Improvement of aerodynamic blade design tools by means of advanced CFD

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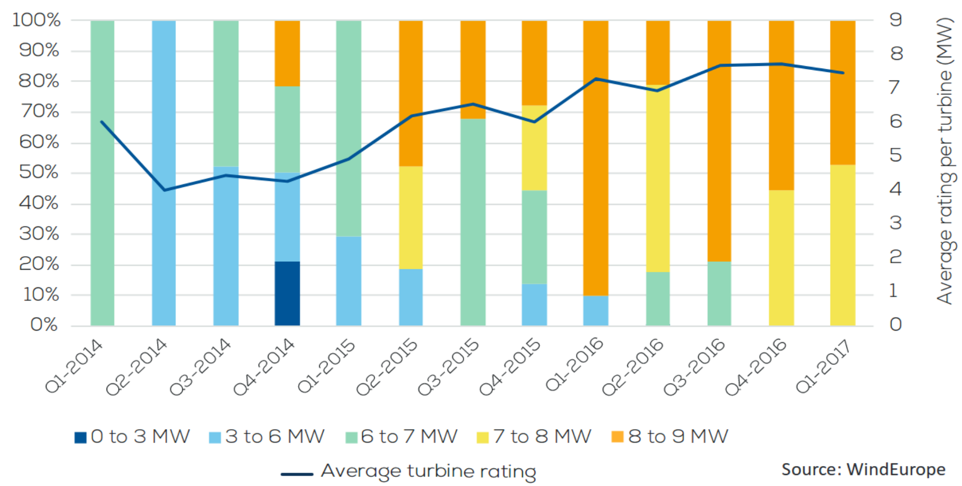
The trend in the offshore market

- Wind turbines are getting larger
  - All offshore wind turbines ordered were in the 7 to 9 MW range
  - Rotor blades are approaching 100 m in length
- What do we need for further improved designs?
  - Aerodynamic modelling
  - Better accuracy needed
  - More cost-efficient turbines

FIGURE 29
Capacity rating of ordered offshore wind turbines in Europe



Source: WindEurope

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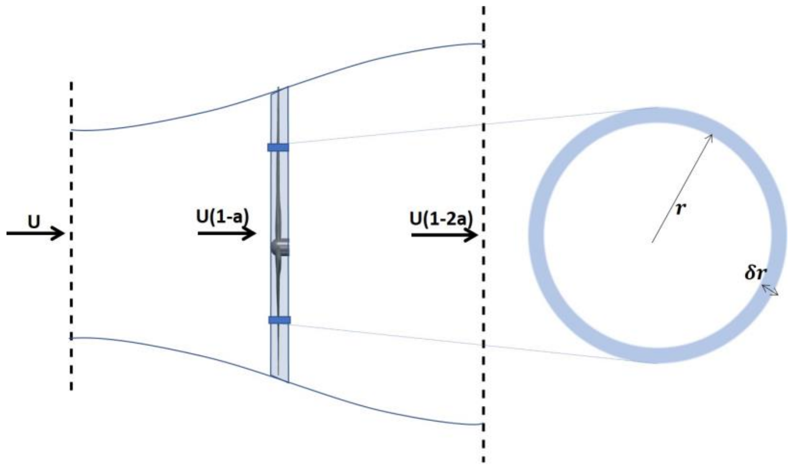
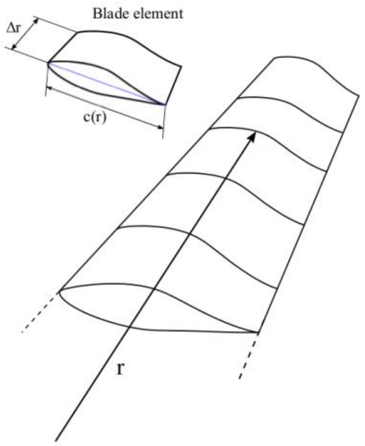
Blade Element Momentum (BEM) theory

- Main aerodynamic design method for wind turbines
- Reasonable results – for most load cases
- Simple theory is improved by engineering add-ons
    - Dynamic Stall, stall delay, yawed inflow …
- The models are often obtained by small scale experiments





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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

@ LM Wind Power

- Leads to more unknowns
- Uncertainties in loads calculation for complex cases
- Direct impact on: structural design, cost of energy

- **Improving BEM engineering models is necessary**

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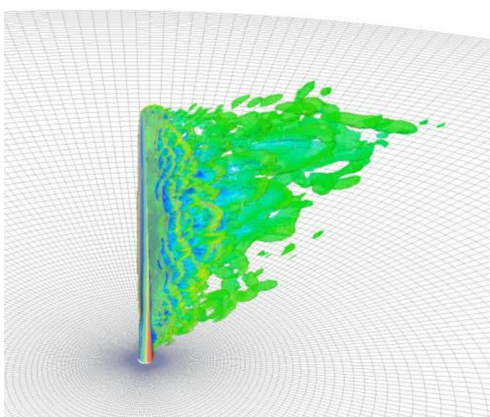
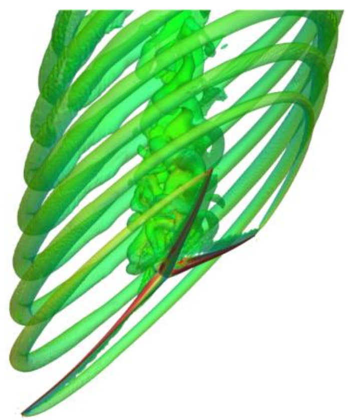
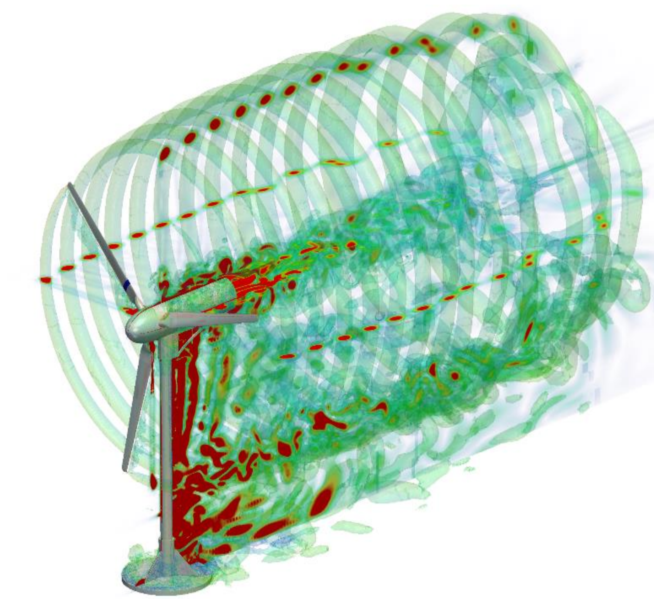
Computational Fluid Dynamics (CFD)

- 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





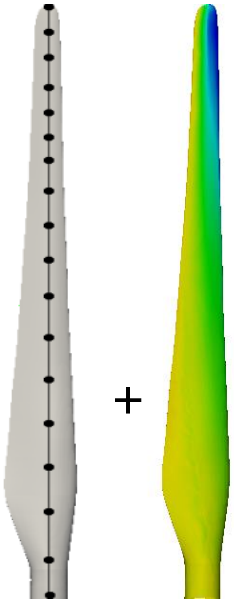


Our Fluid-Structure Interaction (FSI) approach

- FSI framework for flexible blades developed in Oldenburg

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

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



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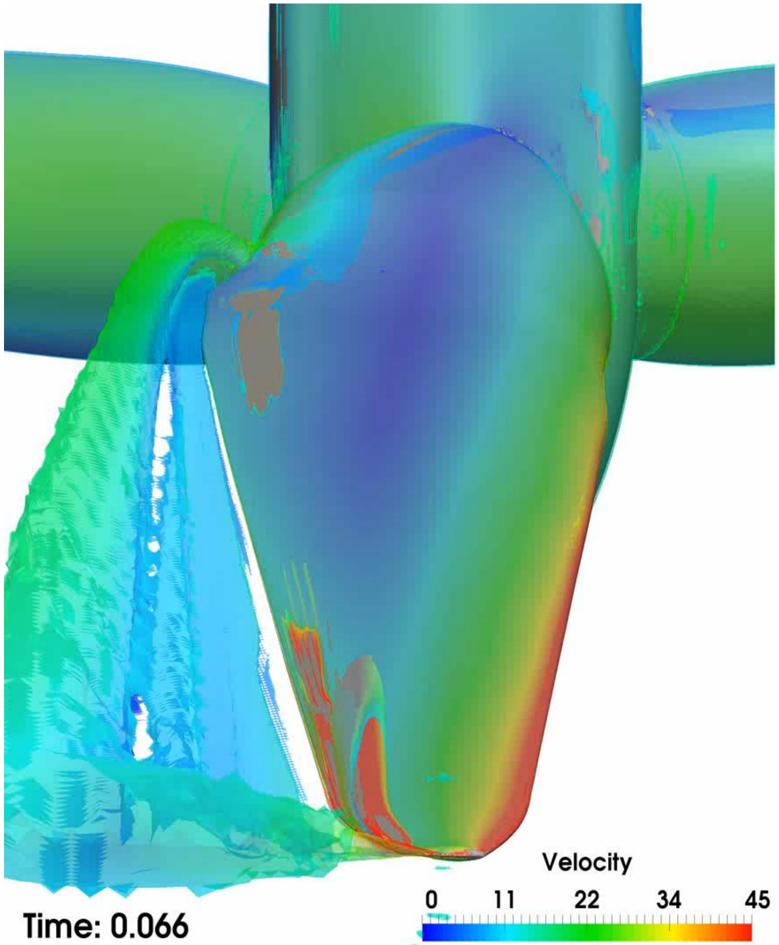
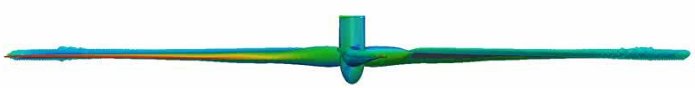
Example: NREL 5 MW subjected to yawed inflow





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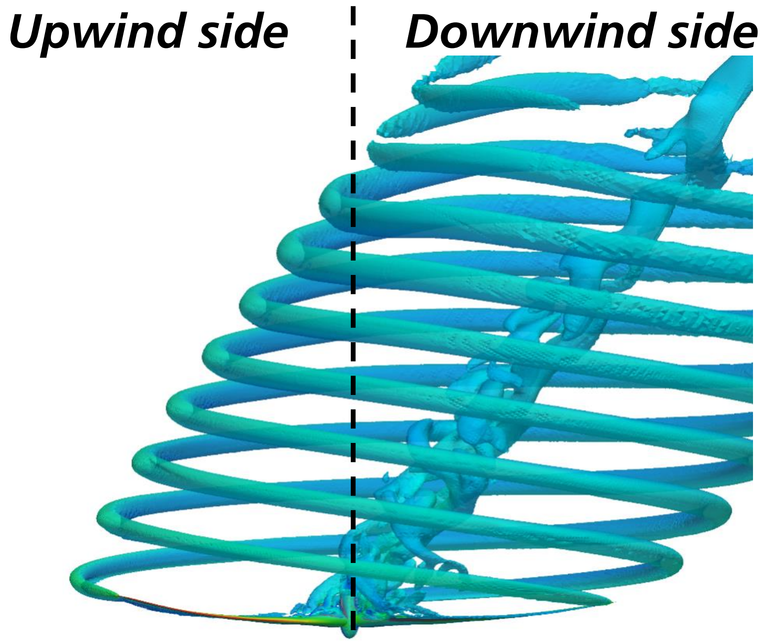
BEM and skewed wake models

- Load unbalance
- Tip and root vortex are dominant
- Variation of local induction in BEM: skewed wake models



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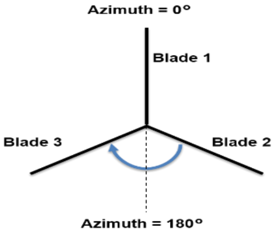
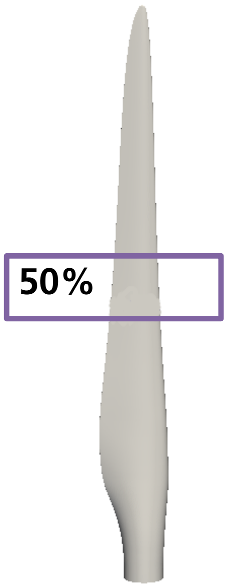
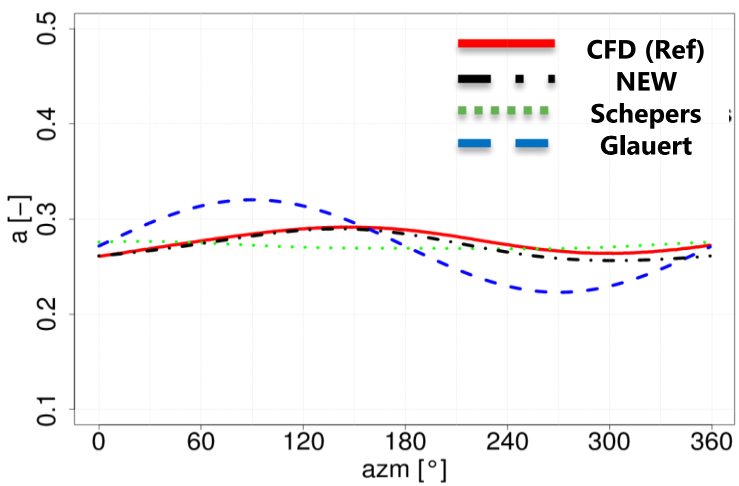


Comparison – DTU 10MW at 20° yaw

- Glauert skewed wake model is standard in industry for yawed flow
- Skewed wake models can be tuned based on CFD results
- The qualitative behavior of the proposed model is closer to reference CFD





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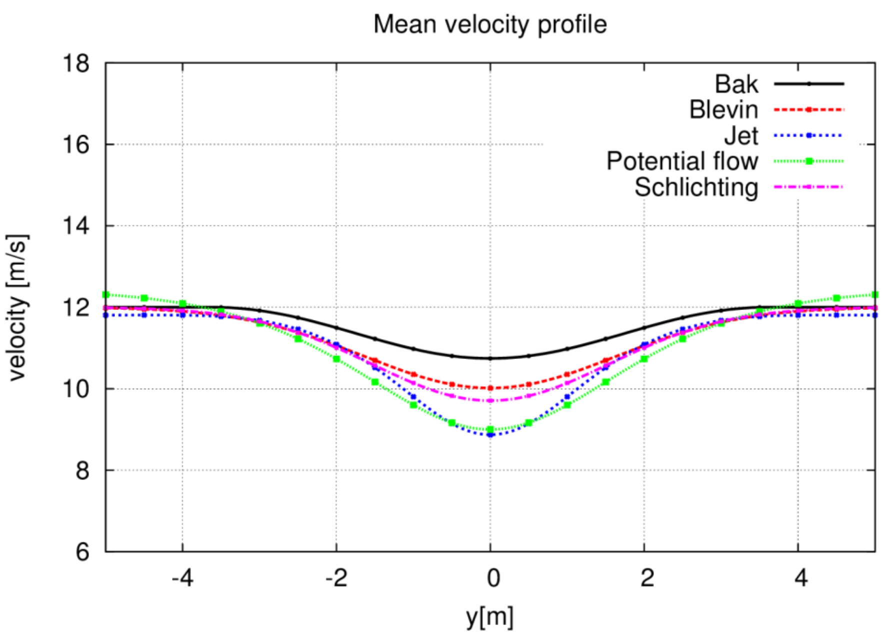
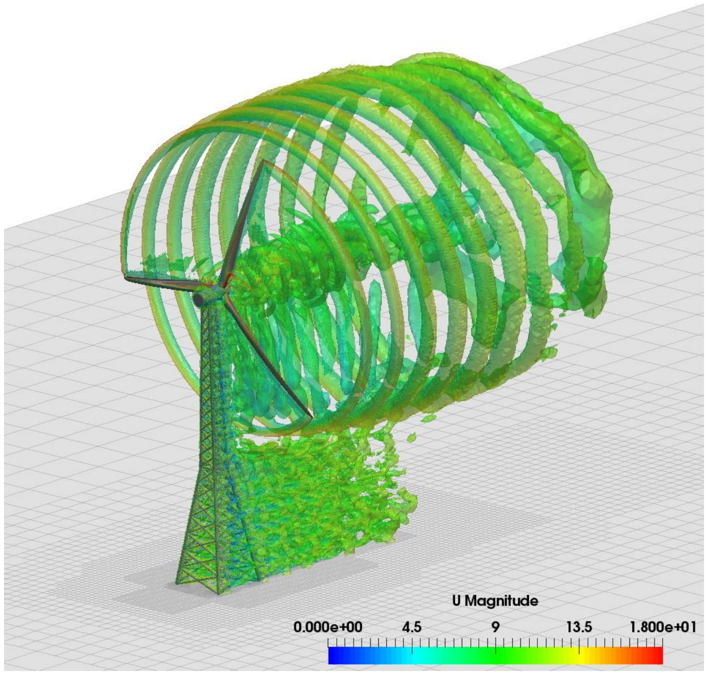
Example: Downwind turbines

- Big drawback of downwind turbines: Blade-tower interaction
- How accurate are the current tower shadow models in BEM?
- Significant discrepancies between different models





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Example: Downwind turbines

- Big drawback of downwind turbines: Blade-tower interaction
- Simulation of NREL 5MW rotor on truss and tubular tower
- Comparison of structural blade deformation

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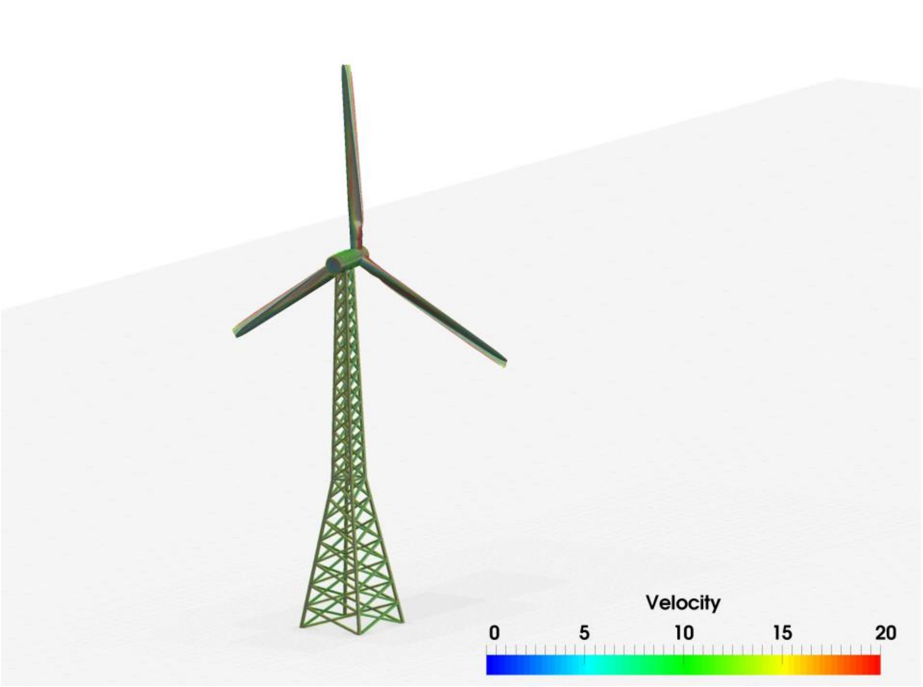

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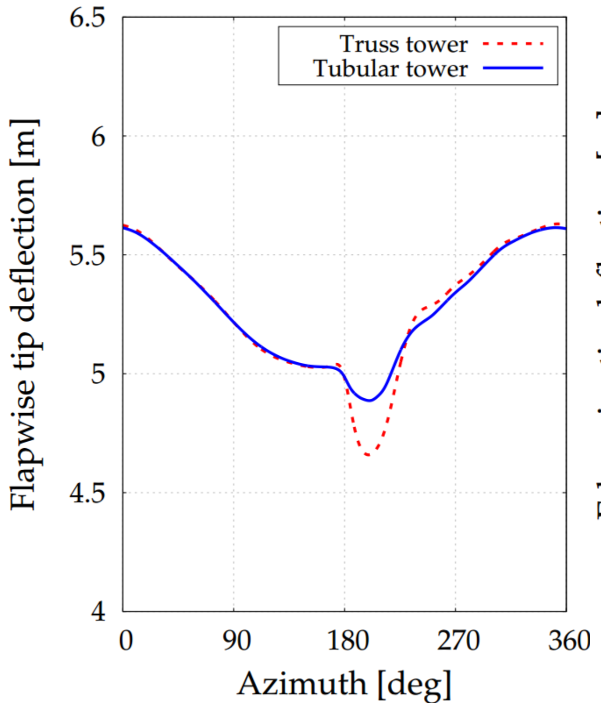
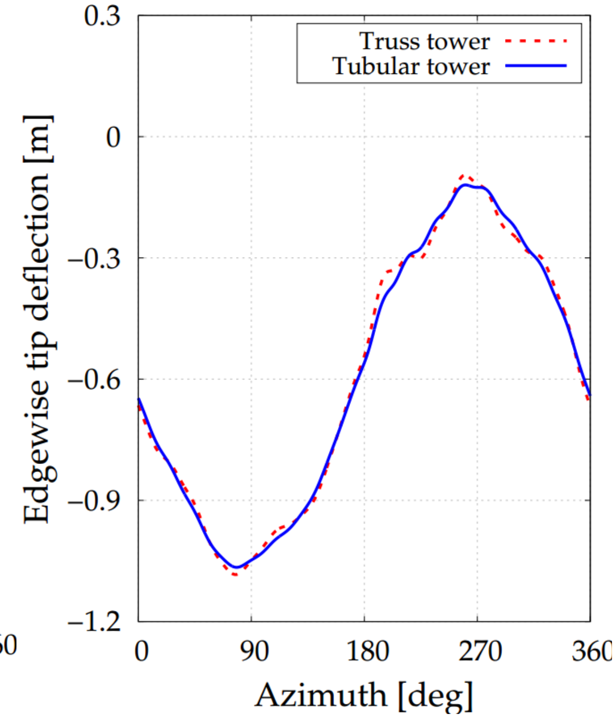
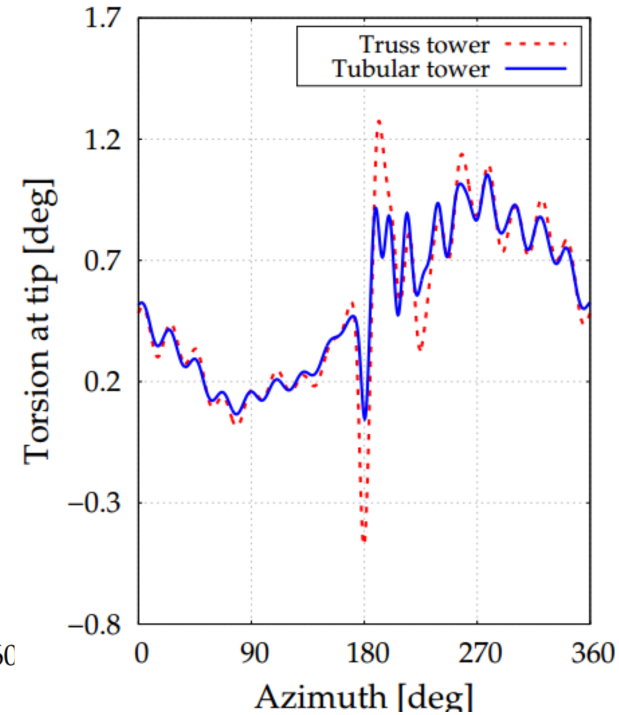
Example: Downwind turbines

- 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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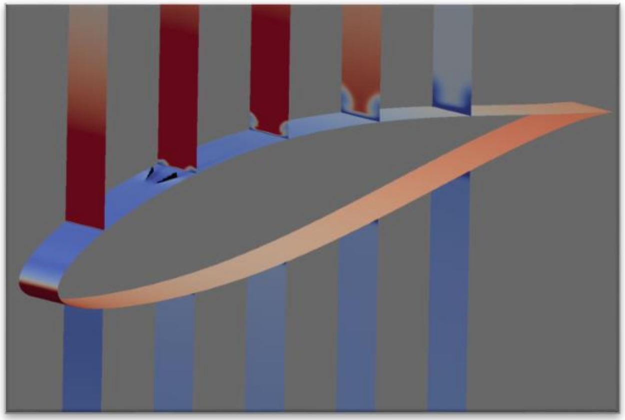
Example: Aerodynamic addons

- 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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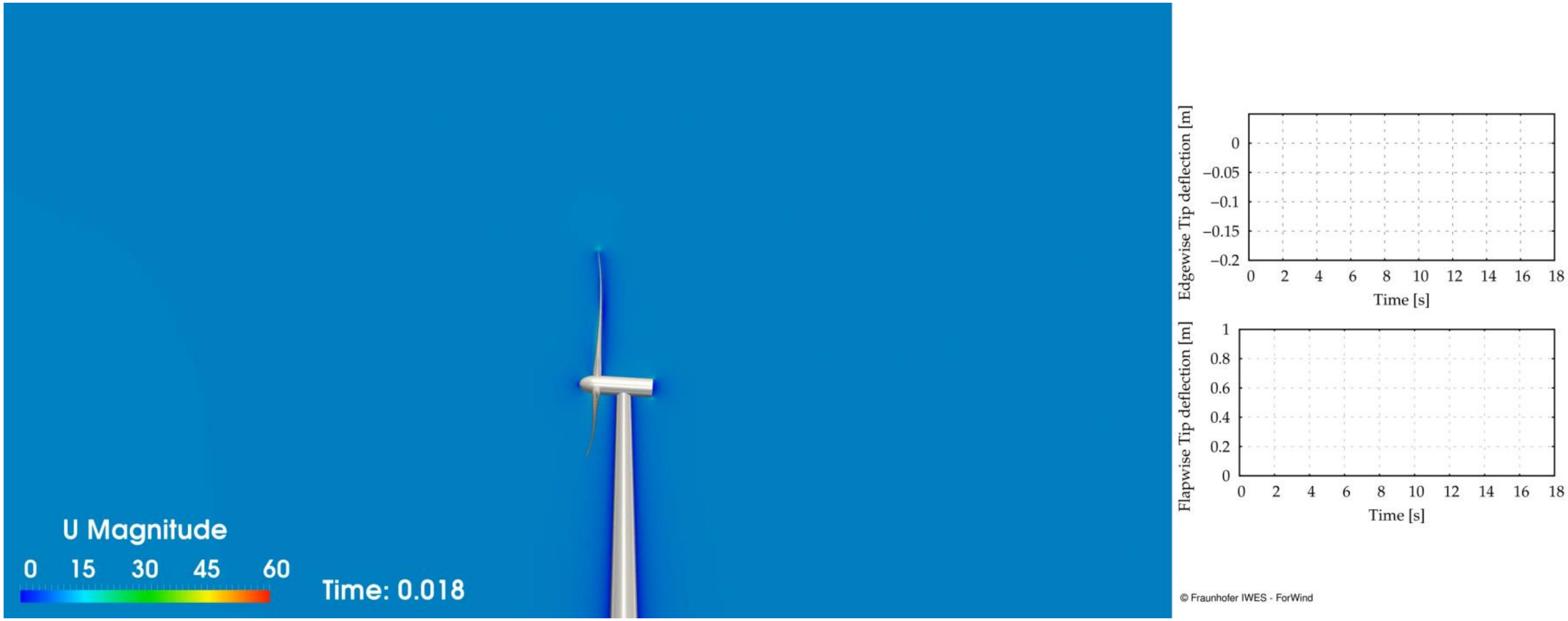
Conclusions

- 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. truss)

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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