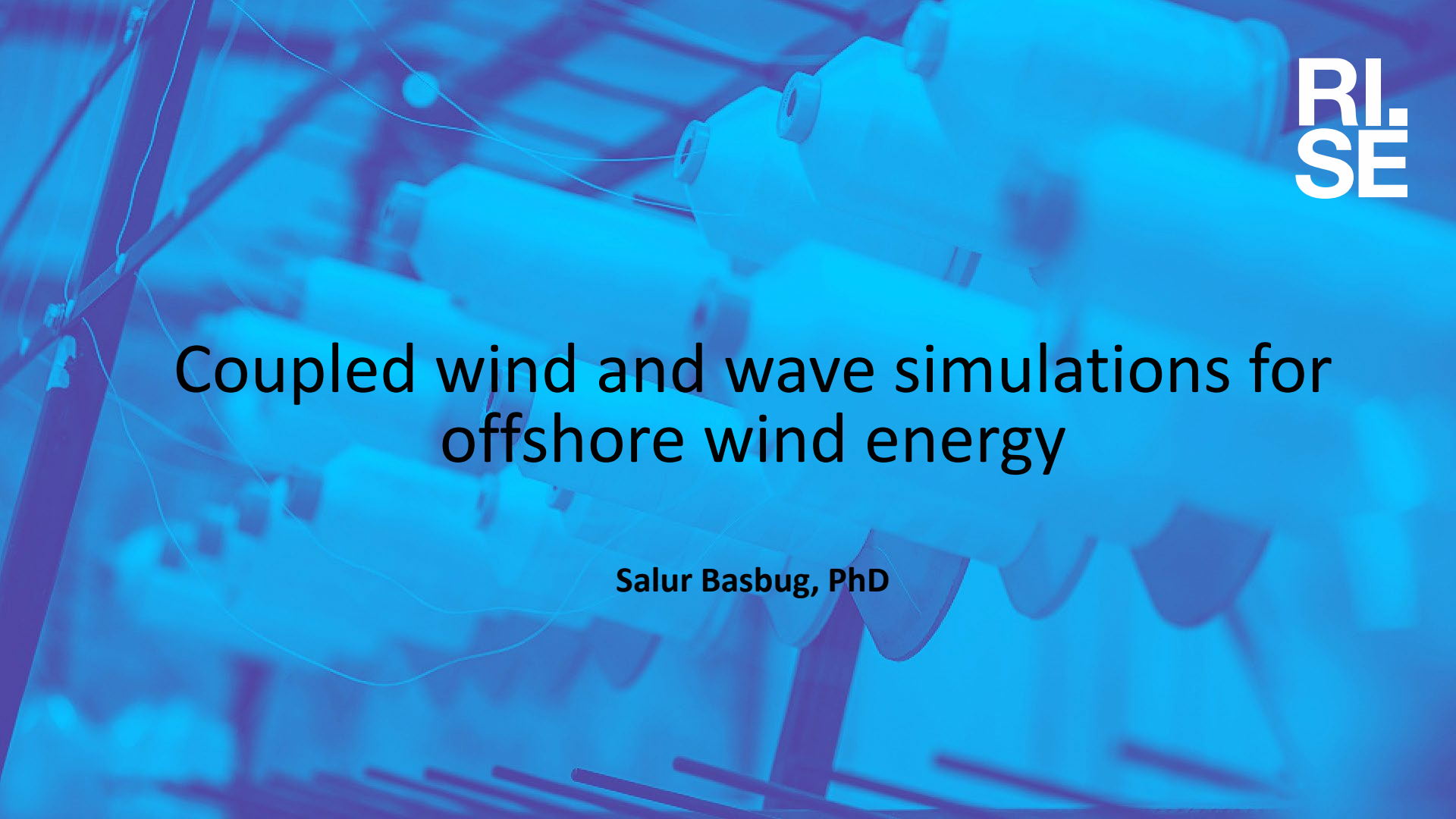
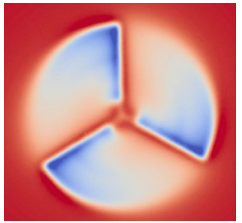


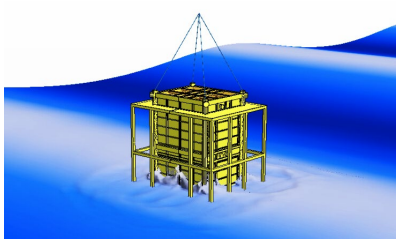
Coupled wind and wave simulations for offshore wind energy

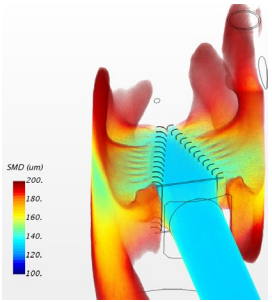
Salur Basbug, PhD

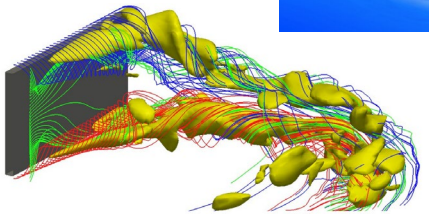
About myself

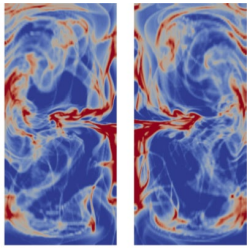
- **RISE** since 2021, the unit **"Renewable Energy from Wind & Sea"**
- CFD: Simulation of fluid mechanics / aerodynamics
- Aker Solutions, *Offshore Oil & Gas*
- PhD at Imperial College London, *Turbulent Mixing*
- MSc thesis at Airbus, *Combustion in Rocket Engines*

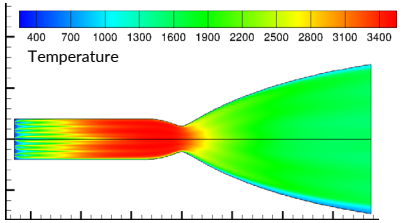












About the project:

”Influence of Wind-Wave Interaction on Offshore Wind Farms”

Background:

- Wind characteristics are influenced by the presence of sea waves (atmospheric boundary layer, turbulence etc.)

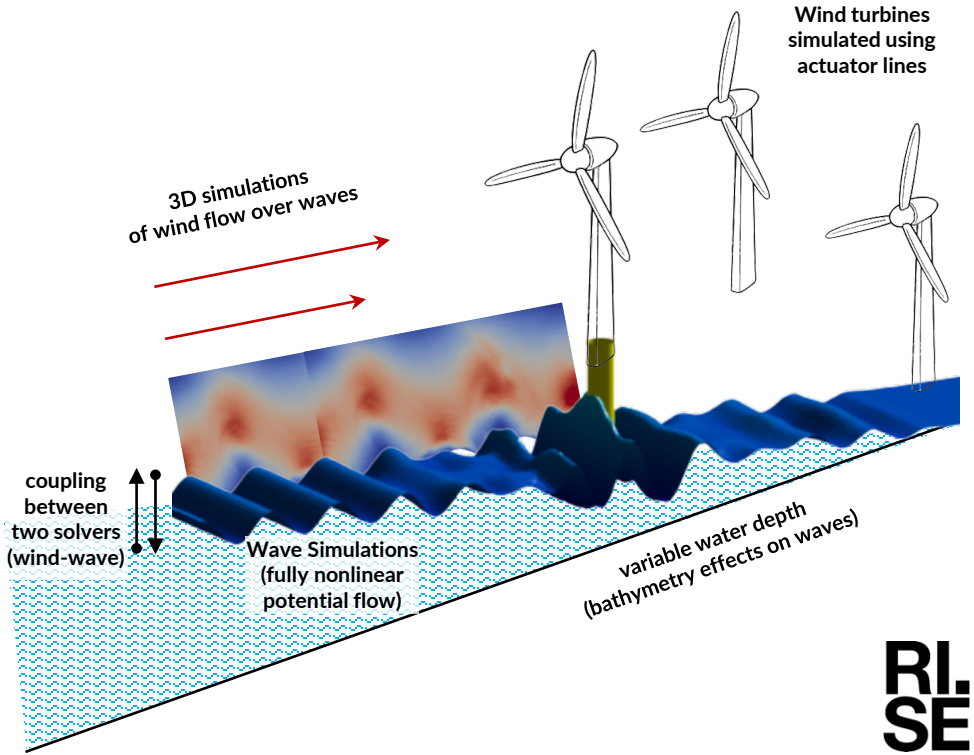
Research Questions:

- How strong is the influence of wind-wave interaction ?
- How does the seafloor bathymetry influence this ?
- Can those be quantified in order to reduce the uncertainties ?

Research Objectives:

- Improvements in the open-source software (Nektar++)
- Provide answers for “research questions” with high fidelity CFD
- Derive benchmarking data based on measurements
- Claes Eskilsson => waves ; Mats Goldberg => data analysis

sponsored by Swedish Energy Agency

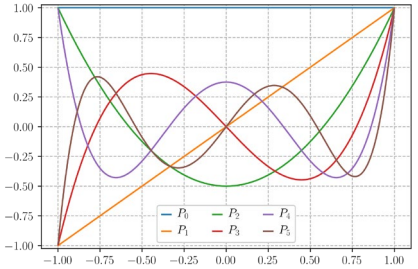


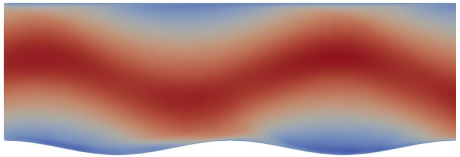
Open-source tool-box NEKTAR++

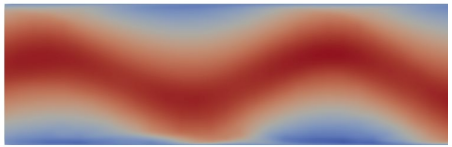
Open-source simulation tool-box Nektar++ chosen for the project:

- Includes different solvers such as acoustic solver, elasticity solver etc.
- Spectral / hi-order finite element method => suitable to model **hi-order waves**
- Potential flow solver for waves and Navier-Stokes solver for wind domain
- Capable of **sigma transformation** => deformation of the wind domain due to waves

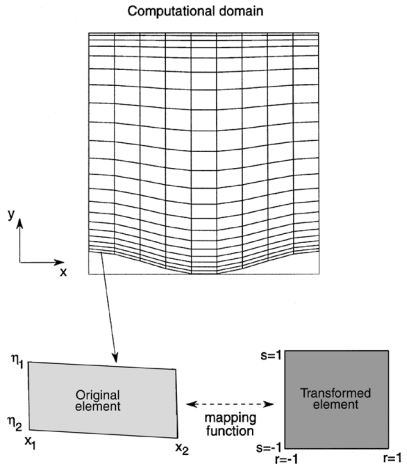
Hi-order refers to polynomial order of the solution computed at finite elements





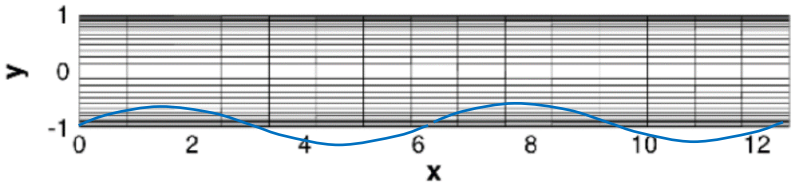


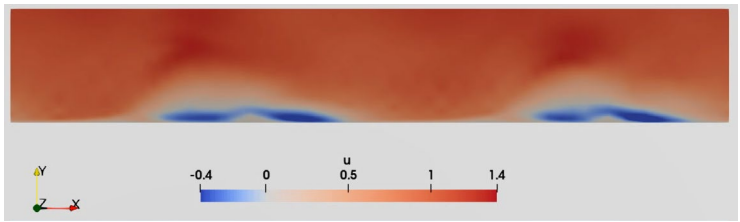
- Instead of solving the wind flow in a deformed domain / mesh ...
- ... we can use sigma transformation and solve equations in a rectangular domain / mesh.
- Hence, no need to deform mesh at each timestep due to moving waves.



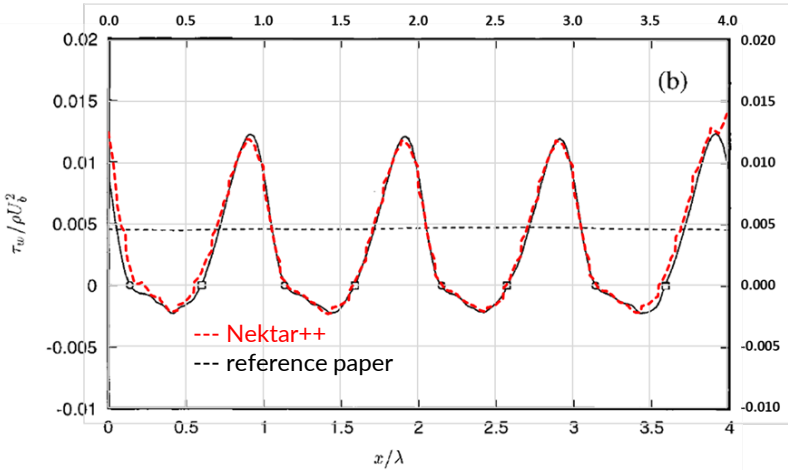
Sigma transformation example

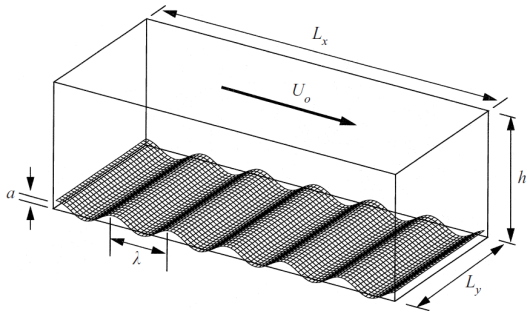
- Validation of Nektar++ sigma transformation capability
- 2D simulation of travelling waves, computed with a static rectangular mesh





Shear stress along the wavy wall

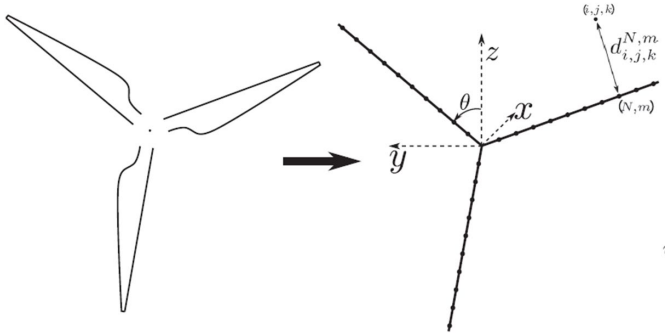




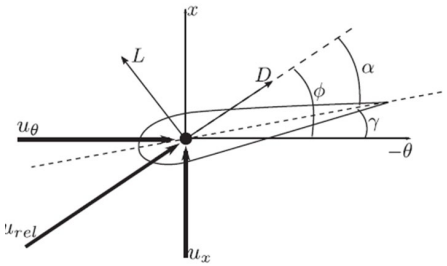
Actuator Line Method (ALM)

- The missing part of Nektar++ was wind turbine simulation capability
- ALM is a common & convenient method for wind turbine simulation => **implemented in Nektar++**

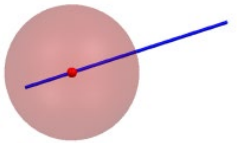
Turbine blades are represented as distributed forces along a line



The flow solver provides the velocity field & airfoil properties read from tabulated data



Point forces are spread in space using a 3D Gaussian distribution

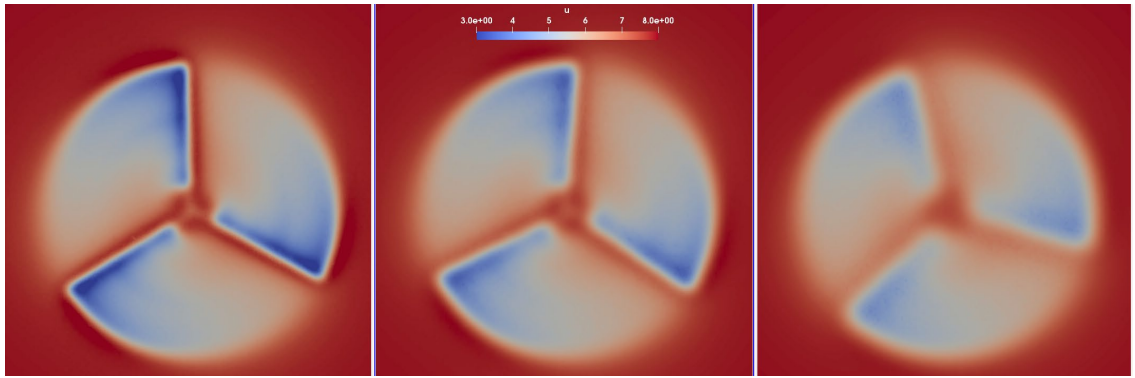


$$\eta_{\epsilon,3d} = \frac{1}{\epsilon^3 \pi^{3/2}} \exp\left[-\left(\frac{d}{\epsilon}\right)^2\right]$$

Force spreading via Gaussian distribution

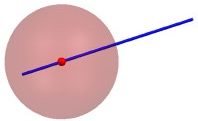
- The selection of epsilon has some influence on ALM results
- Must be selected carefully depending on the blade chord length & simulation resolution

Epsilon = 3.0 m | **4.2 m** | **6.3 m**



Velocity contours at turbine plane

Point forces are spread in space
using a Gussian distribution



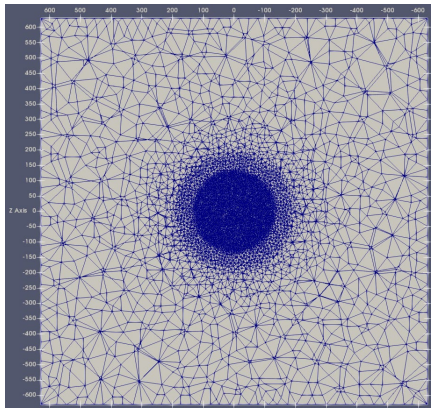
$$\eta_{\epsilon,3d} = \frac{1}{\epsilon^3 \pi^{3/2}} \exp\left[-\left(\frac{d}{\epsilon}\right)^2\right]$$

ALM implementation validation

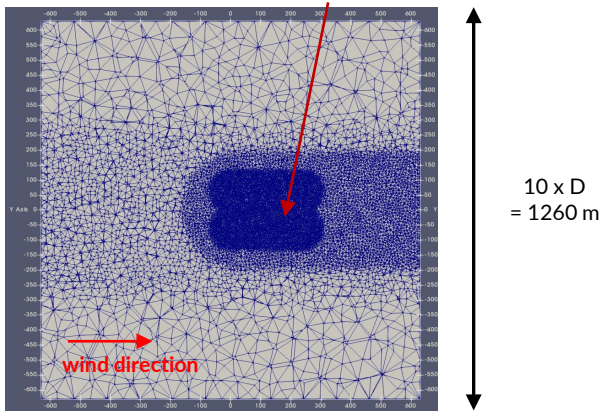
- Used the **NREL 5 MW** turbine for the validation of the ALM implementation
- Domain size = 10 x turbine diameter in every dimension to avoid any blockage effect
- Fine mesh around the turbine location and the wake location
- Implicit LES with spectral vanishing viscosity, 6th order method

	5 MW
Rotor type	3-bladed
Tip speed ratio	7.55
Blade aspect ratio	15.8
Rotor diameter	126 m
Root cut out	5 m
Rotational speed	0.9584 rad/s
Pitch angle	0°
Cone angle	0°
Wind speed	8 m/s

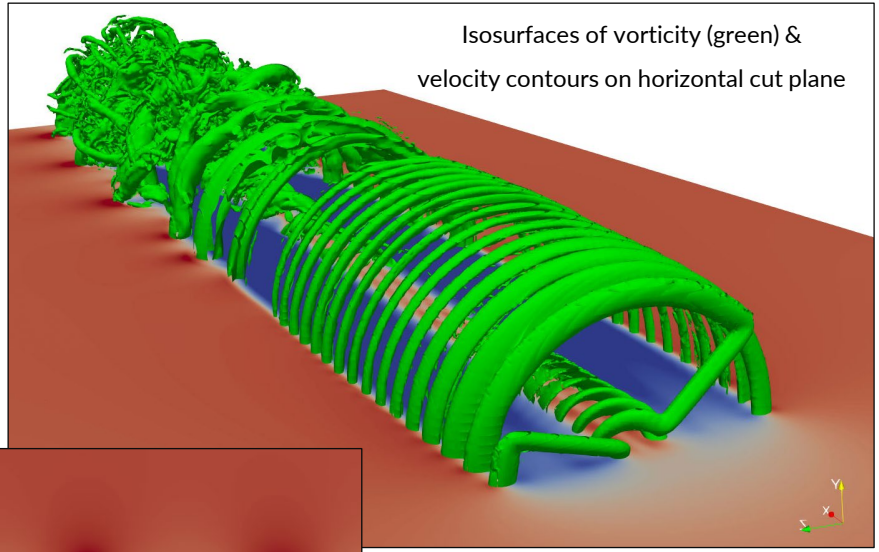
domain front view



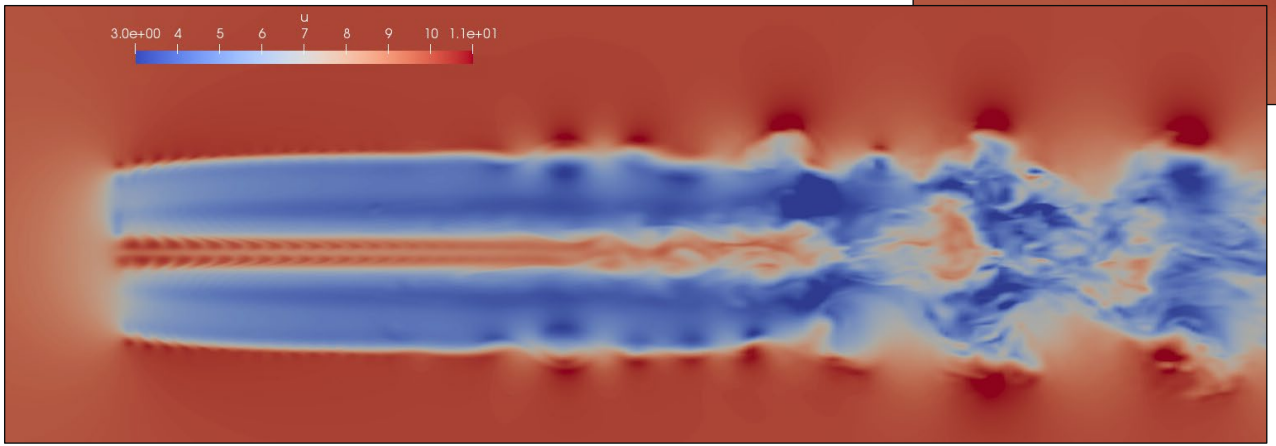
side view & near wake region



Qualitative results



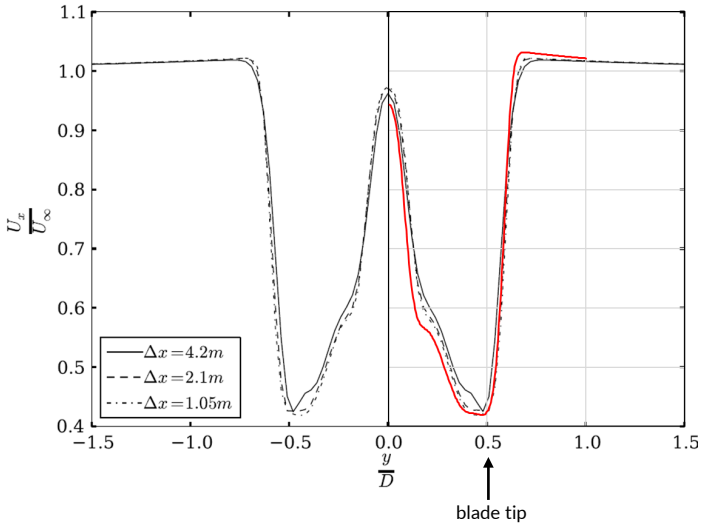
Wake velocity contours at vertical cut plane



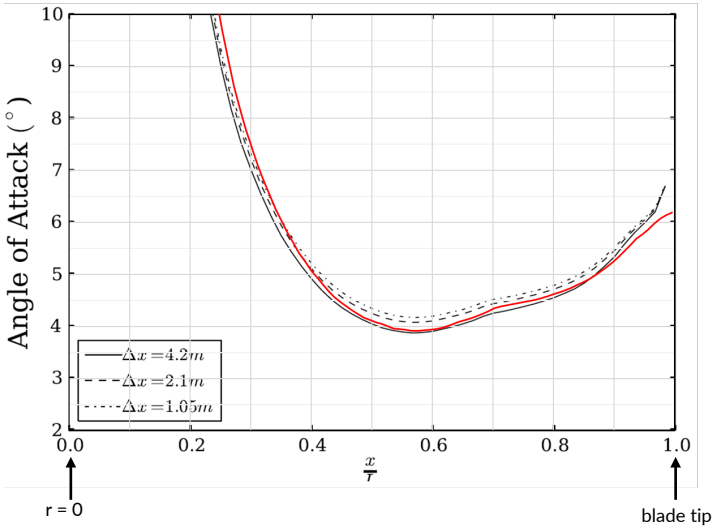
Wake velocity profile & angle of attack

- Simulation results compared with a reference paper (Martínez-Tossas, Churchfield and Leonardi, 2015, NREL)
- Black lines from reference case (OpenFOAM), red lines from my ALM implemention in Nektar++

Velocity profile 1-D behind the turbine



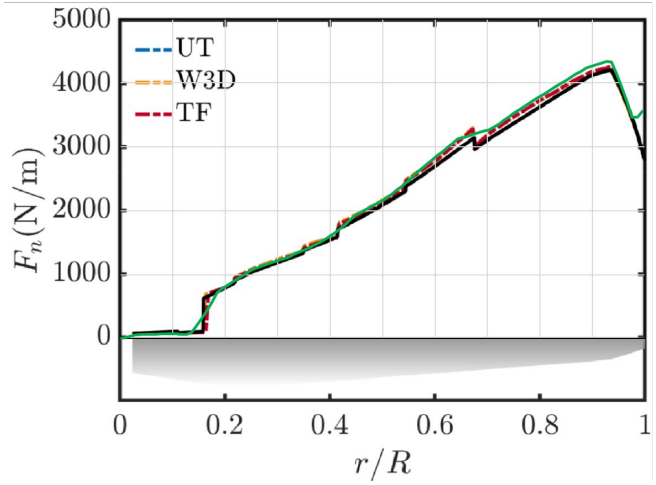
Flow angle of attack along the blade



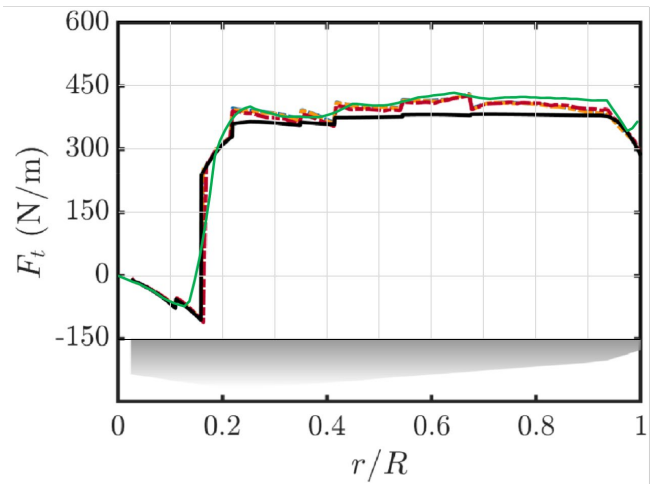
Force components along the blade

- Simulation results compared with a reference paper (Liu et al. , 2022)
- Axial and tangential forces along the blade per unit length, computed with several different methods, using similar parameters (resolution etc.)

Axial force along the blade



Tangential force along the blade



-- Nektar ++

-- UT = LESGO (Univ. of Twente)

-- W3D = WInc3D

-- TF = turbinesFoam

-- BEM method

Mutiple turbines test and next steps…

- Possible to run multiple turbines without additional computational cost (assuming the mesh is unchanged)
- Wave solver & its coupling with wind domain has been developed by my colleague
- Next step: running coupled simulations
- **Thank you for your attention !!**