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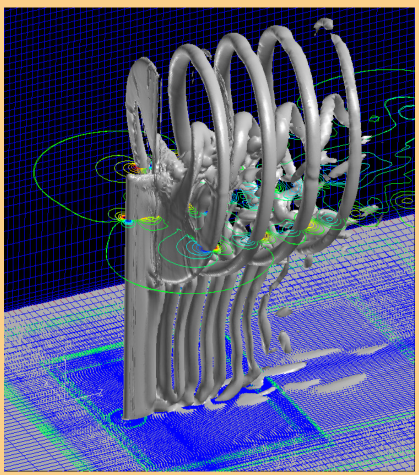
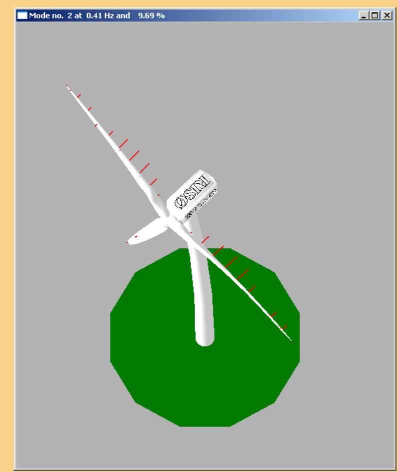


Aerodynamics and Aeroelastics, WP 2



Flemming Rasmussen

Aeroelastic Design

Wind Energy Department

Risø DTU

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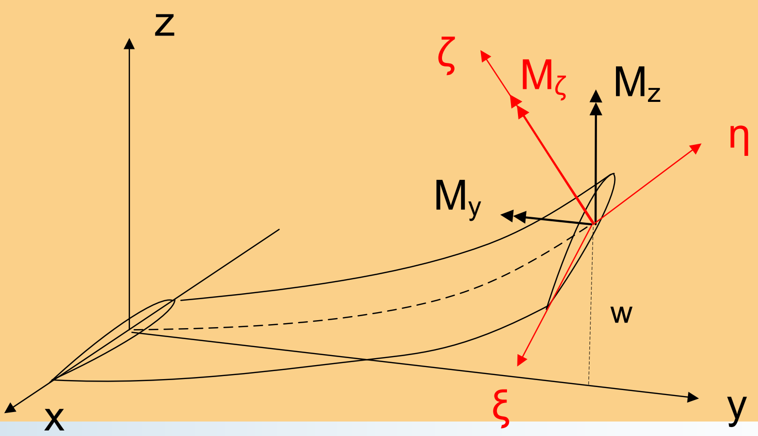
WP 2.1 Structural dynamics, large deflections & non-linear effects

Approach

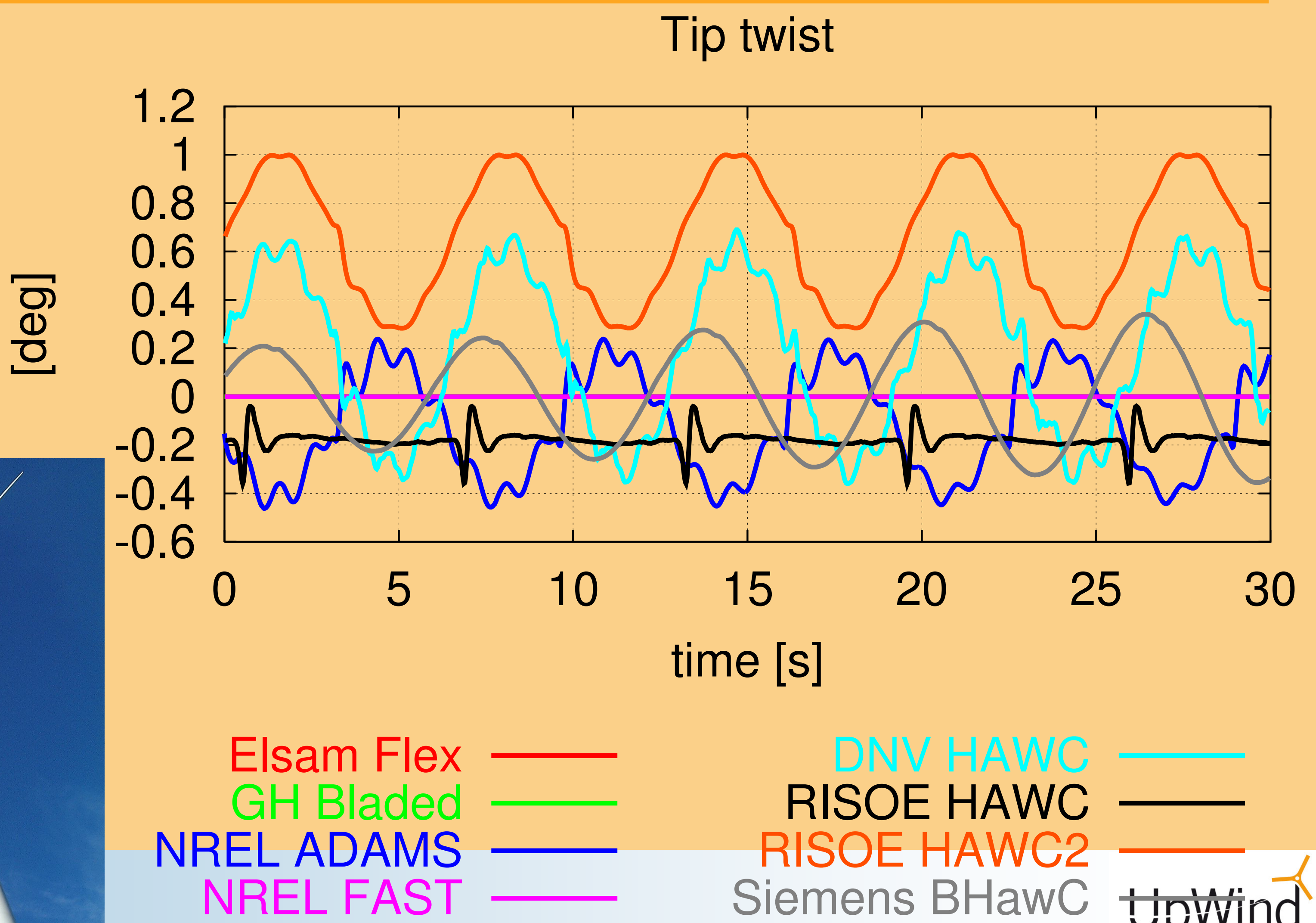
- Identification of important non-linearities in large wind turbines
- Challenge: predict blade torsional deformation in loaded case

Bending-Torsion coupling

When blade flap curvature w'' becomes large, bending moment Mζ contributes significantly to blade torsion moment My.



Tip torsional rotation, IEA-comparison, 8 m/s



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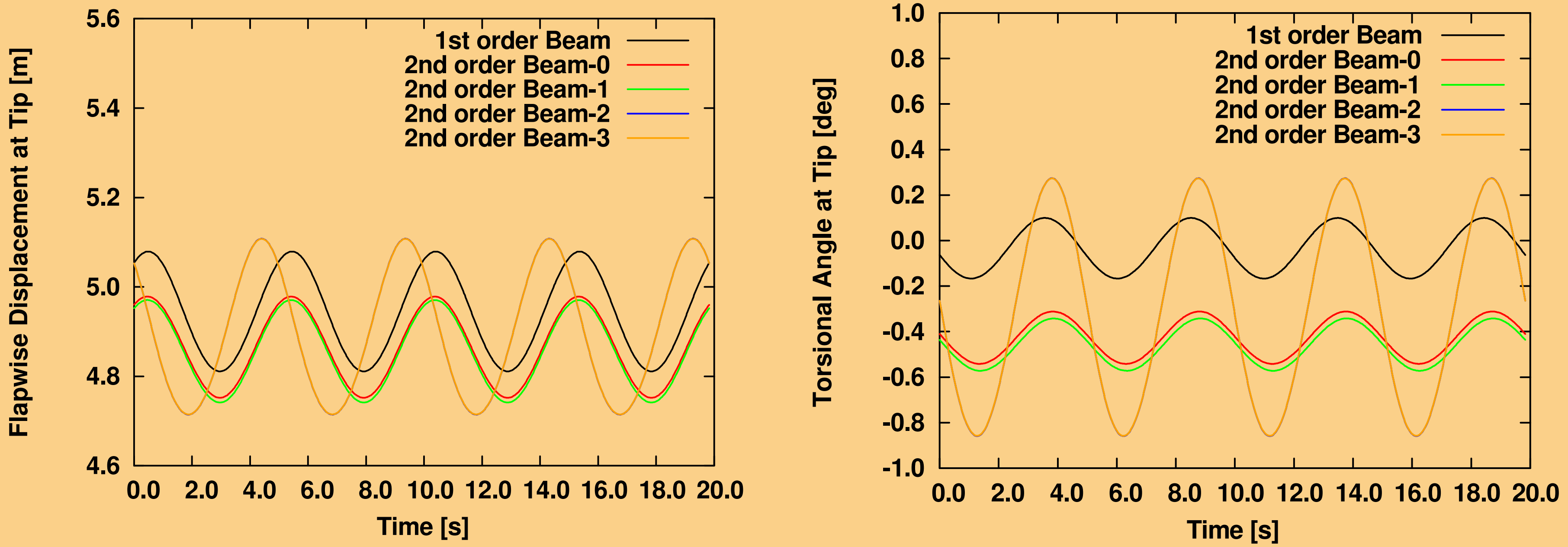
WP 2.1 Non-linear effects (analytical study)

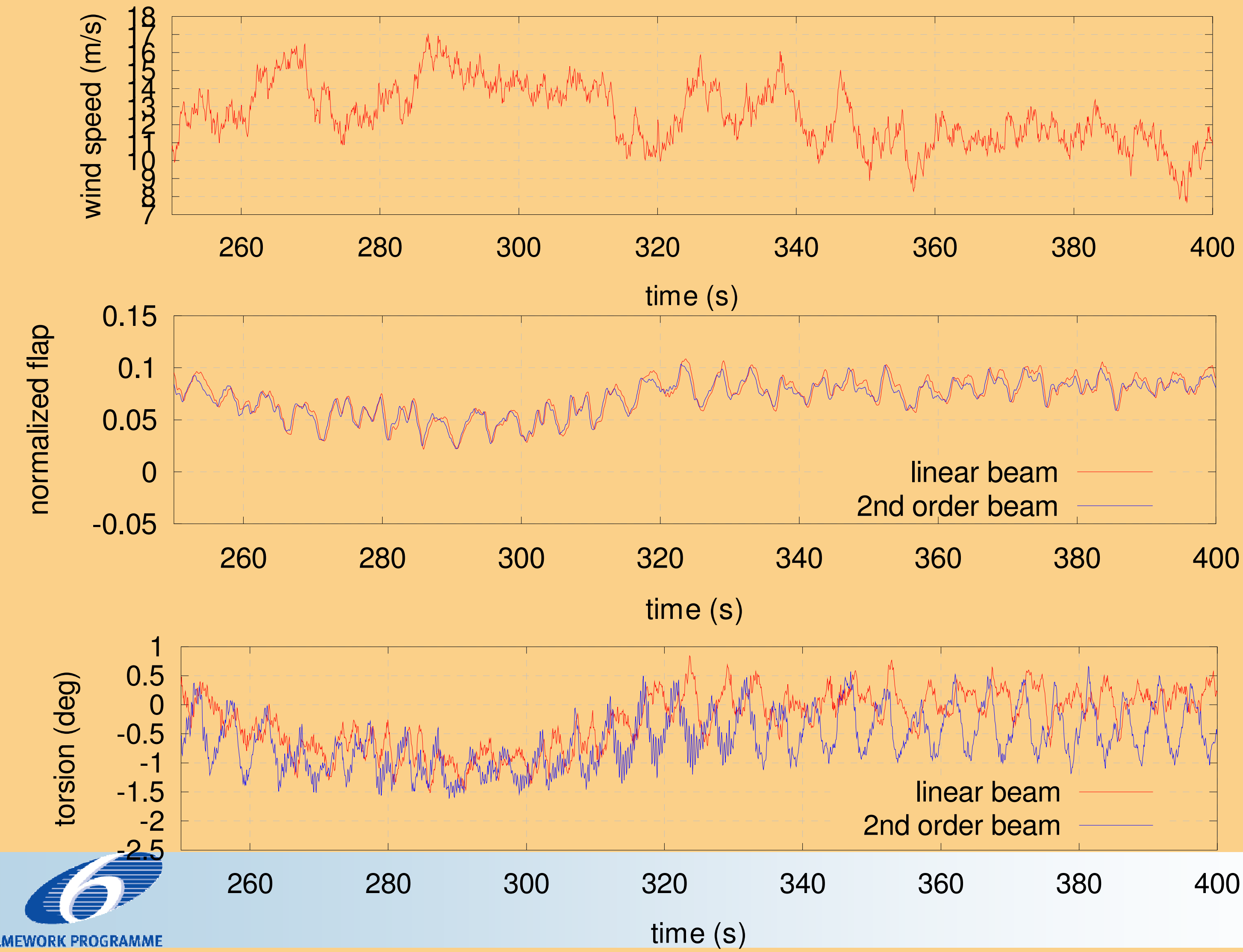
Additions to the baseline, 1st-order, model

- 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)



WP 2.1 Non-linear effects

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



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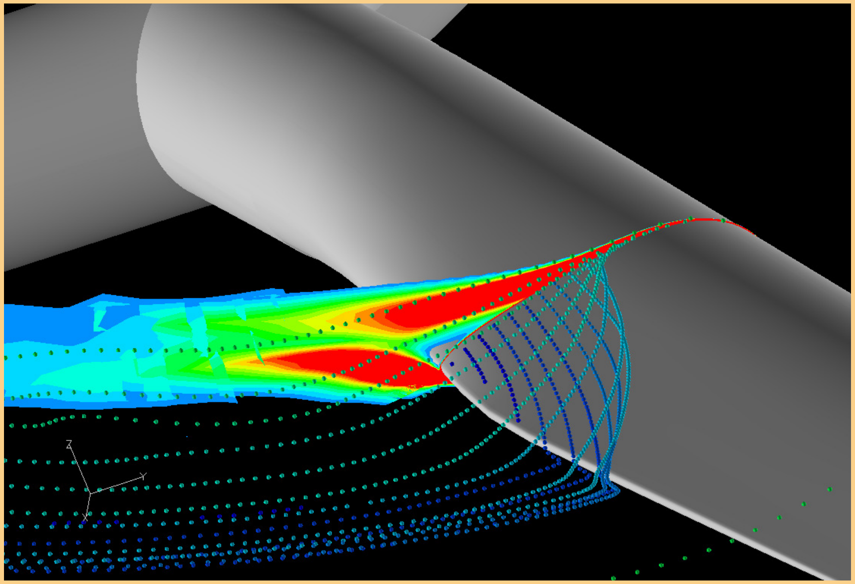
WP2.2 Advanced aerodynamic models

Objectives

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



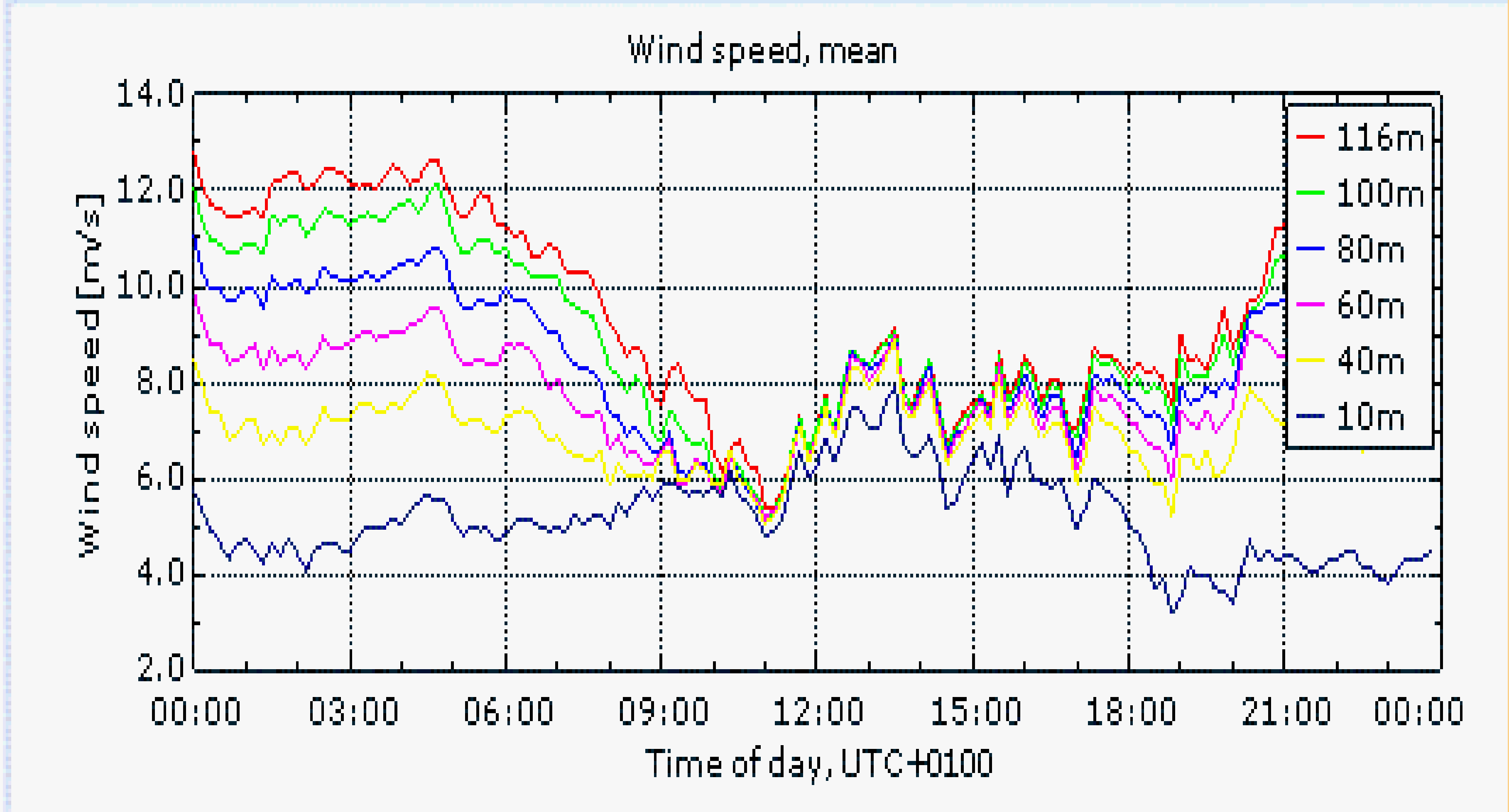
Approach

- inter comparison of results of models of different complexity applied on MW rotors, RWT- 5MW

Simulation cases

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

Wind speed with height, night- day, Høvsøre



from http://veaonline.risoe.dk

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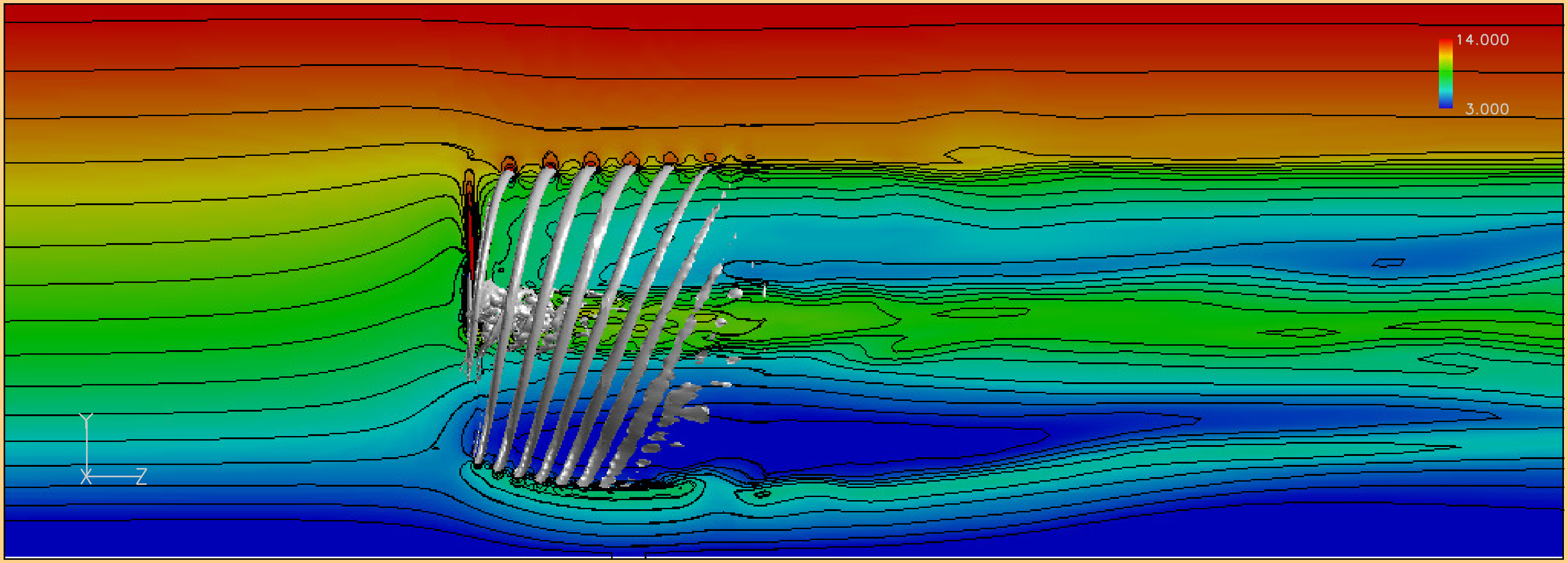
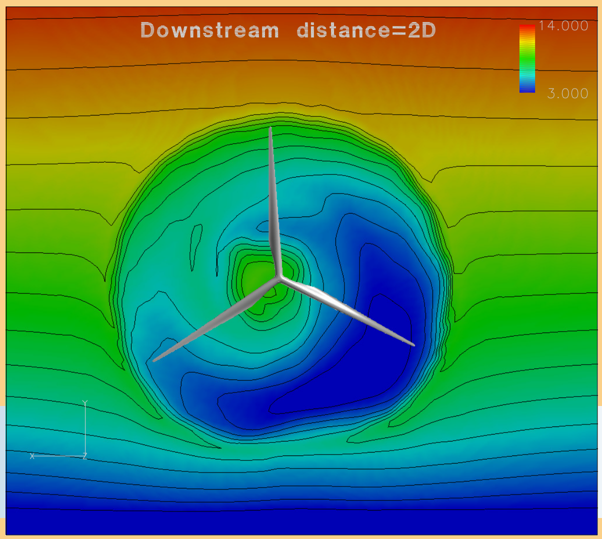
Wake pattern, CFD with strong inflow shear

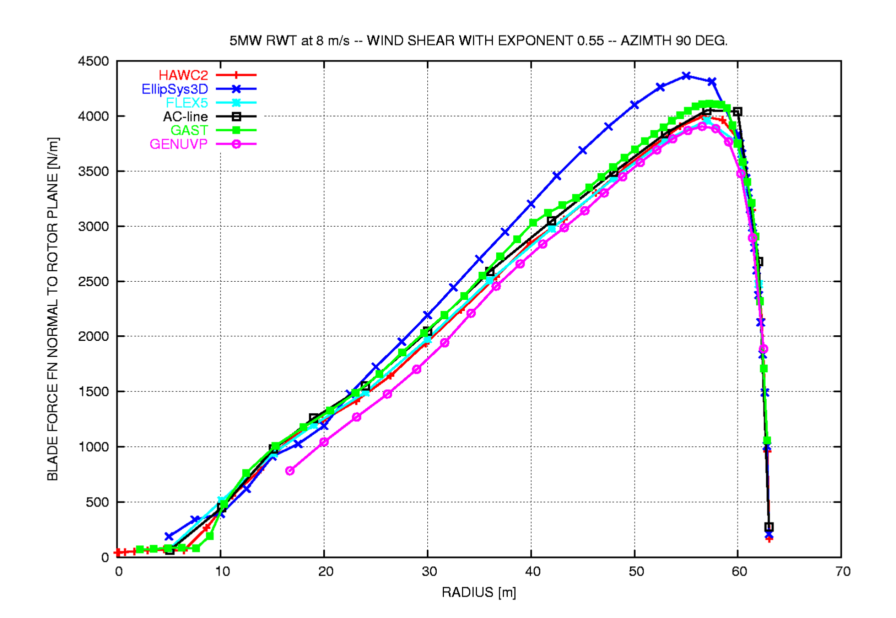




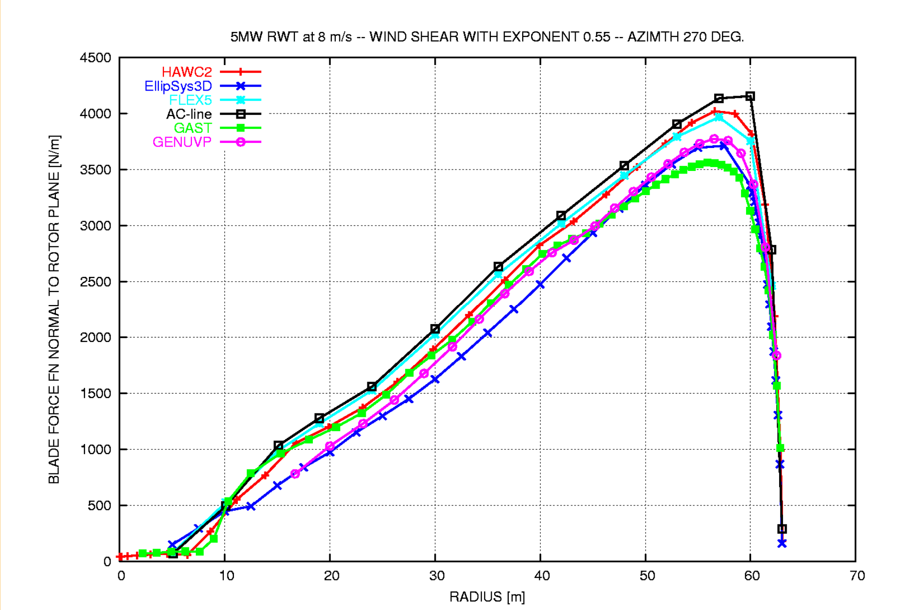
WP2.2 Blade normal force

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

blade 90 deg.



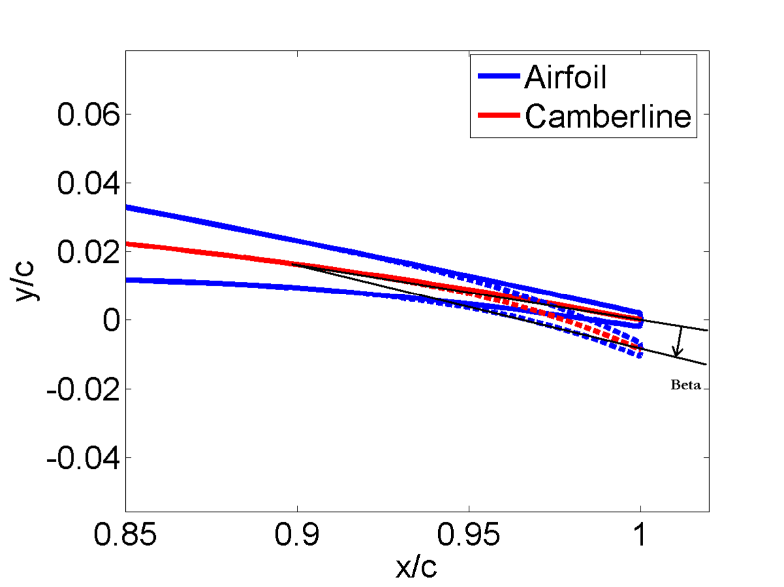
blade 270 deg.

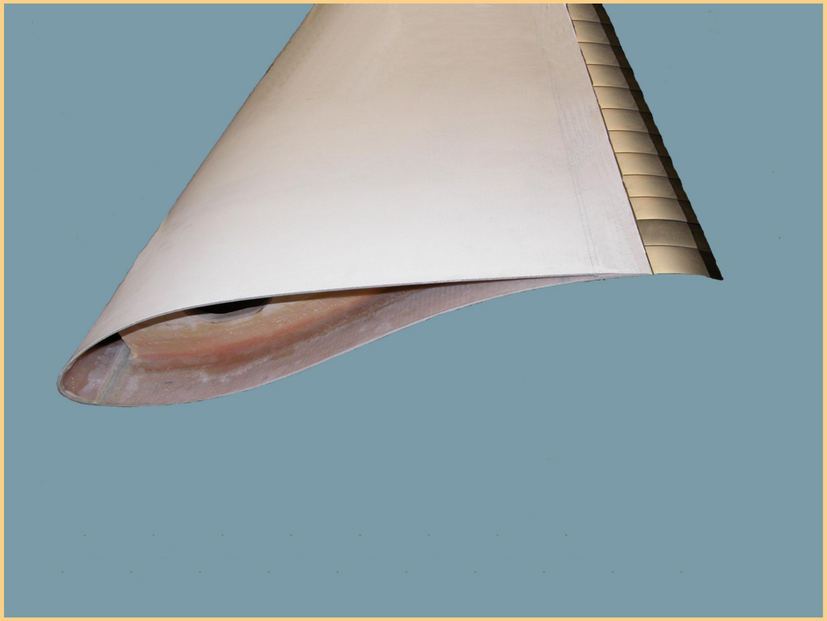


WP 2.3 Advanced control features and aerodynamic devices

Approach:

- Develope detailed models for analysis of a few promising flow control concepts (in close corporation with WP 1A5).
- Deformable camberline.



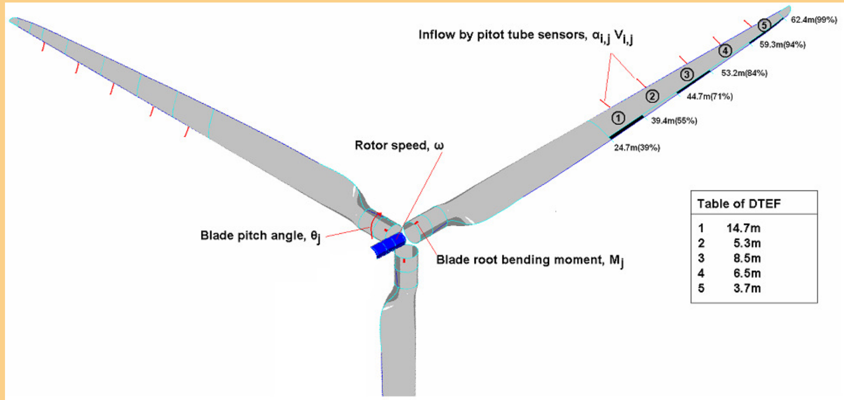


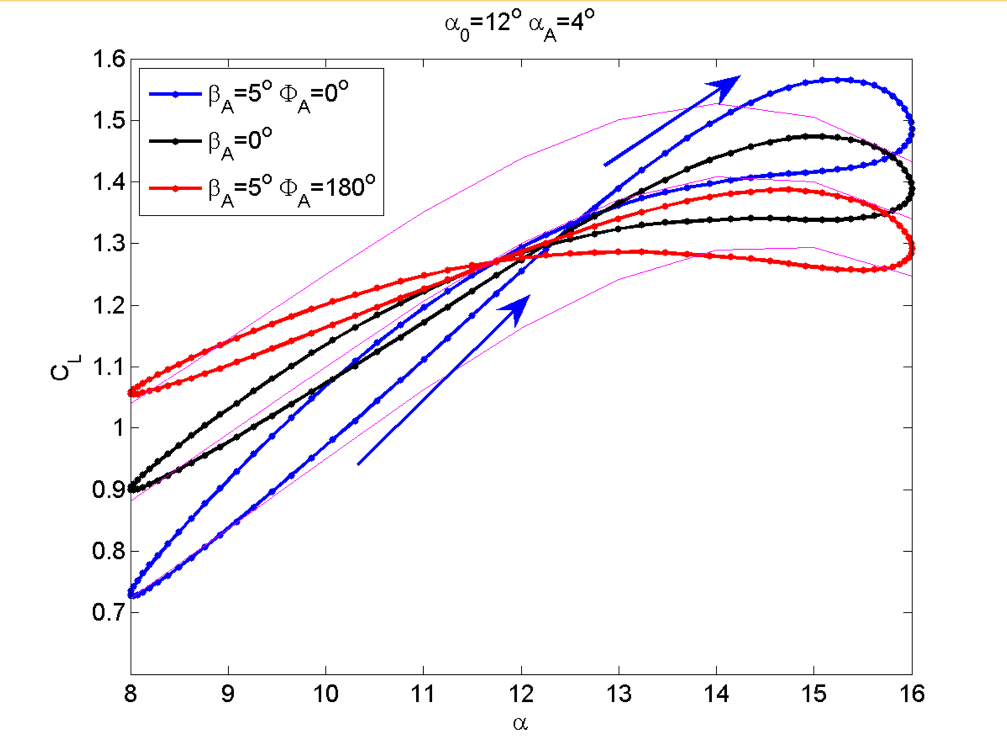
Dynamic Stall: Harmonic Alpha and Beta

Blue: Alpha and Beta in phase

Black: No Beta

Red: In counter-phase (180° shift)





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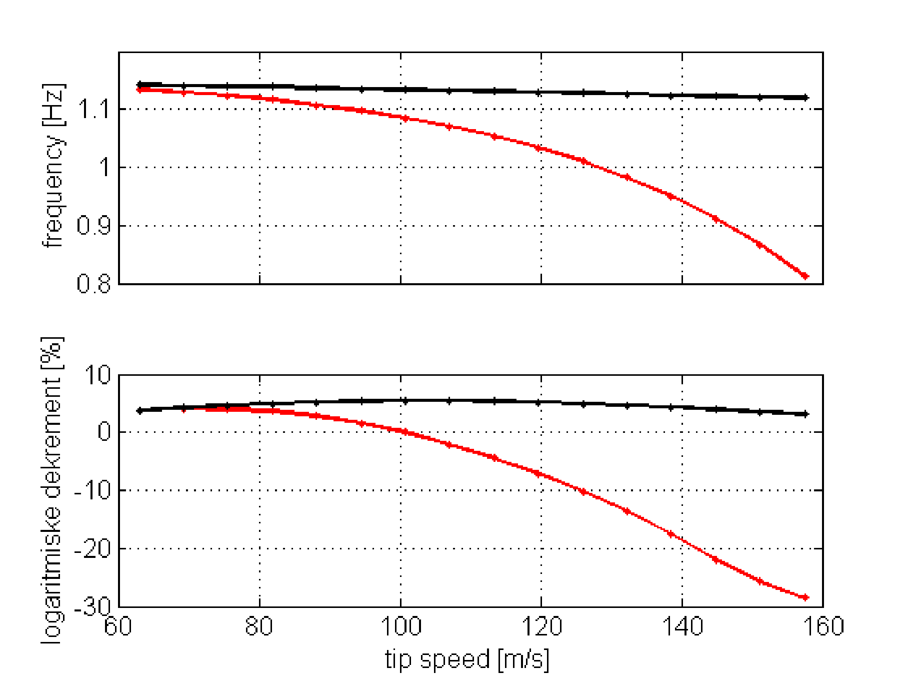
Aeroelastic simulation of load reductions with active trailing edge flap

Reduction / Pitch / Power	7m/s K_α =0	7m/s K_α =1	11m/s	18m/s
10 min. **max blade1**, flapwise root moment	11.8%	6.5%	16.0%	24.0%
10 min. **max tower**, flowwise root moment	8.8%	2.6%	6.5%	15.9%
Blade1, equivalent flapwise root moment	38.1%	36.2%	45.5%	47.9%
Tower, equivalent flowwise root moment	33.2%	31.9%	20.8%	33.3%
Pitch rate, standard deviation	n/a	n/a	10.9%	19.0%
Mean power prod. (+loss) without DTEG	1375KW	1375KW	4694KW	5291KW
Mean power prod. (+loss) with DTEG	1364KW	1395KW	4682KW	5300KW
Percent change in power production	-0.8%	+1.5%	-0.2%	+0.2%

WP 2.4 Aeroelastic stability and total damping

Frequency and damping for a non-deflected and a deflected blade (red), respectively. (5 MW turbine)



Black: non-deflected blade

Red: deflected blade

Effect of large blade deflections on aeroelastic stability limits

Conclusions:

- No significant effect on flutter limit!
- Decreased aerodynamic damping of edgewise bending mode

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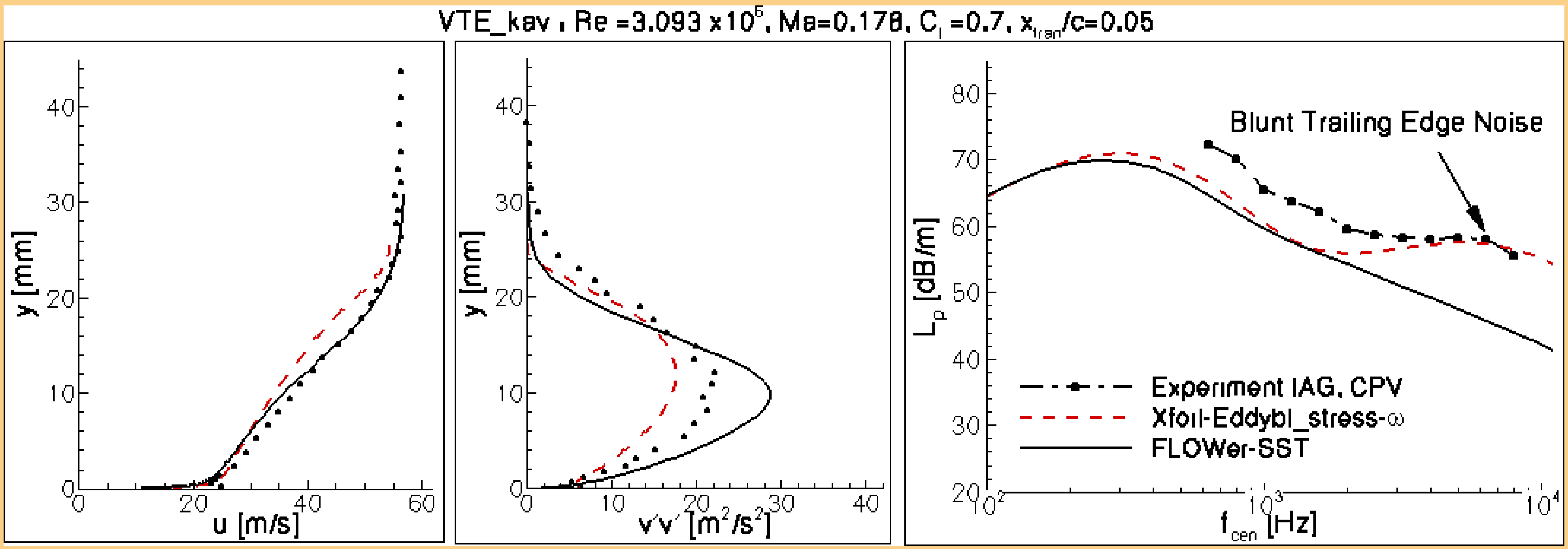
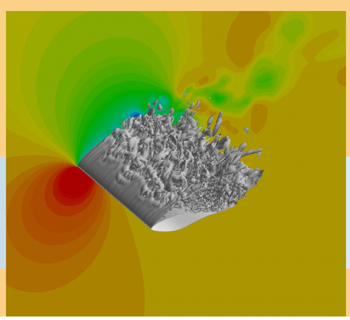
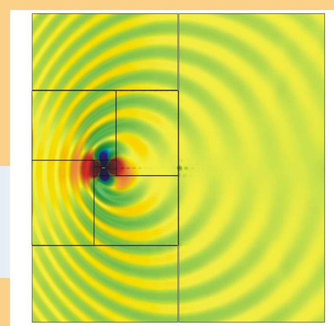
WP 2.5 Computation of aerodynamic noise– coupled CFD-CAA models

Results: VTE_kav, Cl=0.7, Noise Spectra







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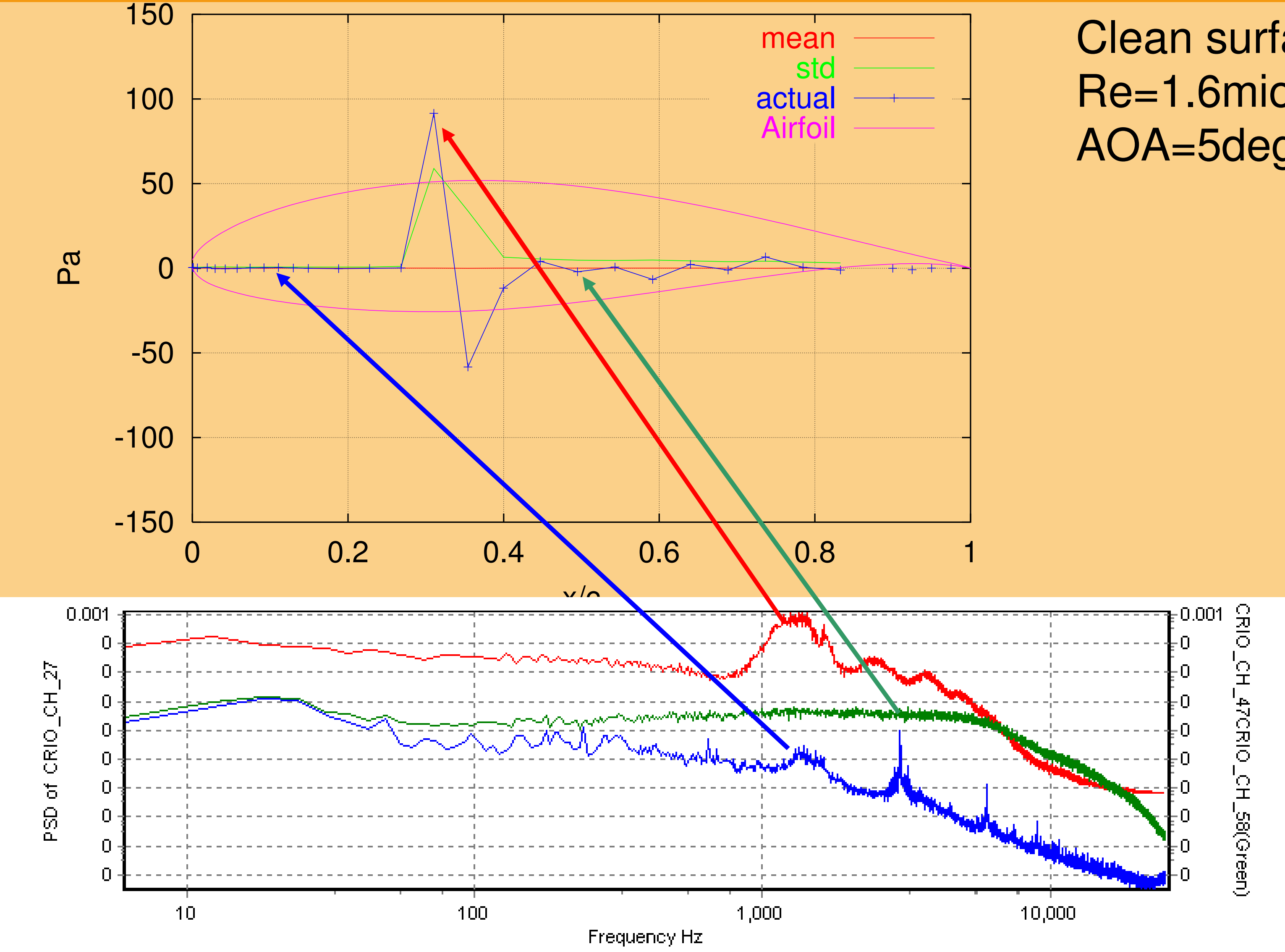
Transition detection: Risø-B1-18 transition points



Clean surface
Re=1.6mio,
AOA=5deg

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WP2 Aerodynamics and Aeroelastics

Summary

- Bending-torsion coupling is important
- Inflow shear is non-trivial
- Large load reductions with variable trailing edge
- Stability analysis including non-linear effects: stability characteristics for some modes are influenced
- Noise prediction: Boundary layer predictions and measurements