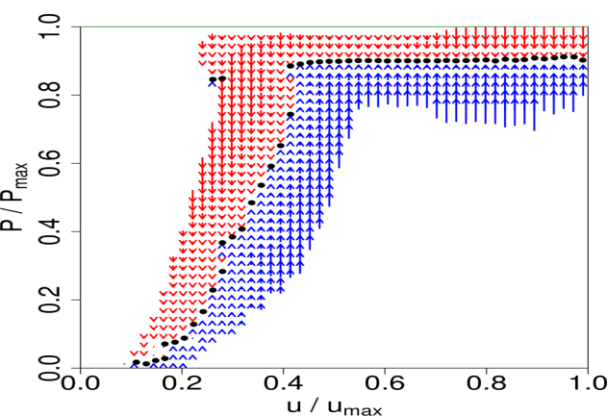
OpenFOAM in Wind Energy

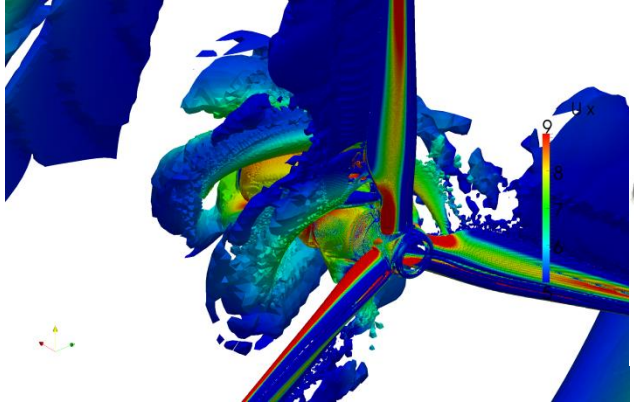
GOFUN 2018, Braunschweig

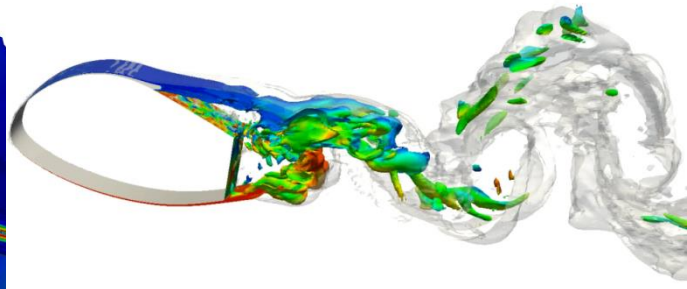
Matthias Schramm

ForWind
Center for Wind Energy Research
Bremen
Hannover
Oldenburg

Fraunhofer
IWES







Fraunhofer IWES and ForWind

- Oldenburg University started with wind physics
- Research on wind fields, aerodynamics and turbulence
- CFD is the link between the groups
- Fraunhofer IWES transfers knowledge to industry

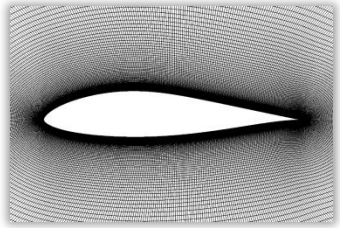
ForWind Center for Wind Energy Research (Bremen, Hannover, Oldenburg)
Fundamental research

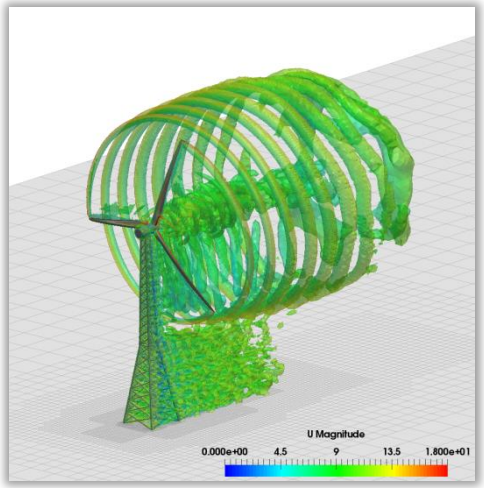
Teamwork

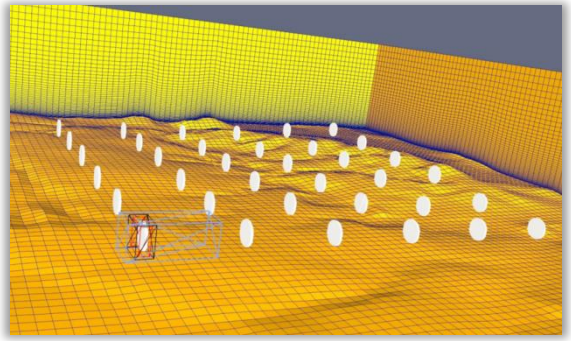
Fraunhofer IWES
Applied research

Agenda

- Airfoil aerodynamics
- Rotor aerodynamics
- Site assessment
- Other topics



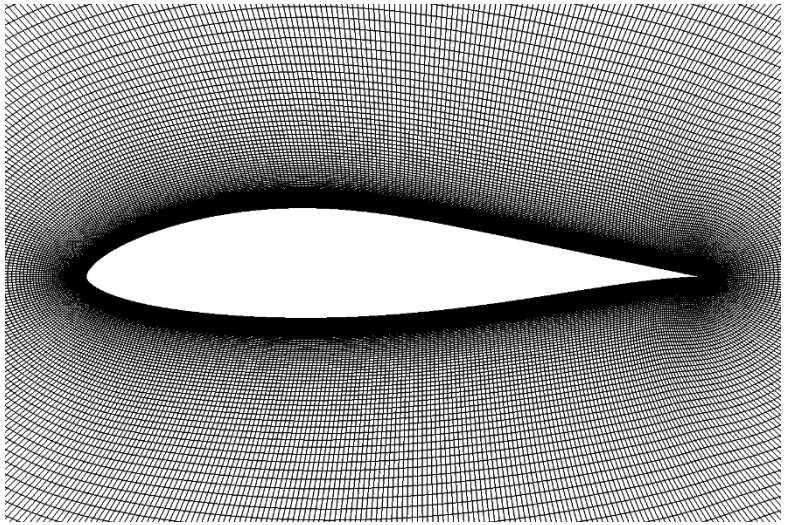




2D-RANS

- Steady 2D-RANS → computationally cheap

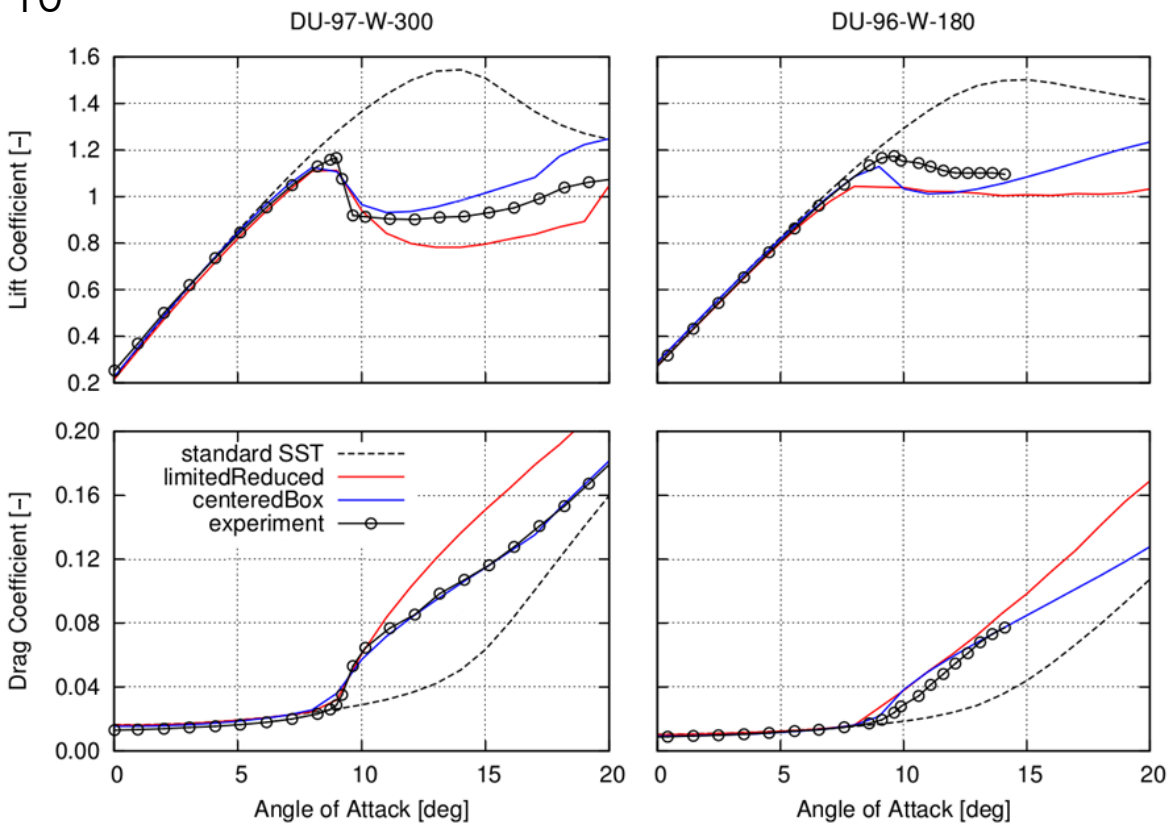
- Fully resolved boundary layer
- Hexahedral meshes
- Use of different turbulence models
  - k–ω-SST
  - Spalart-Allmaras
  - γ-$Re_{\theta t}$-SST
  - k–ω-SST-γ



- Automatized polars via scripts for small and medium angles of attack (not 360°)
- Lift and drag polars using improved coefficients w.r.t. the standards

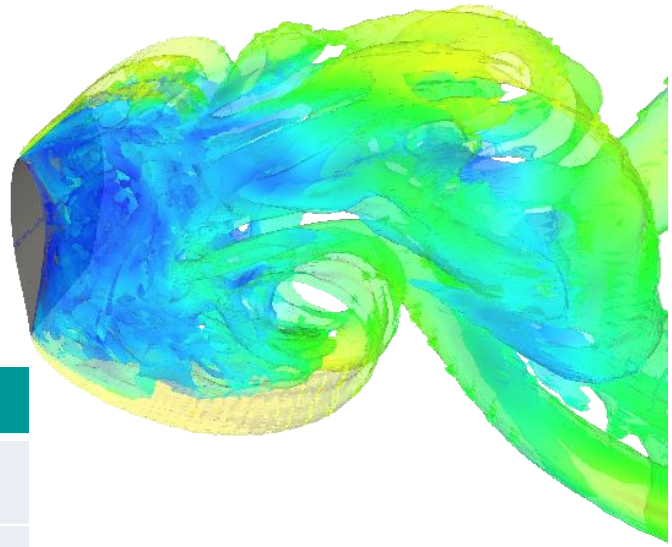
Stall Prediction in 2D-RANS

- Calibrated coefficients for better stall prediction
- Tripped airfoil at Re=$3 \cdot 10^6$
- k–ω-SST

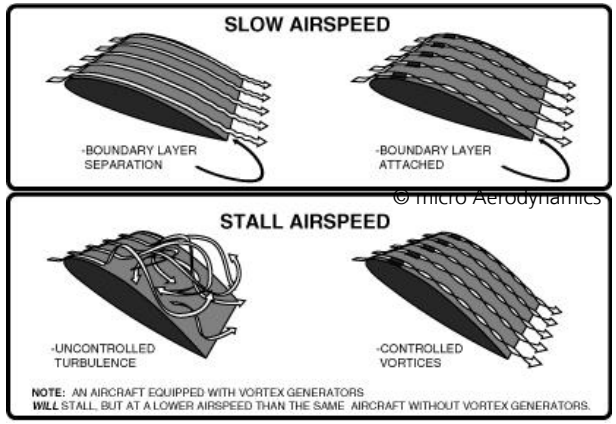


Standstill with 2.5D-DDES

- URANS not suitable for fully separated flow
- DDES can improve accuracy for very high angles of attack (standstill)
- 360°-polars with DDES
- DU 96-W-180, Re=$2 \cdot 10^6$, 3 million cells

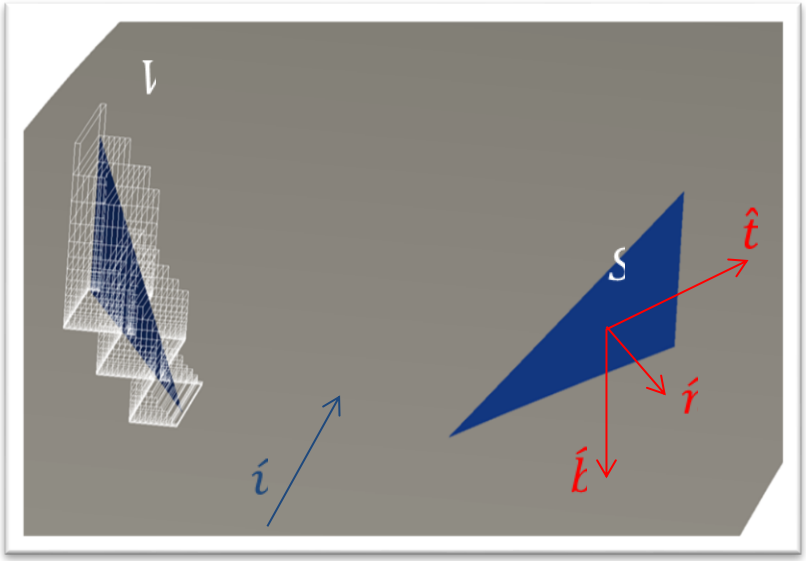


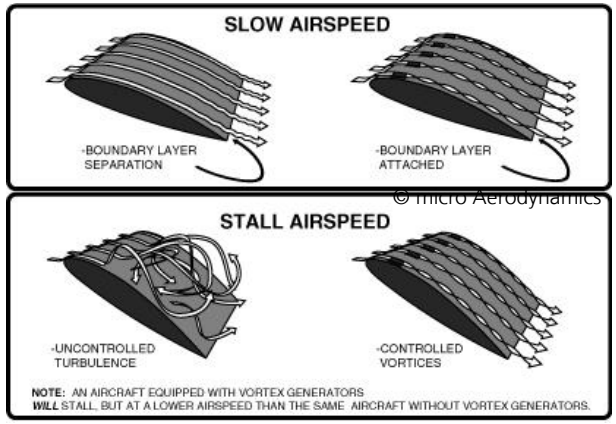
Source	C_l / -	C_d / -
IWES CFD	0.09	1.7
Experiments	0.11	1.9
DTU CFD	0.09	2.3



Modelling of vortex generators in CFD

- Better performance in blade root region
- Installed as Add-Ons on existing blades
- Not always included in design phase
- Use of BAY model (1999)
- Source term in momentum equation





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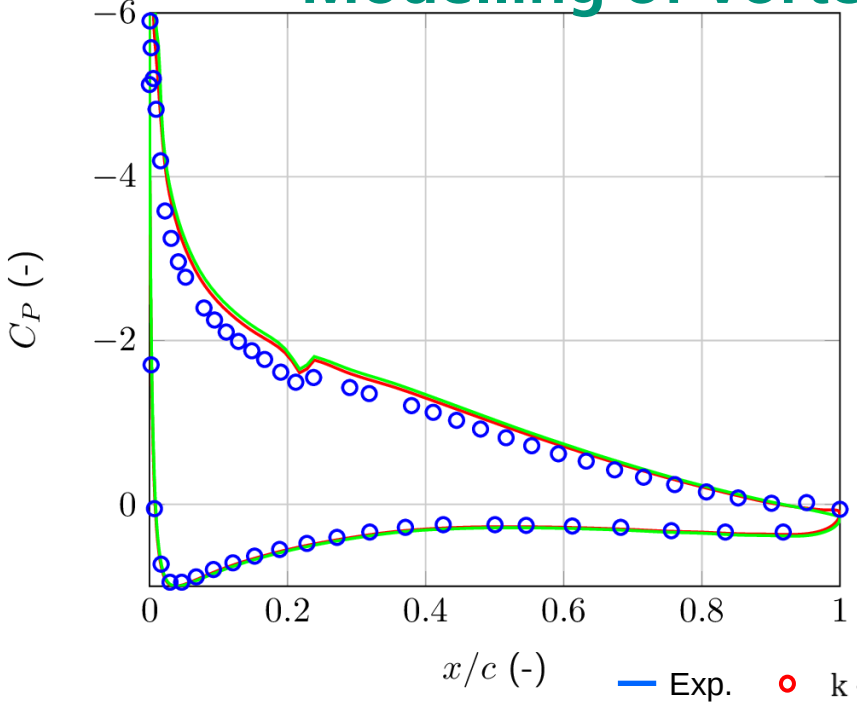

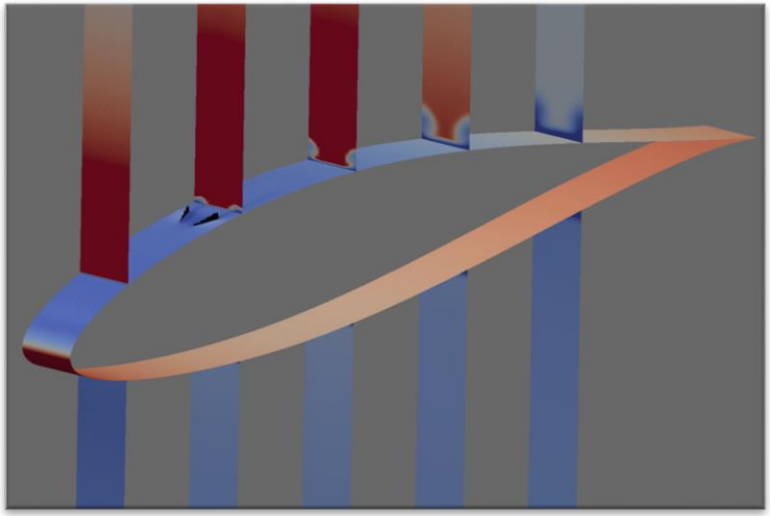

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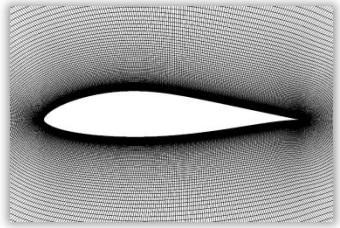
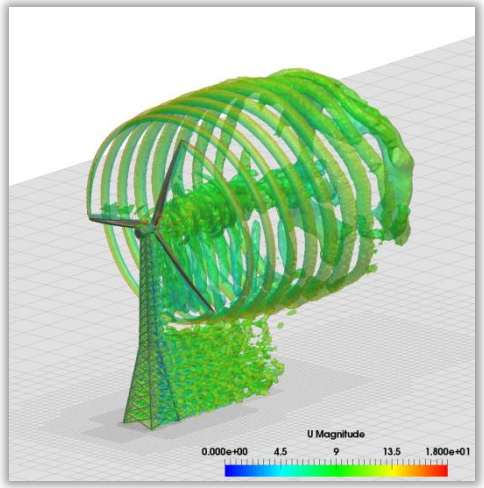
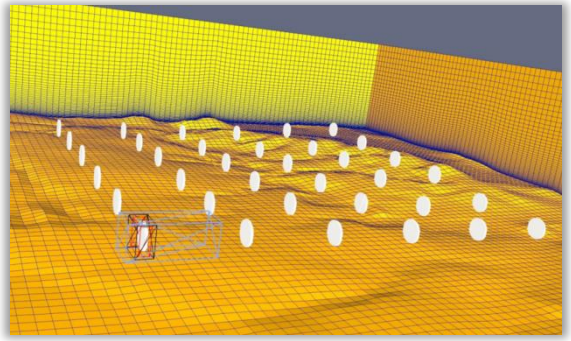
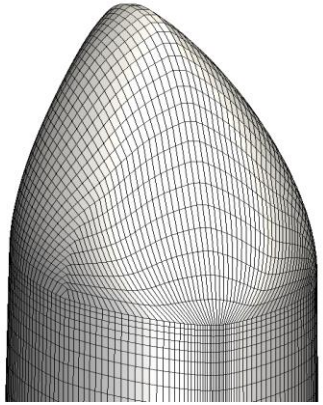
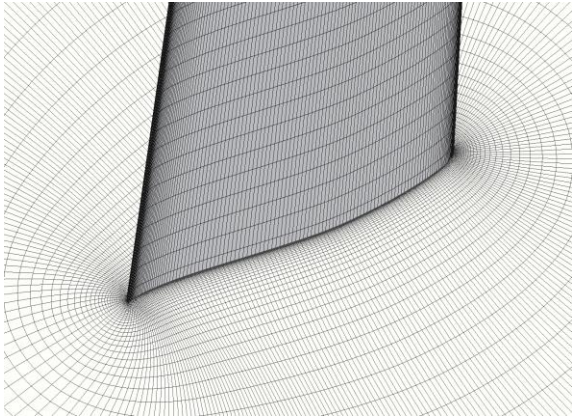










BladeBlockMesher

- Automatic, fast meshing tool for wind turbine rotor blades developed by IWES
- Only airfoil coordinates and their position required
- Based on hexahedral meshes (elliptic or hyperbolic equations)

Rahimi, H., Daniele, E., Stoevesandt, B., Peinke, J.: Development and application of a grid generation tool for aerodynamic simulations of wind turbines. Wind Engineering, 40(2), 148-172 (2016) doi: 10.1177/0309524X16636318

Validation of CFD: Wind Turbine Rotors

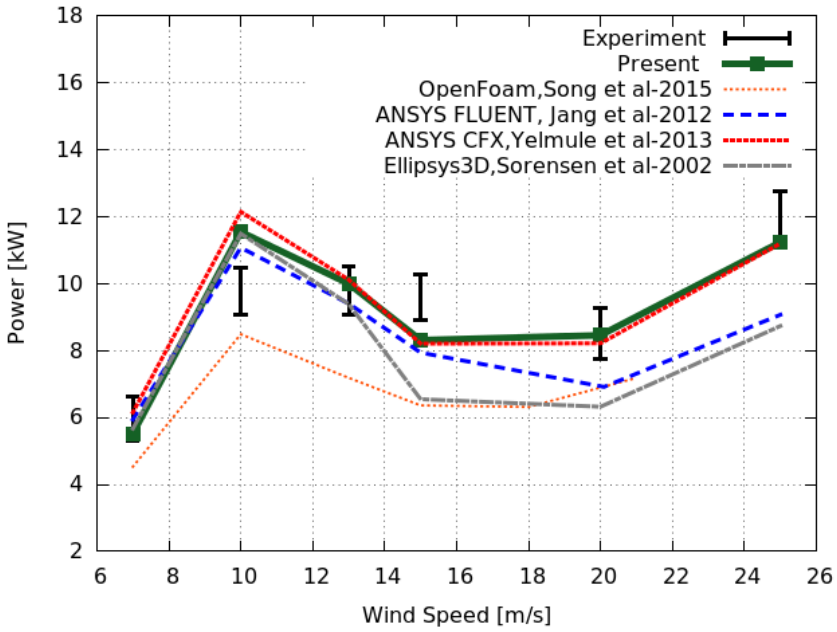
- Very few experiments exist
- Limited wind tunnel size
- Limited Reynolds numbers

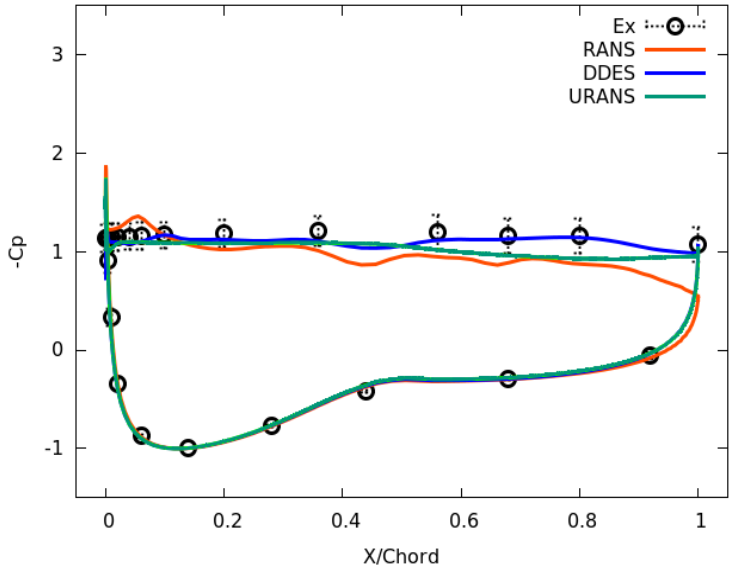
NREL Phase VI turbine (10 m diameter)

MEXICO turbine (4.5 m diameter)

Validation of CFD: NREL Phase VI

- Stall regulated turbine (10 m diameter)
- Upwind and downwind measurements in NASA-Ames wind tunnel
- Experimental pressure distribution and loads for different sections available





25m/s at 30%

Rahimi, H., Medjroubi, W., Stoevesandt, B. and Peinke, J. (in press) Progress in Computational Fluid Dynamics, 'Navier-Stokes-based predictions of the aerodynamic behaviour of stall regulated wind turbines using OpenFOAM',

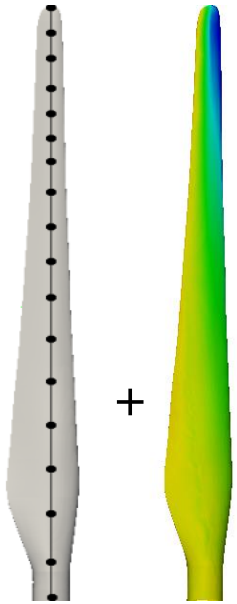
CFD for modern wind turbine rotors

- Wind turbines are getting larger
- Light weight blade design ⇨ Blade flexibility increased
- Non-linear interaction between aerodynamics and structure
- Fluid-Structure Interaction (FSI)
- Coupling of flow and structural solver

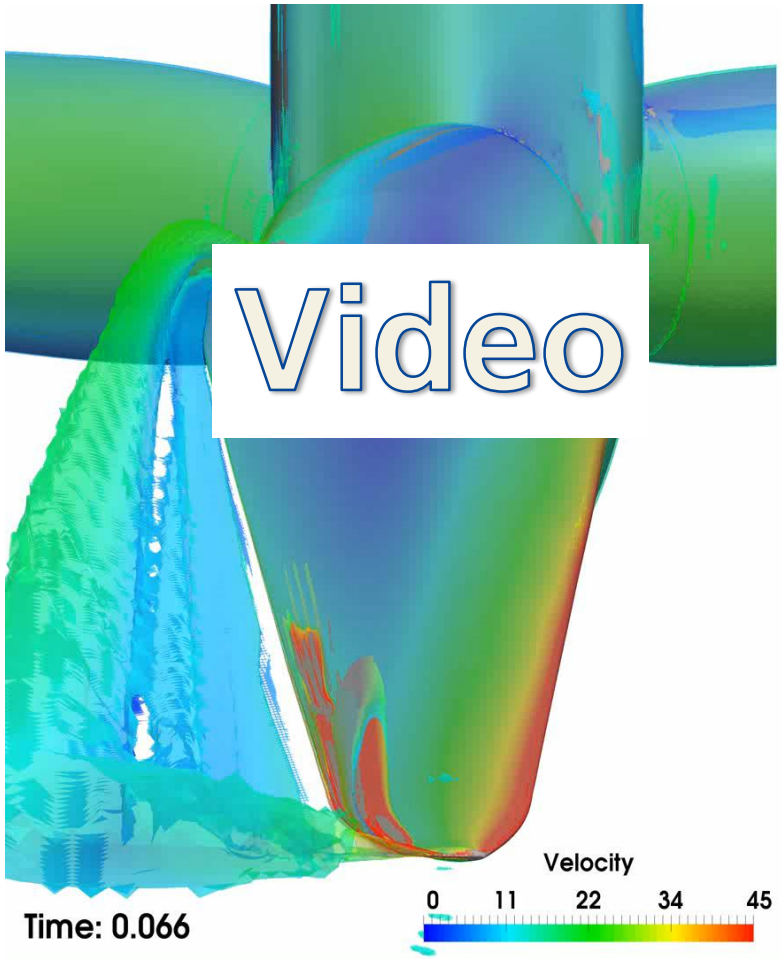
Source: Siemens

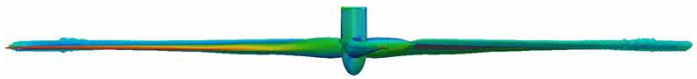
Our FSI approach

- FSI framework developed in Oldenburg
- OpenFOAM and additional implementations
  - Steady-state or dynamic simulations
  - Runtime post-processing (AoA)
  - In-house grid deformation
- Finite Element framework
  - Geometrically exact beam theory (GEBT)
  - Supports large deformations and torsion
  - 6x6 section properties



NREL 5 MW turbine under yawed inflow

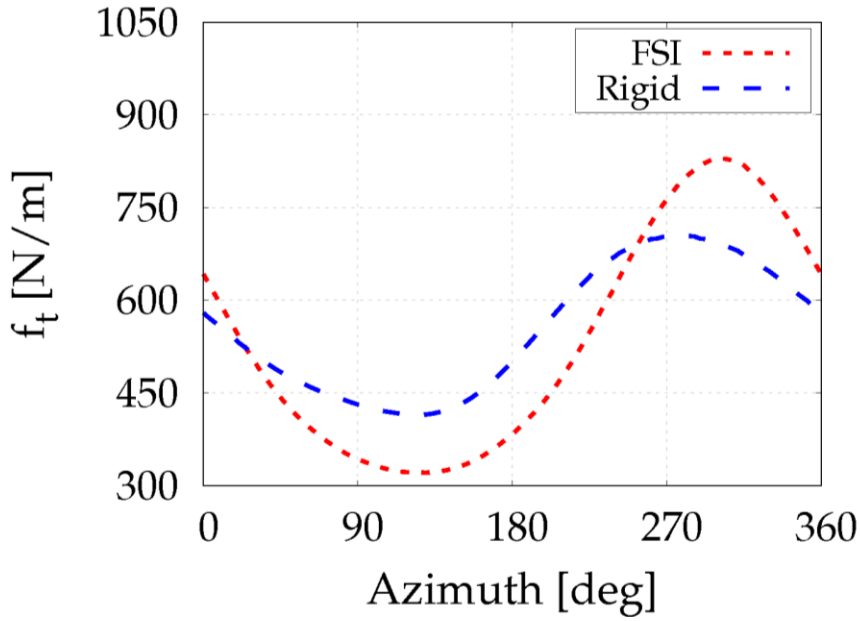




NREL 5 MW turbine under yawed inflow

- Clear effect on aerodynamic loading
- Rigid CFD under-predicts forces
- Blade deformations have clear effect

Tangential



Downwind turbine and tower shadow

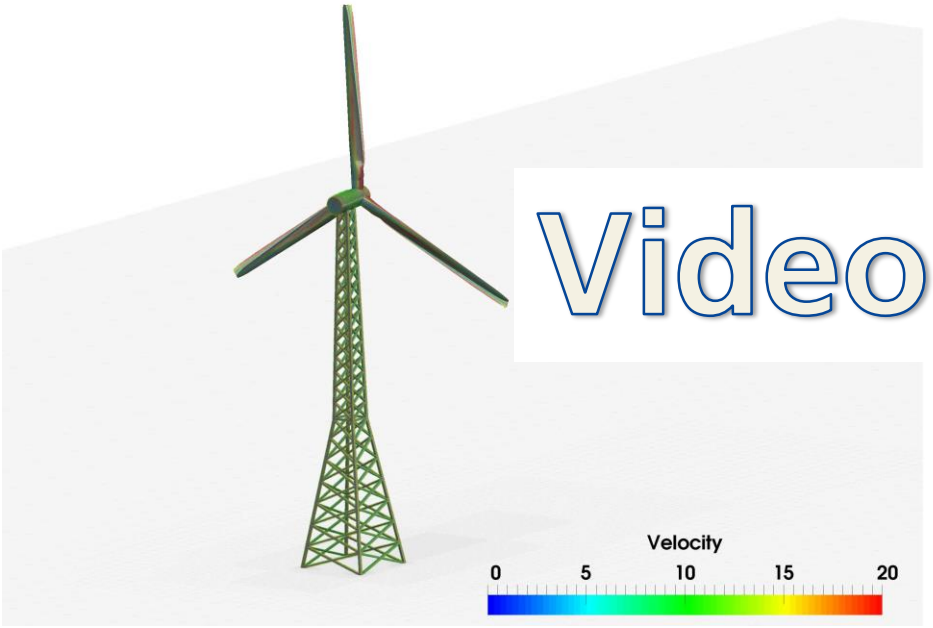
NREL 5MW

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

Downwind turbine and tower shadow

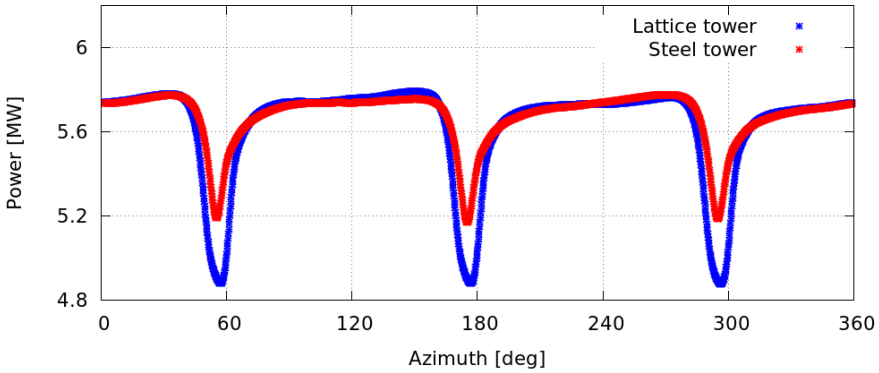
NREL 5MW

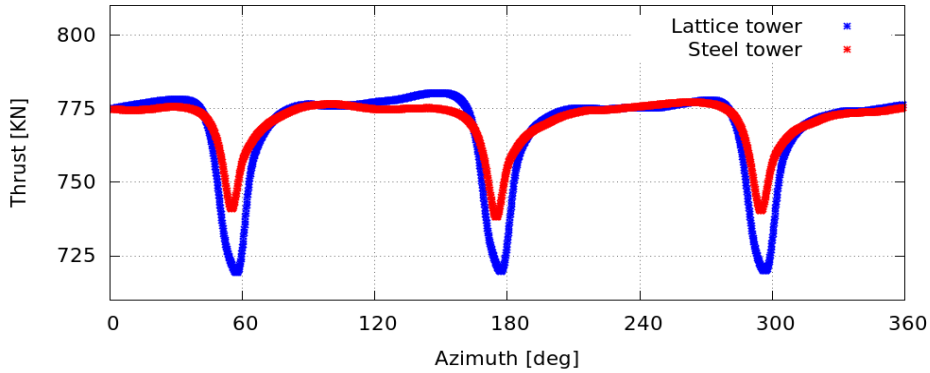
- Time-accurate Delayed-Detached Eddy Simulation (DDES)
- Comparison of sectional blade loading for both tower types
- Fluid-structure coupling for blades for higher fidelity



Downwind turbine and tower shadow

- Similar mean values (deviation < 1%)
- Clear deviation in time resolved results





- Wider tower shadow with lattice tower
- Significant velocity drop for lattice tower
- 2D approach for lattice tower not valid

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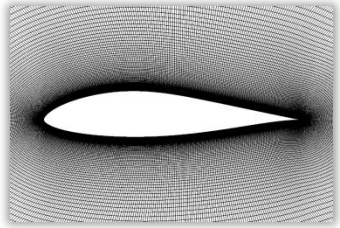
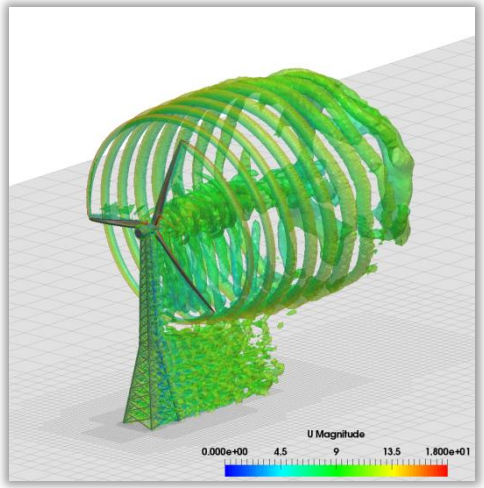
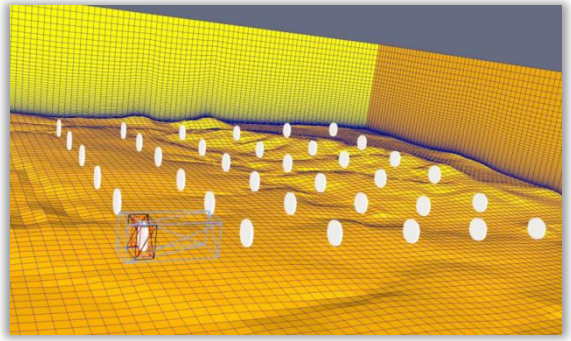
- Other topics

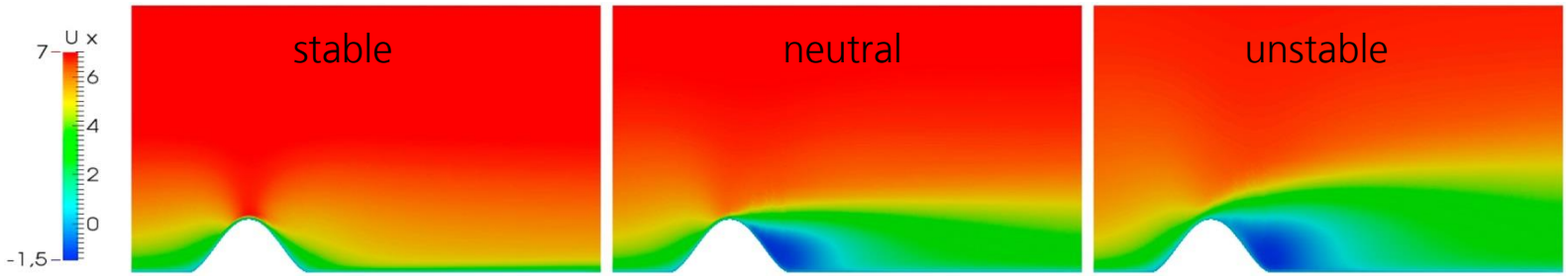






Site assessment

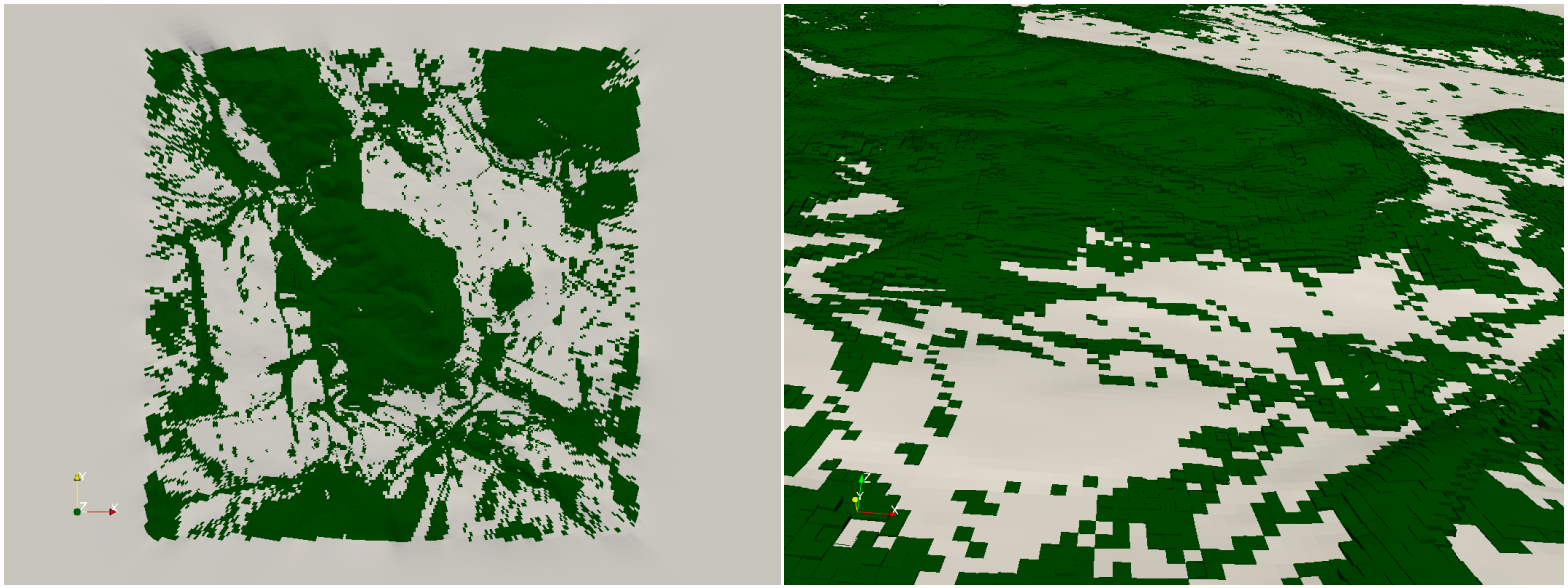
- Optimize the yearly energy output
- Wind rose is site dependent (sometimes 360° necessary)
- Consideration of Coriolis force, complexity of terrain, forests etc.
- Thermal stratification needs to be considered (stability classes)



Chang, Chi-Yao, et al. "A consistent steady state CFD simulation method for stratified atmospheric boundary layer flows." *Journal of Wind Engineering and Industrial Aerodynamics* 172 (2018): 55-67.

Inclusion of forests

- Automatic detection of forest from simple graphics file
- Use of porous cells as sinks in the momentum equation
- Also turbulence equations need to be considered



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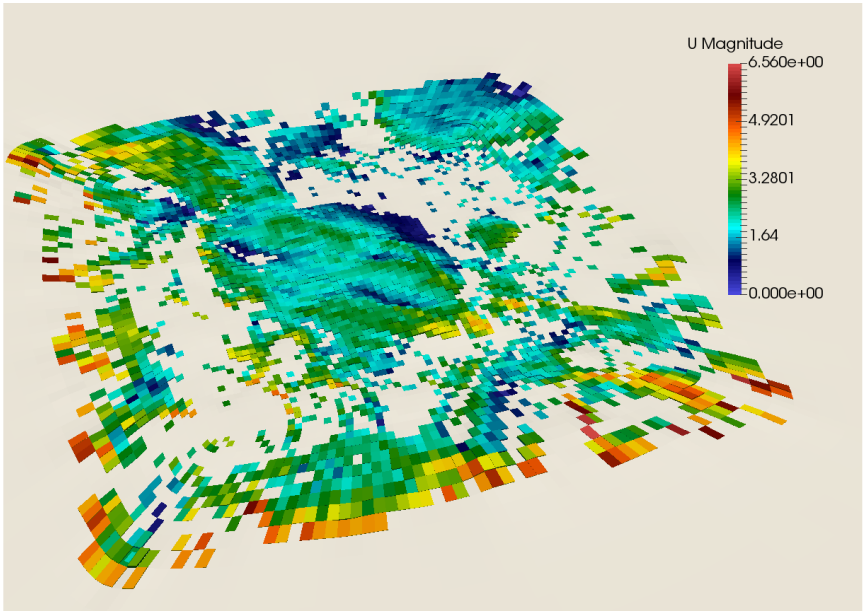
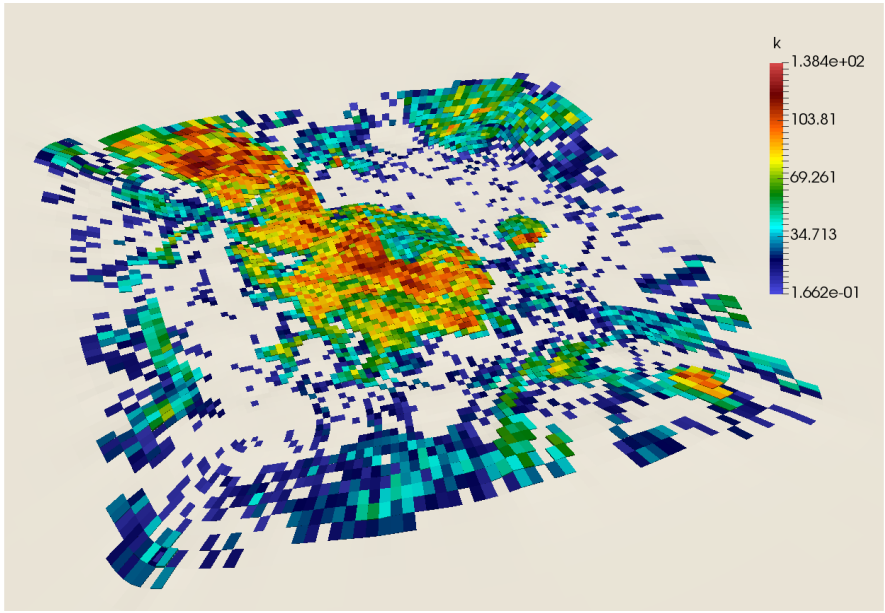
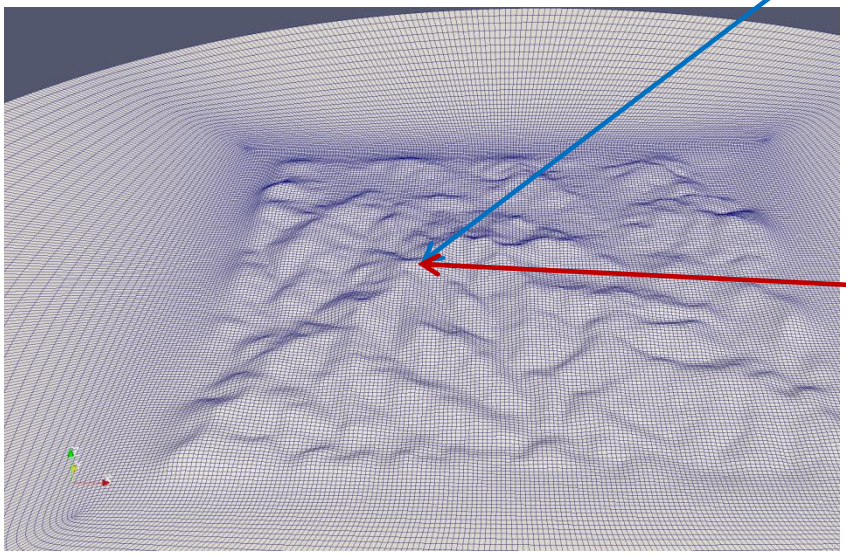




Wind distribution

- Prediction of wind distribution at other location
- Validation by met mast data
- Simulation of complex terrain



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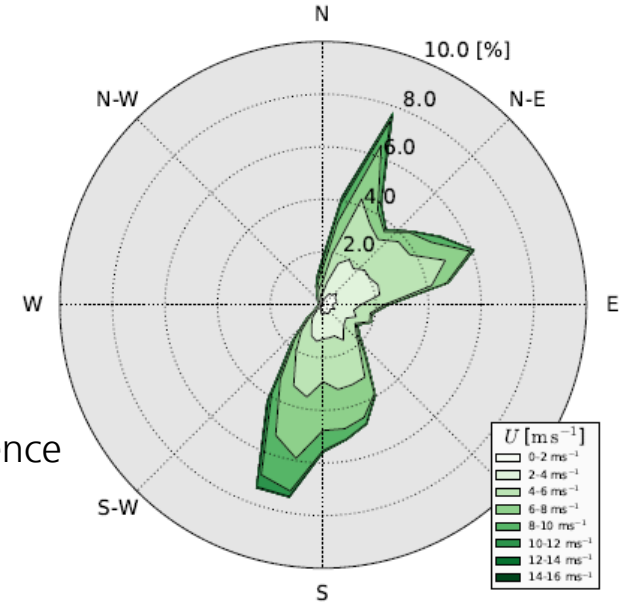
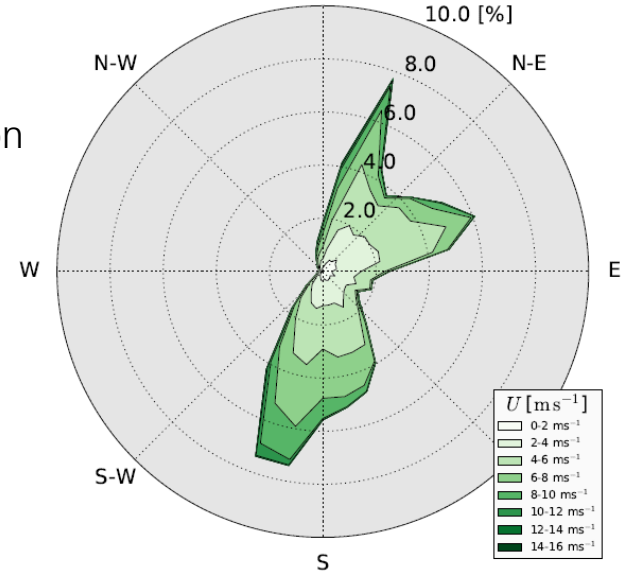


Simulation



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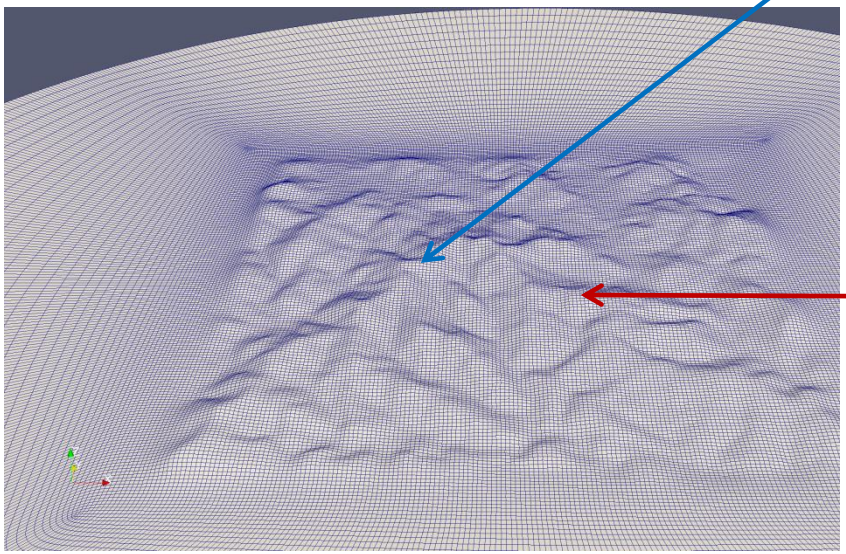

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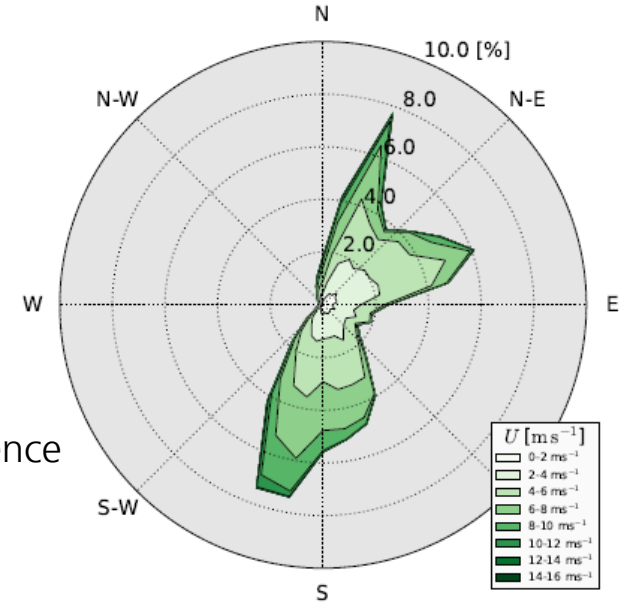
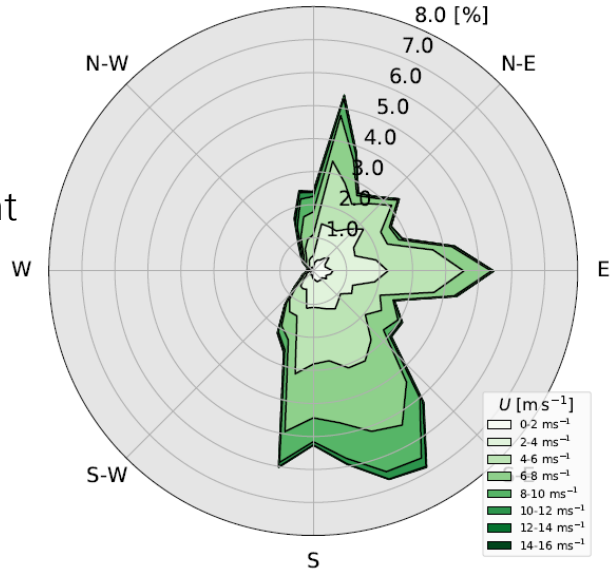
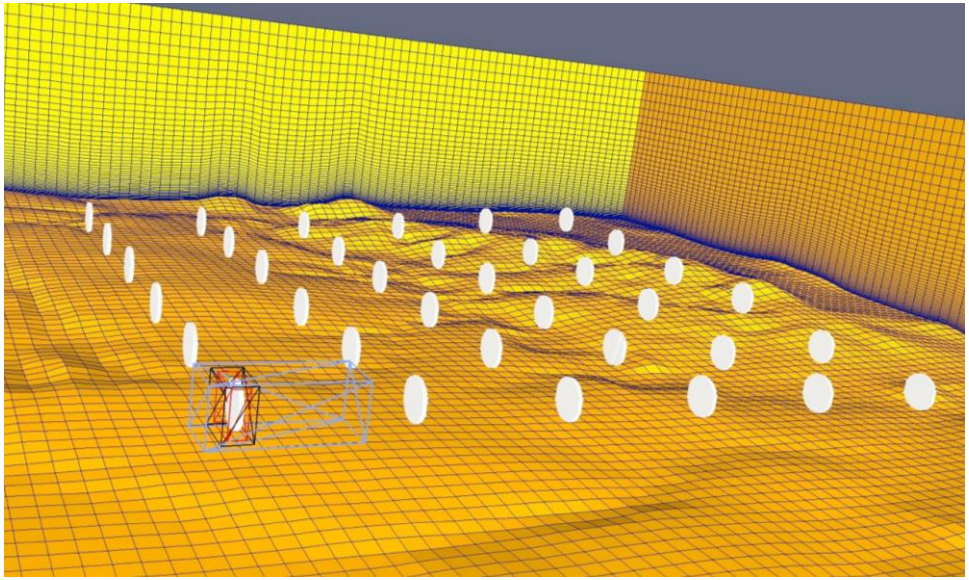


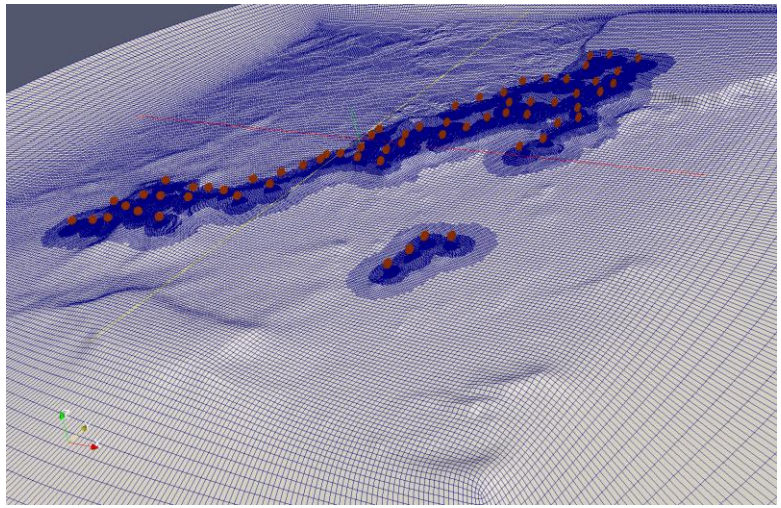
Prediction at different point

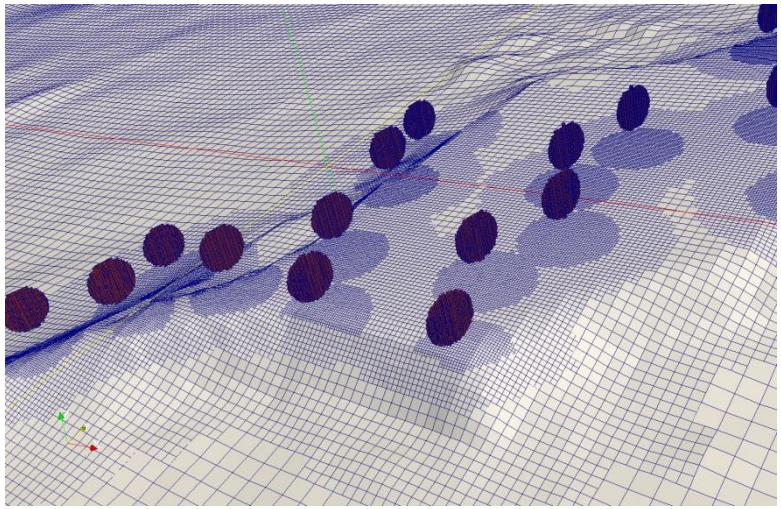


CFD of wind farms

- In-house mesh generation (incl. smoothing)
- Automatic mesh refinement
- Modelling turbines as actuator disks







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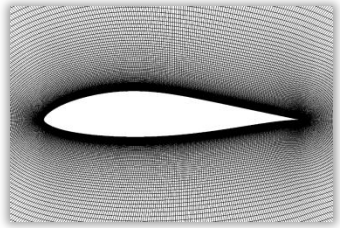
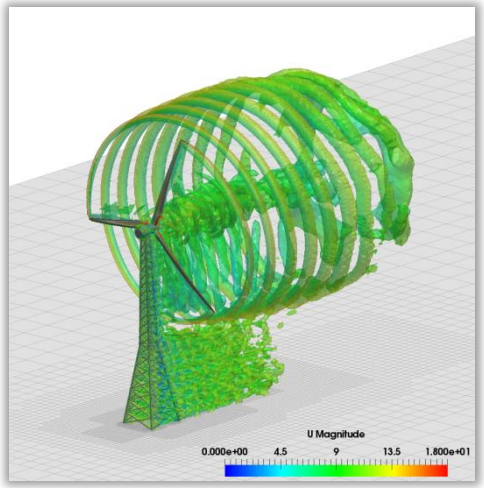
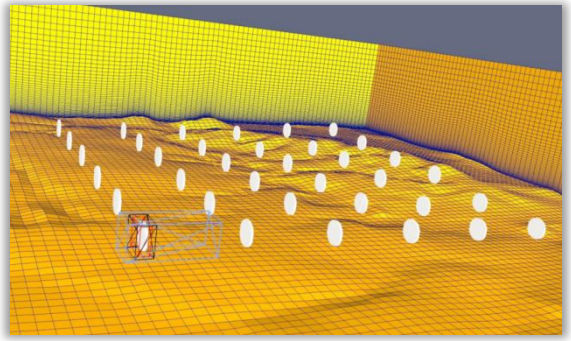
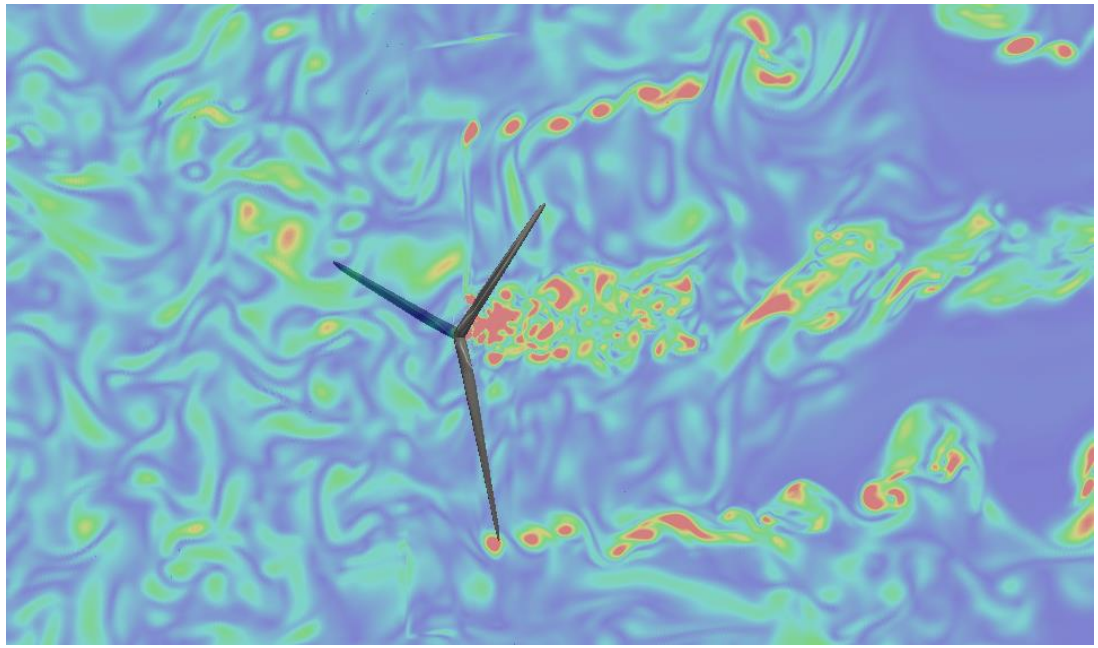




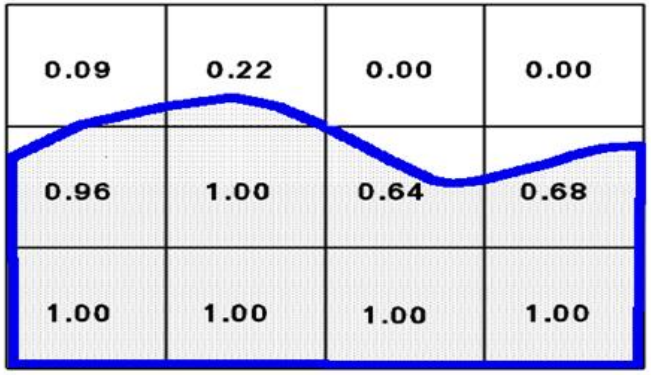


Other topics

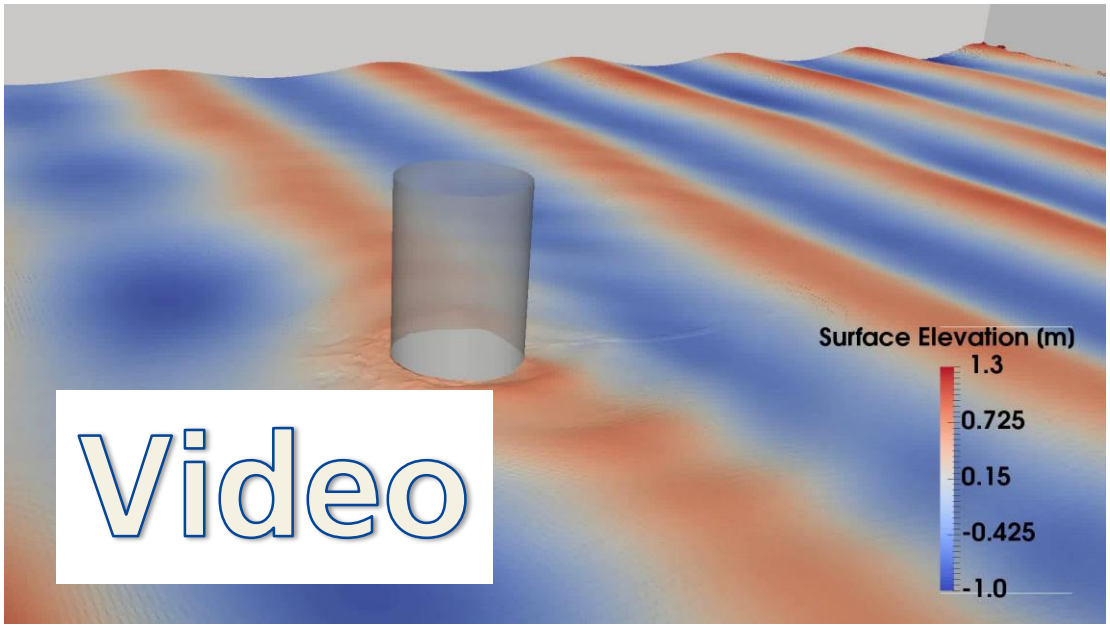
- Shape optimization using the adjoint approach
- Aeroacoustics
- Turbulent inflow
- Add-Ons



Wave interaction



- Multi-phase flow for offshore turbines
- Tower design and load computation
- Volume-of-Fluid approach (olaFoam)
- 20 million cells
- 7 m diameter



Conclusions

- OpenFOAM offers possibility to simulate every interesting CFD in wind energy
  - Airfoil & rotor aerodynamics
  - Aeroacoustics
  - Fluid-Structure Interaction
  - Turbulent inflow
  - Site assessment
  - Wave forces on turbine towers
- Some in-house developments and extensions necessary

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Thank You For Your Attention!

Any questions?

matthias.schramm@iwes.fraunhofer.de
bernhard.stoevesandt@iwes.fraunhofer.de