The use of Open Source CFD to improve blade design

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Wind Turbine
Blade Manufacture
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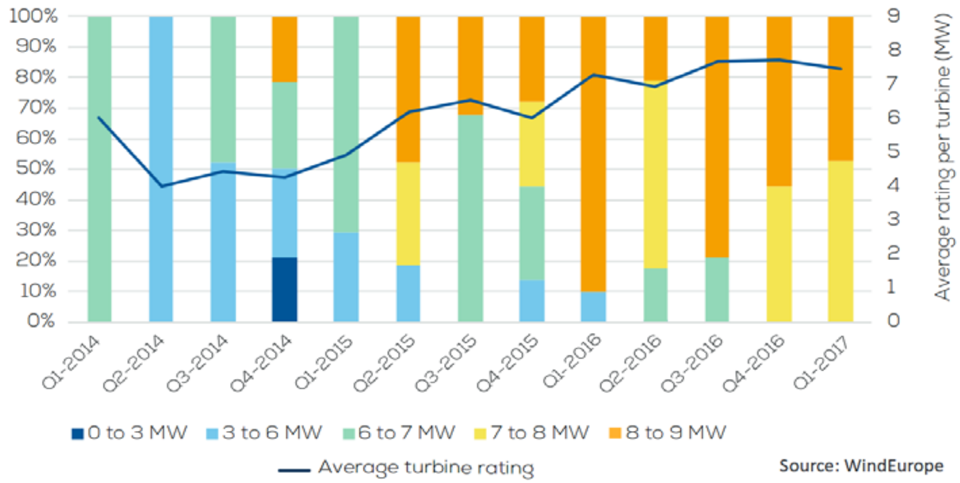
Extracting more energy from wind

- **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



Source: WindEurope

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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

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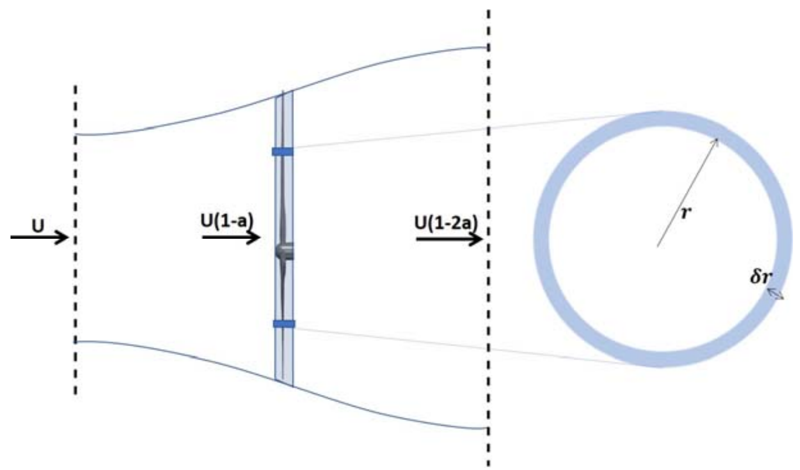
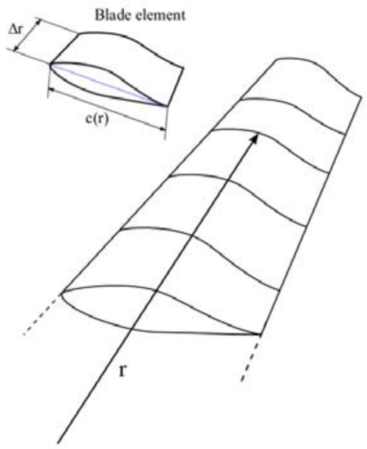
Aerodynamic Design-Tool: BEM

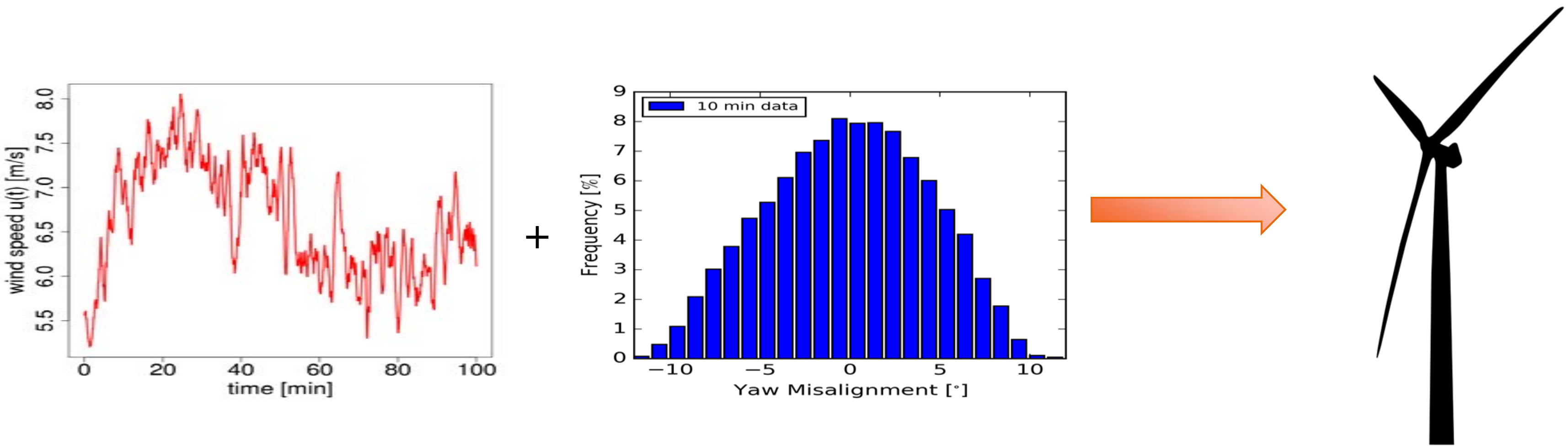
- Main aerodynamic design method for wind turbines
- Reasonable results – for most load cases
- Quick enough to run many design cases





Aerodynamic Design-Tool: BEM

- BEM is derived based on large number of assumptions, valid for steady inflow
- Atmospheric flow is turbulent, highly 3D and unsteady
- 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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BEM Engineering Models

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

@ lmwindpower: The world's longest blade 88.4m

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

- **Improving BEM engineering models is necessary**

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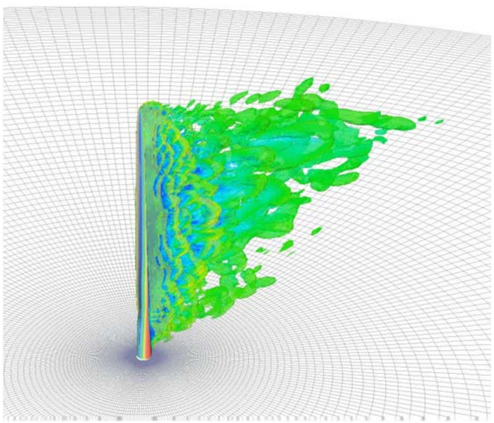
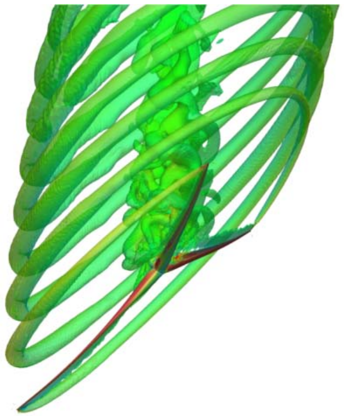
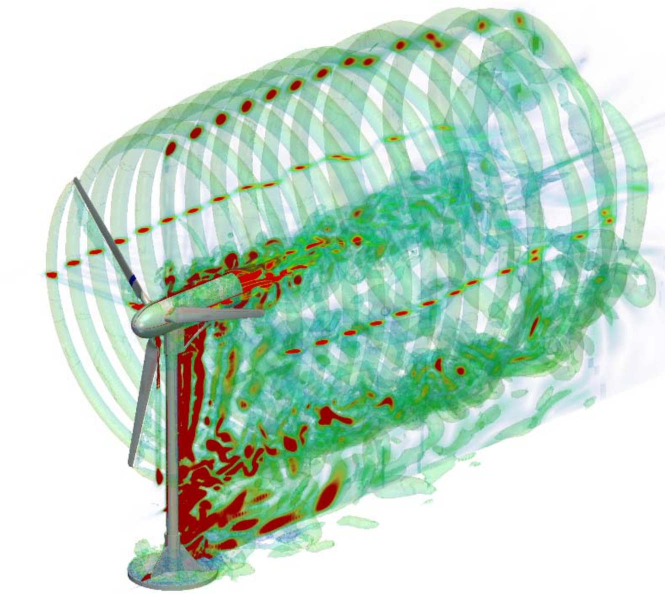
Computational Fluid Dynamics (CFD)

- High fidelity →No empirical corrections models required
- However: Computational expensive
  - Not suitable for calculation of all DLCs
- CFD can be used to
  - Recalibrate existing correction models
  - Development of new models







Use of open source codes for CFD and Aerodynamics

OpenFOAM

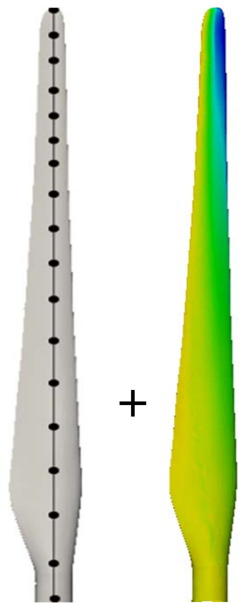
+	−
Open Source – Full control	Open Source – No Bug-Free guarantee
Continuous development and improvement possible	Steep learning curve
Keep your own developments	Lack of exhaustive Documentation
No license fees	Computationally expensive
Large community (e. g. car industry)	

Our Fluid-Structure Interaction (FSI) approach

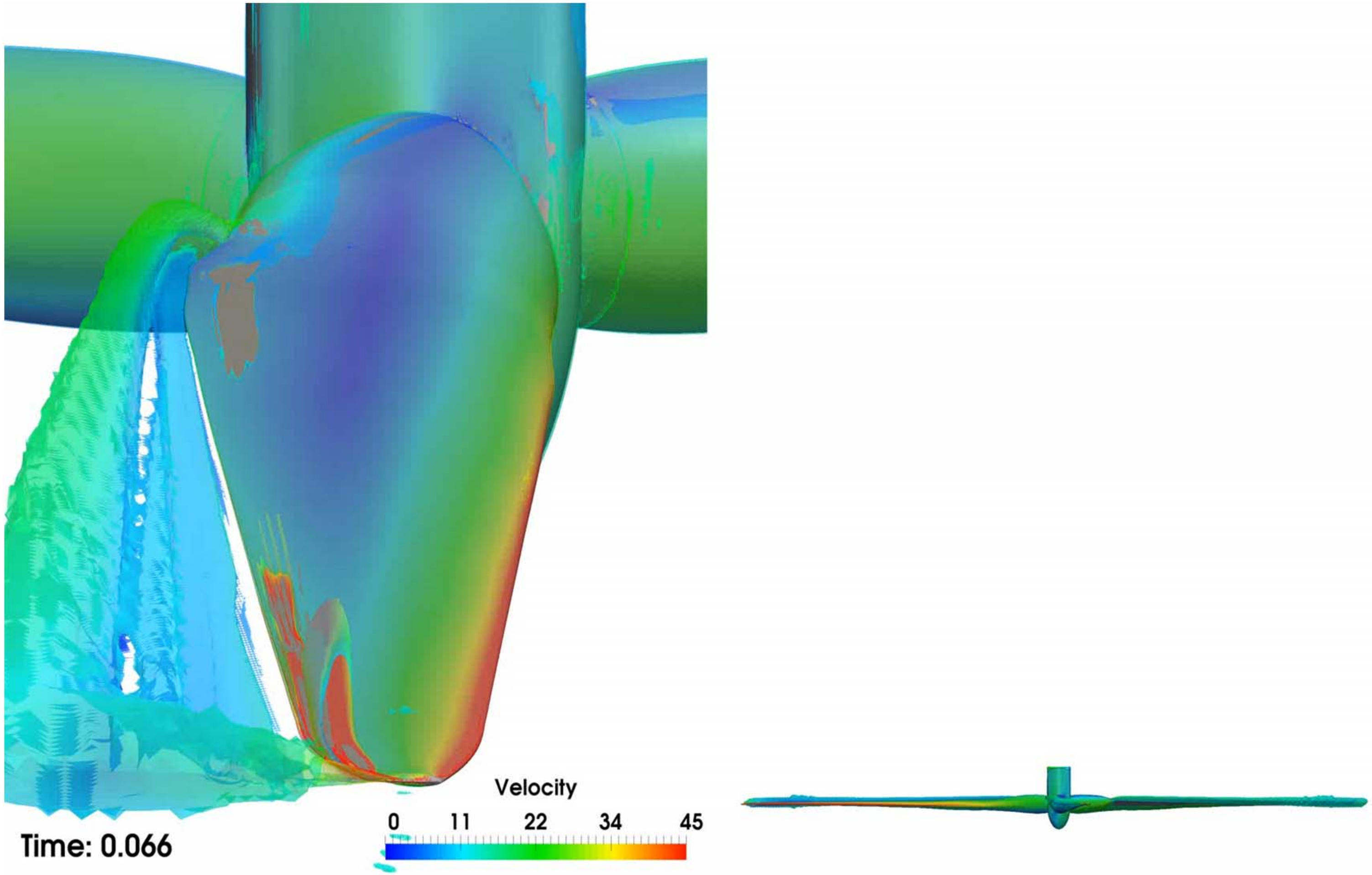
- FSI framework developed in Oldenburg

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

- Finite Element framework
  - Geometrically exact beam theory (GEBT)
  - Supports large deformations and torsion
  - 6x6 section properties



Example: NREL 5 MW subjected to yawed inflow



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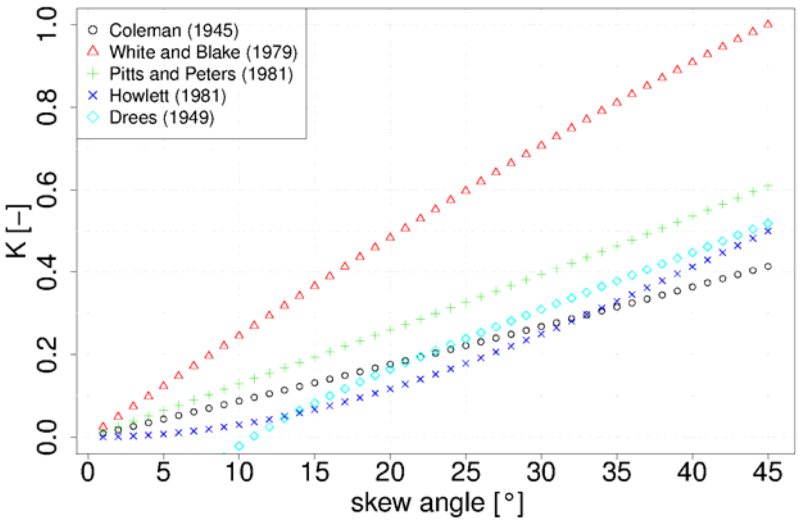
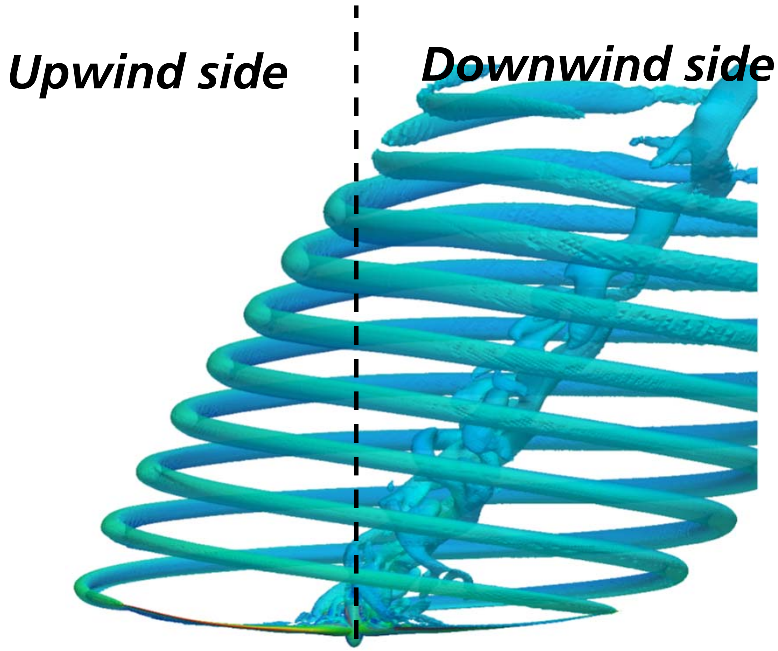
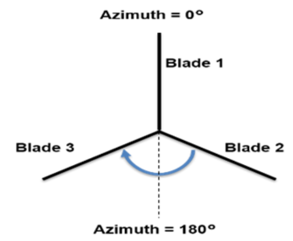
Skewed wake model and BEM

- Glauert model is only true at the tip $a = a_{av}(1 + k\frac{r}{R}\sin\theta)$
- Many attempts are made in the past to improve the k function
- Root vortex also induces axial velocities
  - It is not included in the current correction models

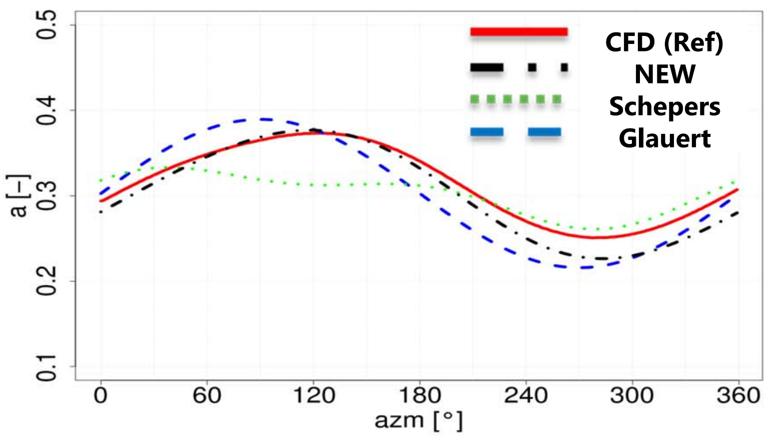


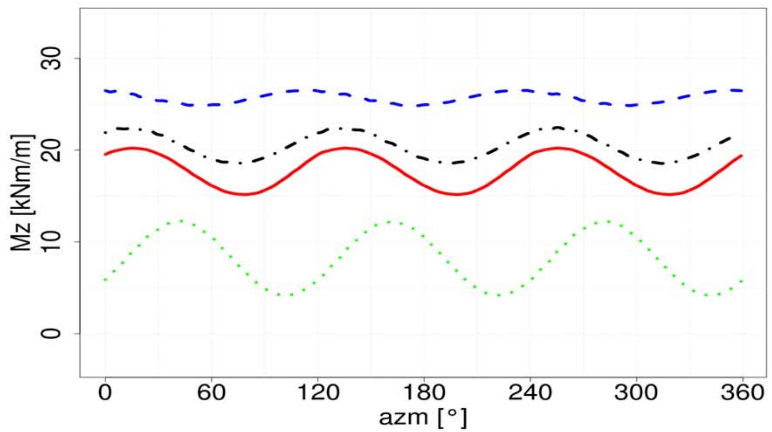


Results - INNWIND 6 m/s at 20° yaw



- A positive yawing moment (stabilizing) can be observed
- The qualitative behavior of the proposed model is closer to reference CFD





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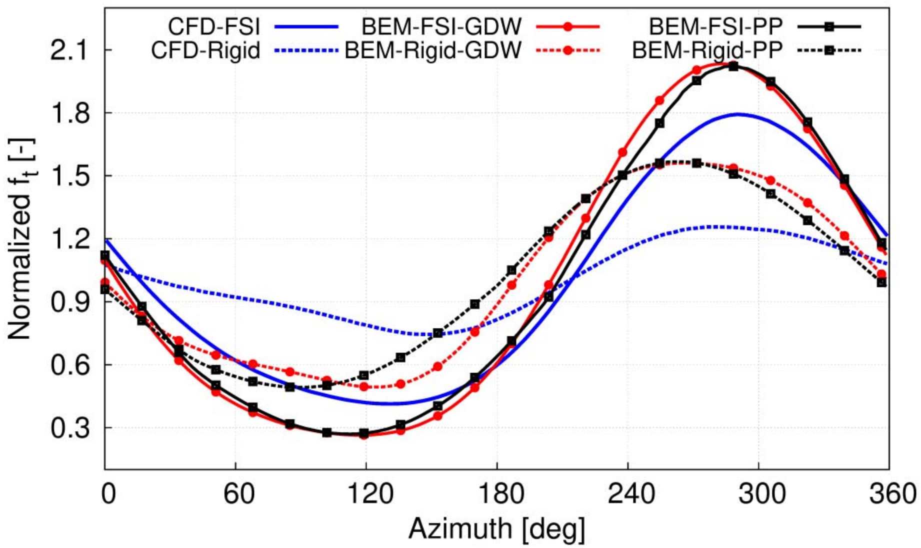
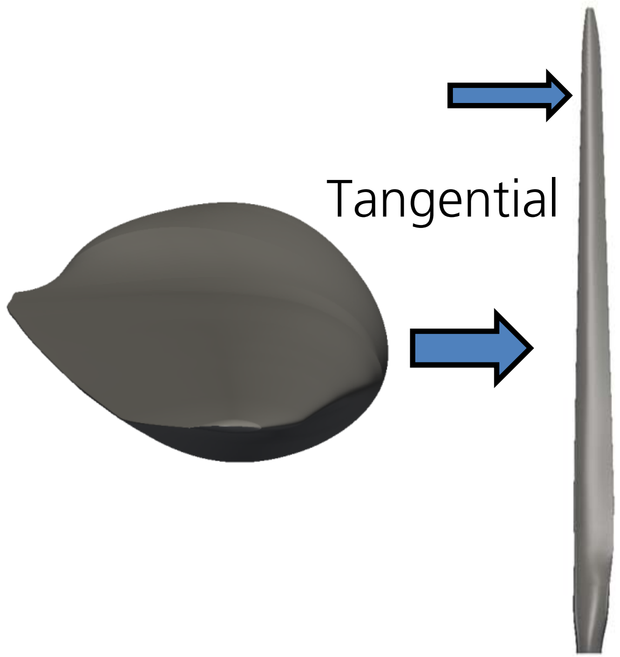
Results: DTU 10 MW subjected to yawed inflow

- Clear effect on aerodynamic loading
- Rigid CFD underpredicts forces
- The BEM based model over predicting the loads
- However, they take in to account the flexibility to some extend





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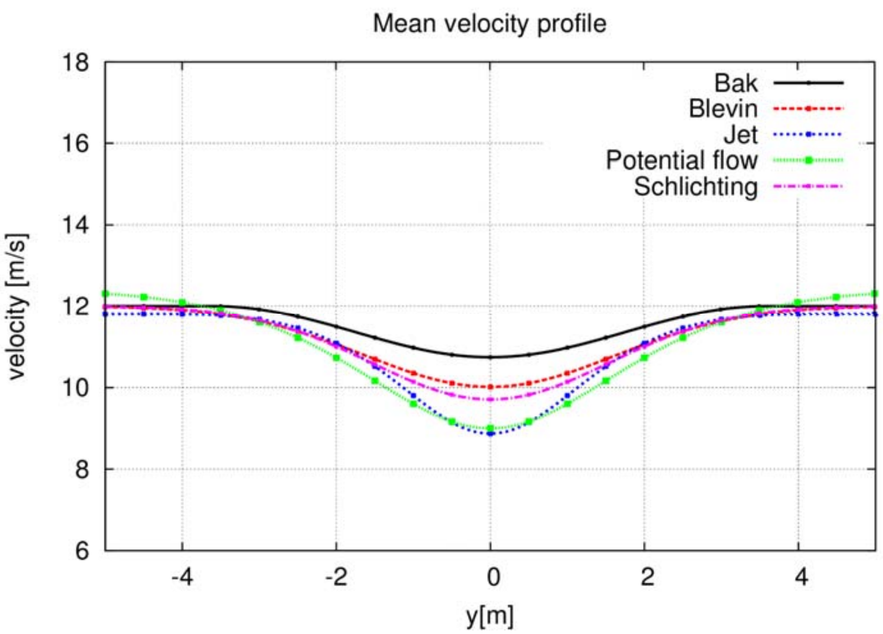
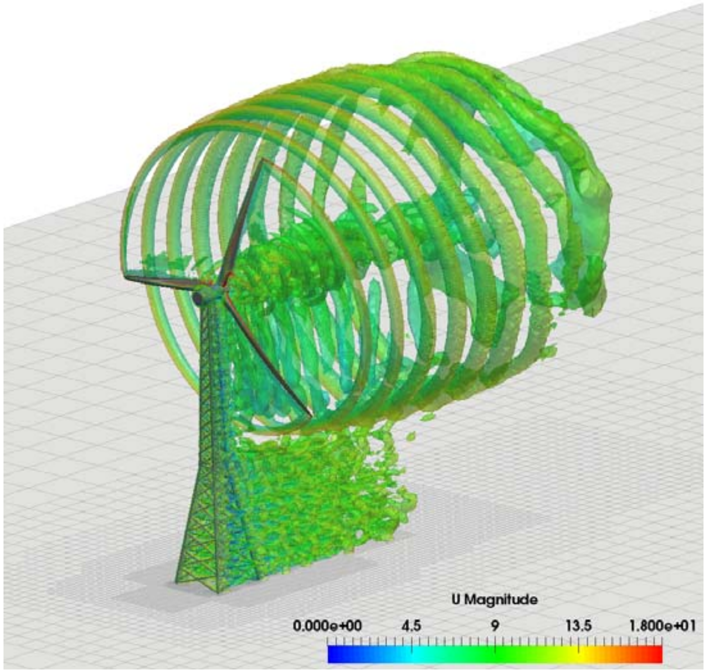
Downwind turbine: Tower shadow

- How accurate are the current rotor tower interaction models in BEM?
- Significant discrepancies between different models
- Can we improve them by CFD? How about different tower types?





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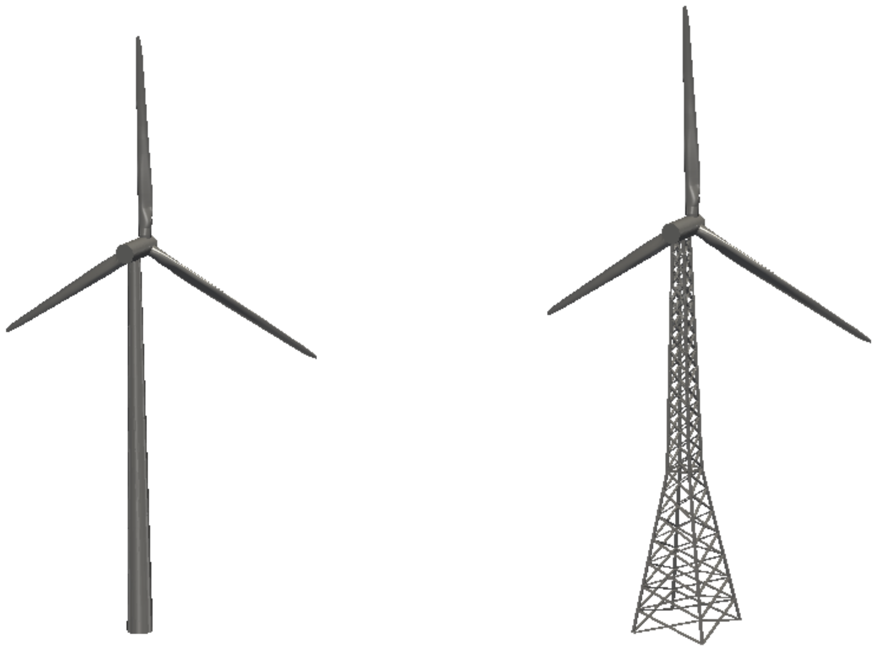
Downwind turbine: Tower shadow

- Big drawback of downwind turbines: Blade-tower interaction
- Idea: Use lattice structure towers instead of tubular towers
- NREL 5 MW in downwind configuration



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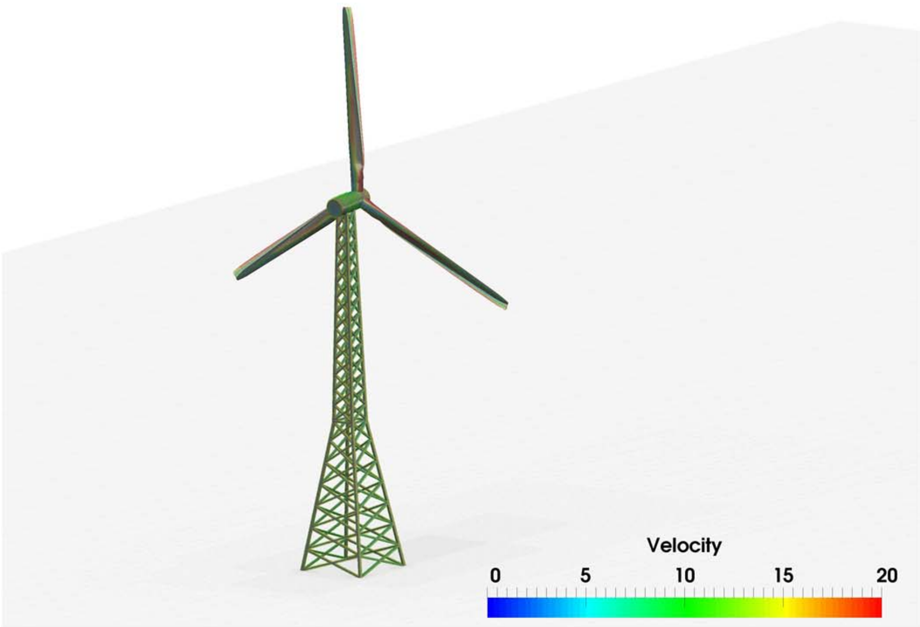
Downwind turbine: Tower shadow

- Time-accurate Delayed-Detached Eddy Simulation (DDES)
- Comparison of structural blade deformations for both tower types
- Fluid-structure coupling for blades for higher fidelity



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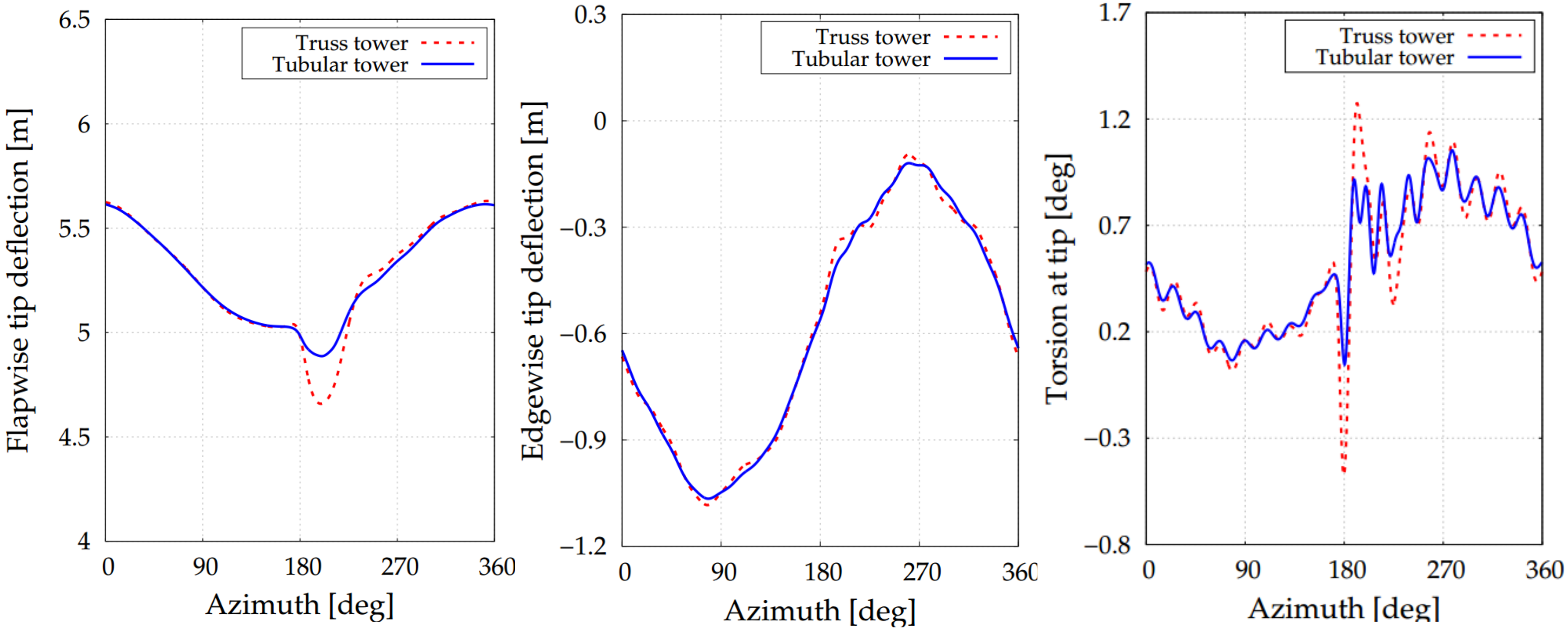
Downwind turbine: Tower shadow

- Truss tower geometry causes more severe effect on loads
- Torsional blade vibrations can cause additional fatigue



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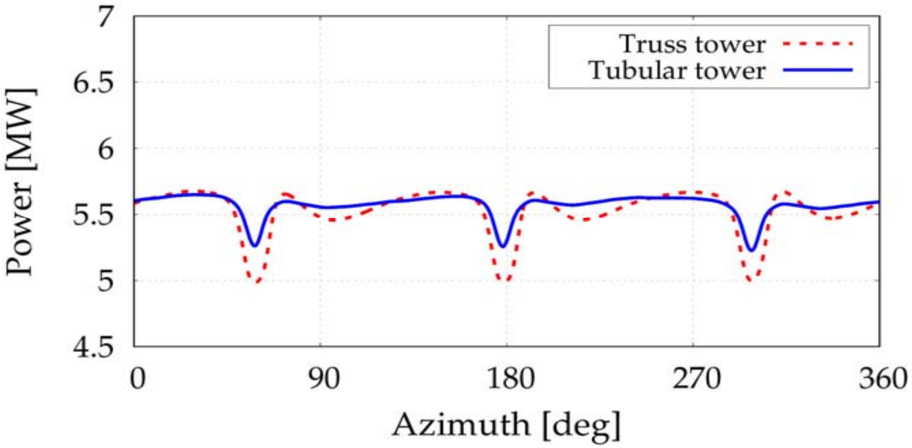
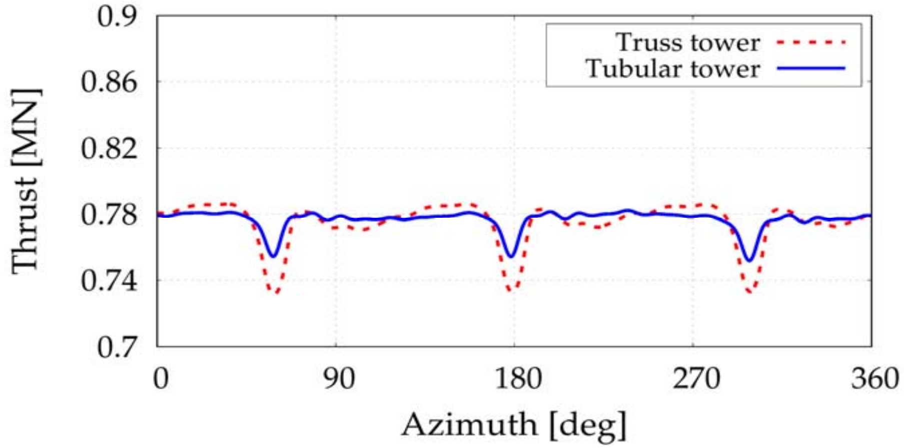
Downwind turbine: Tower shadow

- Truss tower geometry causes more severe effect on performance





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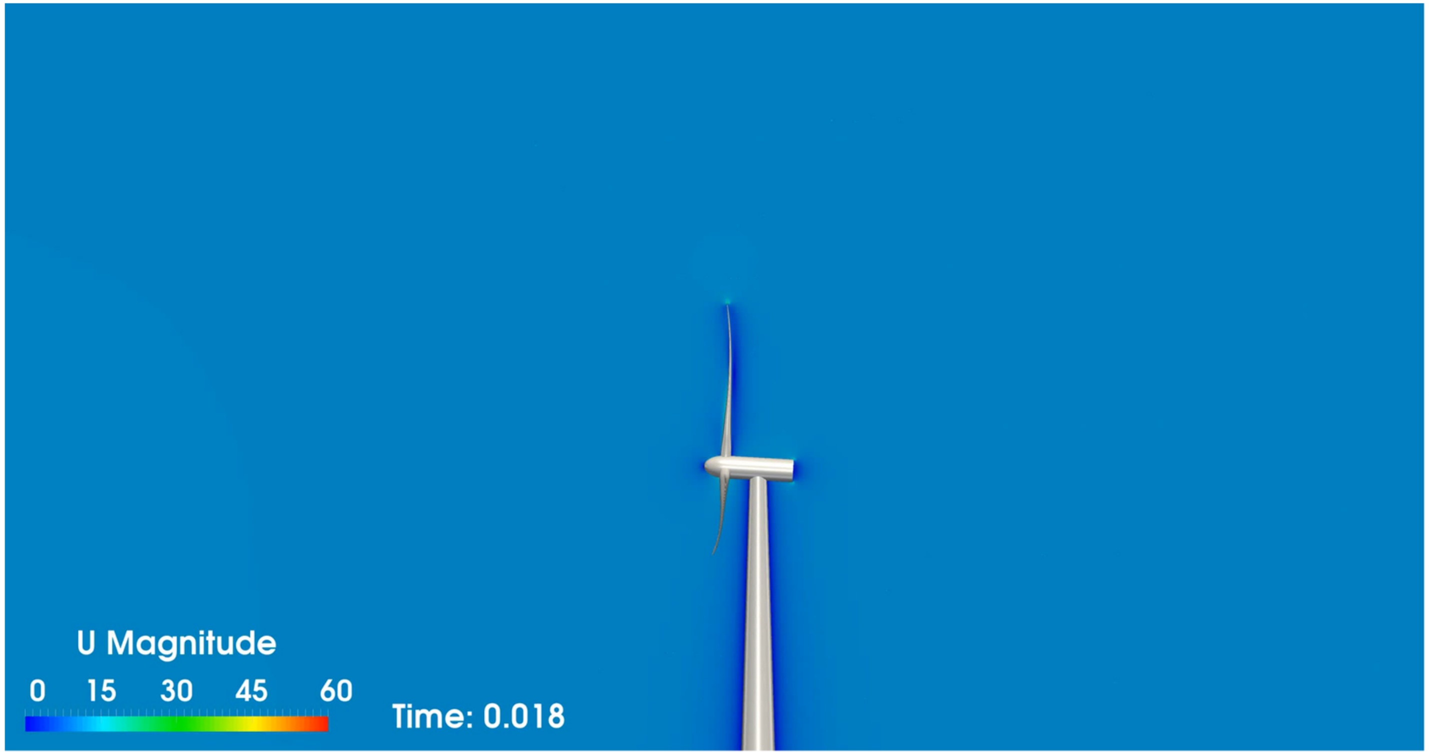
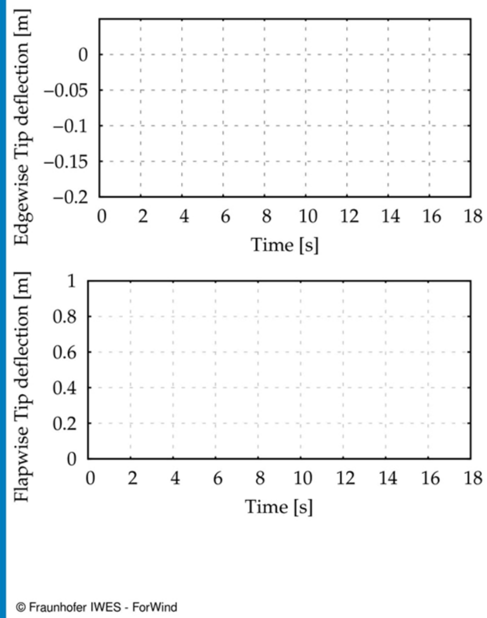
Turbulent inflow - cases

- Investigation of inflow turbulence on rotor performance
- Comparison to load calculation with FAST v8.0 and Aerodyn v15





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Results: Integral Forces

		Blade Resolved	Actuator Line	BEM
Thrust [kN]	Mean	761	698	729
	SD	37.9	33.9	49.7
	EFL	147.6	136.7	190.1
Torque [MNm]	Mean	4.43	4.32	4.35
	SD	0.495	0.452	0.599
	EFL	1.904	1.897	2.209

- Average values for thrust and torque are in reasonable agreement
- Standard deviation and Equivalent Fatigue Loads higher for BEM – more accurate, **fully resolved FSI gives less loads**
- Linear relationship between fatigue loads and standard deviation

Conclusions

- CFD suitable to improve BEM engineering models
- High fidelity framework for full rotor simulations presented
- Fluid-structure coupling for large, flexible blades
- Improvement of skewed wake correction based on CFD
- Investigation of tower shadows (tubular vs. lattice)
- Results indicate that 2D tower shadow might not be valid

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Thank You For Your Attention

Any questions?

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