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Session BS4: Aerodynamics & Aeroelastic Stability

Stability Analysis of Parked Wind Turbine Blades

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Integrated Wind Turbine Design

Work carried out in WP1B1 of UpWind Project

- ✓ Innovative blade design
  - ✓ Aeroelastic design improvements
  - ✓ State-of-the-art issues are investigated
- ✓ Aero-servo-elastic stability of blades and wind turbines in operation has been tackled by the wind energy community

Objective/Motivation

- ✓Examine stability of blades under parked conditions
- ✓ Parked conditions (instead of idling) to facilitate the calculations
- ✓ Contribution to fatigue loading of blades to be also considered during design phase:
  - ✓ Extreme winds of 50 years recurrence period
  - ✓ High angles of attach in the stall regime
  - ✓ Massive flow separation at whole blade span
- ✓ Application on a 40-meter blade designed in Upwind

Challenges

- ✓ Prediction of aerodynamic loads in fully separated flow conditions
  - ✓ Dynamic stall models provide loads for angles of attack in the maximum lift regime
  - ✓ Not tuned for incidences of $\pm 90^o$
- ✓ Actuator disk theory is not valid
  - ✓ Polars of airfoils are not measured at such angles of attack
- ✓ Standards include load cases for parked blades at extreme yaw misalignments

The Tool

- ✓ Baseline Tool:
  - ✓ Industry standard aeroelastic stability tool
  - ✓ Beam element method with twelve DOFs per element
  - ✓ Multi-body approach for dynamic and structural coupling of components
  - ✓ Blade element momentum theory for aerodynamics modelling
  - ✓ Extended Onera Lift and Drag modelling of unsteadiness and dynamic stall through 'Aeroelastic Beam Element' approach

The Tool

- Modification for parked conditions:
  - 2D strip theory, neglecting wake effects
- Linearization
  - Reference steady-state (static problem)
  - First order system

$$\dot{\boldsymbol{x}} = \boldsymbol{A}(\boldsymbol{x_0}, \dot{\boldsymbol{x}}_{\boldsymbol{0}}) \cdot \boldsymbol{x} + \boldsymbol{B}$$

- Eigenvalues of constant coefficient matrix ***A*** provide natural frequencies and damping of the blade

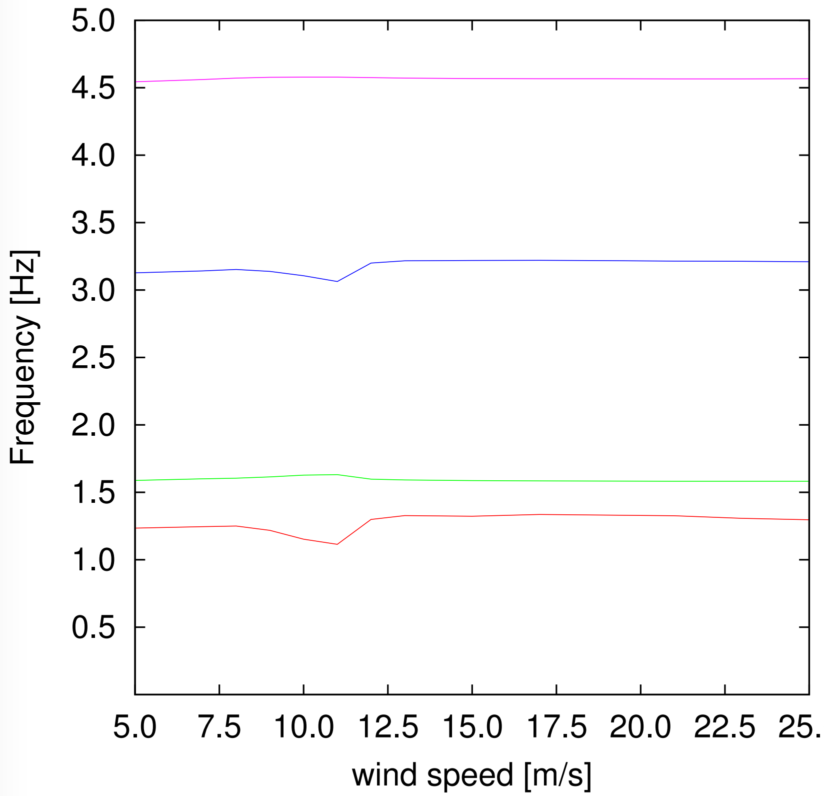
The Blade

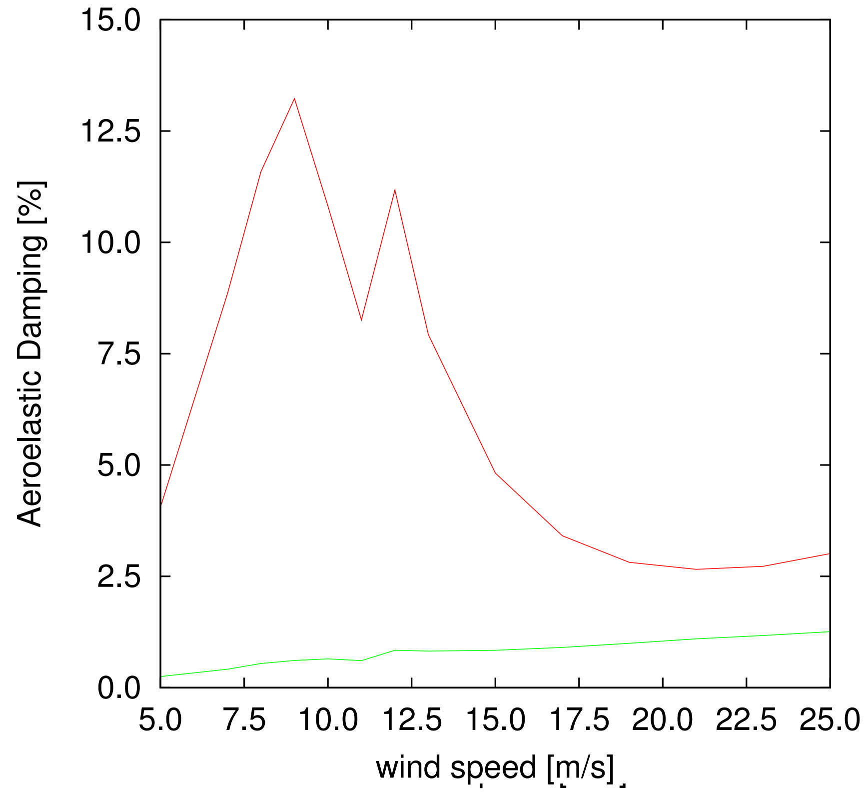
- ✓ Reference blade (around 40m) designed in UpWind.
  - ✓ Infinitely stiff
  - ✓ No structural damping

Mode Description	Natural frequency [Hz]	
	0 rpm	**16.7 rpm**
1st flap	1.17	1.24
1st lag	1.55	1.56
2nd flap	2.95	3.04
2nd lag	4.31	4.35
3rd flap	5.95	6.03
3rd lag	9.41	9.46

Aeroelastic performance of the blade

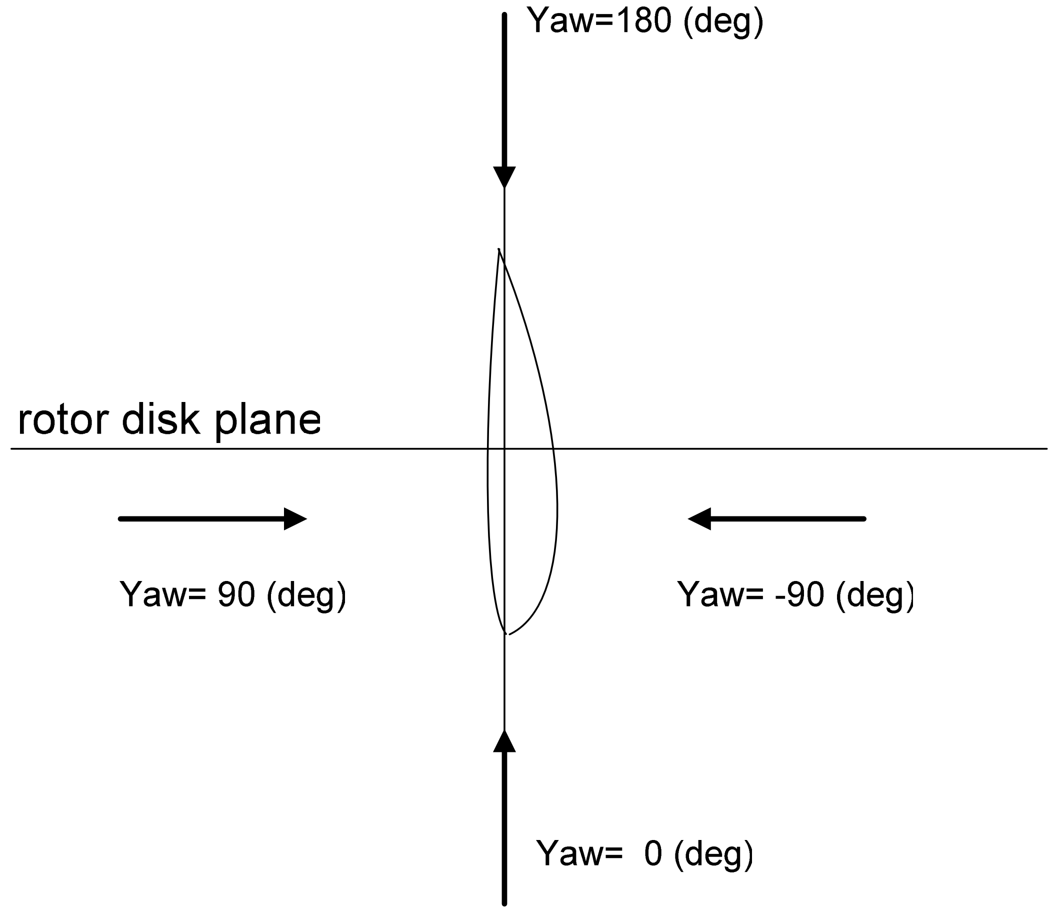
✓ Frequencies and damping of first and second flap and lag modes





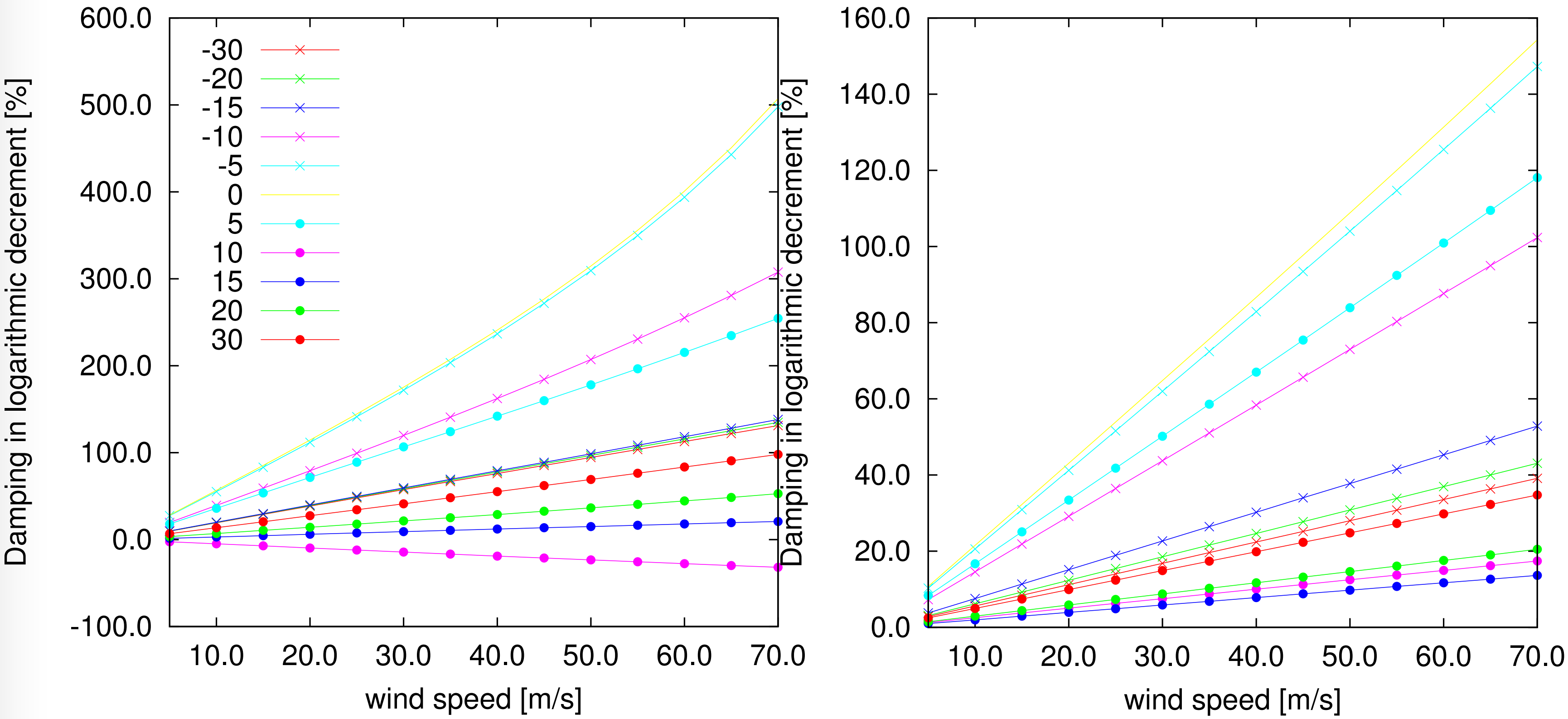
Stand-still blade analysis

✓ Definition of yaw angle



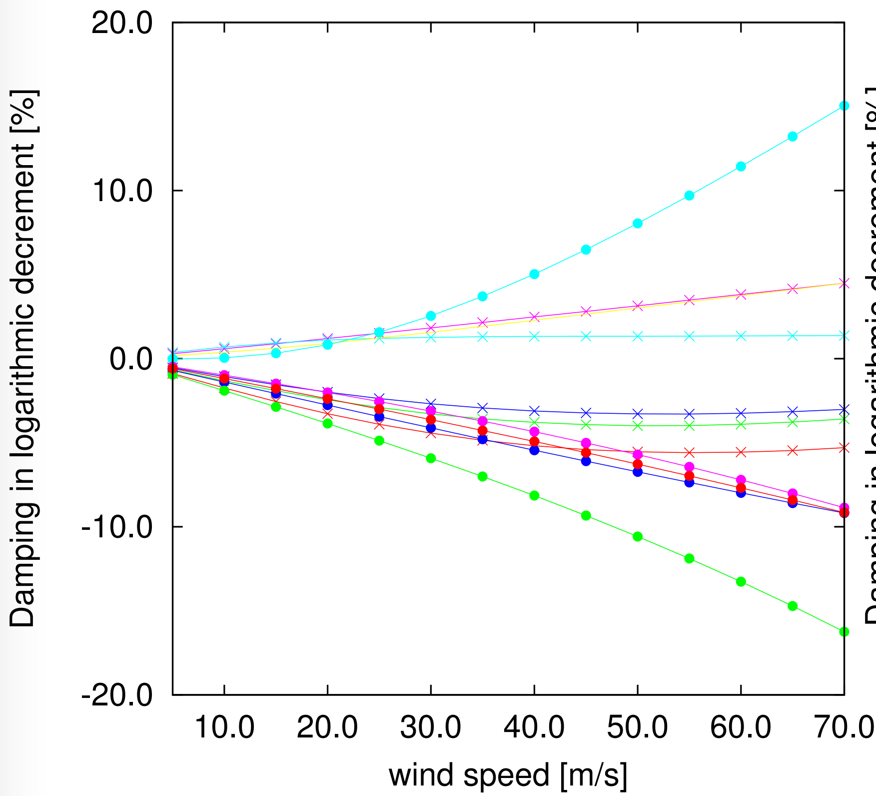
Stand-still blade analysis

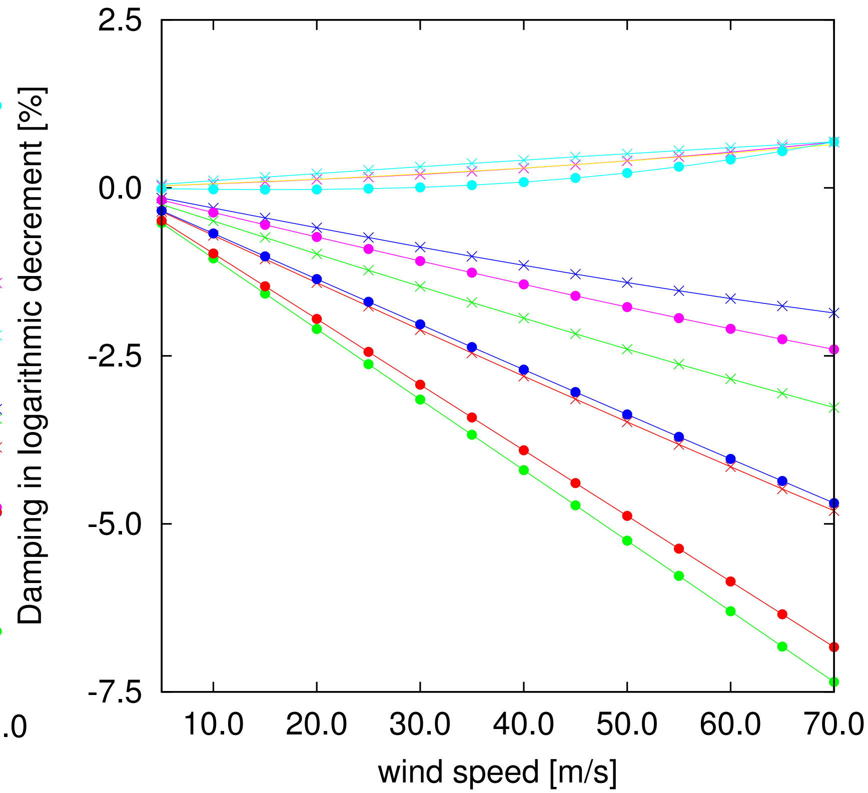
- ✓ Aeroelastic damping of first and second flap mode using quasi-steady aerodynamics



Stand-still blade analysis

✓ Aeroelastic damping of first and second lag mode using quasi-steady aerodynamics





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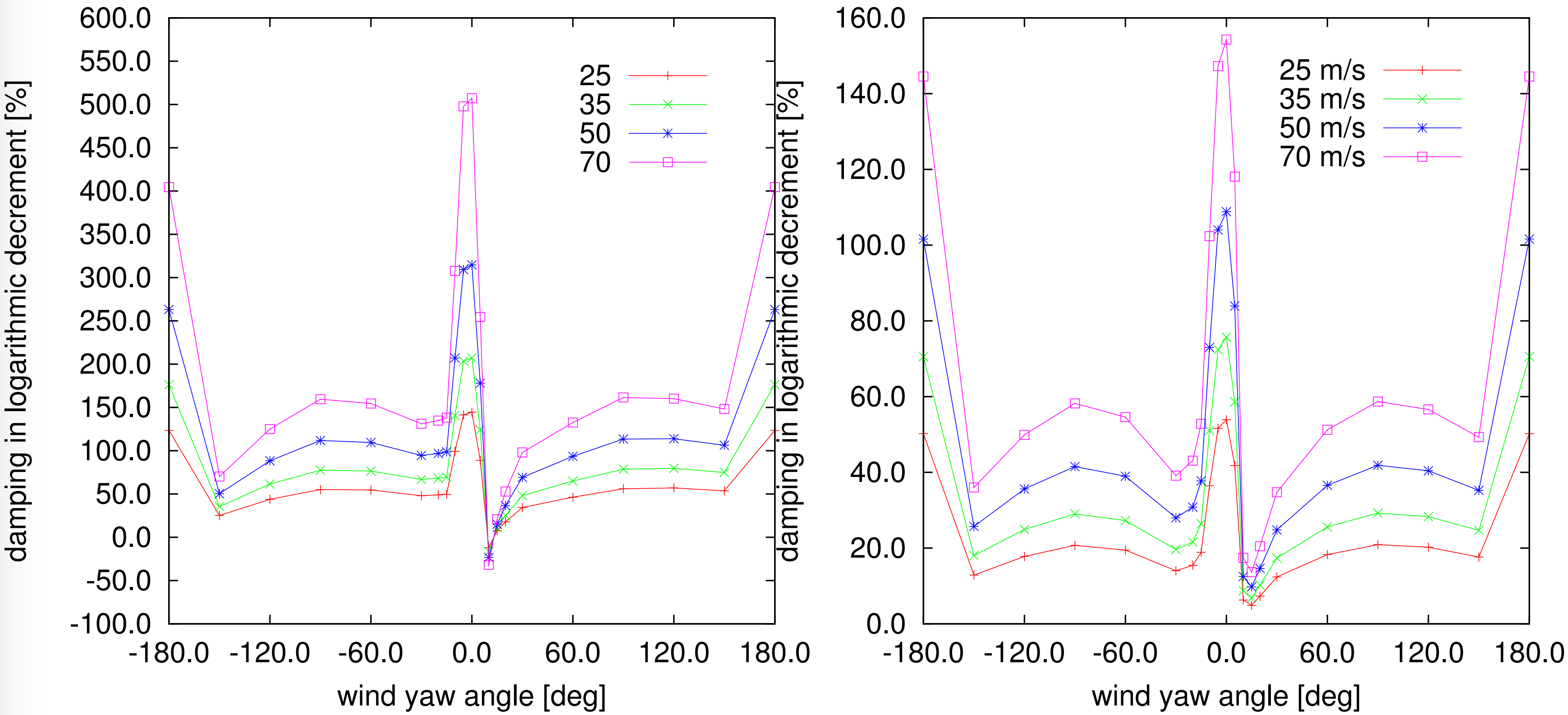

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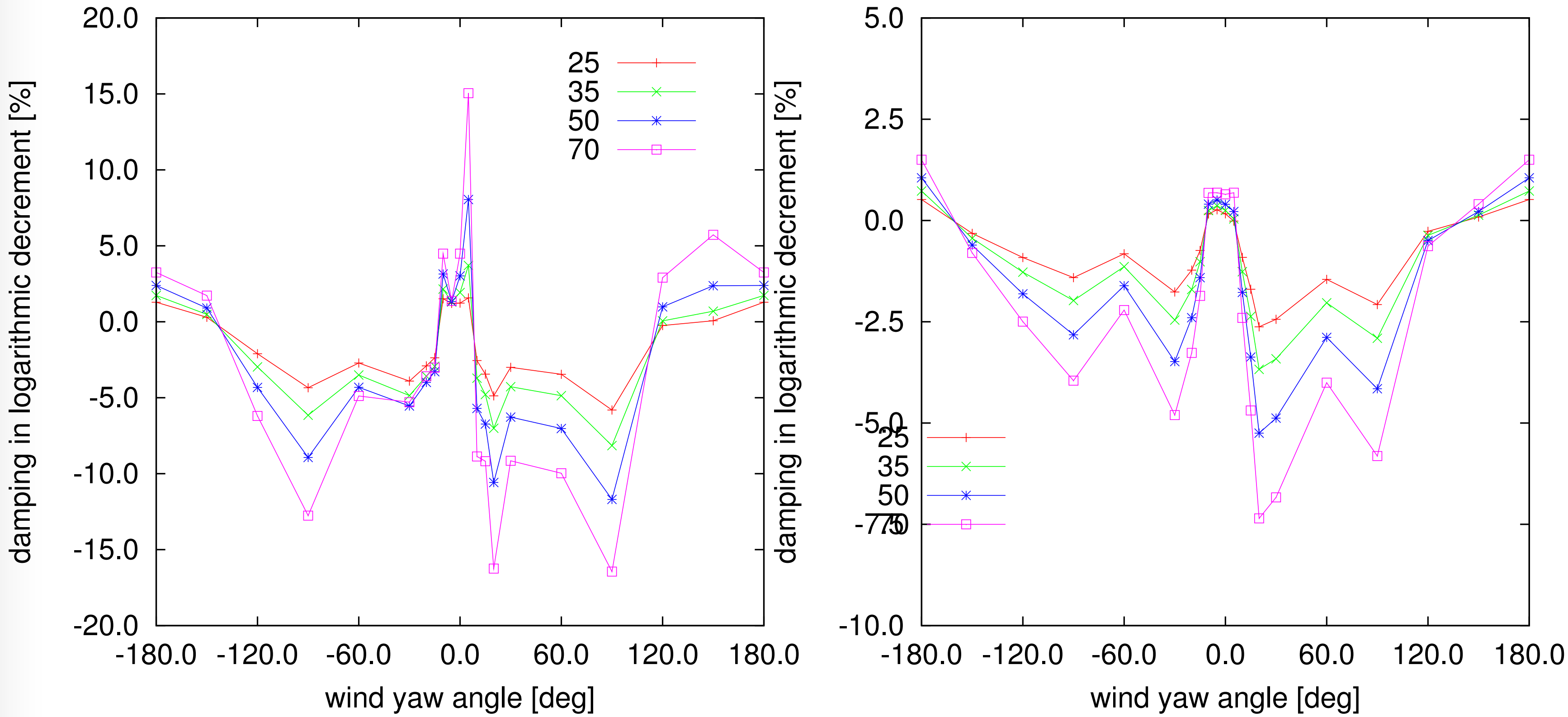
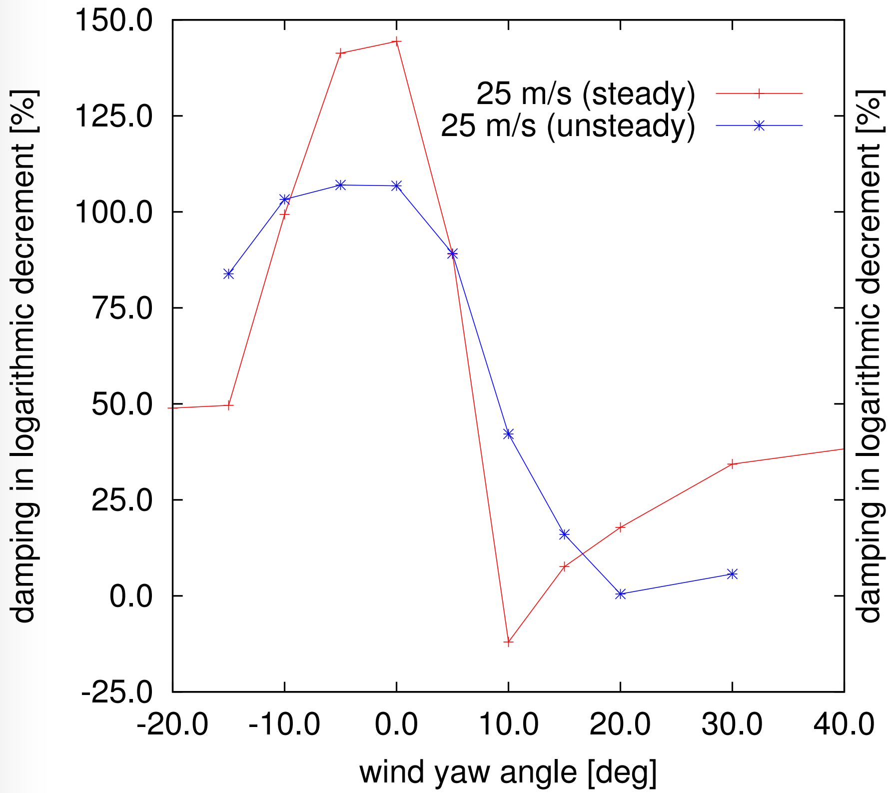
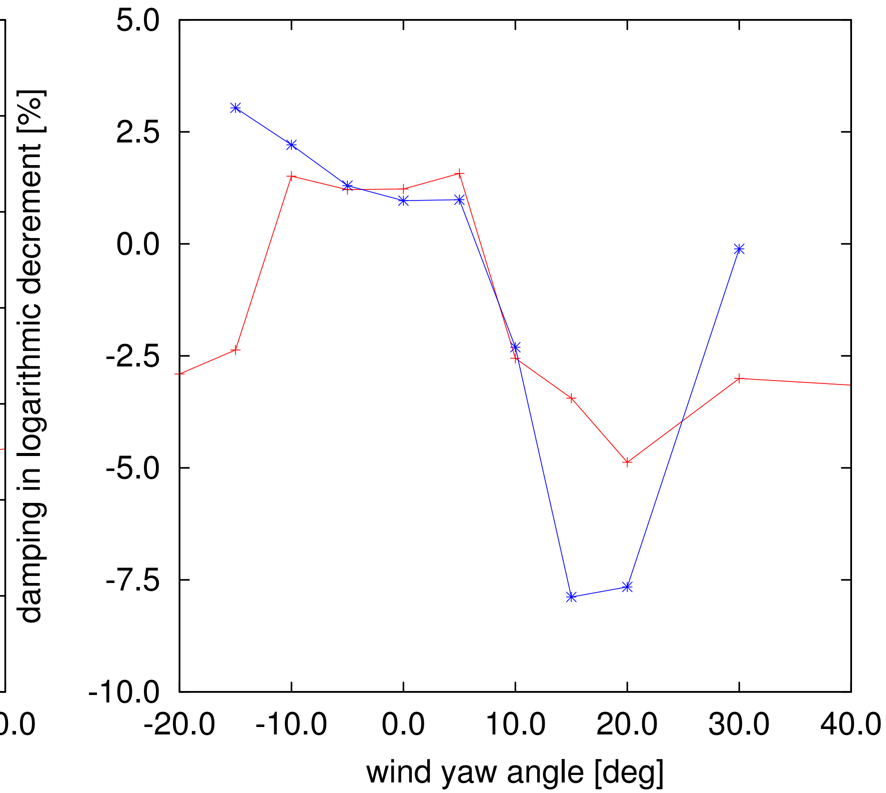


Stand-still blade analysis

✓ Aeroelastic damping of first flap and lag modes for quasi-steady and unsteady aerodynamics





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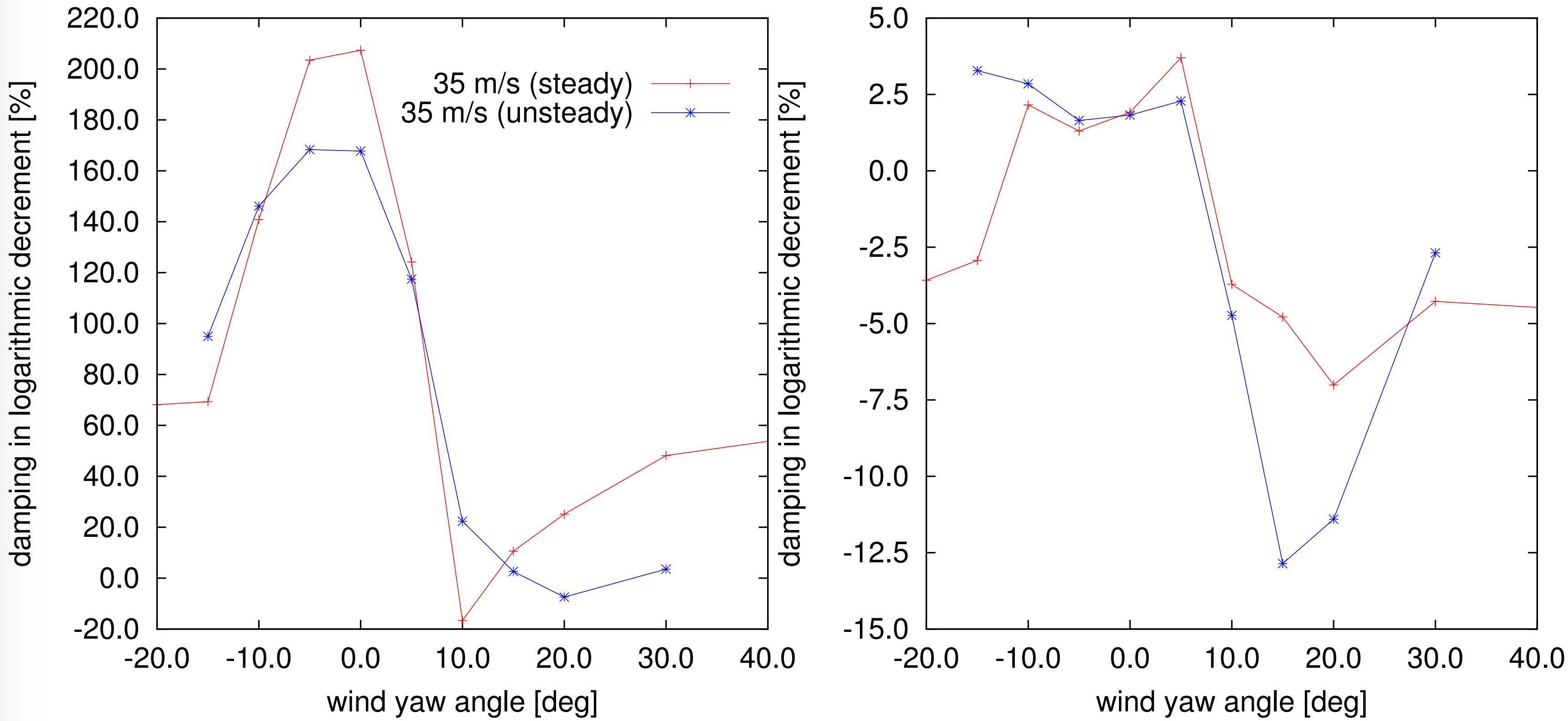

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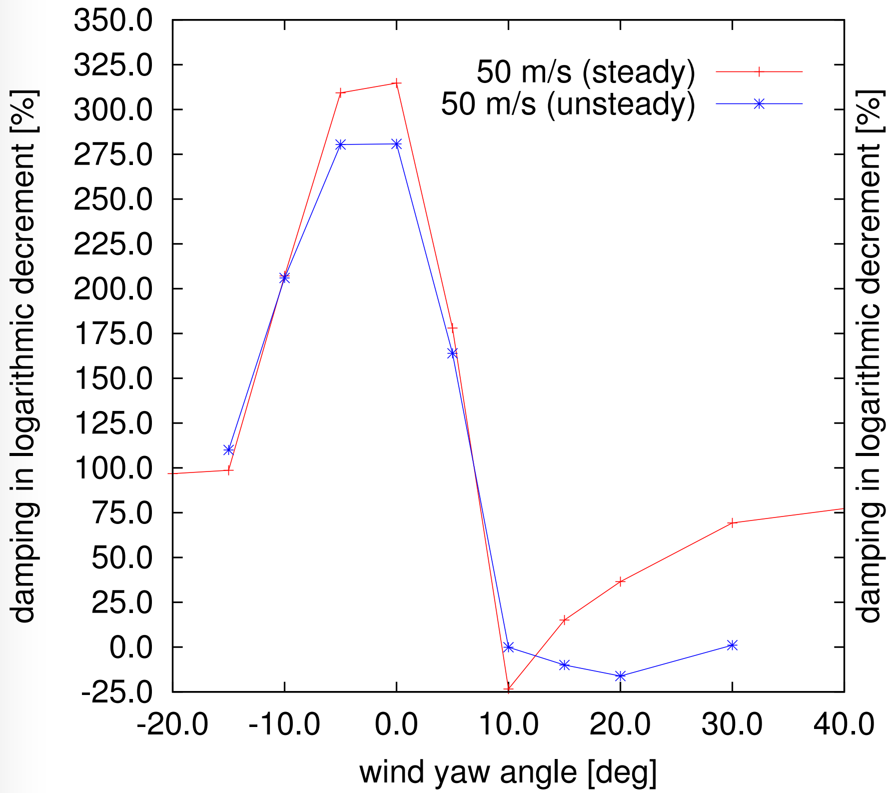
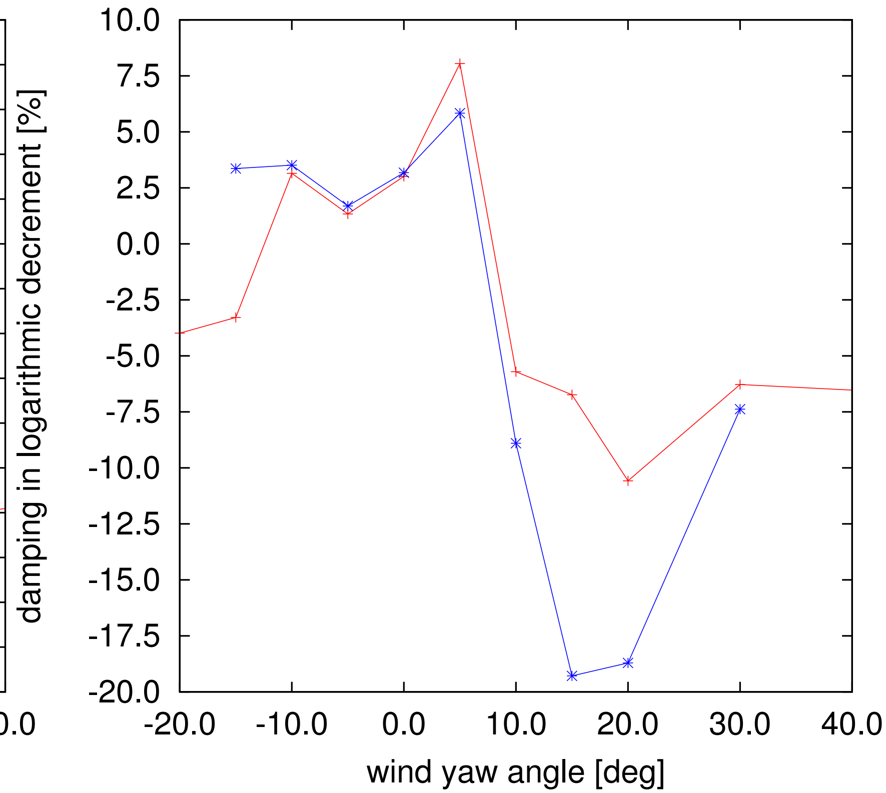




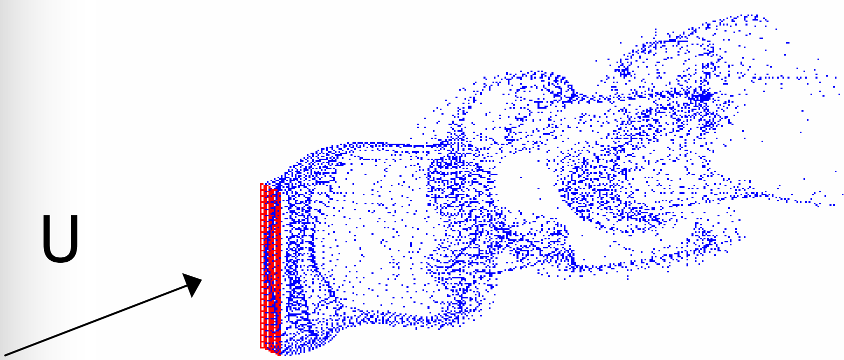
Conclusions

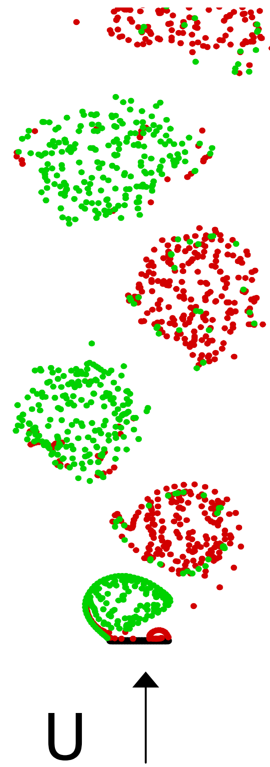
- ✓ Aeroelastic stability of a wind turbine blade under parked conditions for yaw conditions in the range $\pm 180^{o}$ and wind speeds up to 70 m/s
- ✓ Lowest aerodynamic damping appears in lead-lag mode
- ✓ Potential instabilities in flap mode would be limited to a narrow incidence band
- ✓ Unsteady modelling results in higher instabilities in lag modes compared to the quasi-steady

Outlook

- ✓ Vortex type model of massively separated flows
- ✓ Vorticity emission takes place both from LE and TE
- ✓ Unsteady vortex shedding effect is taken into account

3D flat plate model





2D flat plate model

Acknowledgements

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- ✓ Audience for its attention