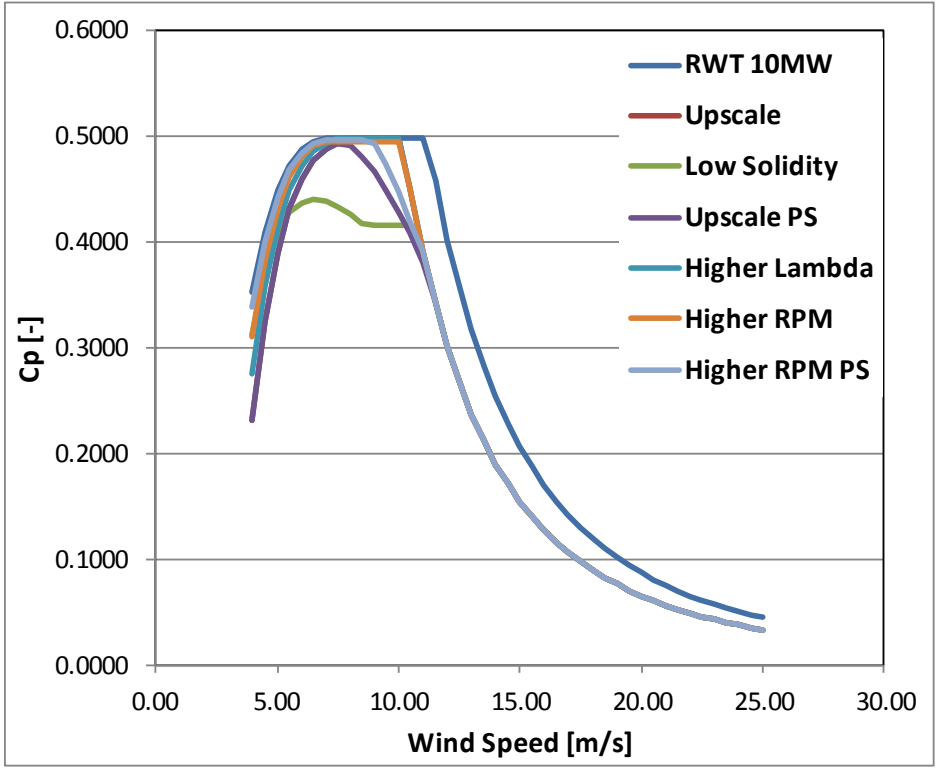



urbine 11, y/D = 0.1796

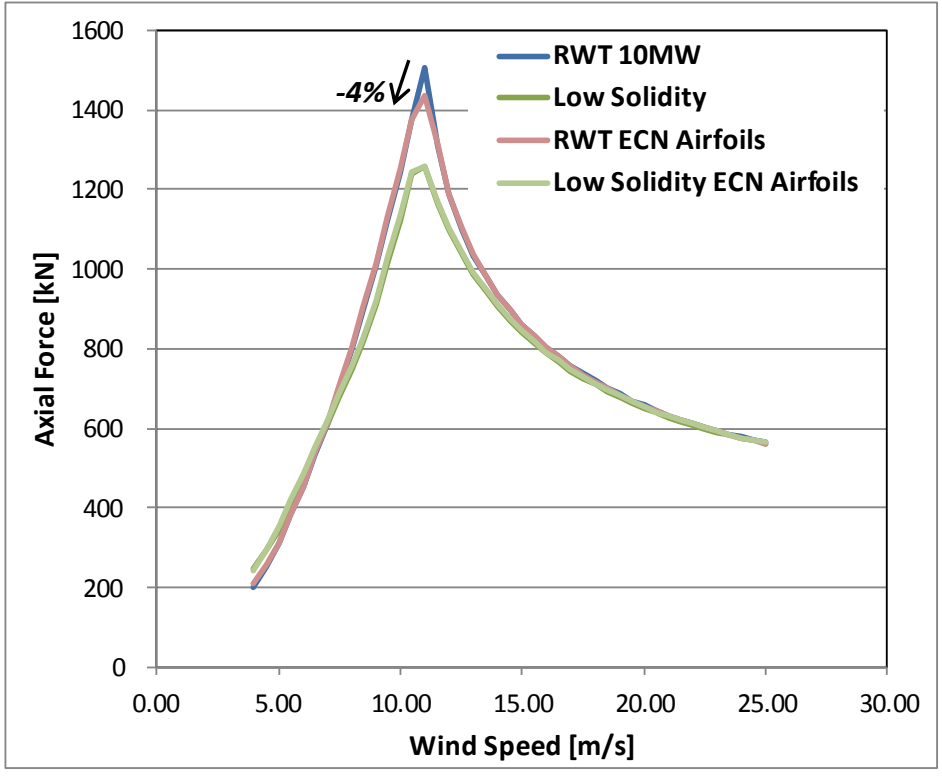

Free stream
Local
1,300
1,200
1,100
1,000
900
800
700
600
500
400
300
200
100
0
0
1
2
3
4
5

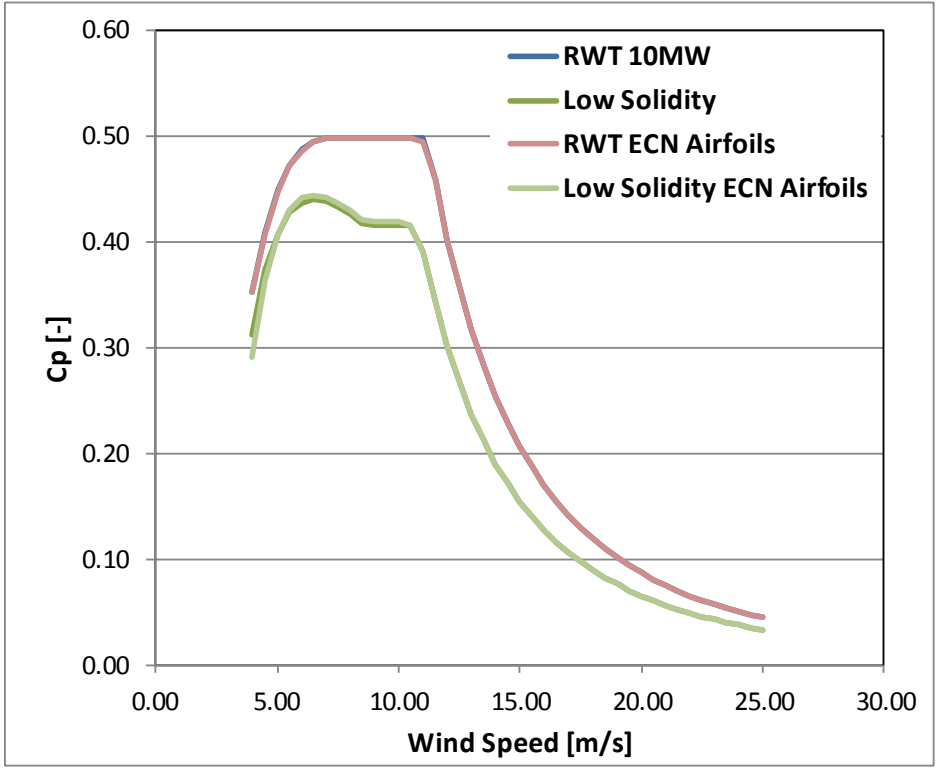
Wind Turbine Level



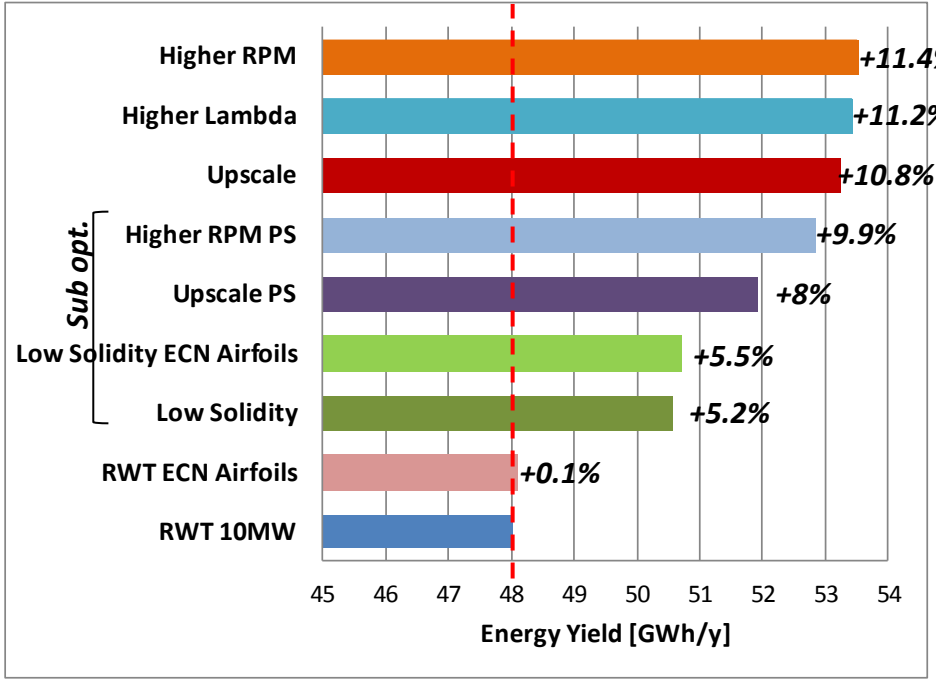


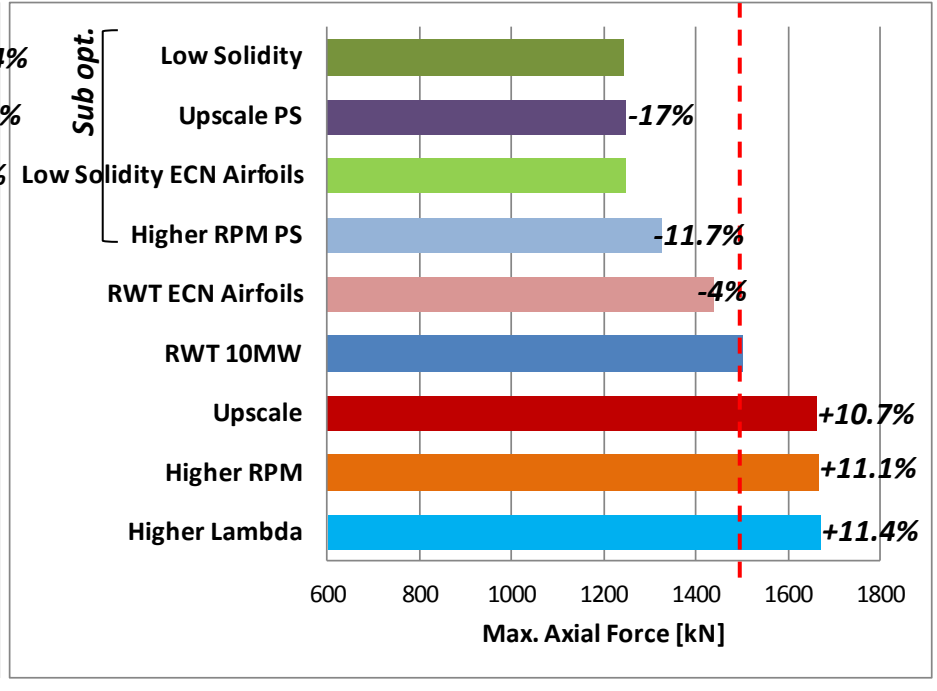
Wind Turbine Level – With ECN Airfoils



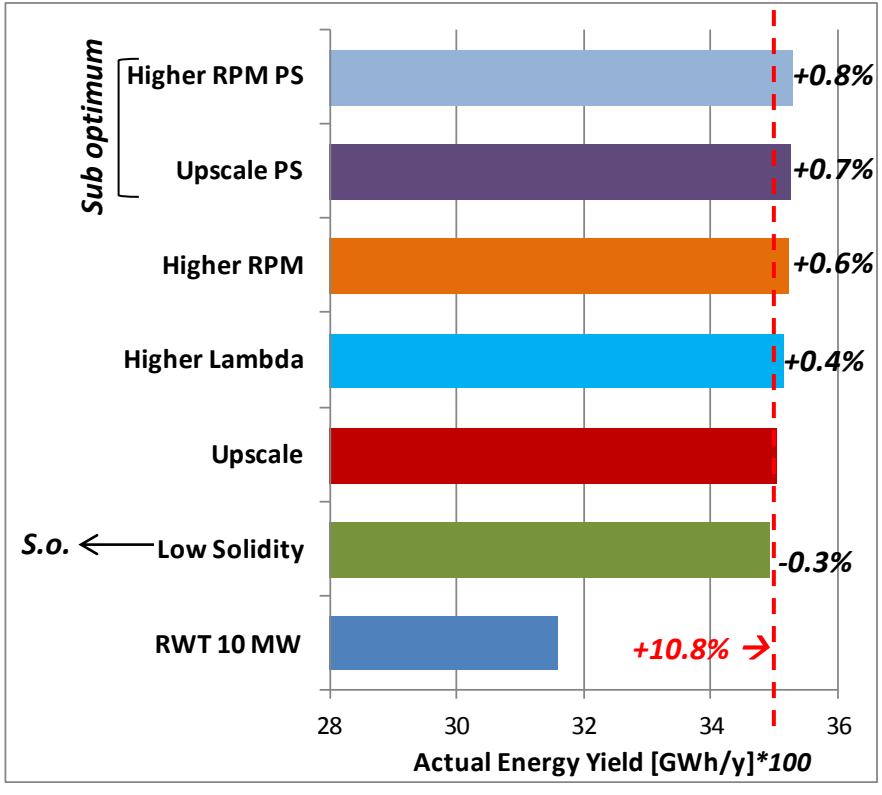


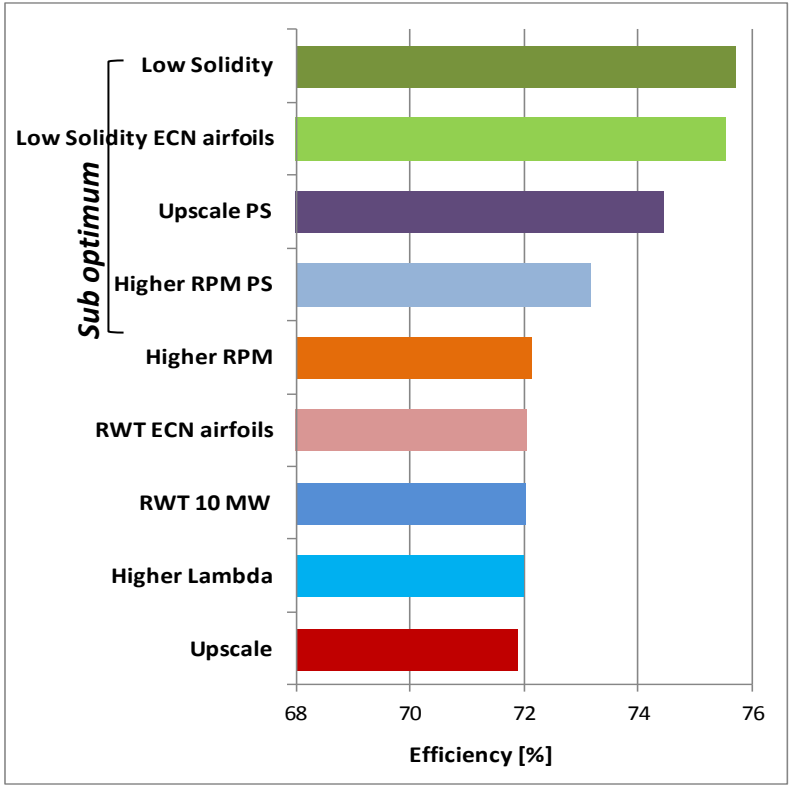
Wind Turbine Level Overall



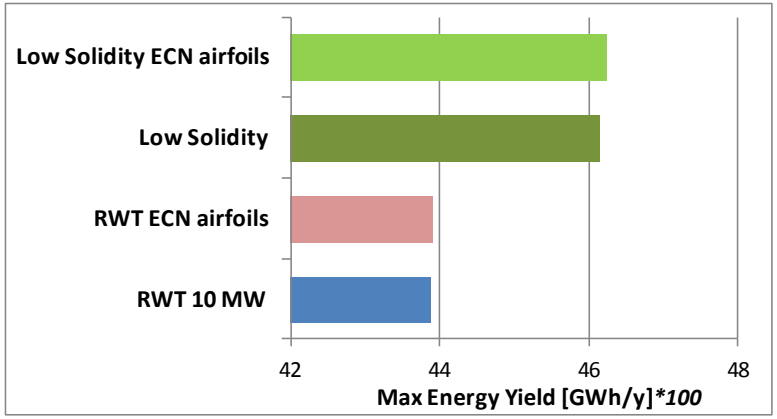


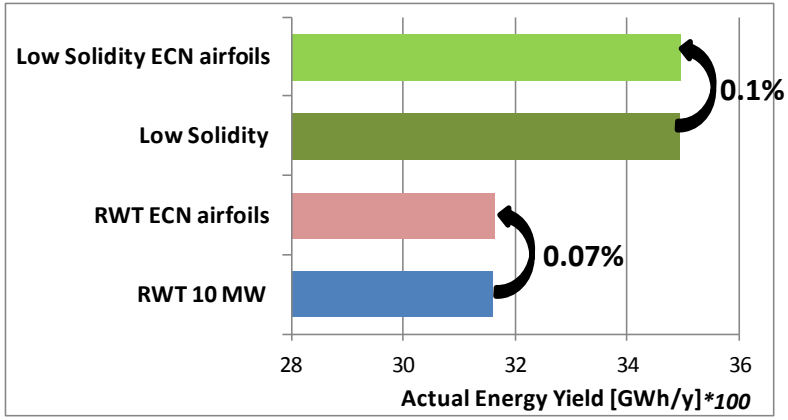
Wind Farm Level

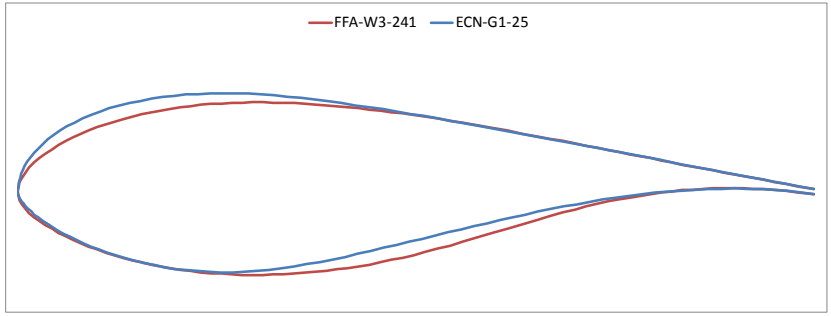


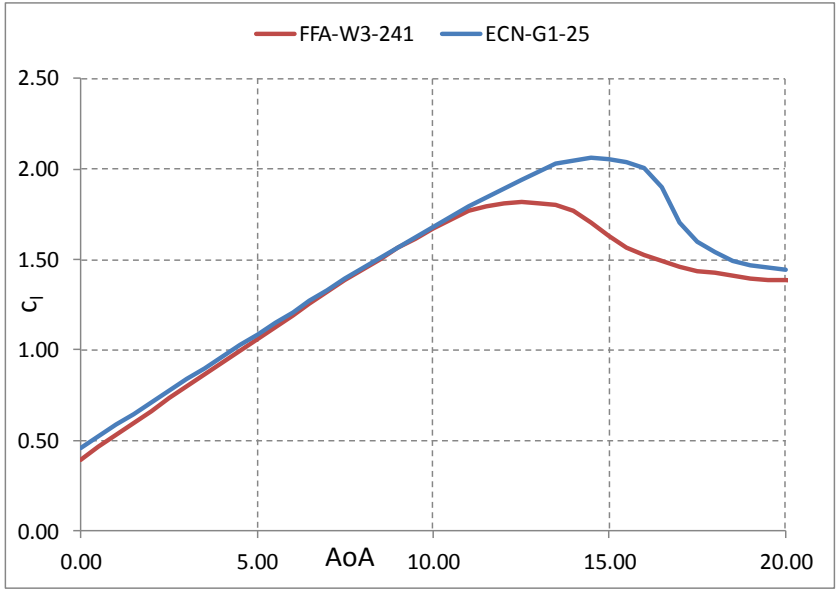


Wind Farm Level – Effect of Airfoils









Conclusions and Discussion

- Design trends in large rotors for offshore wind farms are evaluated by a parametrical study.
- Concepts are evaluated in a wind farm environment.
- These results are highly dependent on the chosen farm parameters. Nevertheless, they still indicate the potential of the integral design for future wind farms.
- Preliminary results for the current ECN airfoils do not lead to a large gain in farm power output. However the latest studies are aiming to help to reduce the wake losses and to improve the structural efficiency of the blade.

Most important Conclusion:

Airfoil design, turbine design and control, wind farm design and farm control should be done integrally in order to operate an offshore wind farm in most optimum conditions for the reduction of CoE.

Acknowledgements

- Edwin BOT (ECN)
- Kurt Hansen (DTU)

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www.innwind.eu

Thank you!

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Future Work

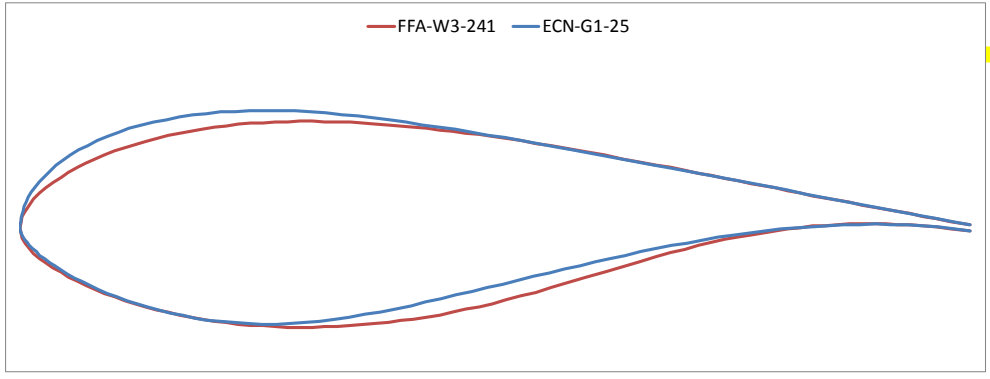
- Perform the same analysis with relatively increased distances between the wind turbines
- Design new airfoil families per concept, taking into account these results and performance in farm in general.
- Re-evaluate the rotor designs for site-specific conditions together with new airfoils.
- Putting the analysis results into ECN's cost models for the financial results
- Performing similar study for another wind farm with wind measurements at higher altitudes.
- Looking into details in rotor design.

Rotor Concepts and Parameters (1/8)

Concept name →	(1.)RWT	(2.)Upscale, (3.)Low Solidity, (4.)Upscale PS	(5.)Higher Lambda	(6.)Higher RPM, (7.)Higher RPM PS
Capacity [MW]	10	10	10	10
Tip speed	89.64	89.64	103.55	113.54
Lambda	7.50	7.50	8.66	9.50
rpm	9.60	8.31	9.60	10.53
radius	89.166	103	103	103
Power density	400.36	300.04	300.04	300.04

For the rest of the concepts ECN airfoils are applied to (1.), (3.);
(8.) RWT ECN Airfoils *(Power output is equal to RWT, loads are reduced)*
(9.) Low Solidity ECN Airfoils (*BRBM are equal)*

Effect of Airfoils – Looking back



Structural properties

	FFA-W3-241	ECN-G1-25
area	0.14020	**0.13970**
slen	2.11800	**2.13000**
skin Ixx/t	0.01350	**0.01360**
centroid Xc	0.38100	**0.36700**