Computational simulation of two wind turbines in tandem using actuator line model

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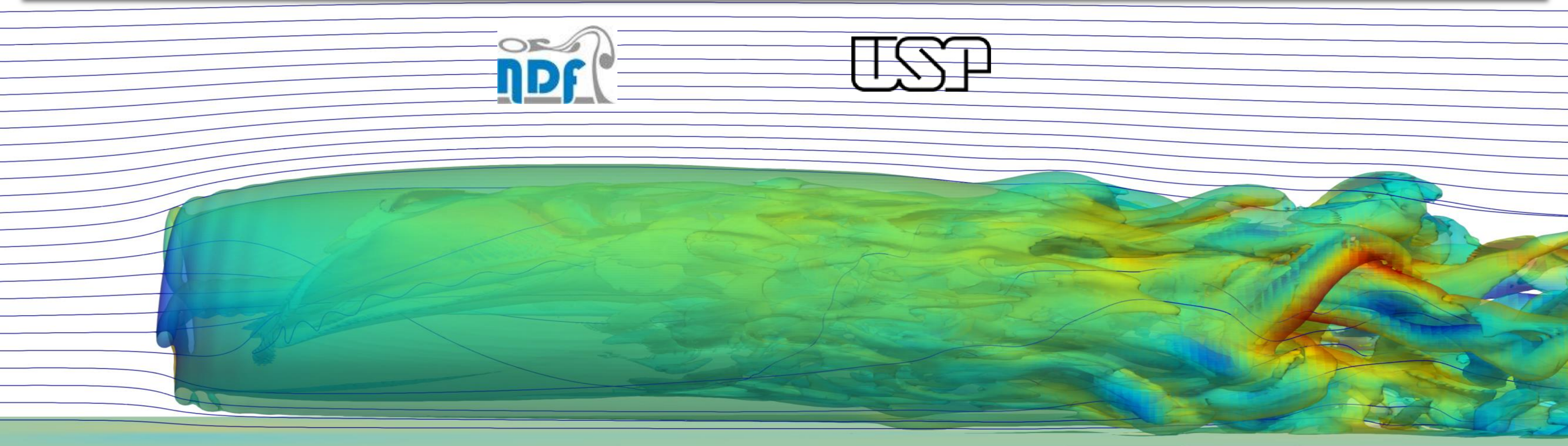
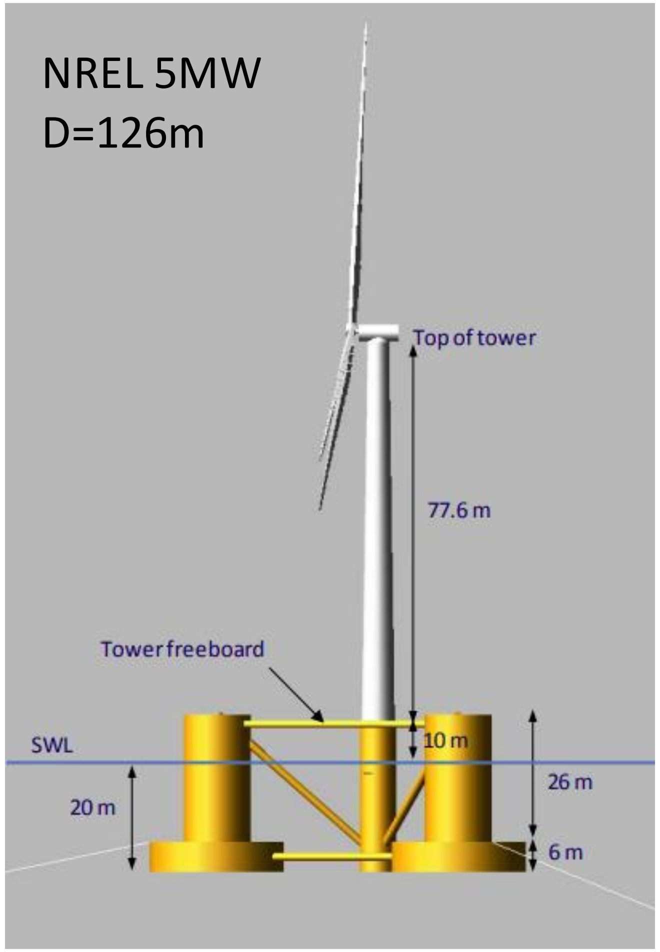


Agenda

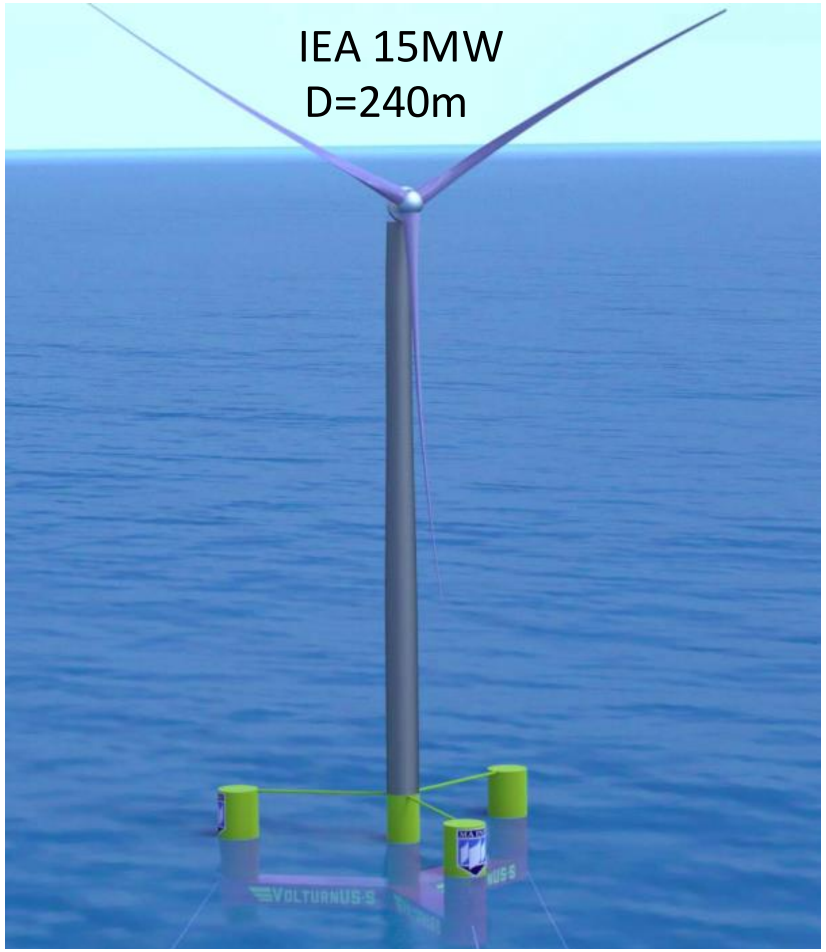
- Introduction
- Methodology
- Code verification
- Simulation Results
- Conclusion

Introduction – The Offshore Wind Turbine

OC4 Semi-Submersible Platform



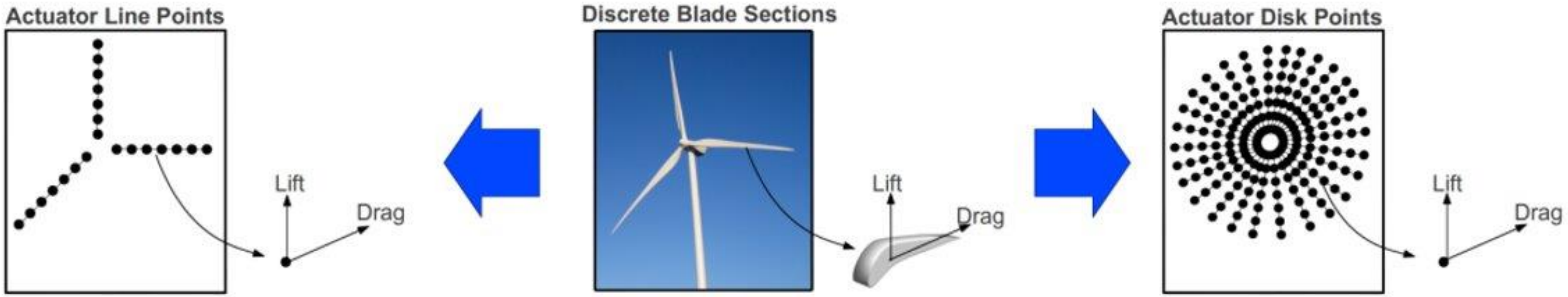
UMaine Semi-Submersible Platform



Methodology – CFD Approach

$$\nabla \cdot \vec{u} = 0,$$

$$\frac{\partial \vec{u}}{\partial t} + (\vec{u} \cdot \nabla)\vec{u} = -\frac{1}{\rho}\nabla p + \nu \Delta \vec{u} + \vec{f}.$$



Source: (Martinez et al., 2012)

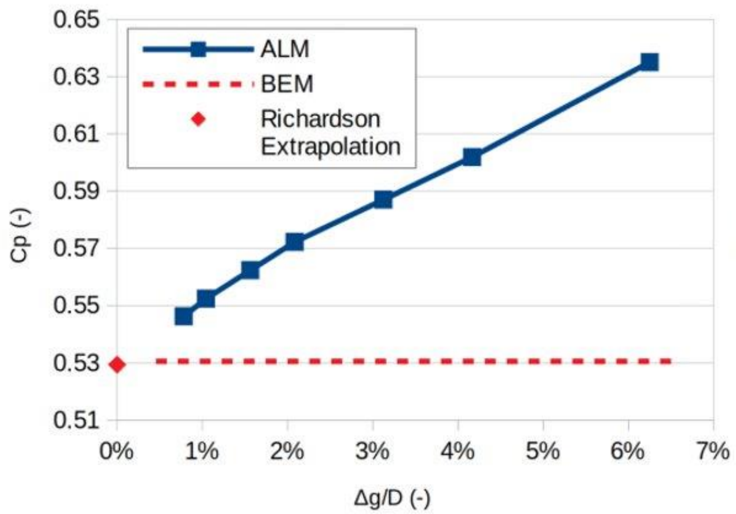
One Turbine: Code Verification

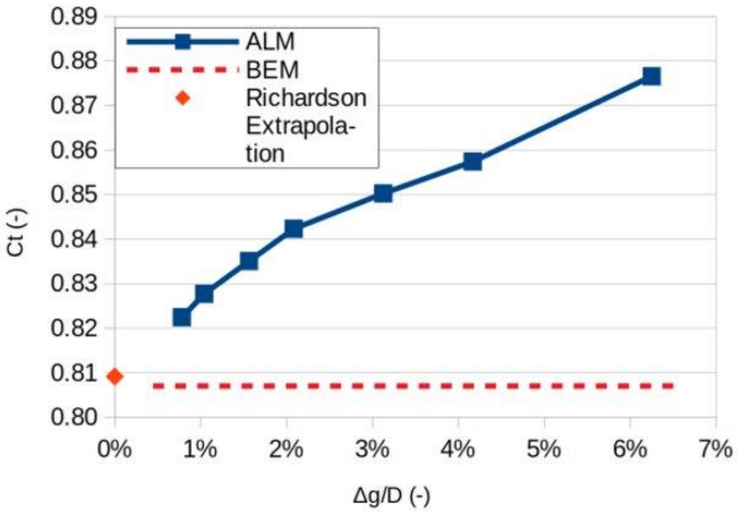
- TurbinesFoam: OpenFOAM library for Actuator Line Models (ALM)

- OpenFAST: NREL code with Blade Element Momentum (BEM)

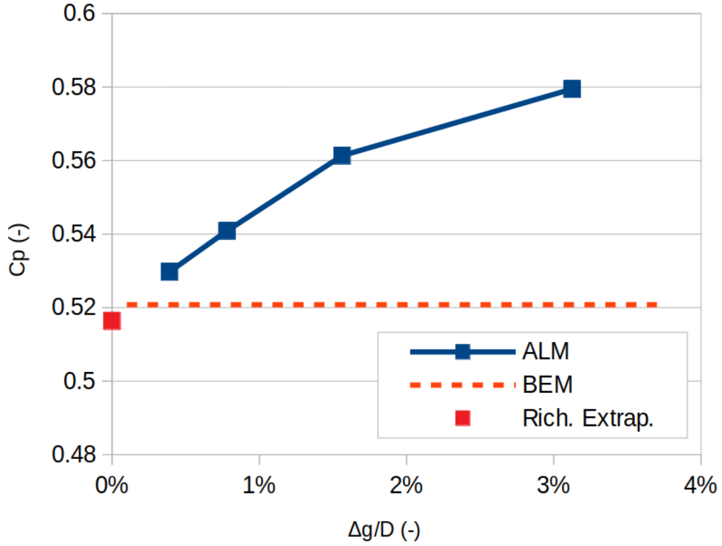
ALM cell grid of 1% of turbine diameter converges with <5% difference

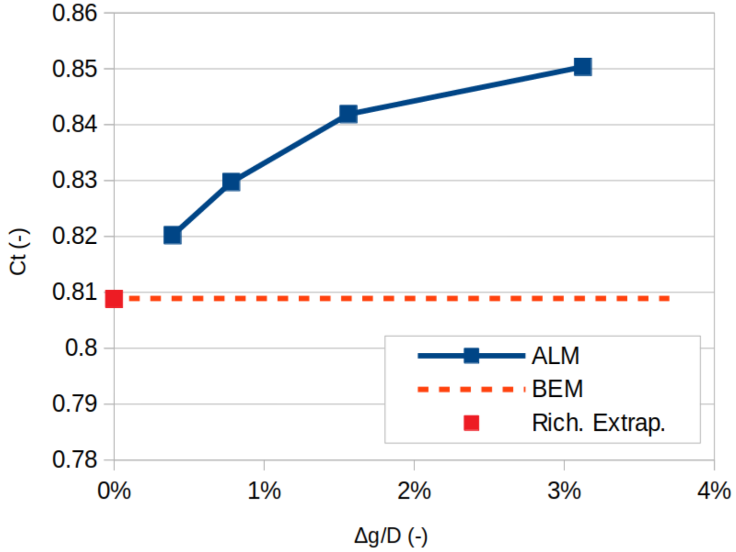
NREL 5MW





IEA 15MW





Grid Convergence Table

NREL5MW

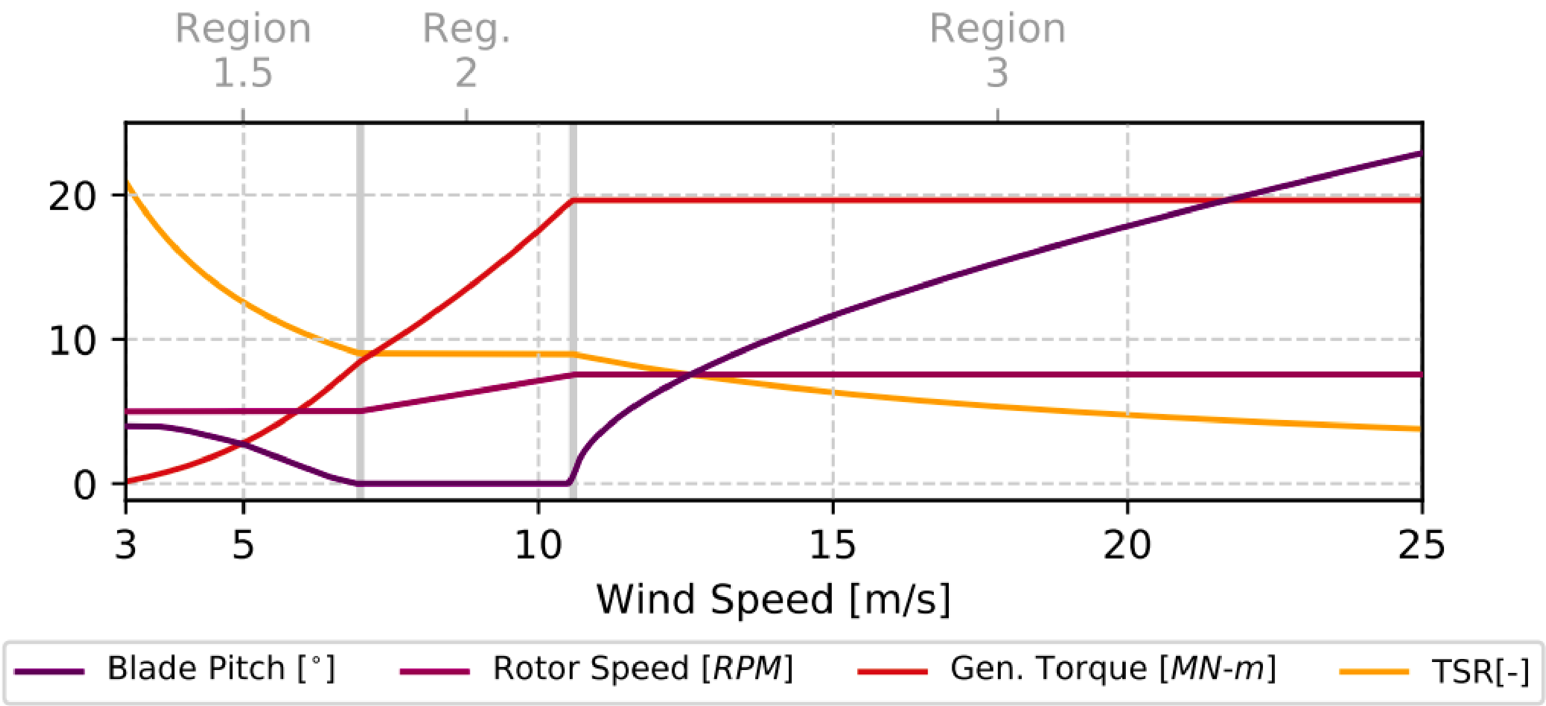
cell size (m)	D/Δg	Δg/D	Cp	Ct	Cp error	Ct error
3.94	32	3.13%	0.5870	0.8502	10.64%	5.36%
2.63	48	2.08%	0.5722	0.8423	7.86%	4.38%
1.97	64	1.56%	0.5623	0.8351	6.00%	3.48%
1.31	96	1.04%	0.5524	0.8277	4.12%	2.57%
0.98	128	0.78%	0.5462	0.8224	2.97%	1.91%

IEA15MW

cell size (m)	D/Δg	Δg/D	Cp	Ct	Cp error	Ct error
7.5	32	3.13%	0.5795	0.8504	11.27%	5.12%
3.75	64	1.56%	0.5613	0.8419	7.78%	4.08%
1.875	128	0.78%	0.5409	0.8297	3.86%	2.57%
0.9375	256	0.39%	0.5297	0.8202	1.72%	1.40%

Two Turbines in Tandem: case study

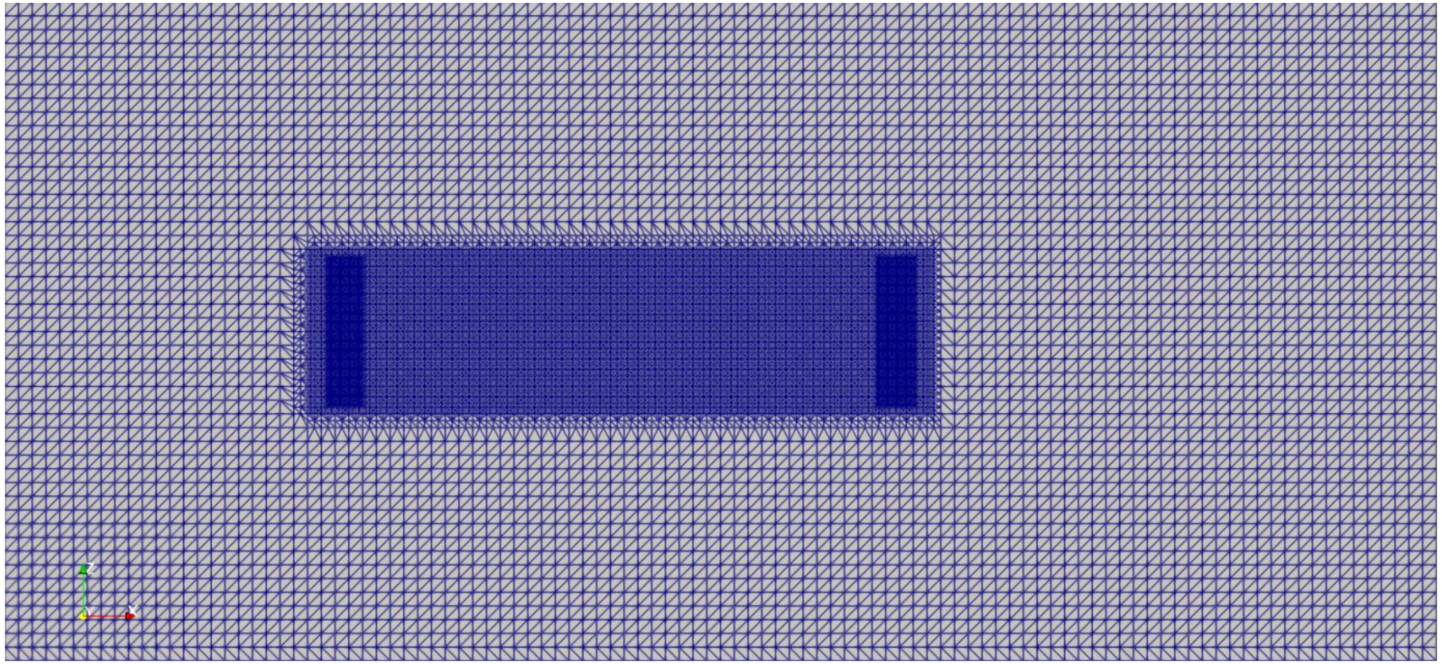
- Two IEA15MW rotor operating in region 2
- Uniform Inflow=8m/s and TSR=9. Slip Walls.



Two Turbines in Tandem: mesh

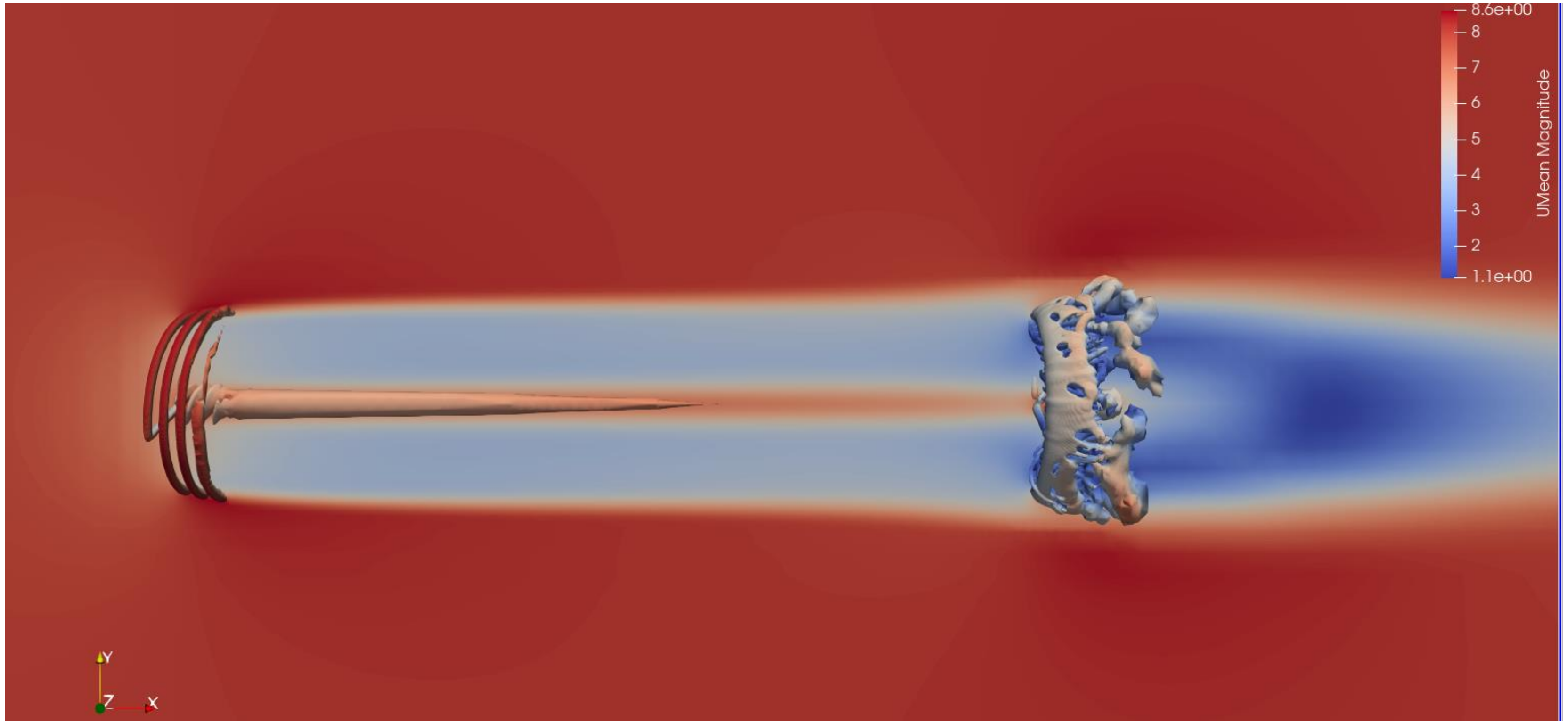
Created with OpenFOAM (blockMesh and snappyHexMesh)
Domain: 13Dx6Dx6D with cell size D/8=30m.
Cylindric refinement at the turbine (D/128=1.875m) and at the wake between turbines (D/32=7.5m)
Distance between turbines: 5D. Turbine diameter: D=240m. 2.6 mi cells.

U inflow



Two Turbines in Tandem: uniform inflow

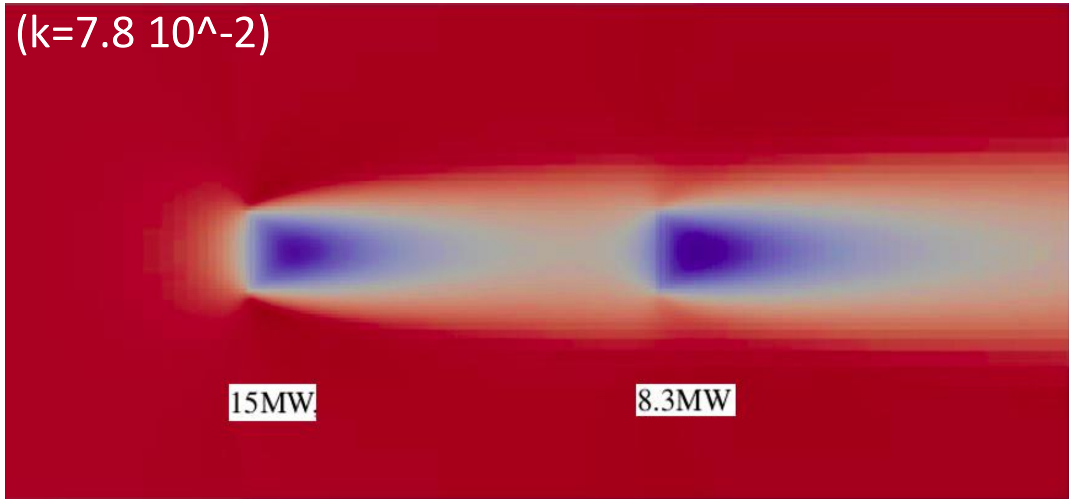
Using LES -> No turbulence at the inlet
Significant power loss at the downstream turbine: 98% (wind speed near cut-in)



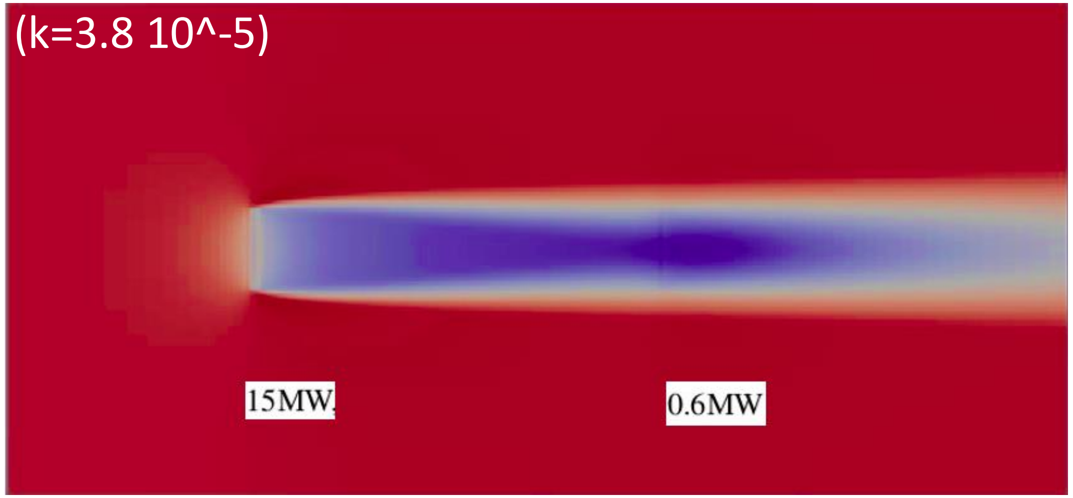
The wake recovery in RANS

- Actuator Disc Model (ADM) with RANS k-ε model in OpenFOAM
- Turbulence can significantly impact the power production of the downstream turbine
- For LES, one must use synthetic turbulence or precursor simulation

Higher turbulence at inlet



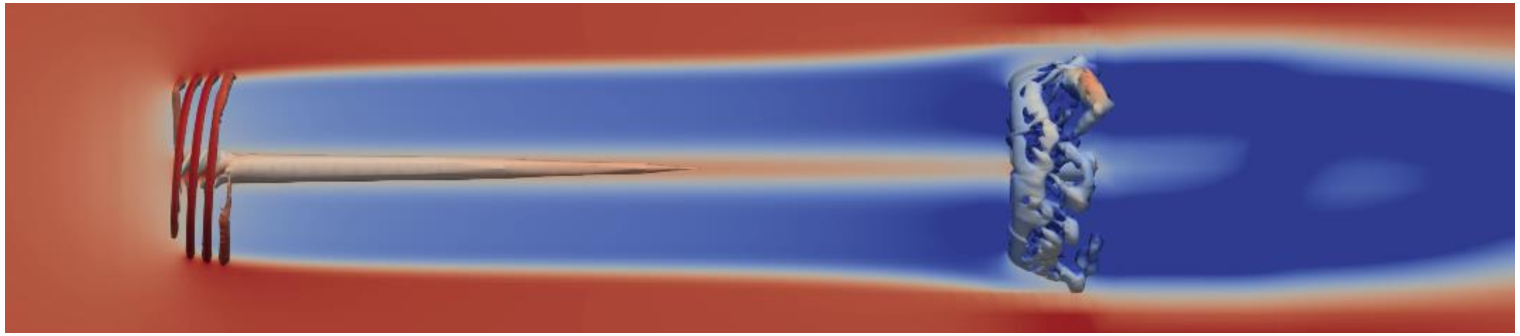
Lower turbulence at inlet



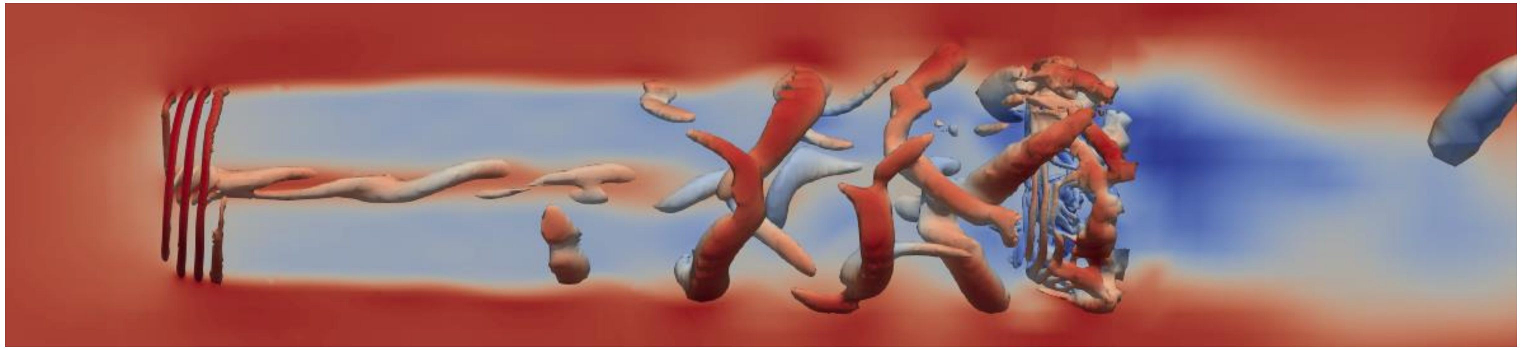
Synthetic Turbulent for LES

DF-SEM: Divergence-Free Synthetic Eddy Method

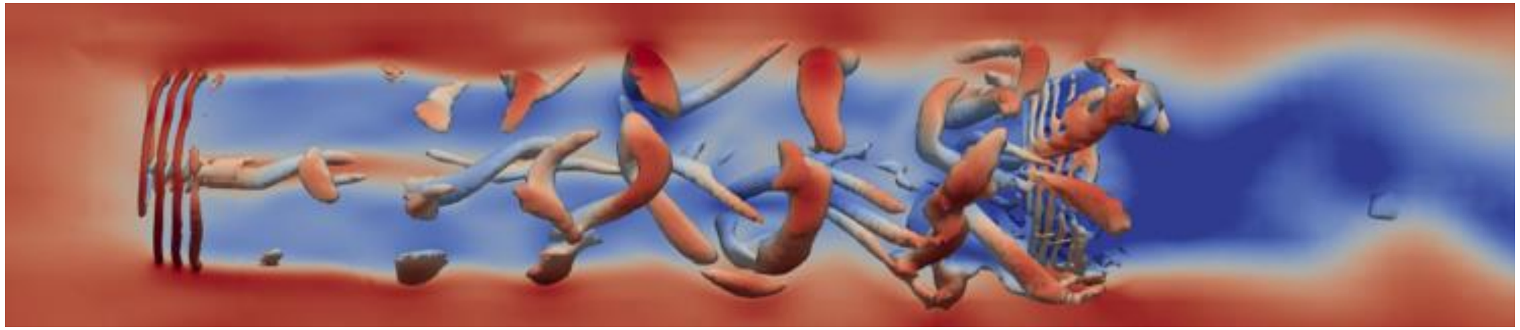
- No turbulence R=0
  Power Loss: 98%



- Turbulence R=0.0005
  Power Loss: 86%



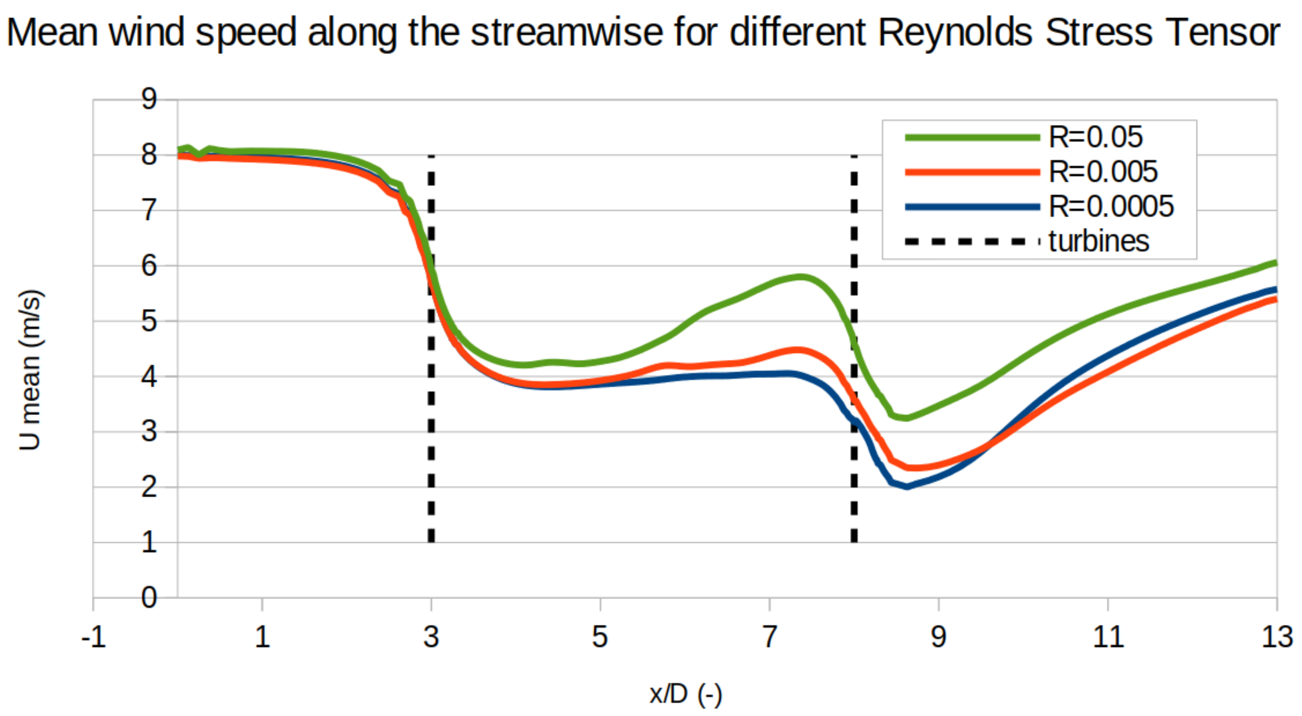
- Turbulence R=0.005
  Power Loss: 75%



R: Diagonal Reynolds Stress Tensor

Mean values along the streamwise (10D)

Summary Results



Turbine Distance	Turbulence Parameter R	Power ratio (Cp2/Cp1)	Thrust ratio (Ct2/Ct1)	Cp2 Mean	Ct2 Mean	Cp2 StDev	Ct2 StDev
5D	0	1.48%	45.86%	0.0079	0.3785	0.0101	0.0174
5D	0.0005	13.83%	54.96%	0.074	0.4542	0.0259	0.0286
5D	0.005	25.07%	61.92%	0.1349	0.5127	0.038	0.0371
5D	0.05	37.41%	69.74%	0.2024	0.5778	0.051	0.0433
10D	0.005	53.98%	78.86%	0.2897	0.6522	0.0465	0.0373

Conclusions

- ALM can provide the same results as BEM if the grid is properly converged, with the advantage of wake flow details.
- Turbulence is fundamental for predicting power and thrust
  - RANS: Turbulence at the inlet can be easily modelled.
  - LES: One must use a synthetic generator or a precursor simulation.
- Turbulence increase wake recovery and mean wind speed.
- The increase of turbulence lead to higher aerodynamic power prediction downstream.
- Turbine distance may have more impact on wake recovery.

Acknowledgments

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Thank you!

Questions?