Improvement of aerodynamic blade design tools by means of advanced CFD

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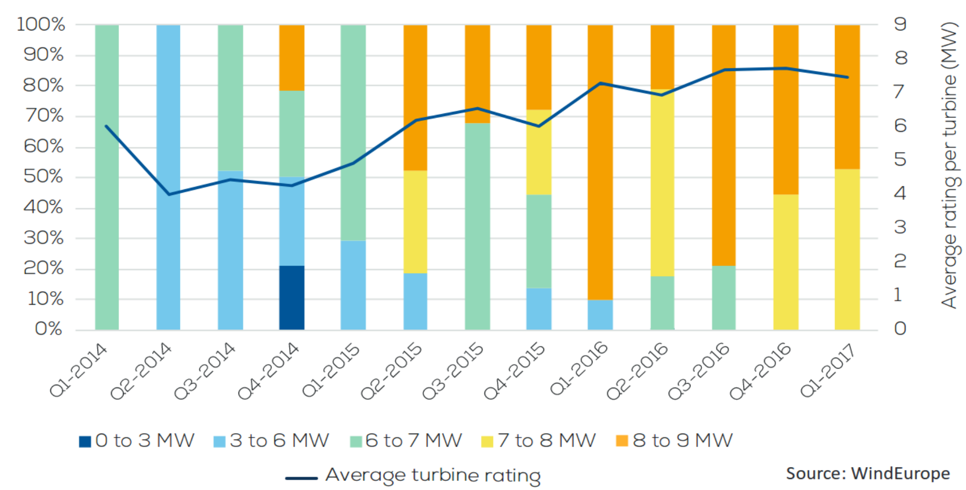
Extracting more energy from wind

- **Enlarging the rotor blades of new wind turbines**
  - In the first quarter of 2017:
    - All offshore wind turbines ordered were in the 7 to 9 MW range
- **Improving the design (optimized design)**
  - More accurate modelling
  - More cost-efficient turbines
  - Lower cost of energy

FIGURE 29
Capacity rating of ordered offshore wind turbines in Europe



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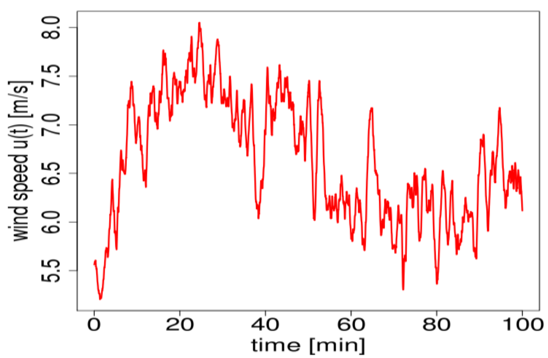
Wind turbines are getting larger

- Light weight blade design
- Blade flexibility increased
- Non-linear interaction between aerodynamics and structure

Source: Siemens

Aerodynamic Design-Tool: BEM

- Main aerodynamic design method for wind turbines
- Reasonable results – for most load cases
- Basic BEM is improved by engineering add-ons
  - Dynamic Stall, stall delay, yawed inflow …
- The models are often obtained by small experimental or low fidelity tools



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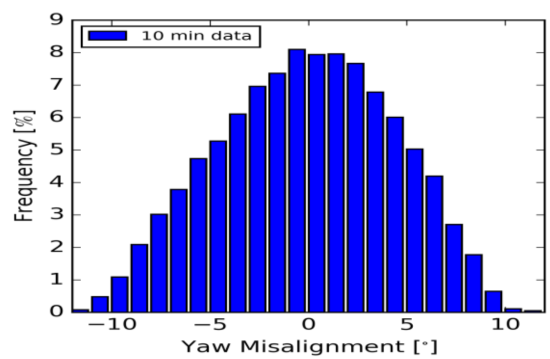

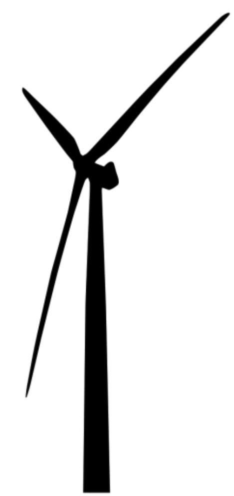

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BEM Engineering Models

- Rotor designs of the new large turbines are challenging
- Thick(er) airfoils, high(er) flexibility and high(er) Reynolds

- Leads to more unknowns and non-linear behavior
- Uncertainties in loads calculation for complex cases
- Direct impact on: structural design, extracted energy

@ lmwindpower: The world's longest blade 88.4m

- **Improving BEM engineering models is necessary**

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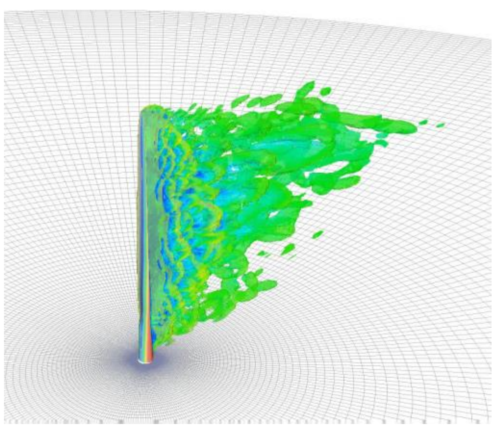
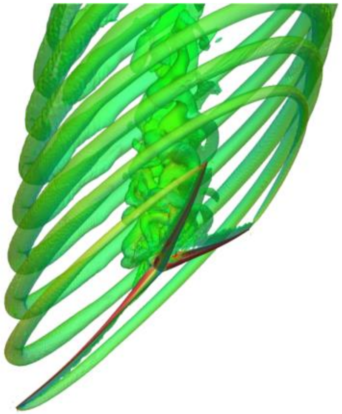
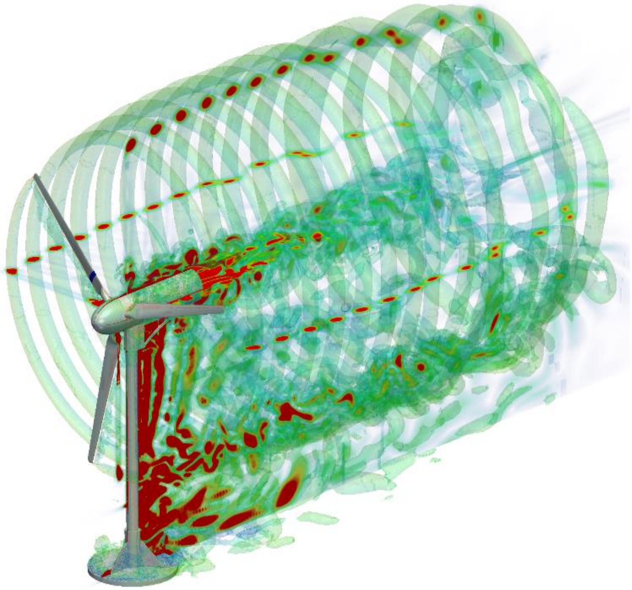
Computational Fluid Dynamics (CFD)

- High fidelity →No empirical corrections models required
- However: Computational expensive
  - Not suitable for calculation of DLCs
- CFD can be used for
  - Investigation of complex phenomena
  - Development of new models







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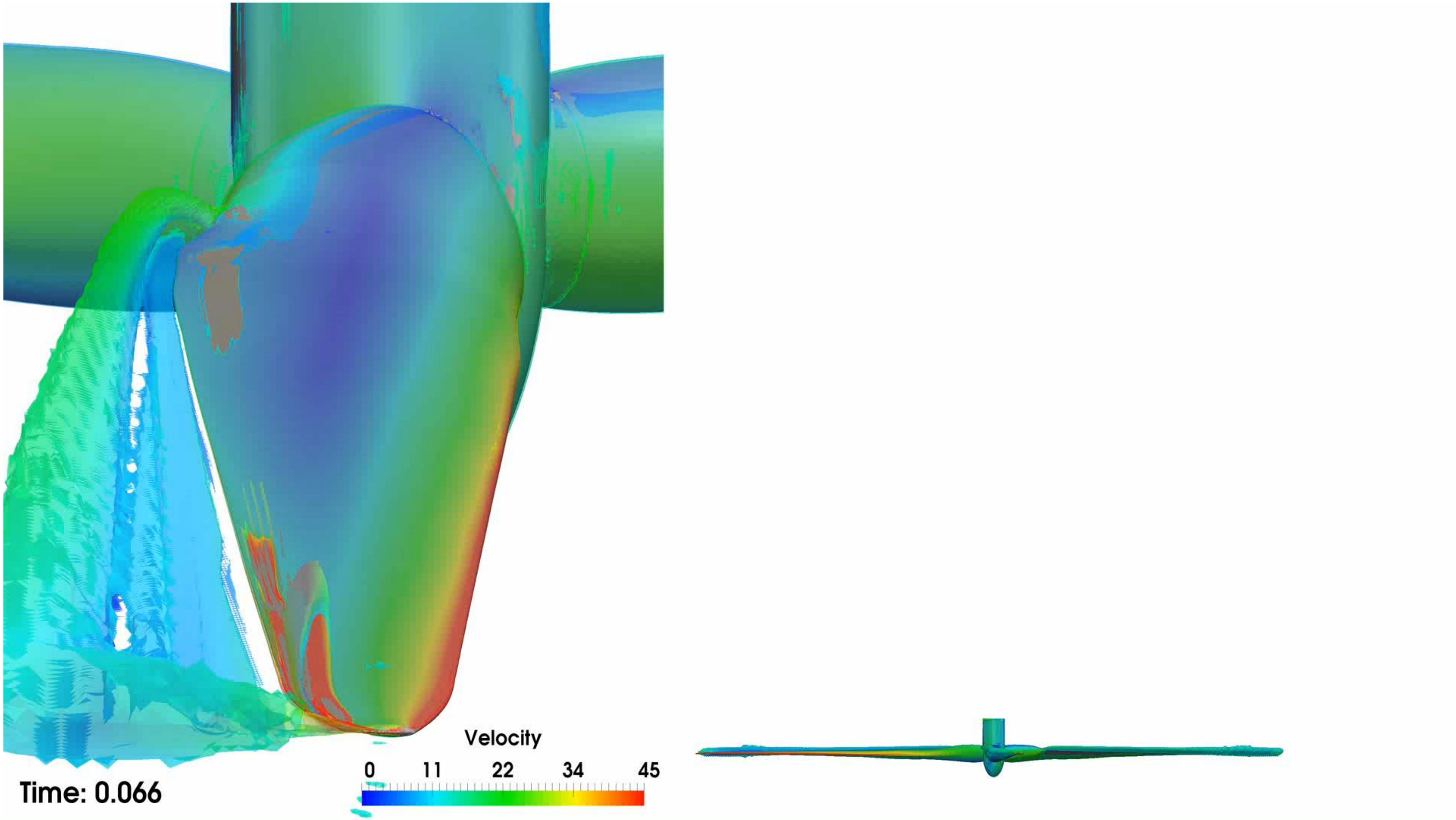
Example: NREL 5 MW subjected to yawed inflow



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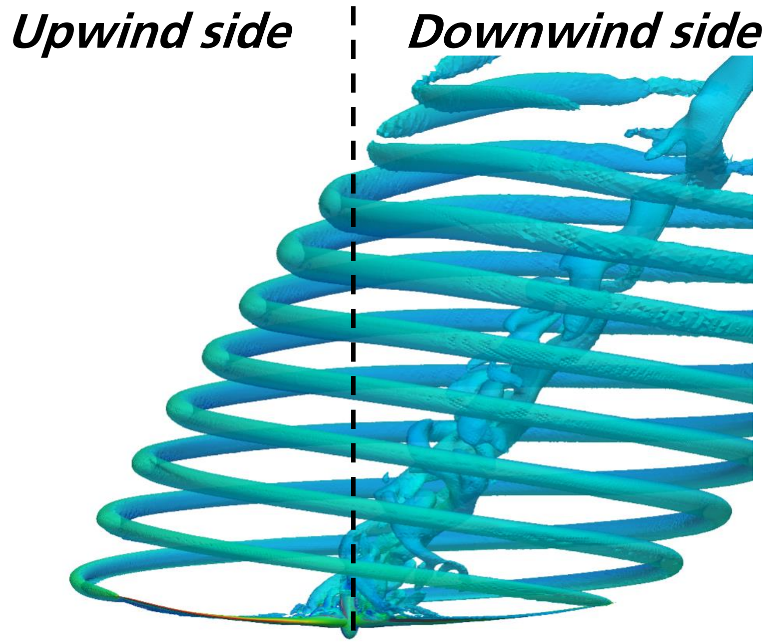
Skewed wake model and BEM

- Load unbalance
- The influence of tip and root vortex changes with blade size
- Influence of blade size not included in current correction models



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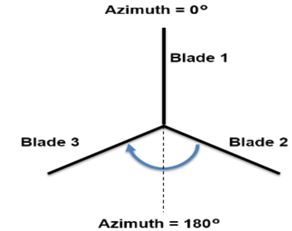
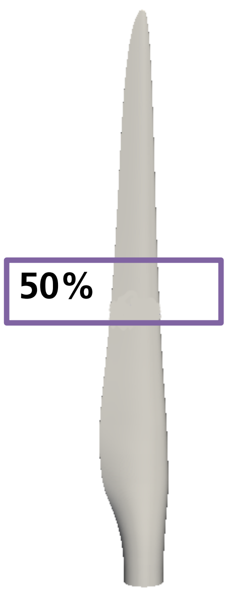
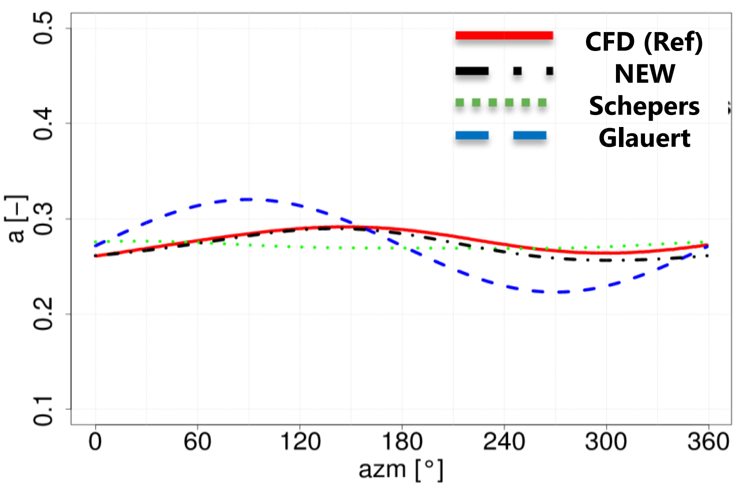
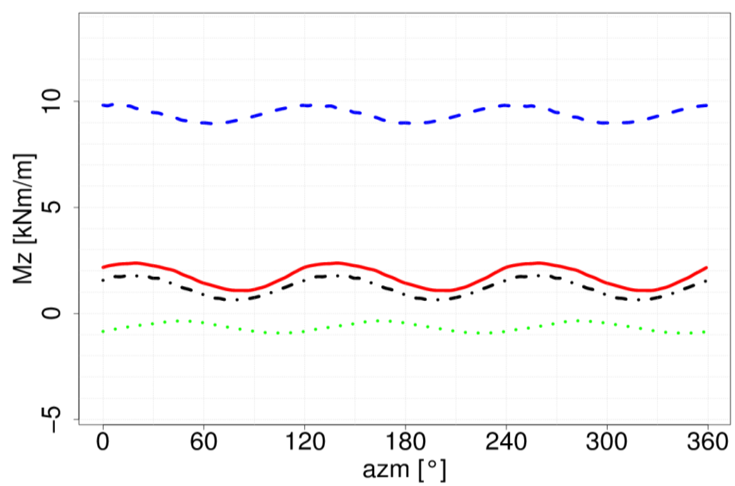
Results - INNWIND 6 m/s at 20° yaw



- Glauert skewed wake model is standard in industry for yawed flow
- New model developed based on CFD results
- The qualitative behavior of the proposed model is closer to reference CFD







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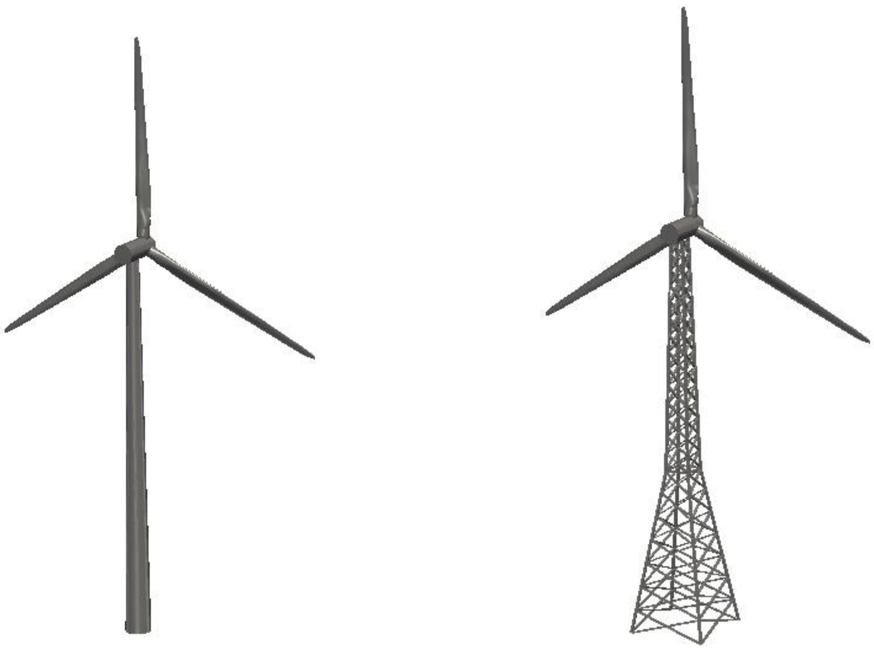
Example: Downwind turbine tower shadow

- Big drawback of downwind turbines: Blade-tower interaction
- Idea: Use lattice structure towers instead of tubular towers
- Comparison of structural blade deformations for both tower types



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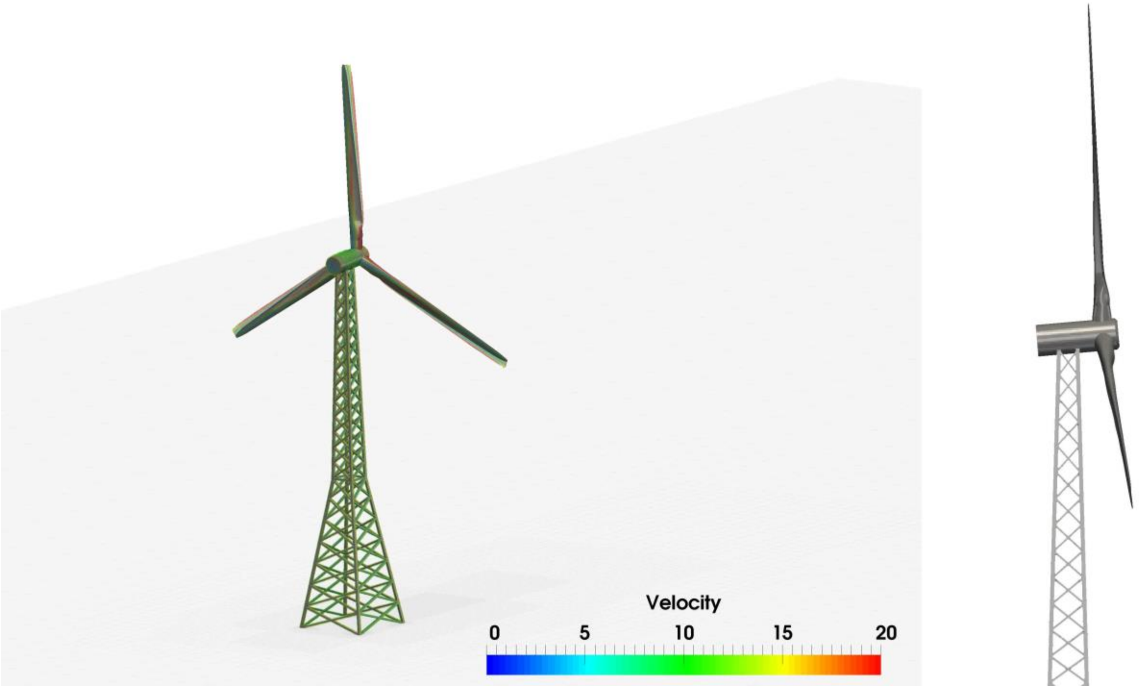
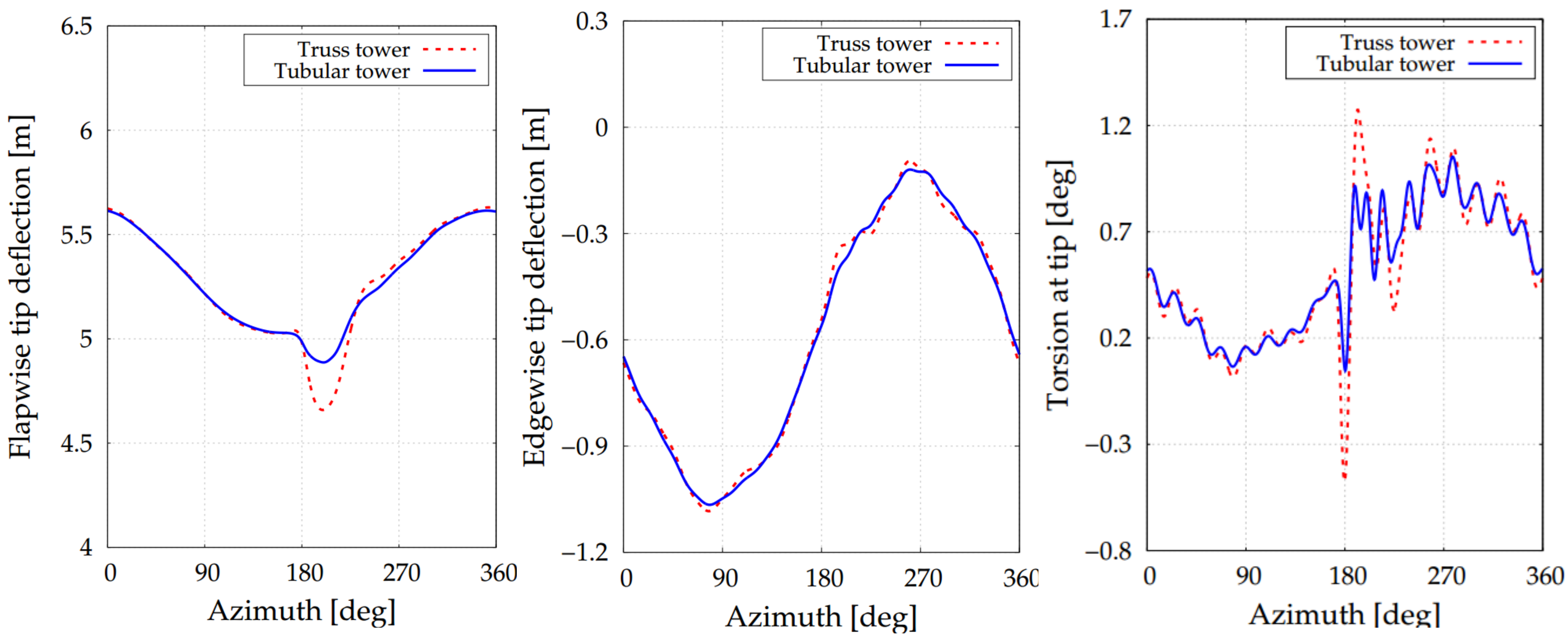


Downwind turbine: Tower shadow

- Truss tower geometry causes more severe effect on loads
- Torsional blade vibrations can cause additional fatigue
- Cannot be predicted by industrial aerodynamic design tools



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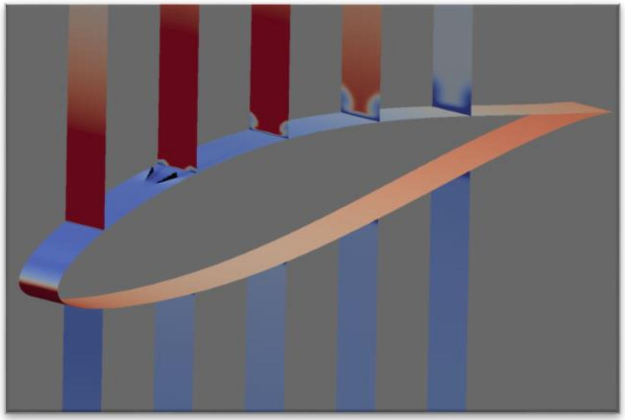
Example: Aerodynamic addons

- Aerodynamic addons are used to improve blade performance

www.3m.com/wind



- Vortex generators
  - Reduction of flow separation
  - Increase of lift
- Active flow control (AFC) devices
  - Known from aeronautics
  - Blow-out and suck-in of air in boundary layer
  - Investigated in research project TOpWind

TOpWind

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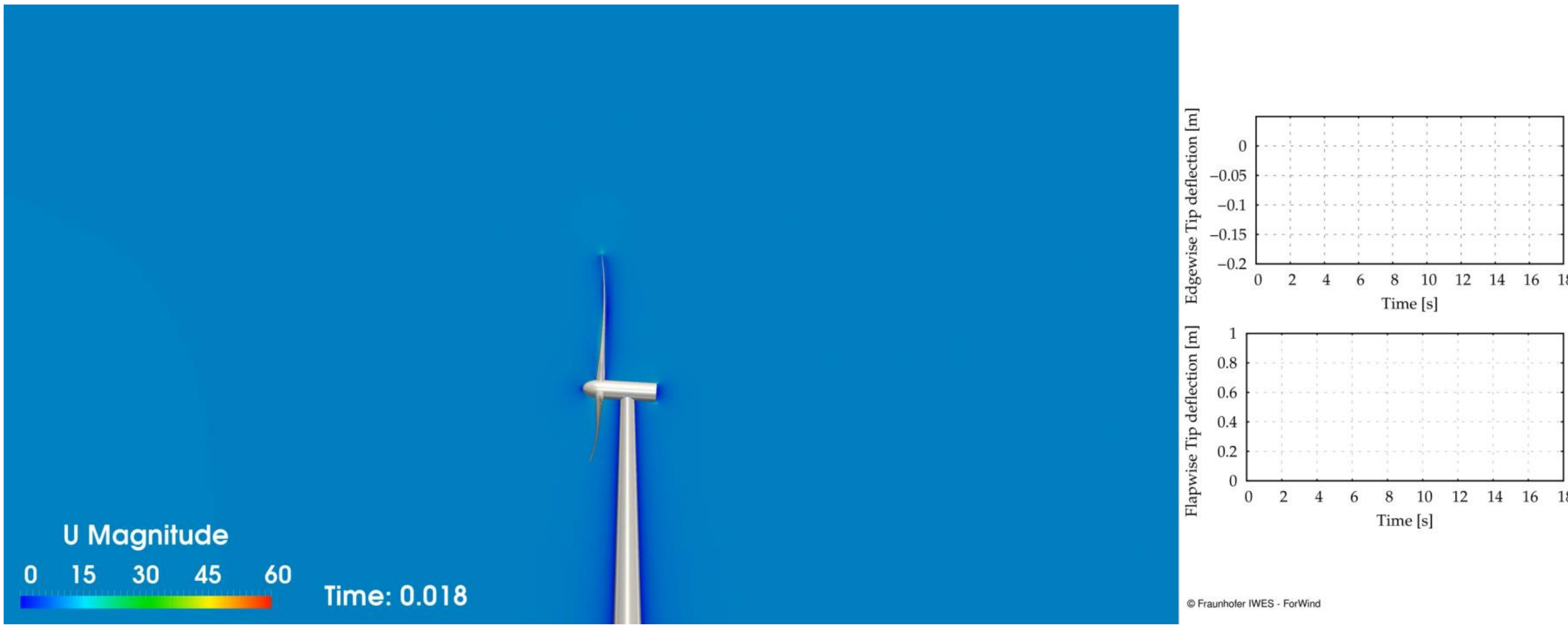
Conclusions

- High fidelity framework for full rotor simulations presented
- Fluid-structure coupling for large, flexible blades
- CFD suitable to improve BEM engineering models
- Improvement of skewed wake correction based on CFD
- Investigation of tower shadows (tubular vs. lattice)

Future work

- Investigation of inflow turbulence on rotor performance
- Simulation of smart load alleviation methods



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Thank You For Your Attention

Any questions?

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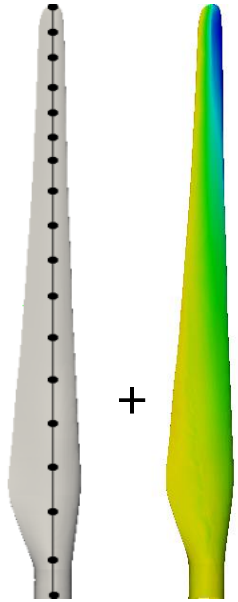
AUX: Our Fluid-Structure Interaction (FSI) approach

- FSI framework developed in Oldenburg

- Open source CFD toolbox OpenFOAM
  - Steady-state or dynamic simulations
  - Runtime post-processing (AoA)

- Finite Element framework
  - Geometrically exact beam theory (GEBT)
  - Supports large deformations and torsion



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