A Parametric CFD Study Of Morphing Trailing Edge Flaps Applied On A 10 MW Offshore Wind Turbine

Universität Stuttgart

WINDFORS
Wind Energy
Research Cluster

AVATAR
AdVanced Aerodynamic Tools for lArge Rotors

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Eva Jost

e.jost@iag.uni-stuttgart.de

Thorsten Lutz, Ewald Krämer

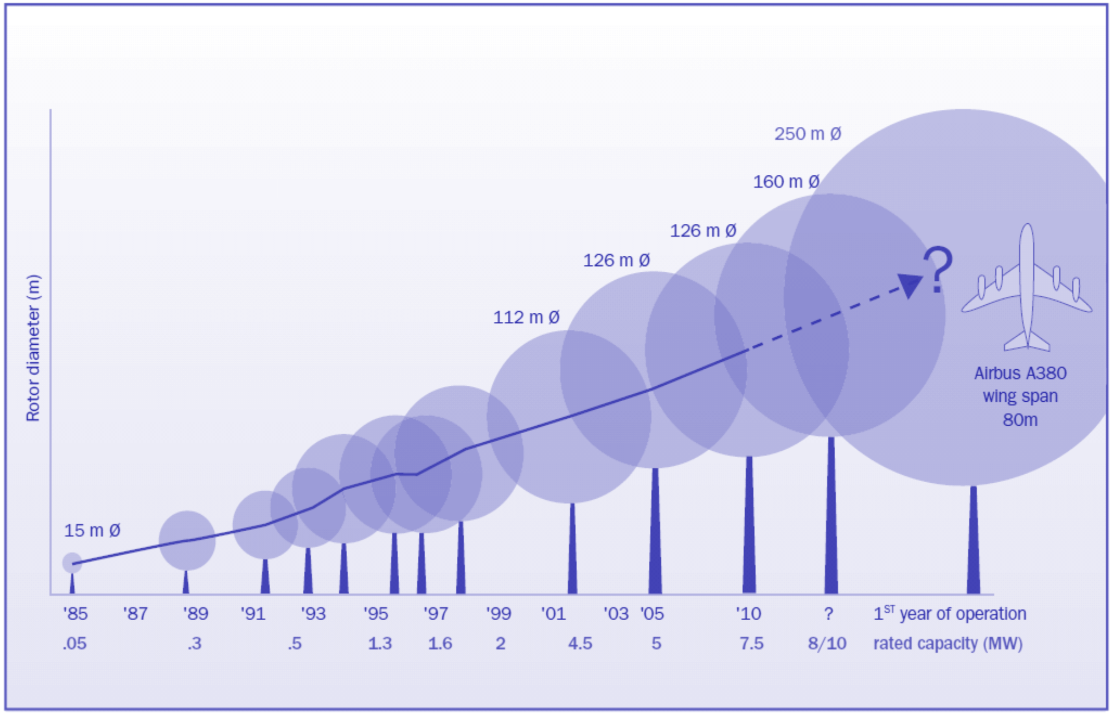
IAG
Institute of Aerodynamics
and Gasdynamics

Overview

1. Introduction
2. Numerical setup
3. Results
    1. 3D simulation results
    2. Comparison to 2D simulation results
    3. Comparison of different deflection angles
    4. Comparison of different wind speeds
4. Conclusion

Overview

Why trailing edge flaps?



Scaling rules

Parameter	Proportionality
Power	$\sim R^2$
Thrust	$\sim R^2$
Rotor mass	$\sim R^3$

Demand of new technologies to reduce loads, load variations and mass:

Structure, Control, Aerodynamics, …

Active trailing edge flaps

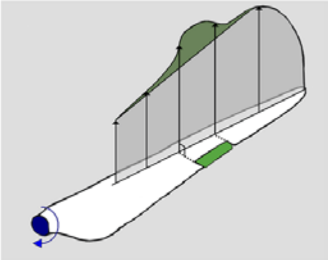
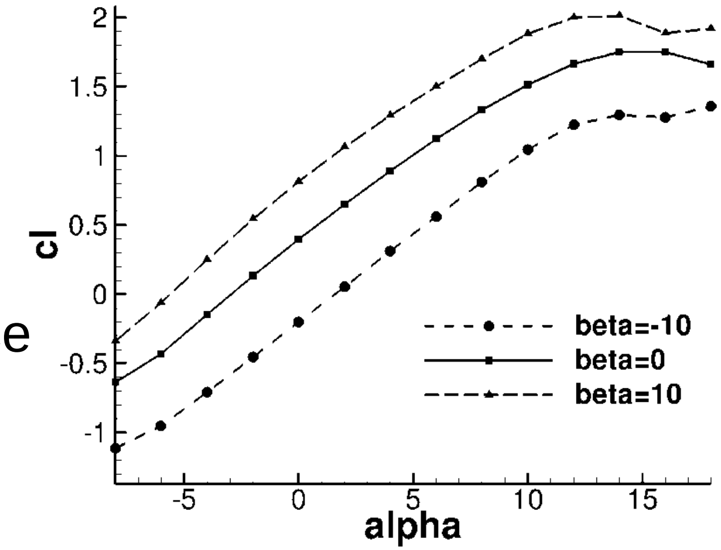


Figure top left: UpWind – Final report, March 2011, www.upwind.eu
Figure bottom right: http://www.renewableenergyfocus.com/view/7457/wind-turbine-controllable-rubber-trailing-edge-flap-tested/

Functioning

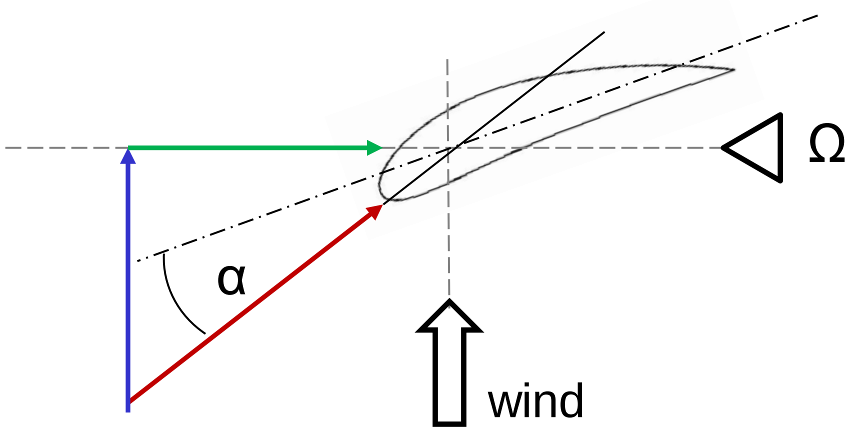


Reduction of dynamic load variations due to:

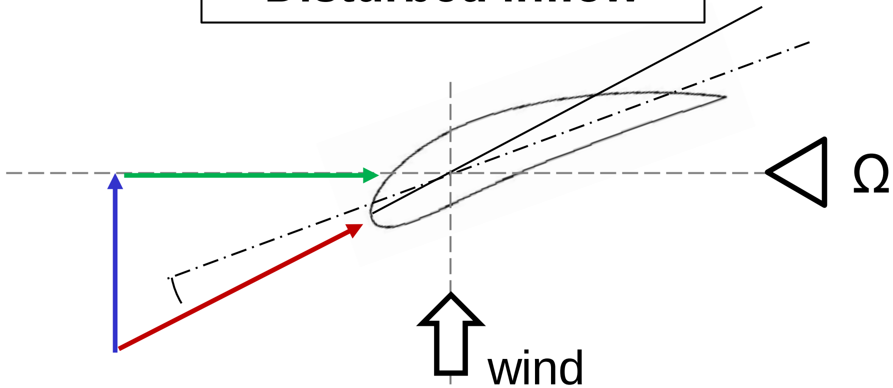
- Tower shadow
- Atmospheric boundary layer and turbulence
- Yawed inflow

Basic functioning:

Undisturbed inflow



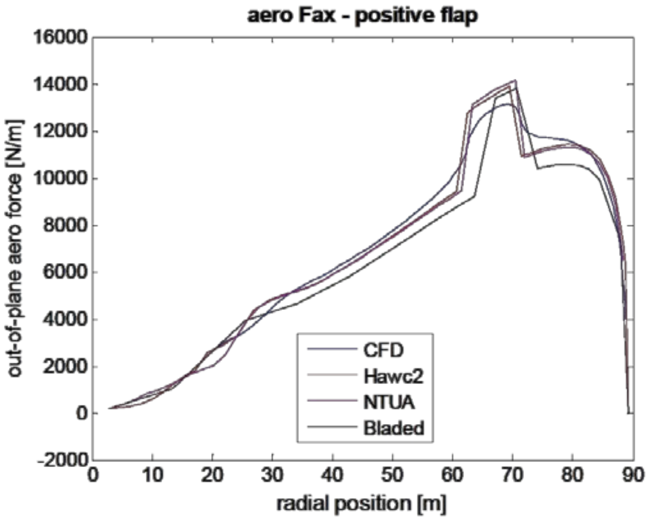
Disturbed inflow

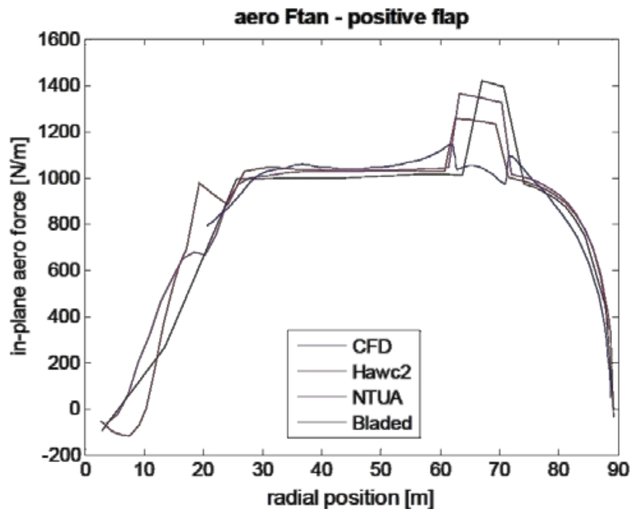


approach velocity c, wind velocity v, rotational velocity u=ωR

Previous work

- Prove of concept based on BEM and vortex methods
- Fatigue load reduction of blade root bending moment
  - BEM method ~ 18 %[1] ,Vortex method ~ 30 %[2]
- Difficulty: Modeling of steady and unsteady viscid 3D aerodynamics





Next step: CFD simulation as high fidelity method

[1] S. Navalkar, J. van Wingerden, E. van Solingen, T. Oomen, E. Pasterkamp and G. van Kuik, “Subspace predictive control to mitigate periodic loads on large scale wind turbines,“ *Mechatronics* , vol. 24, pp. 916-925, February 2014.

[2] V. Riziotis and S. Voutsinas, “Aero-elastic modelling of the active flap concept for load control,“ in *Proceedings of the EWEC*, Brussels, Belgium, 2008

Figures: E.Jost, A. Barlas, V. Riziotis, S.T. Navalkar, “Innwind Report D2.3.2”, www.innwind.eu

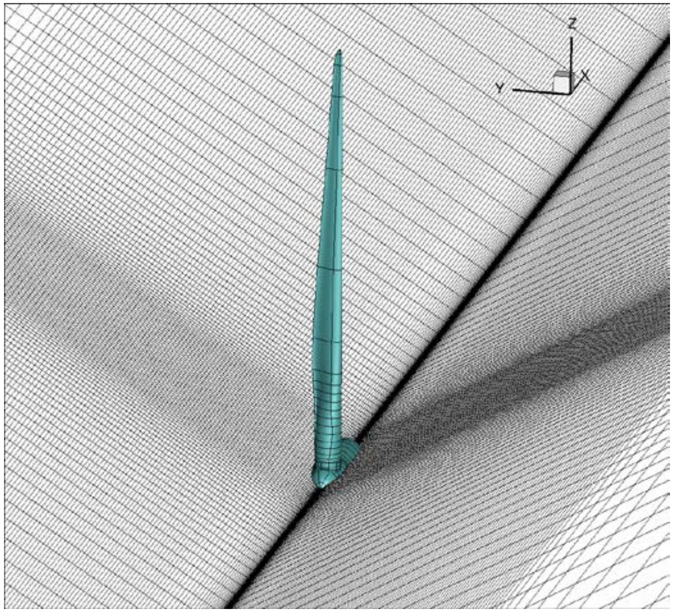
Objectives

Investigate the influence of steady 3D effects:

Simulation of the pure rotor with different flap configurations (varying chord and radial extension)

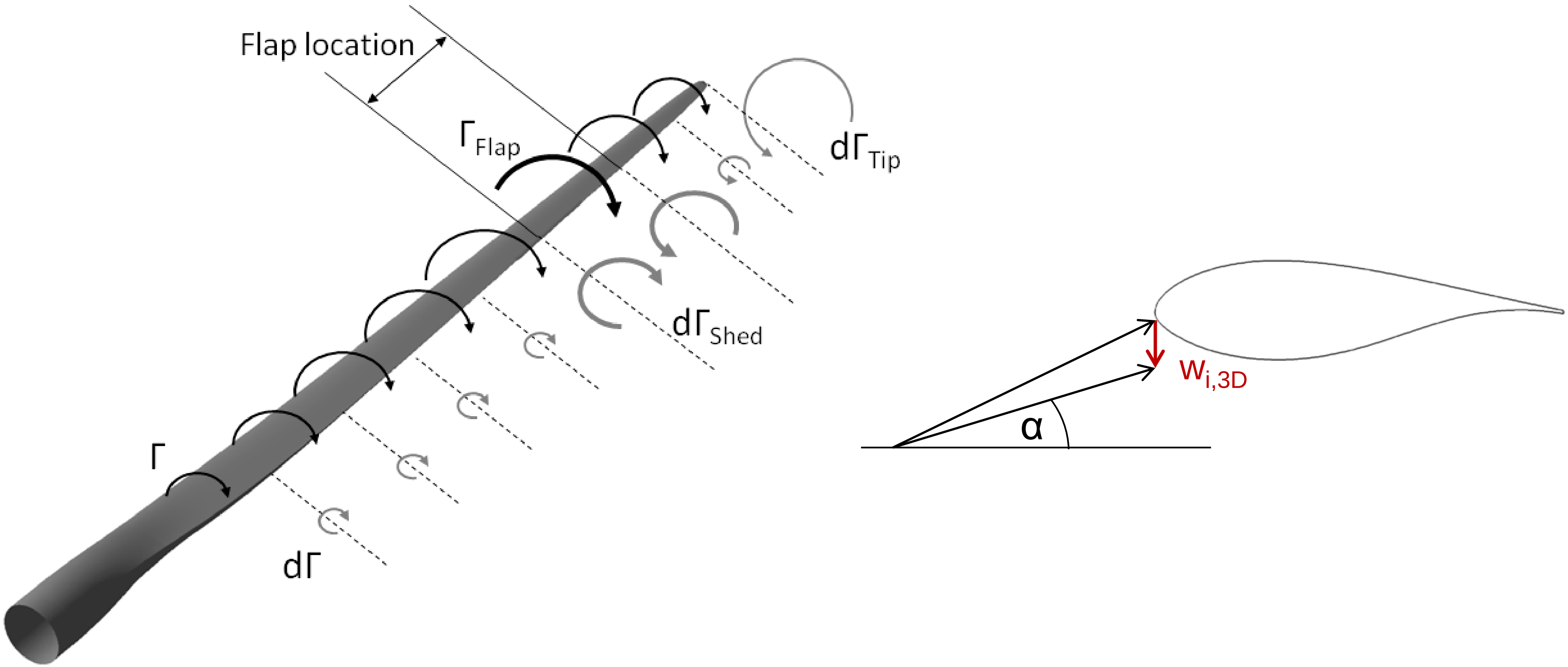
→ Comparison to 2D airfoil simulations

Selected rotor: DTU 10 MW reference wind turbine



3D aerodynamic effects

Steady deflection, beta positive:



Overview

Simulation process chain

Mesh generation

Gridgen/Pointwise

Automesh: Automatic parameterized blade meshing

CFD code

FLOWer:
- developed by DLR[1]
- Compressible block structured finite-volume solver
- Moving/overlapping meshes (CHIMERA)

Extensions with regard to wind turbine application
- Dirichlet boundary condition for turbulent inflow
- **Grid deformation based on radial basis functions**
- Load integration during runtime

Post-processing

Load integration

Angle of attack extraction

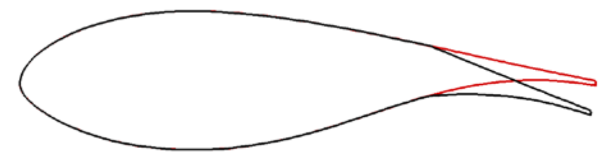
FFT analysis

[1] N. Kroll and J. Fassbender, MEGAFLOW – Numerical Flow Simulation for Aircraft Design, Berlin/Heidelberg/New York: Springer Verlag, 2002.

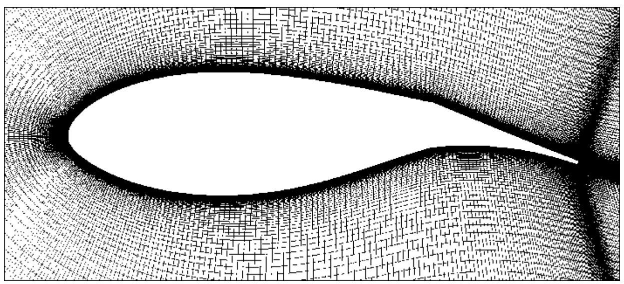
Extension for trailing edge flaps

- Mesh deformation based on radial basis functions[1]

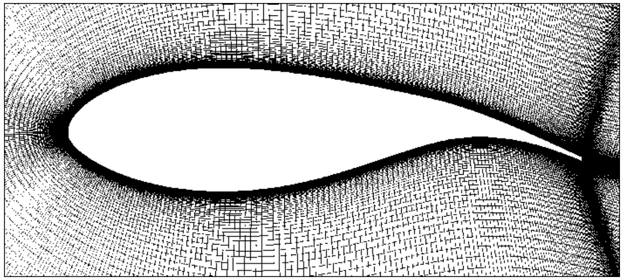
2D simulation with flaps:



Baseline airfoil
Deformed airfoil

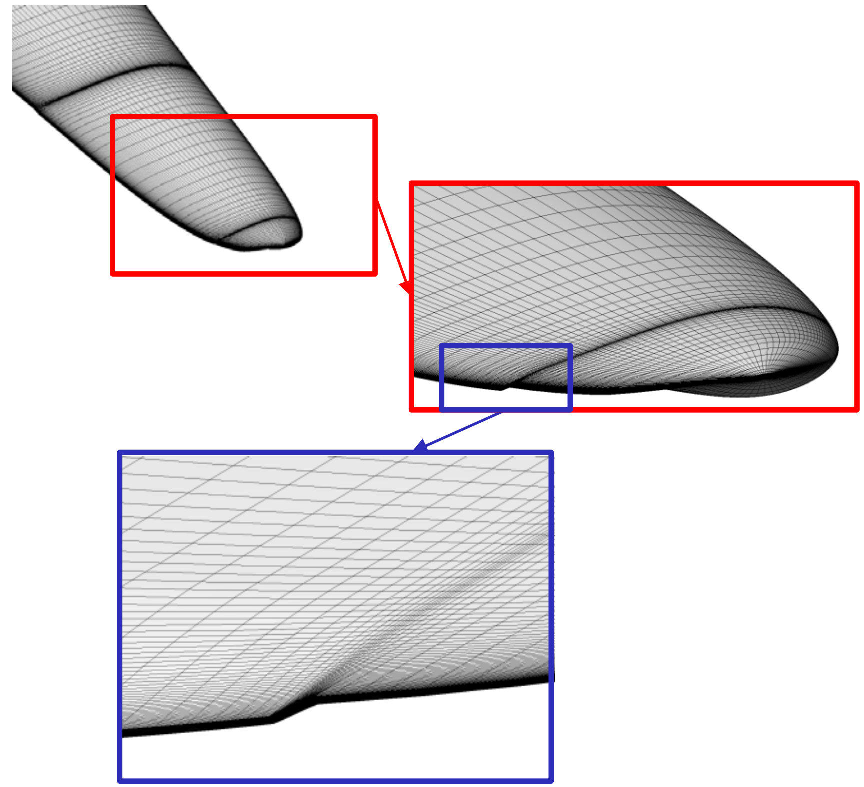


Rigid flap



Morphing flap

3D simulation with flaps:



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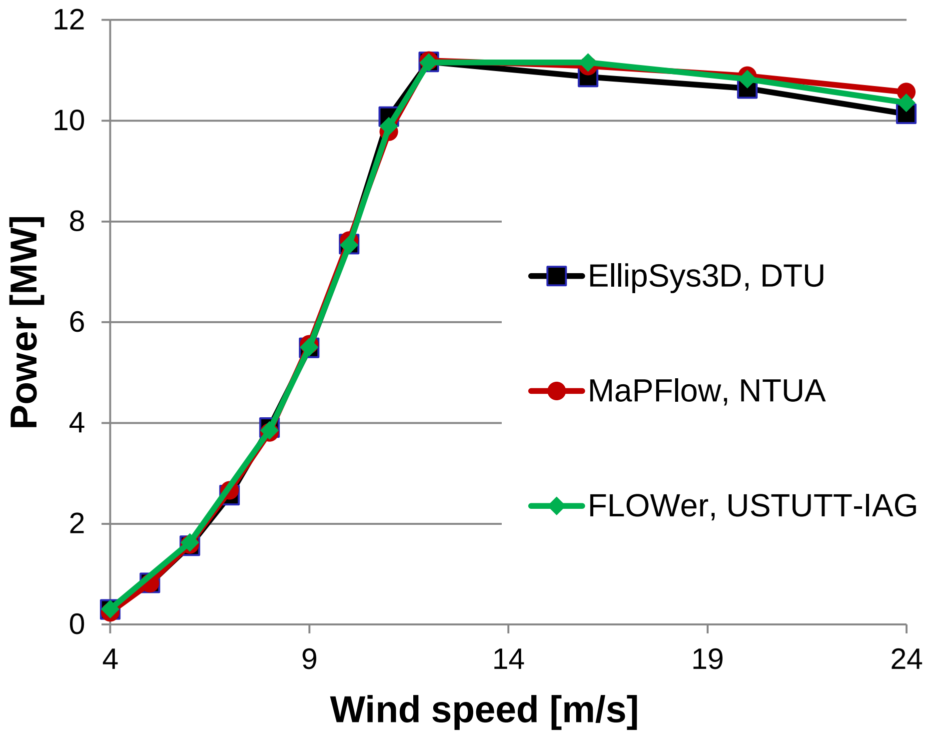
[1] M. Schuff, P. Kranzinger, M. Keßler and E. Krämer, "Advanced CFD-CSD coupling: Generalized, high performant, radial basis function based volume mesh deformation algorithm for structured, unstructured and overlapping meshes," in *40th European Rotorcraft Forum*, Southhampton, 2014.

Simulation setup - Baseline

Baseline without trailing edge flaps:

- Setup used in the code-to-code validation within FP7 project AVATAR (Deliverable 2.3[1])
- 120°-model with periodic boundary conditions
- 4 different grids: blade, spinner, nacelle and background
- Turbulence model: Menter SST
- Fully turbulent boundary layer

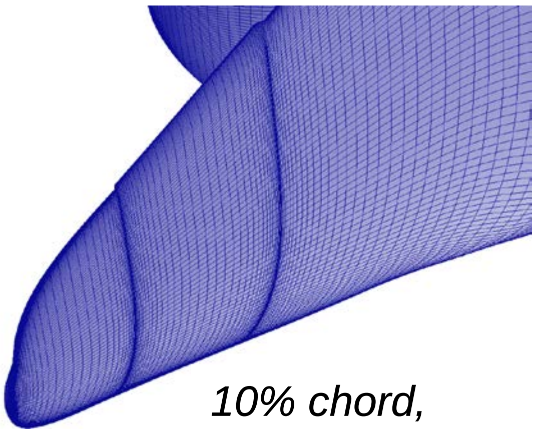


[1] and plot modified from: N. Sørensen, M. Hansen, N. Garcia, L. Florentie, K. Boorsma, S. Gomez-Iradi, J. Prospathopoulus, G. Barakos, Y. Wang, E. Jost and T. Lutz, "AVATAR Deliverable 2.3: Power Curve Predictions," 1 June 2015. [Online]. Available: http://www.eera-avatar.eu/fileadmin/mexnext/user/report-d2p3.pdf.

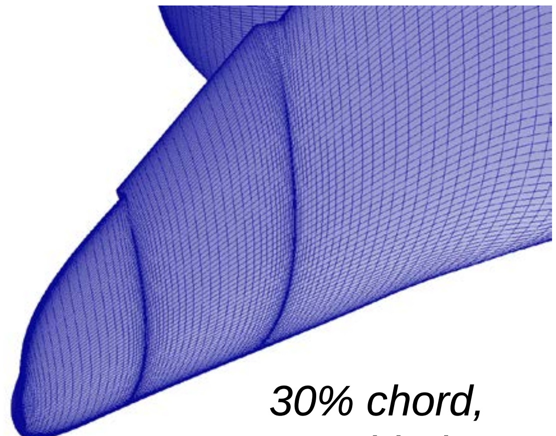
Simulation setup with trailing edge flaps

Simulated flap configurations:

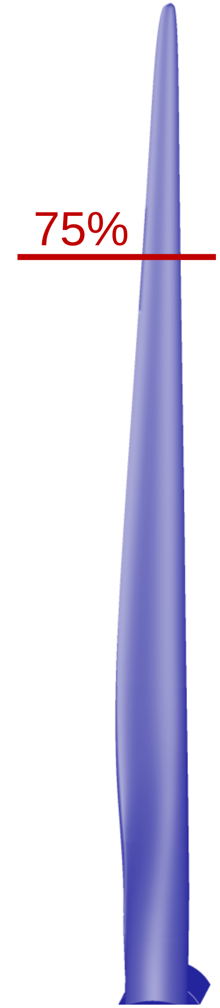
- 4 different flap configurations: Combination of two different chord extensions (10% , 30%) with two radial extensions (10% and 20%)
- Flap centered at 75% blade radius (~ 66.86m)
- Deflection angle β=+/-10°



10% chord,
20% blade span



30% chord,
20% blade span

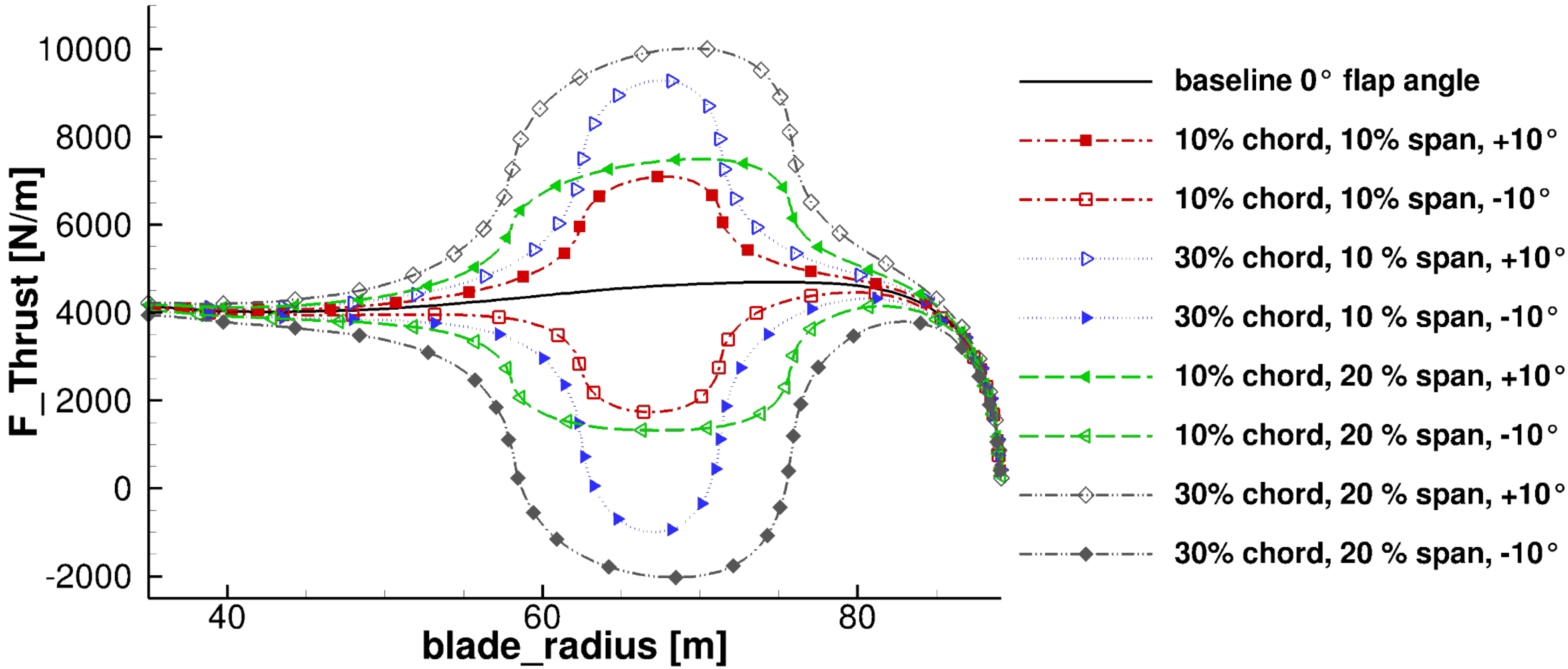


Operational conditions:

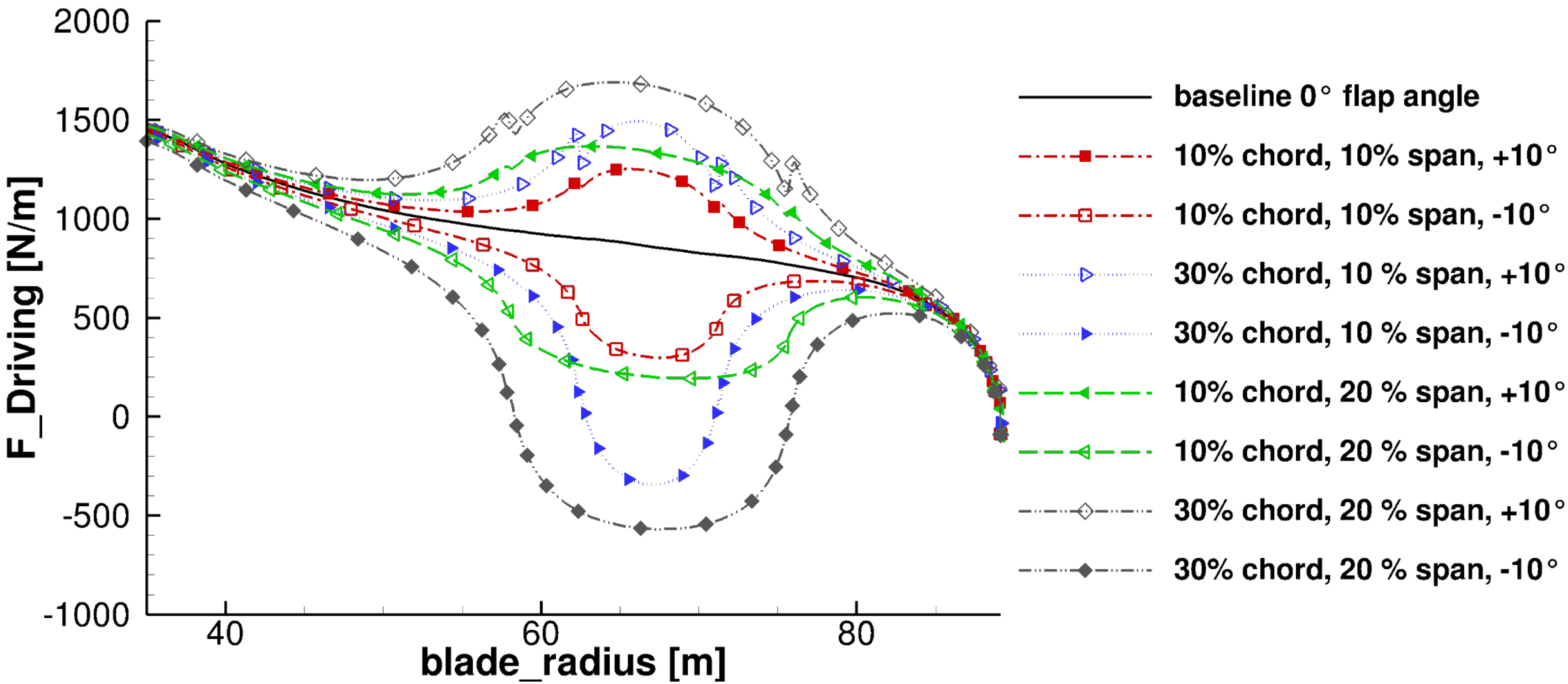
- 15 m/s wind speed, 10.96° pitch angle, 9.6 rpm

Overview

Radial thrust +/-10° deflection angle



Radial driving force +/-10° deflection angle



Comparison of lift coefficients 3D at mid flap position

- Extraction of the angle of attack and lift coefficient based on the reduced axial velocity method[1]

	No flap	β=10°, 20% blade span		β=10°, 10% blade span	
		10% chord	30% chord	10% chord	30% chord
c_l	0.488	0.788	1.05	0.751	0.979
$\Delta c_{l,\beta=0}$	-	0.3	0.562	0.263	0.491

- Results for β=-10° are comparable and will be presented in the conference paper.

[1] J. Johansen, N. Sørensen, "Aerofoil characteristics from 3D CFD Rotor Computations", Wind Energy, vol. 7, pp 283-294, 2004

Comparison of aerodynamic coefficients 2D/3D

- Simulation of the airfoil at mid flap position (75 % radius, FFA-w3-241) in 2D
- Conditions extracted from 3D simulation: Re=15.6e6, Ma=0.2, α=1.13

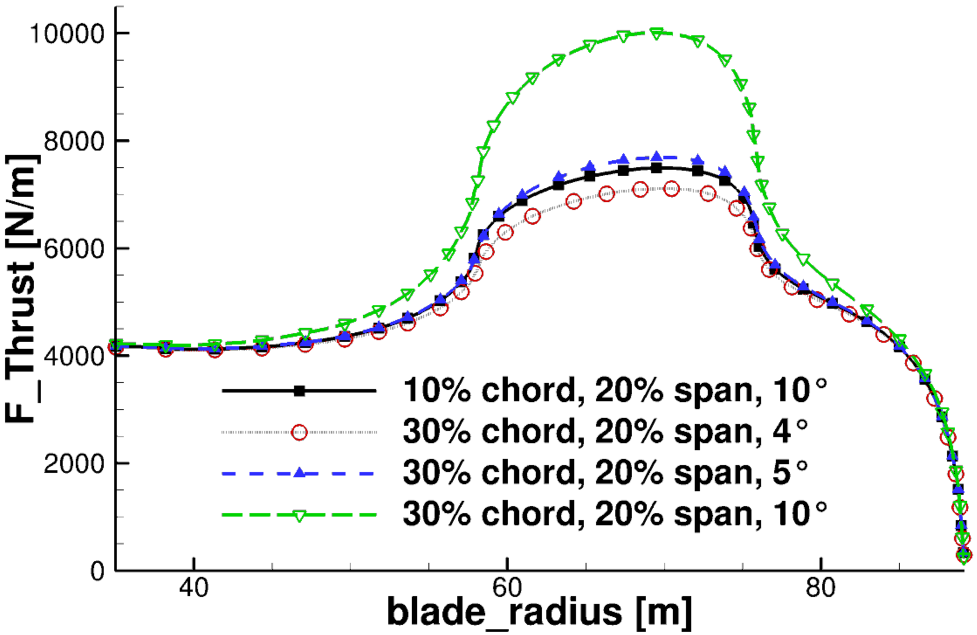
→ **Comparison of c_l and $\Delta c_{l,\beta=0}$**

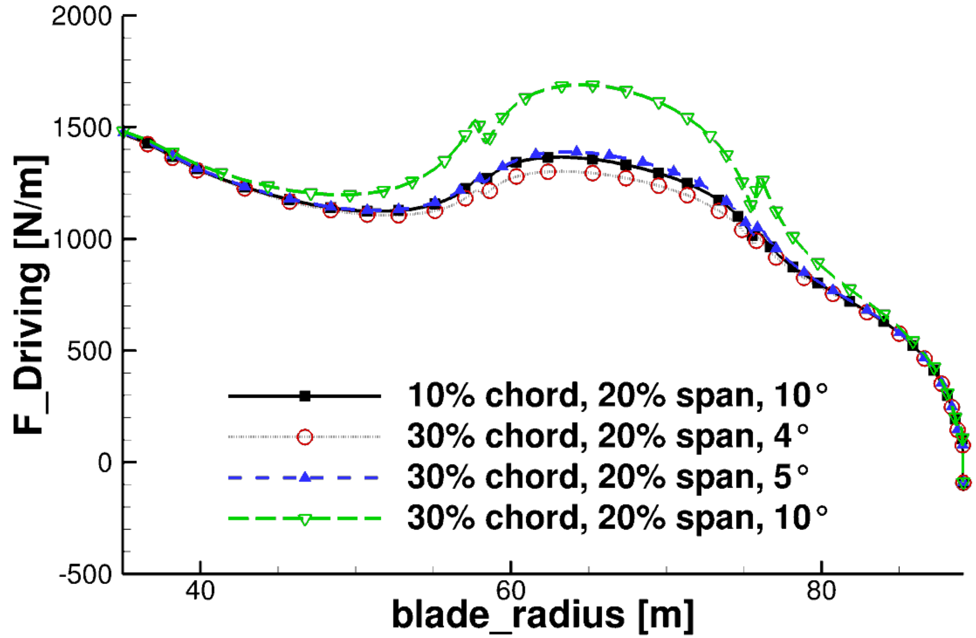
	No flap	**β=10**	
		10% chord	30% chord
$c_{l,2D}$	0.483	0.859	1.198
$\Delta c_{l,\beta=0,2D}$	-	0.376	0.715
$\Delta c_{l,3D,10\%span}/\Delta c_{l,2D}$	-	**70 %**	**69 %**
$\Delta c_{l,3D,20\%span}/\Delta c_{l,2D}$	-	**80 %**	**79 %**

- Results for β=-10° are comparable and will be presented in the conference paper.

Adaption of deflection angle

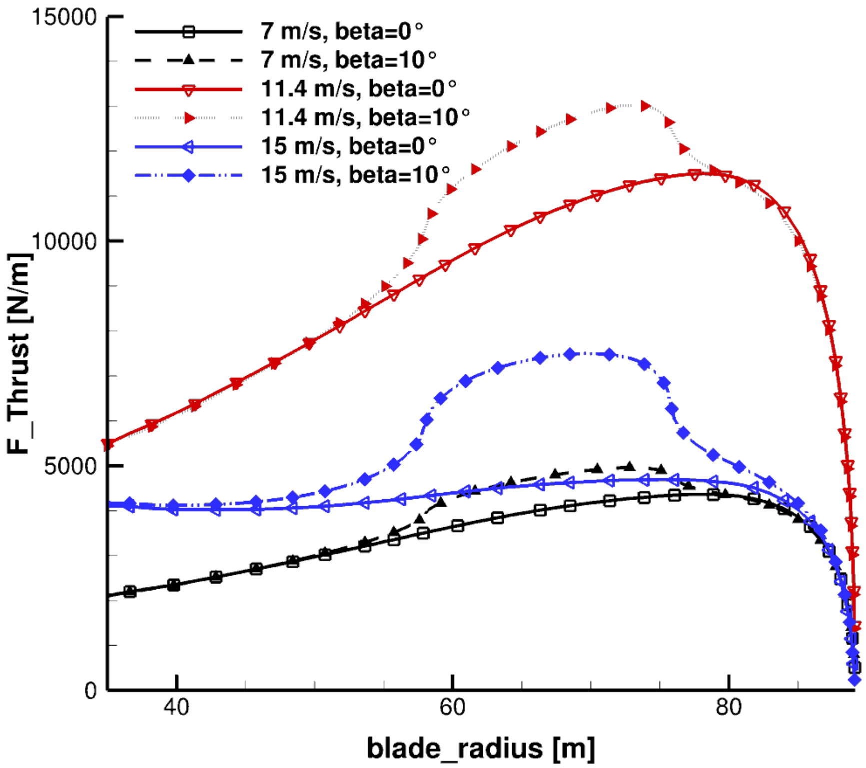
20 % blade span:

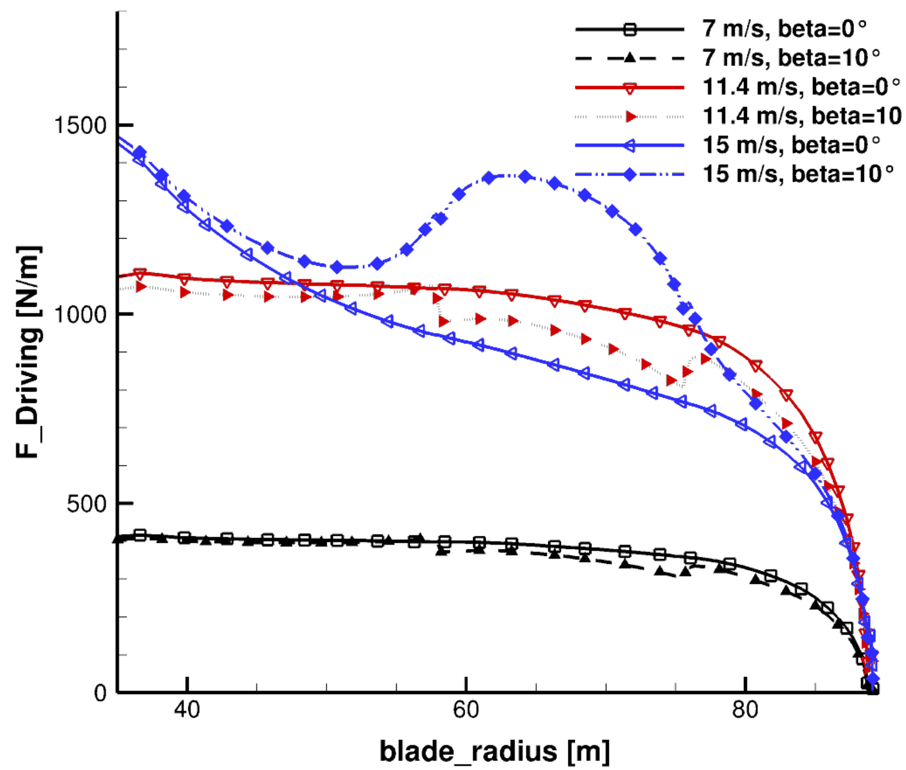




Different wind speeds

20 % blade span, 10% chord:





Overview

Conclusion

- 3D effects play an important role on trailing edge flaps and reduce their efficiency.
- Up to 35 % reduction of the lift variation compared to the 2D airfoil case have been found.
- A longer extension along the blade span is thus favorable.
- Trailing edge flaps are more efficient at higher wind speeds.

Outlook

- Unsteady effects (Theodorsen theory)
- Simulation of the full turbine

Thank you for your attention.
Questions?

WindForS
Wind Energy
Research Cluster

University of Stuttgart
Germany

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AdVanced Aerodynamic Tools for lArge Rotors