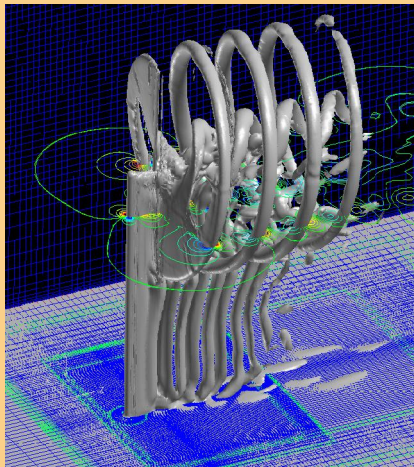


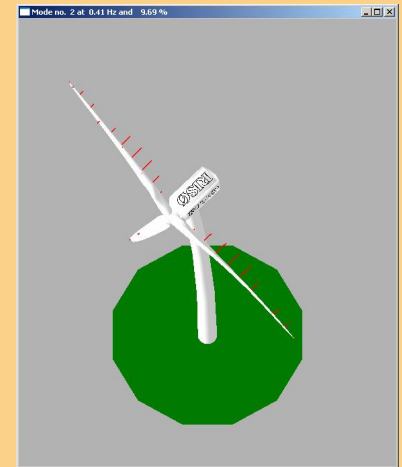
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Aerodynamics and Aeroelastics, WP 2



Flemming Rasmussen
Aeroelastic Design
Wind Energy Department
Risø DTU



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WP2 Aero-dynamics and Aero-elastics

OBJECTIVES

Overall: To develop an aeroelastic design basis for large multi MW turbines.

Specific:

1. Development of **nonlinear structural dynamic** models (modeling on the micromechanical scale is input from WP3).
2. **Advanced aerodynamic models** covering full 3D CFD rotor models, free wake models and improved BEM type models. (The wake description is a prerequisite for the wake modeling in WP8).
3. Models for **aerodynamic control features and devices**. (This represents the theoretical background for the smart rotor blades development in WP 1.B.3)
4. Models for analysis of **aeroelastic stability** and **total damping** including **hydroelastic interaction**
5. Development of models for computation of **aerodynamic noise**.

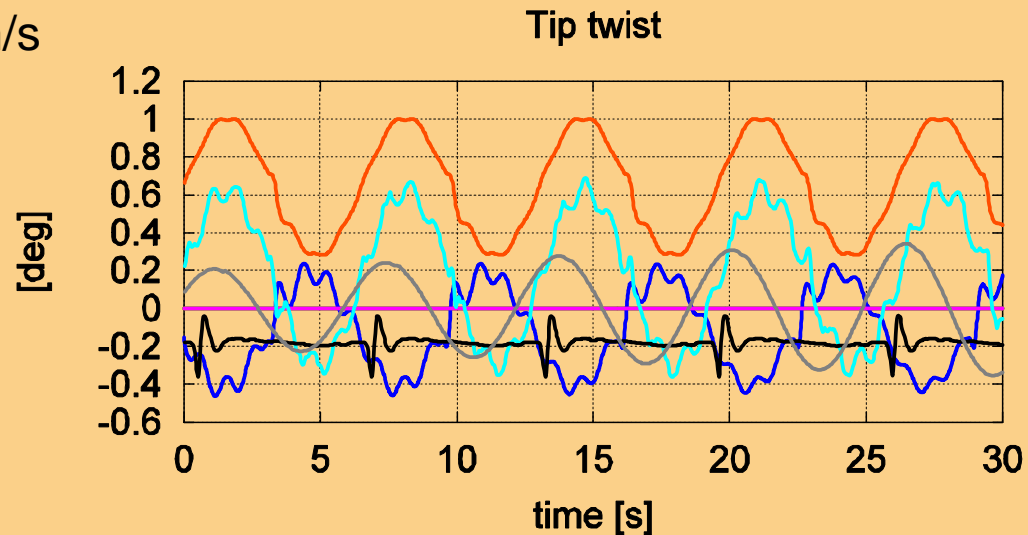


WP 2.1 Structural dynamics, large deflections & non-linear effects

Approach

- ✎ Identification of important non-linearities in large wind turbines
- ✎ Implementation of non-linear beam models in aero-elastic tools

Example: Tip twist deformation, IEA comparison, RWT, 8 m/s



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Elsam Flex —
GH Bladed —
NREL ADAMS —
NREL FAST —

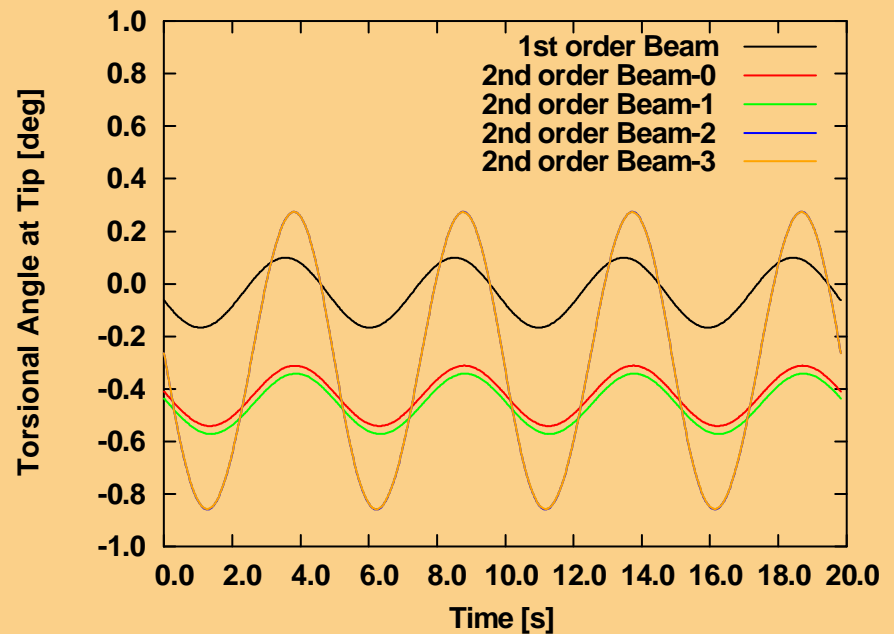
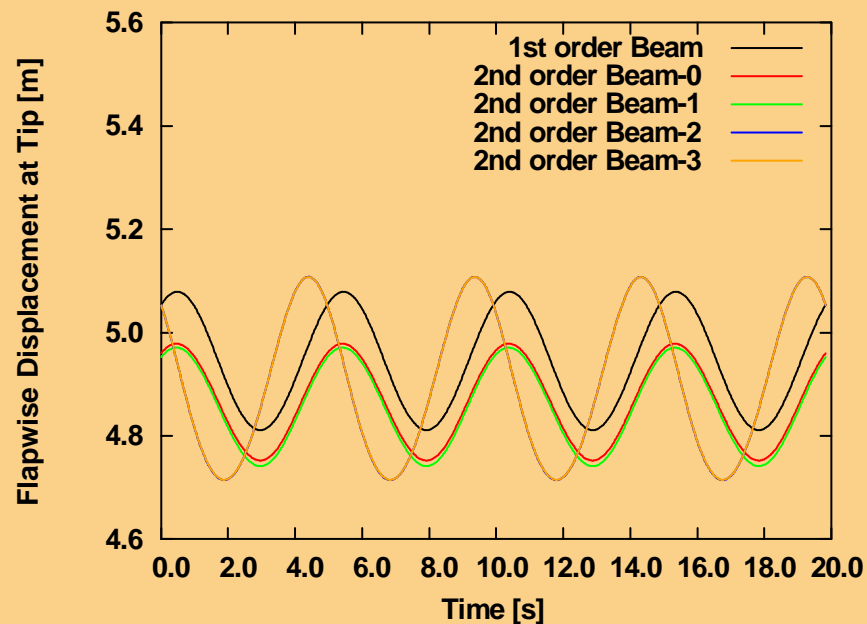
DNV HAWC —
RISOE HAWC —
RISOE HAWC2 —
Siemens BHawC —



WP 2.1 Non-linear effects

Additions to the baseline, 1st-order, model

- ↘ Formulation of dynamic equations in the deformed state (same structural couplings as in baseline but 2nd-order kinematics and dynamics)
(2nd order beam-0)
- ↘ Tension – torsion coupling terms (2nd order beam-1)
- ↘ Bending – torsion coupling terms (2nd order beam-2)
- ↘ Pre-twist – torsion coupling term (2nd order beam-3)



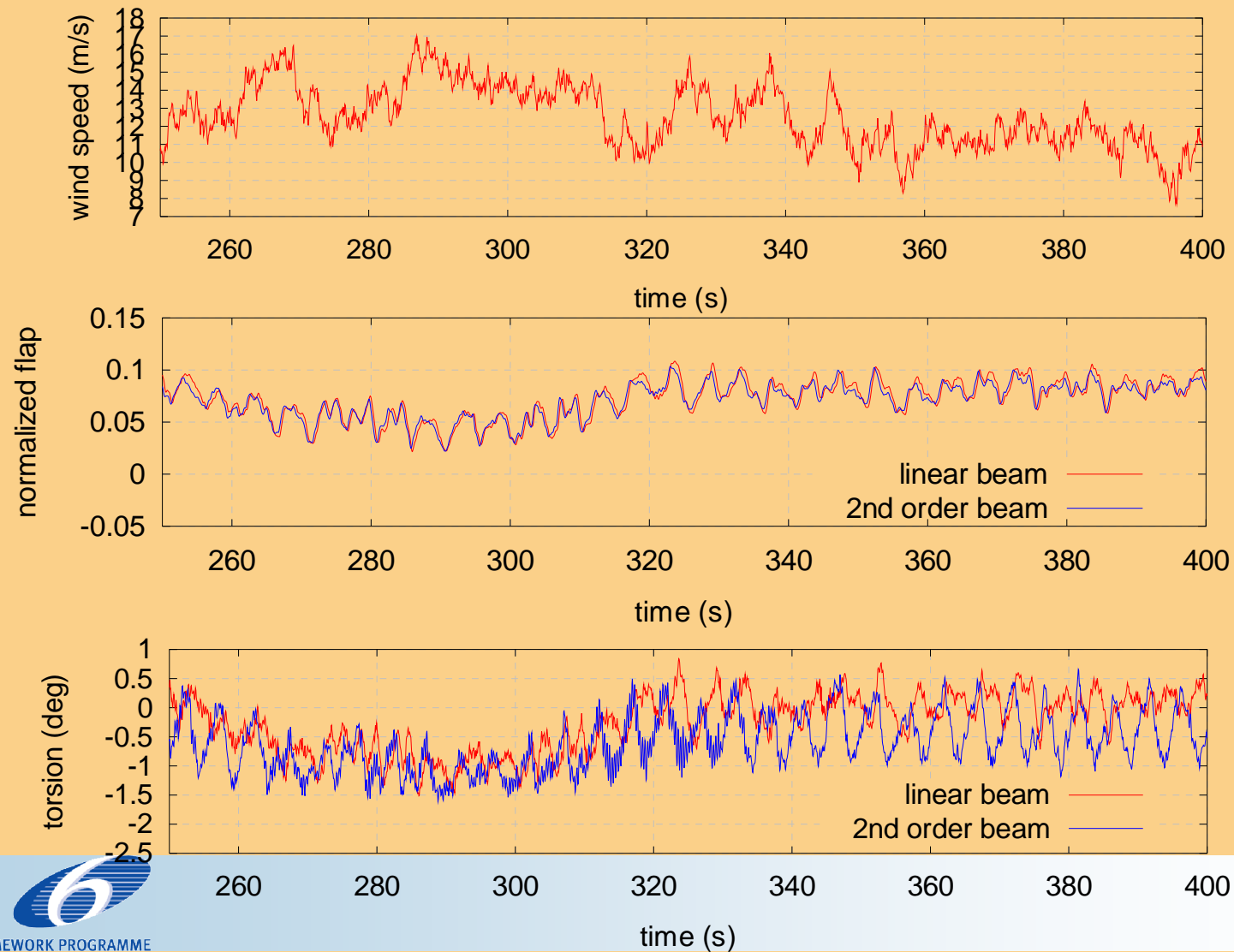
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Wind speed: 11 m/s



WP 2.1 Non-linear effects

Linear vs. non linear beam model analysis, NTM at 11.4 m/s



WP 2.1 Structural dynamics, large deflections & non-linear effects

Summary

- ✧ Significant contributions obtained by
 - Formulating the dynamic equations in the deformed state
 - Including bending – torsion coupling terms



WP2.2 Advanced aerodynamic models

Objectives

- to identify the limitations in the engineering aerodynamic modeling in BEM type codes

Approach

- inter comparison of results of models of different complexity applied on MW rotors, RWT- 5MW
- Shear and turbulence wind inflow for CFD-models

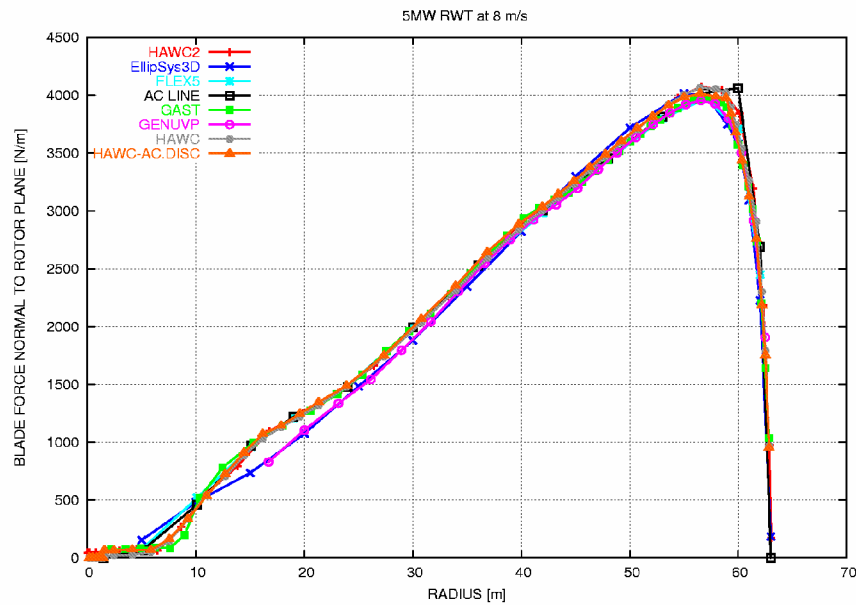
Simulation cases

- uniform inflow on RWT turbine (stiff model)
- strong wind shear in inflow
- unsteady inflow (turbulent)- not yet performed

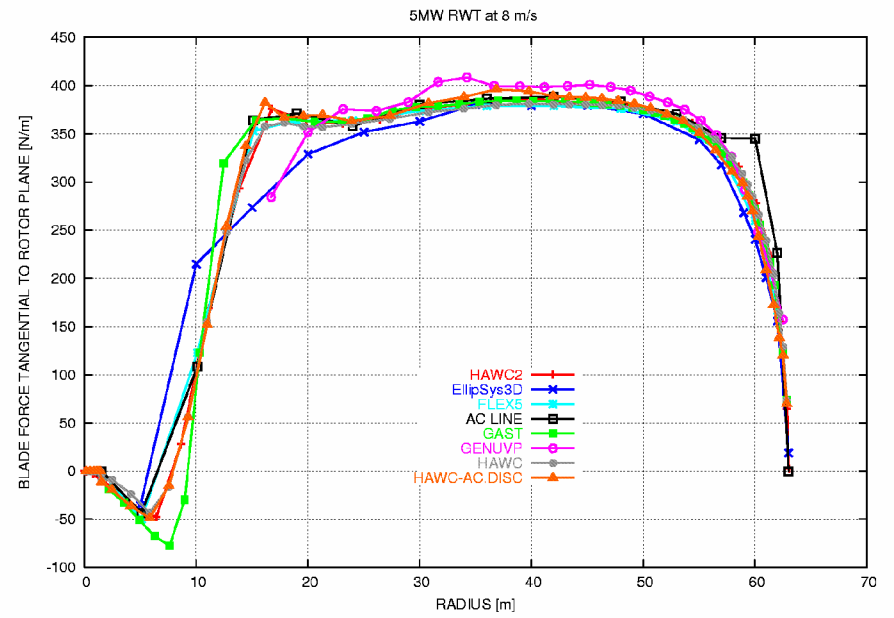


WP2.2 Blade forces normal and tangential

Simulations with various codes at 8 m/s uniform inflow



normal



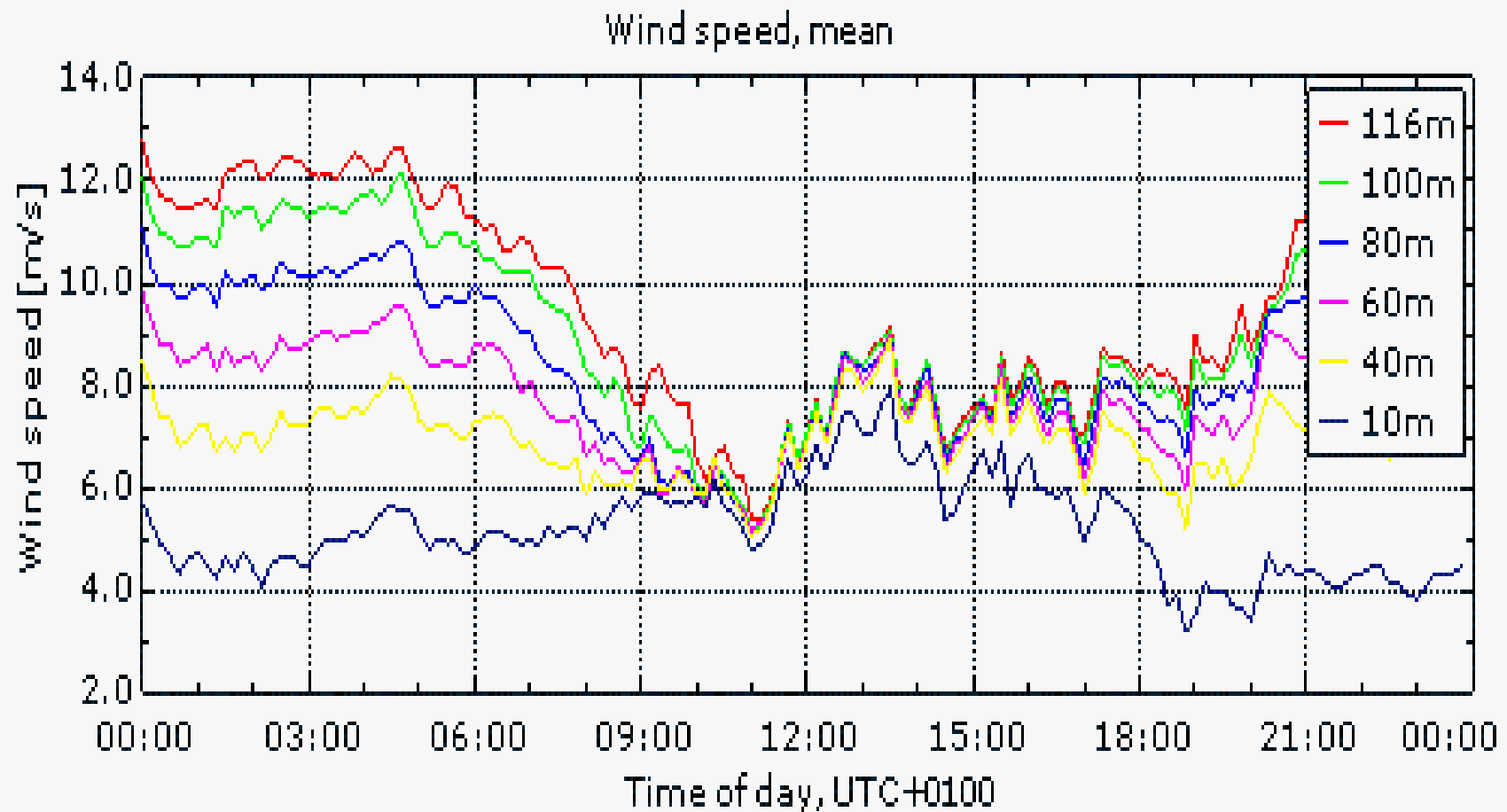
tangential



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Wind speed with height, night- day, Høvsøre

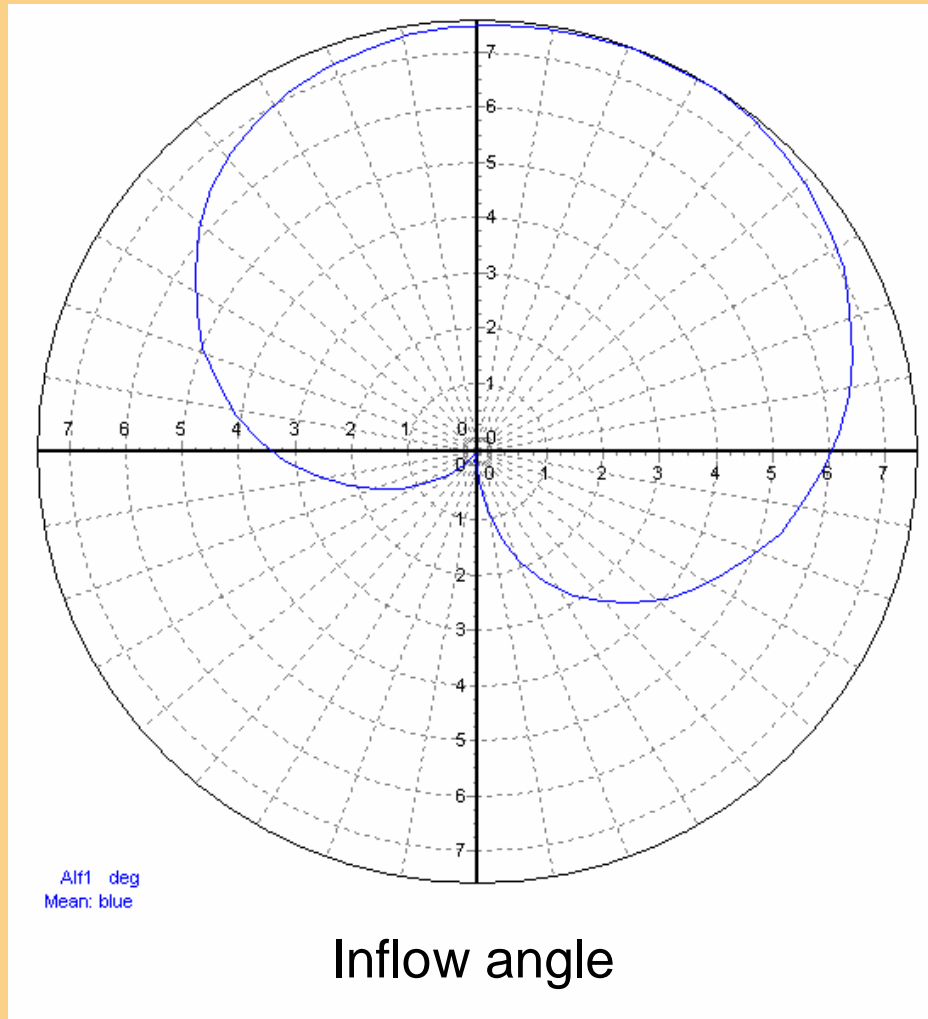


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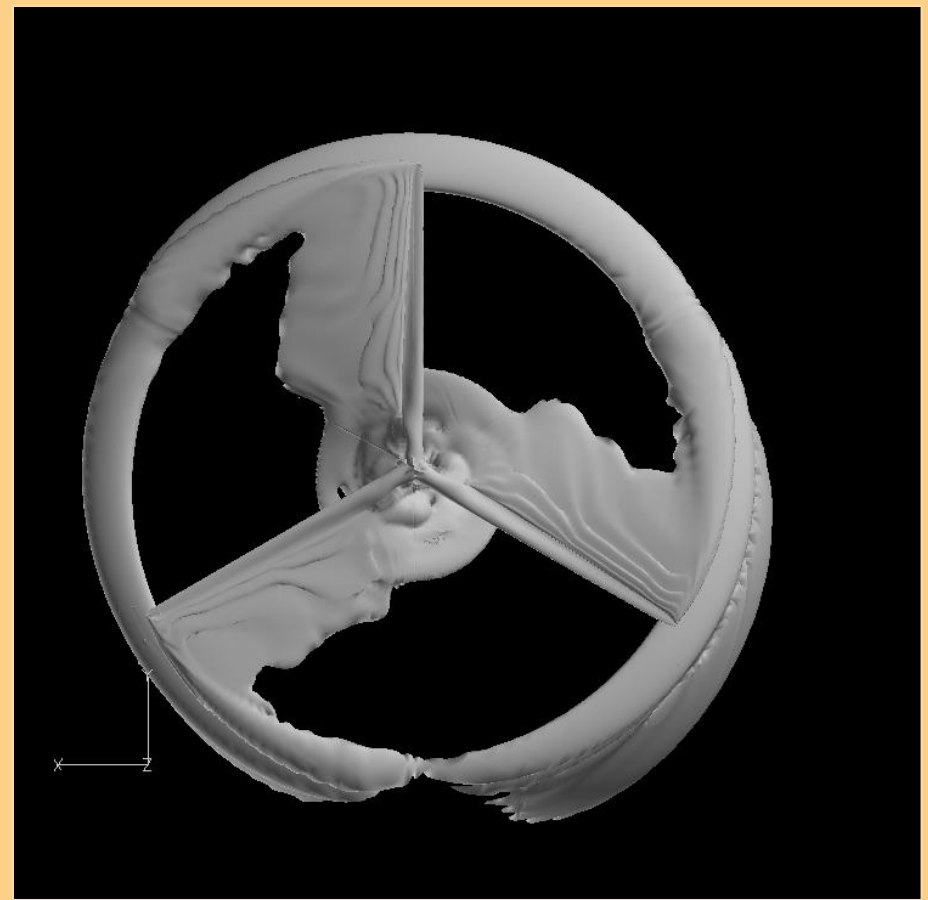
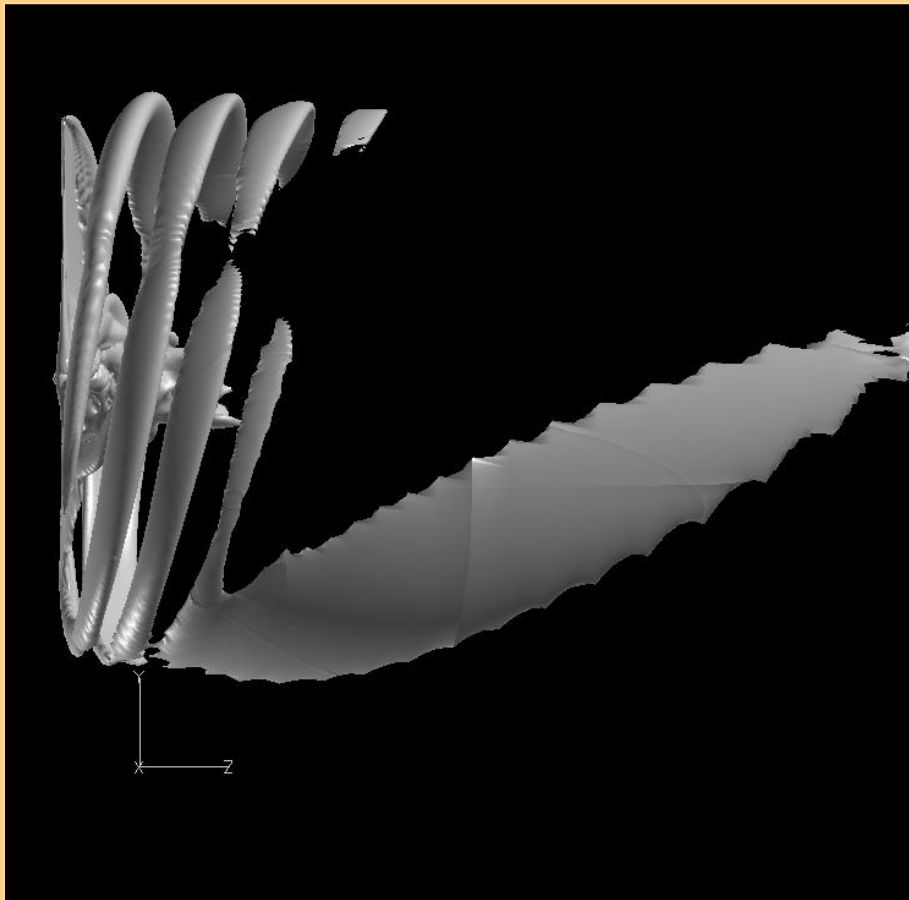
from <http://veaonline.risoe.dk>

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Measured inflow angle on the NM80 at Tjæreborg during a period with strong shear and low turbulence



Wake pattern, CFD with strong inflow shear



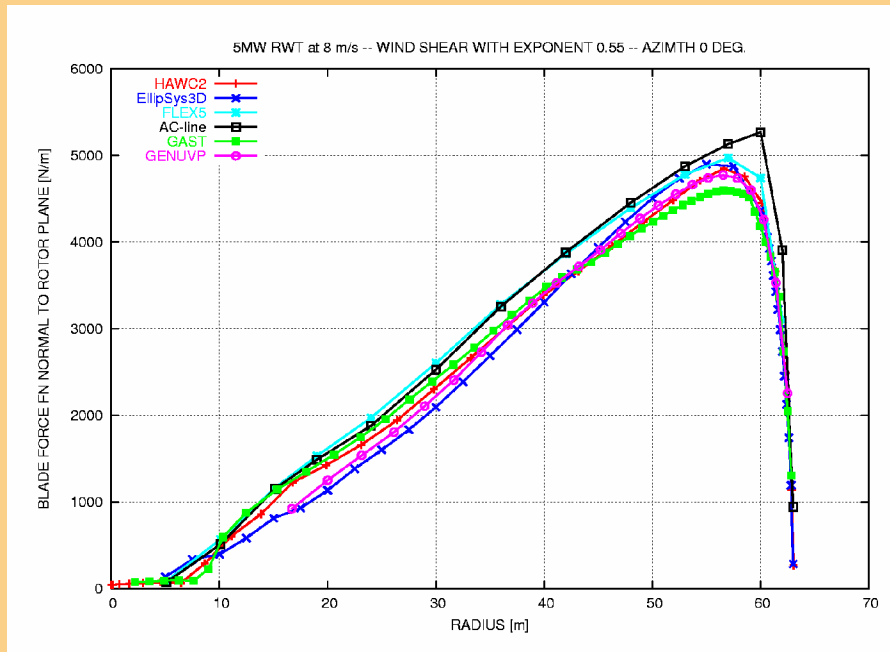
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UpWind 

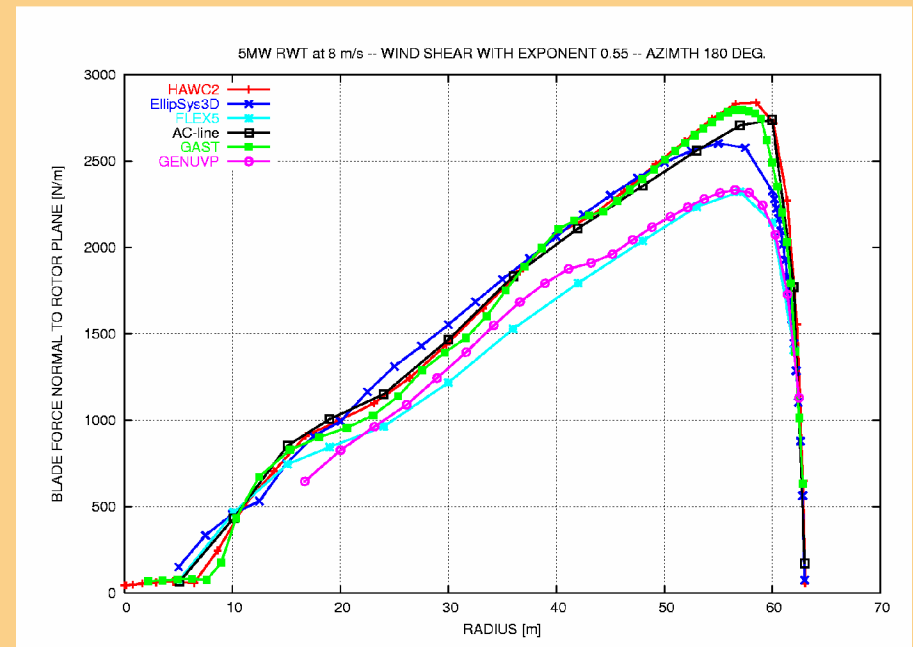
WP2.2 Blade normal force

8 m/s - strong inflow shear - exponent 0.55, $U(z) = U_{hub} \left(\frac{z}{z_{hub}} \right)^{0.55}$

blade up



blade down

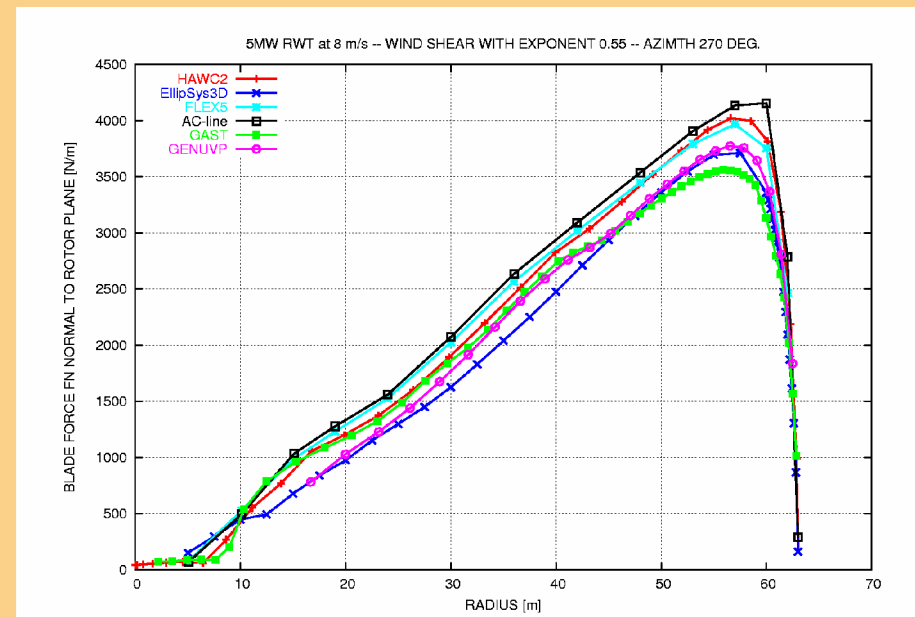
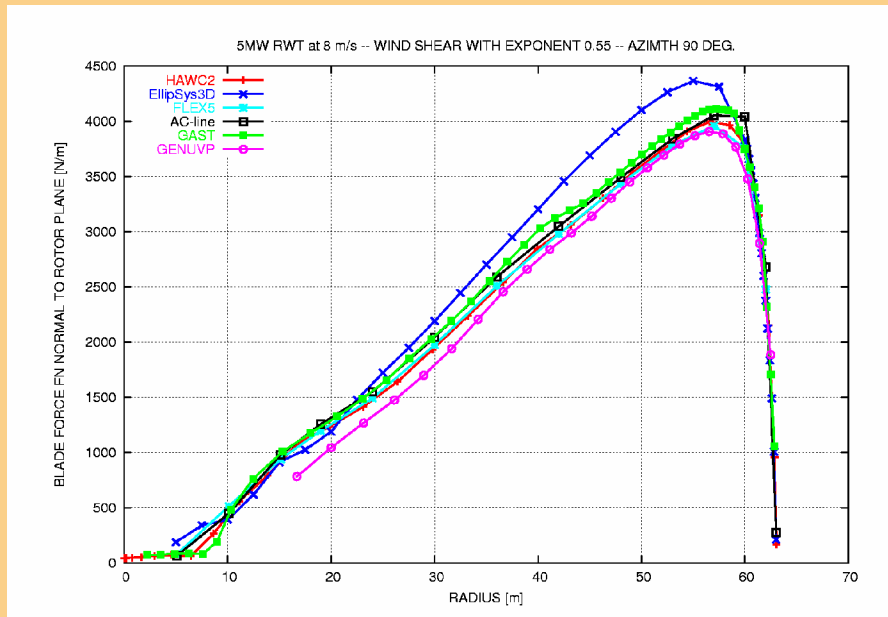


WP2.2 Blade normal force

8 m/s -- strong inflow shear - exponent 0.55

blade 90 deg.

blade 270 deg.



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WP2.2 Advanced aerodynamic models

Summary

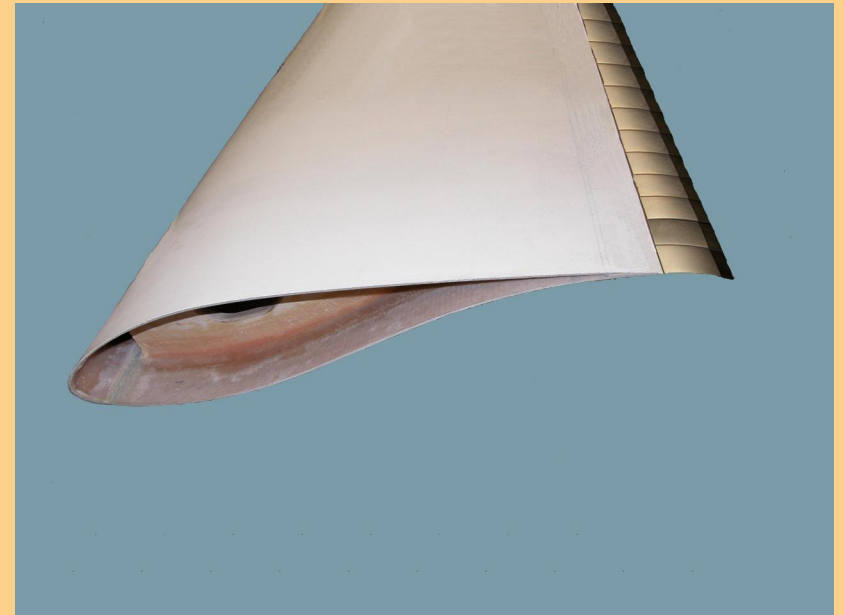
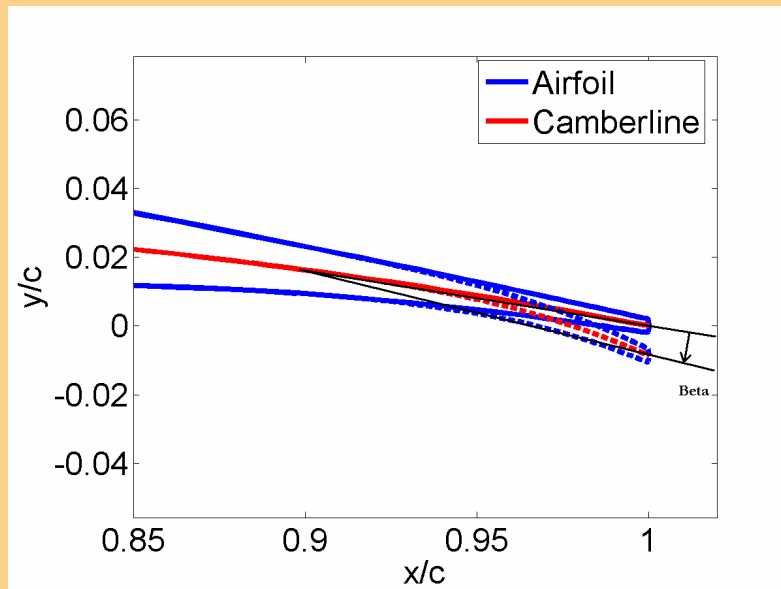
- ✧ uniform inflow and low wind speed a good correlation is found between all models
- ✧ at high wind speed and uniform inflow considerable deviations are seen on the load distribution along the blade
- ✧ for the strong wind shear case, considerable deviations between the models are seen



WP 2.3 Advanced control features and aerodynamic devices

Approach:

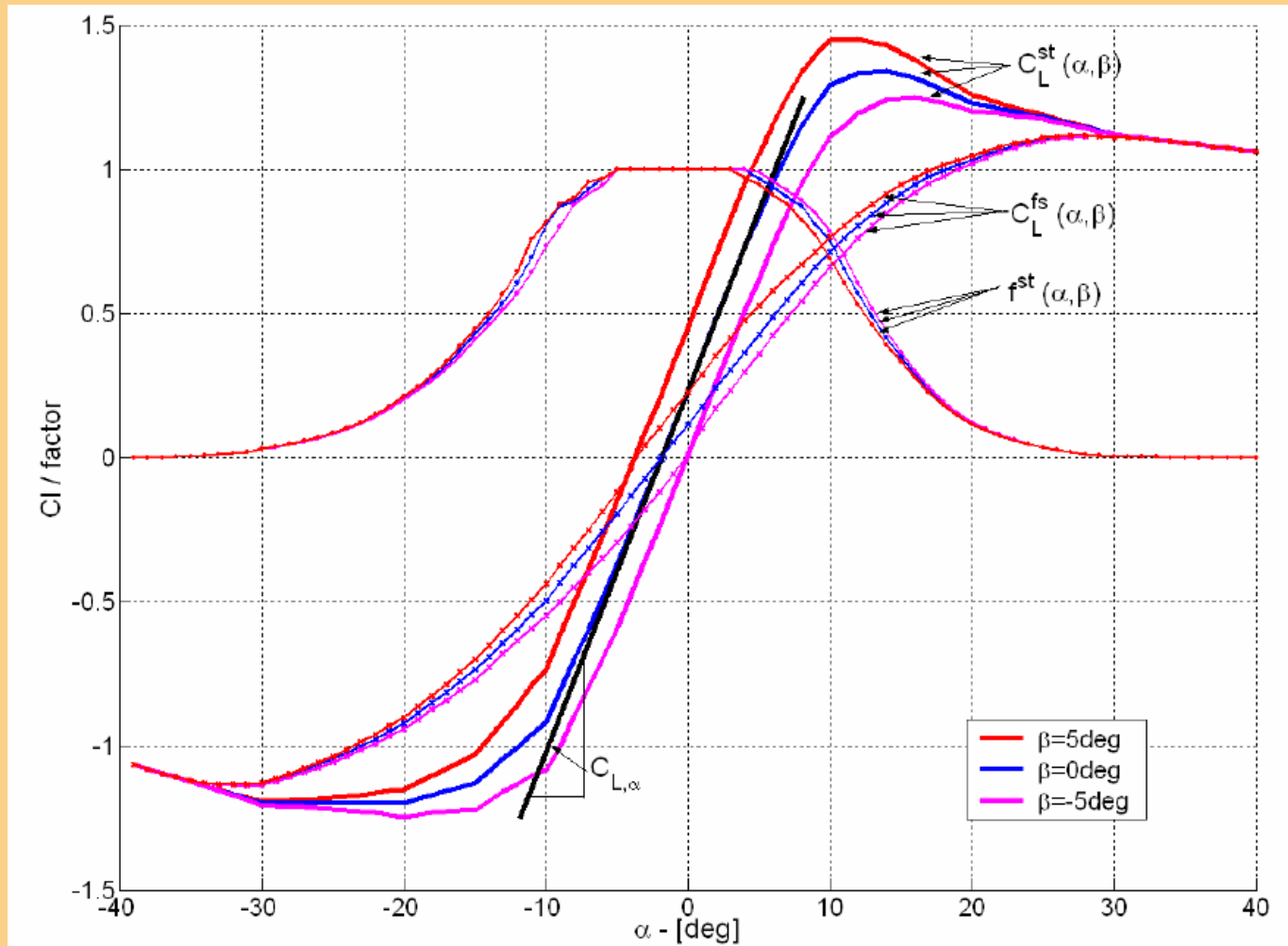
- Develop detailed models for structural and aerodynamic analysis for a few promising flow control concepts (in close corporation with WP 1A5).
- Deformable camberline.



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Dynamic Stall model: Main input: $C_L^{st}(\alpha, \beta)$

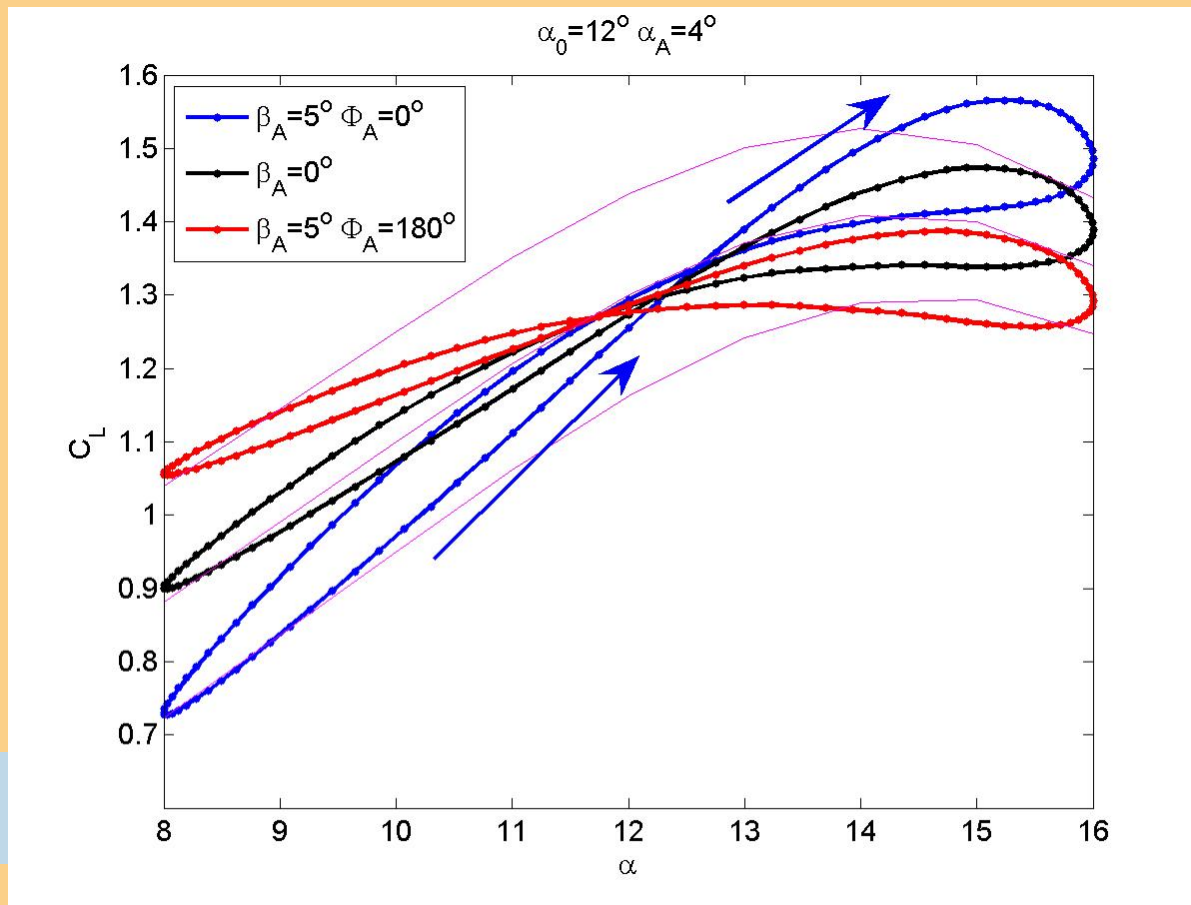


Dynamic Stall: Harmonic Alpha and Beta

Blue: Alpha and Beta in phase

Black: No Beta

Red: In counter-phase (180° shift)



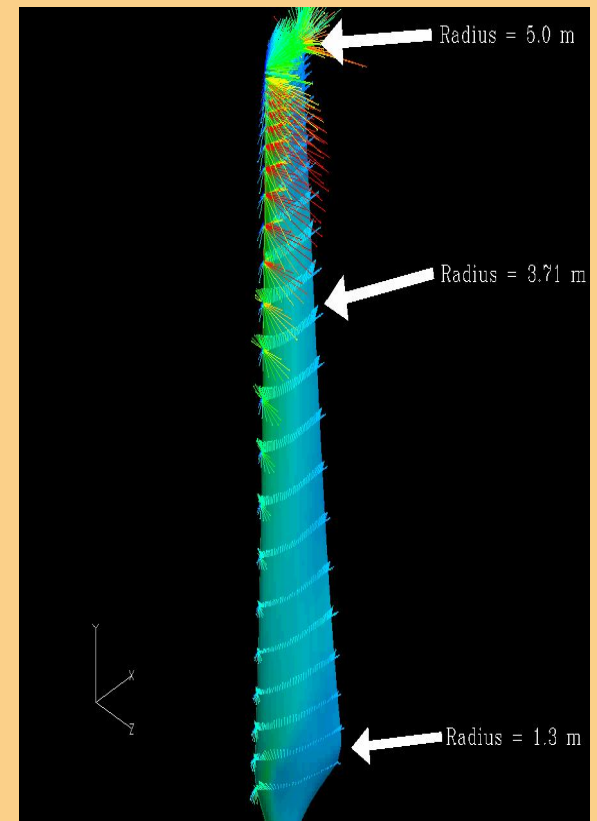
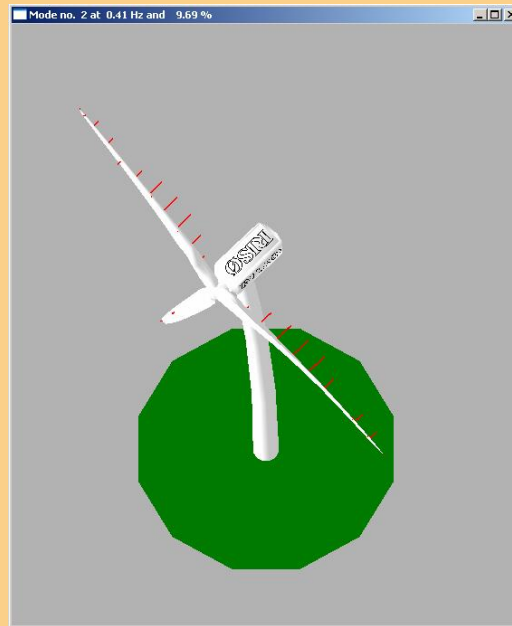
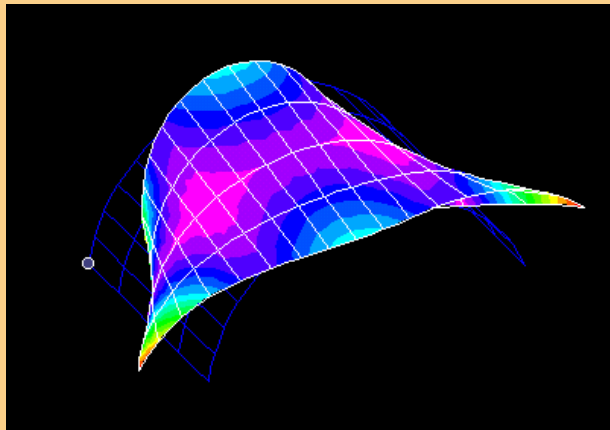
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WP 2.4: Aeroelastic stability and total damping including hydrodynamics

Approach:

- Aerodynamic damping and aeroelastic stability of the RWT 5 MW turbine
- Blade structural damping model
- CFD-structure coupling



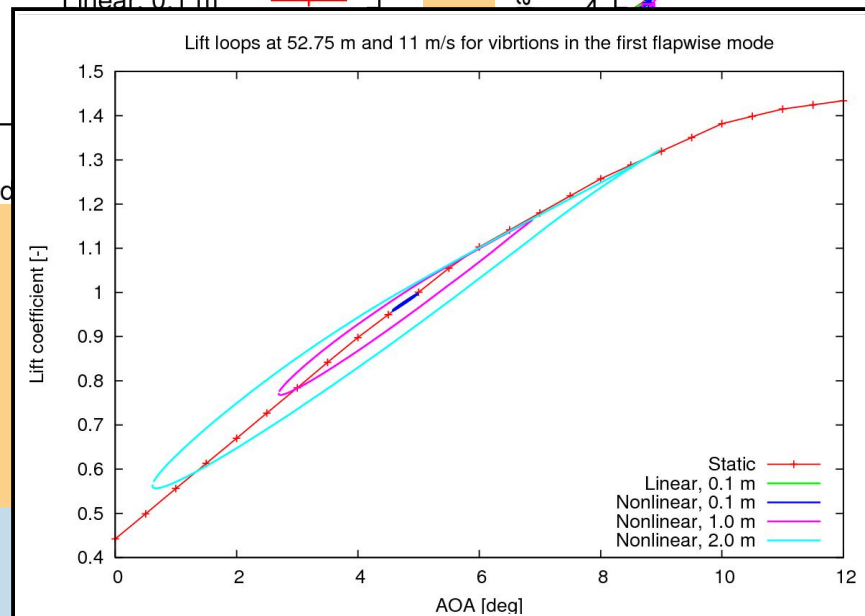
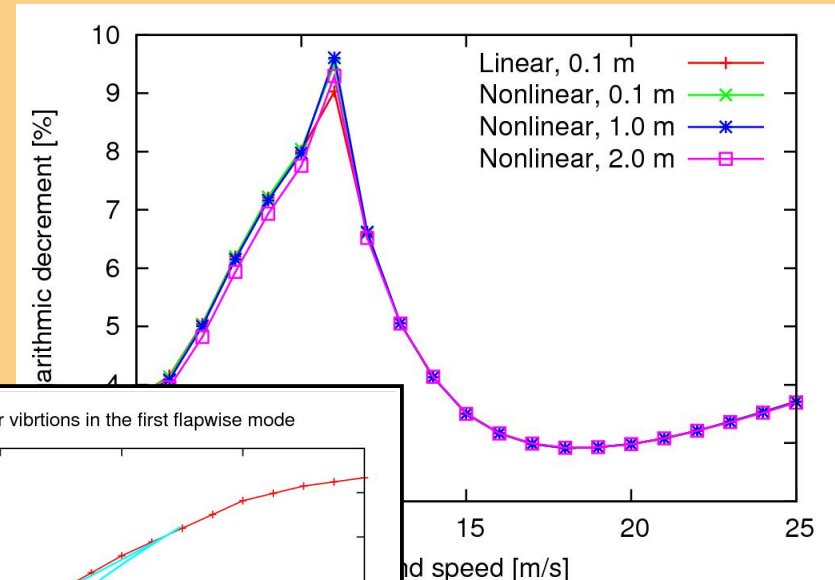
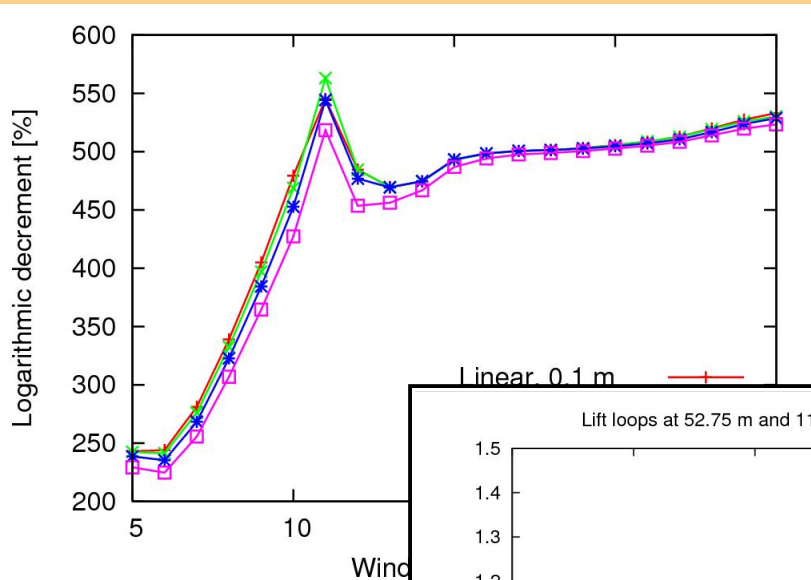
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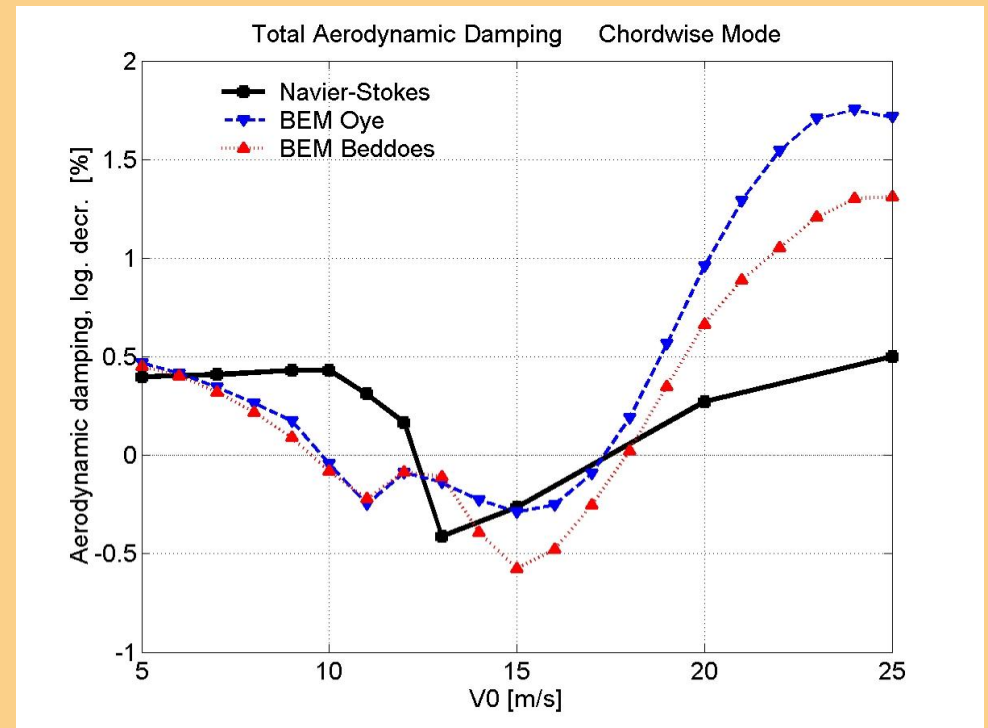
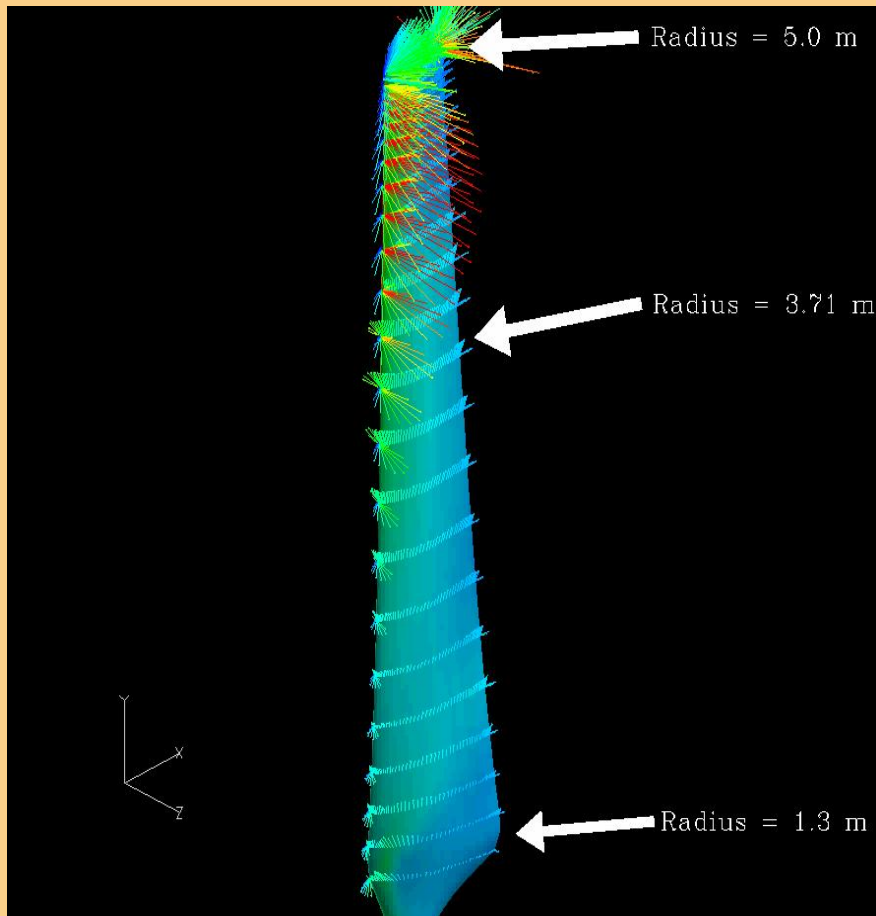
WP 2.4: Aerodynamic damping of blade modes for RWT 5 MW

First flapwise mode

First edgewise mode



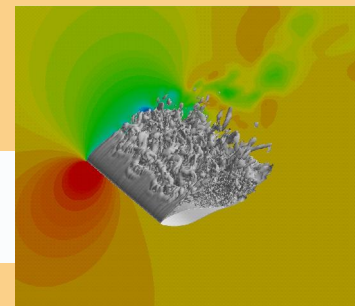
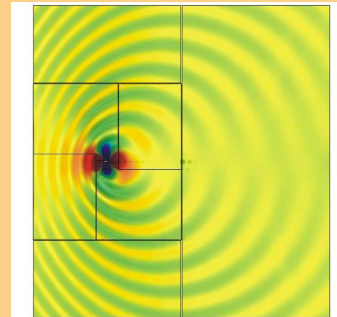
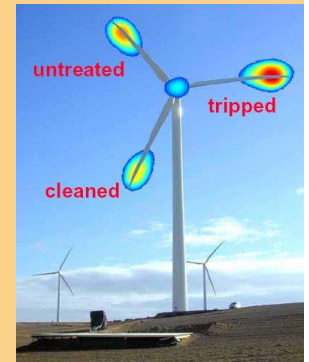
WP 2.4: Aeroelastic stability and total damping including hydrodynamics.



WP 2.5 Computation of aerodynamic noise— coupled CFD-CAA models

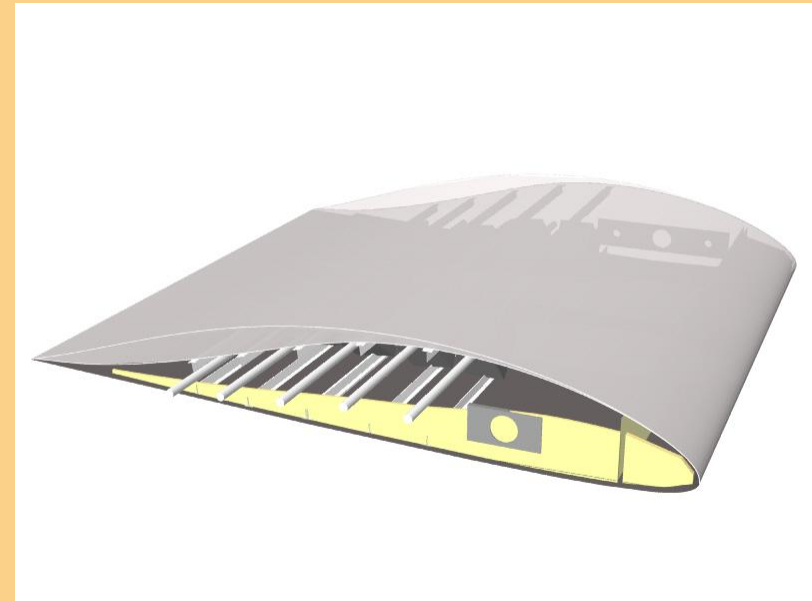
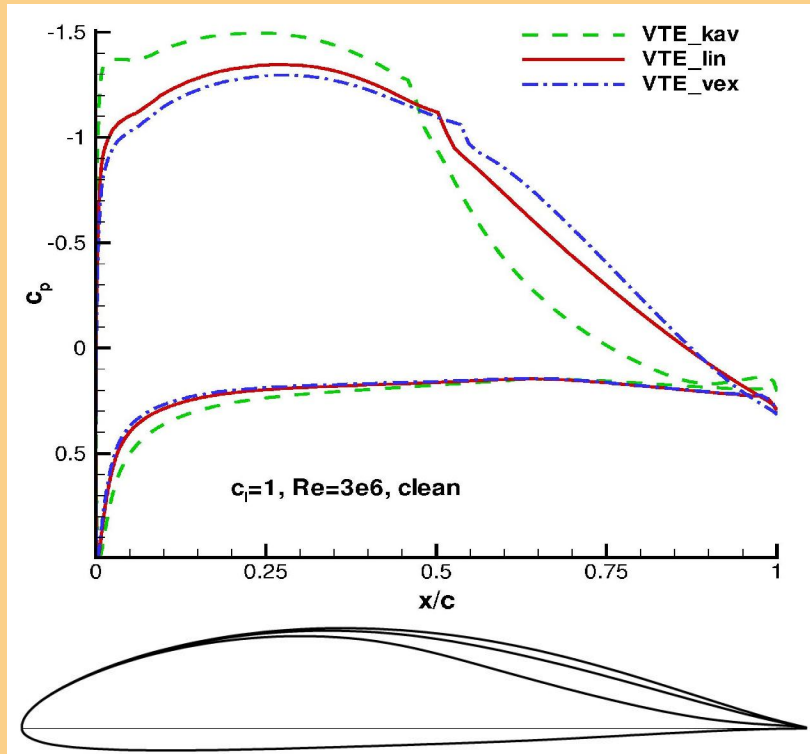
Approach:

- Boundary-layer experiments to validate and select appropriate turbulence models.
- Improve the capability of existing stochastic turbulence models for CFD-CAA coupling.
- Development of CAA schemes for computation of aeroacoustic noise generation as function of detailed turbulence data from CFD computation on a 2D airfoil.



Test Cases : VTE Model Developed at LWT (SIROCCO Project)

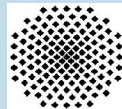
- goal: variation of boundary-layer parameters at trailing-edge
- requires strong contour change over major part of chord length
- three variations: VTE_lin, VTE_kav (and VTE_vex)



Wind tunnel model
with adjustable shape



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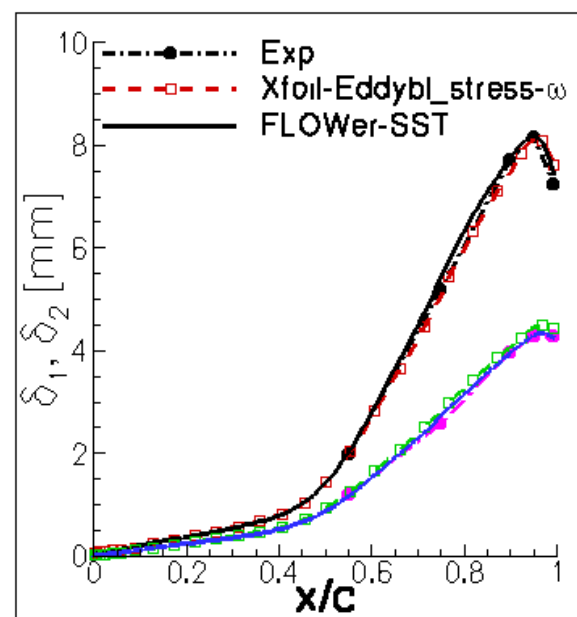
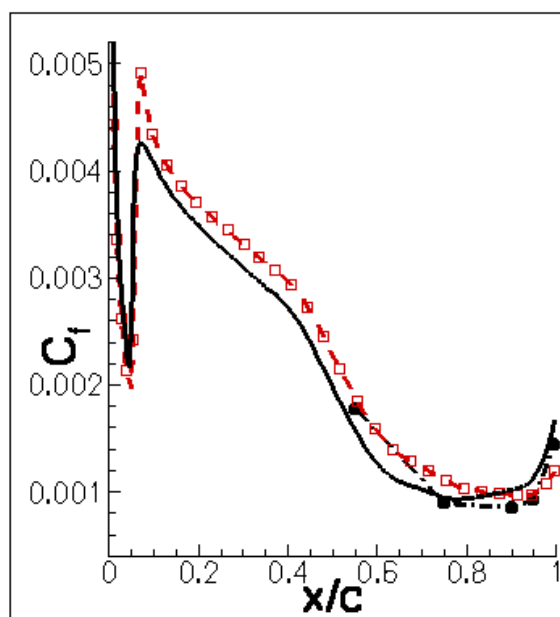
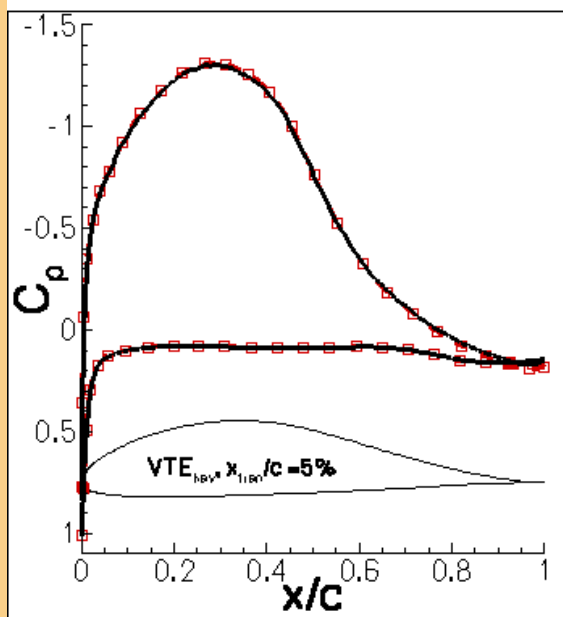
Universität Stuttgart

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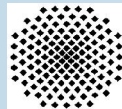
UpWind

Results: VTE_kav, Cl=0.7, BL Parameters

VTE_{kav} : $Re = 3.093 \cdot 10^6$, $Ma = 0.178$, $C_l = 0.7$, $x_{tran}/c = 0.05$



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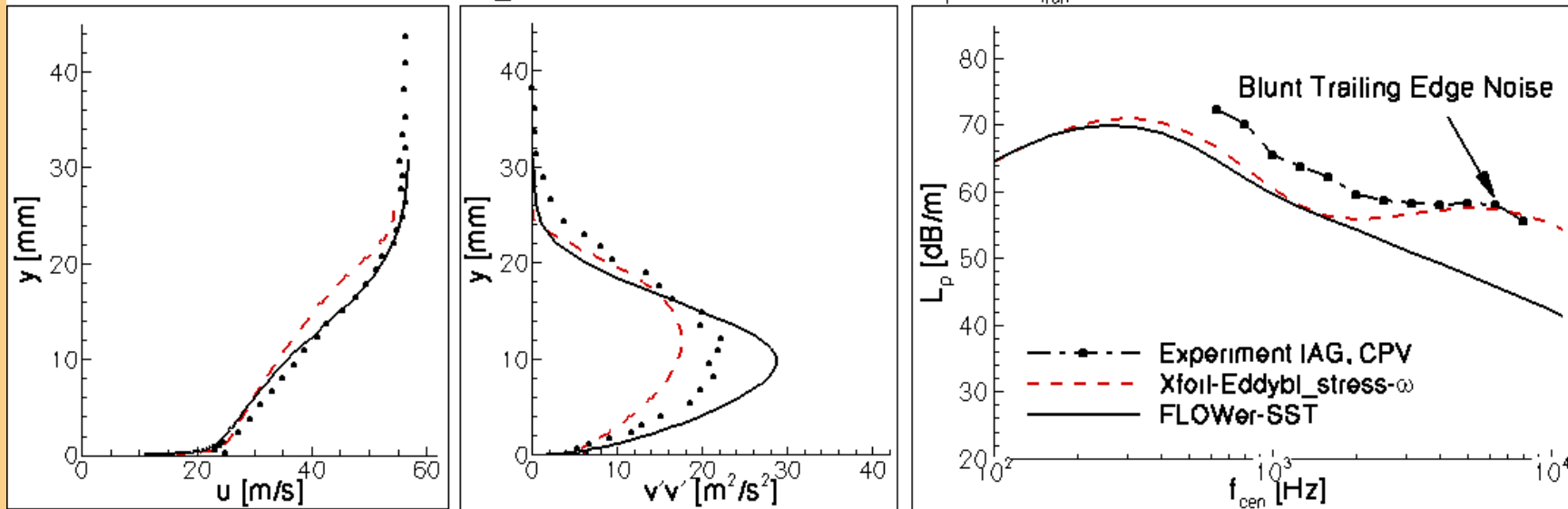
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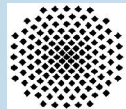
UpWind

Results: VTE_kav, $Cl=0.7$, Noise Spectra

VTE_kav, $Re = 3.093 \times 10^5$, $Ma=0.178$, $C_l=0.7$, $x_{tr}/c=0.05$



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UpWind