



Application of Hi Fidelity aerodynamic models in aeroelastic studies

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ERCOFTAC Autumn Festival, 15 October 2026, NTUA, Athens



Several in-house Fluid Structure Interaction modelling options have been developed at NTUA:

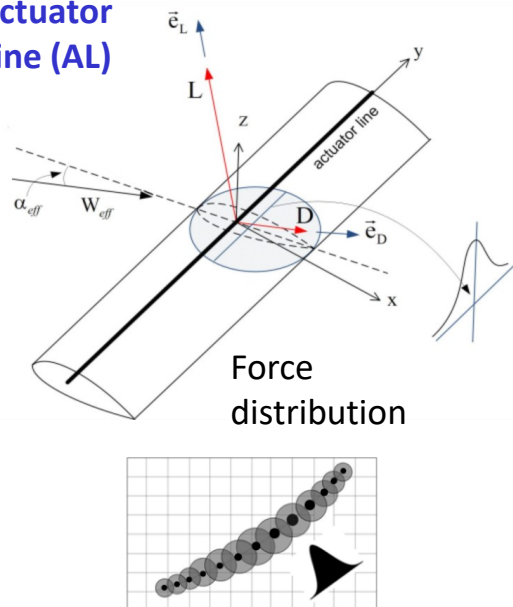
- Aerodynamic and hydro-aero-elastic analysis of wind turbines and wind farms
- Helicopter rotor aeroelasticity
- Aeroelastic response of cylinders
- PV aeroelasticity

aerodynamic module

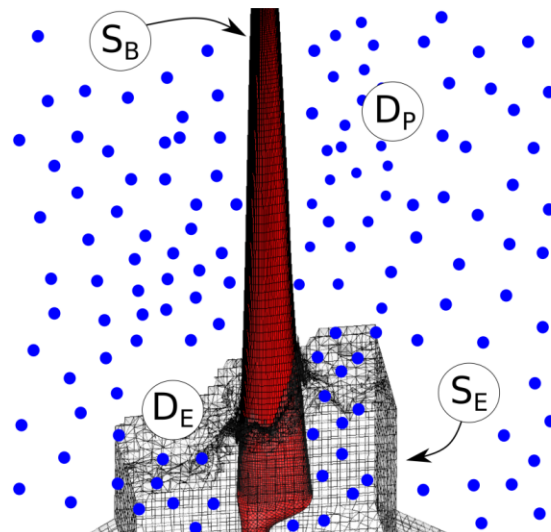
A wide range of in-house aerodynamics analysis tools have been developed over the years:

- Enhanced Blade Element Momentum (BEM) models
- Lifting line / lifting surface / panel free wake vortex models
- Actuator disk and line CFD URANS/DDES/LES models
- Fully resolved CFD URANS/DDES/LES models
- Hybrid CFD models (Eulerian – Lagrangian)

Actuator Line (AL)

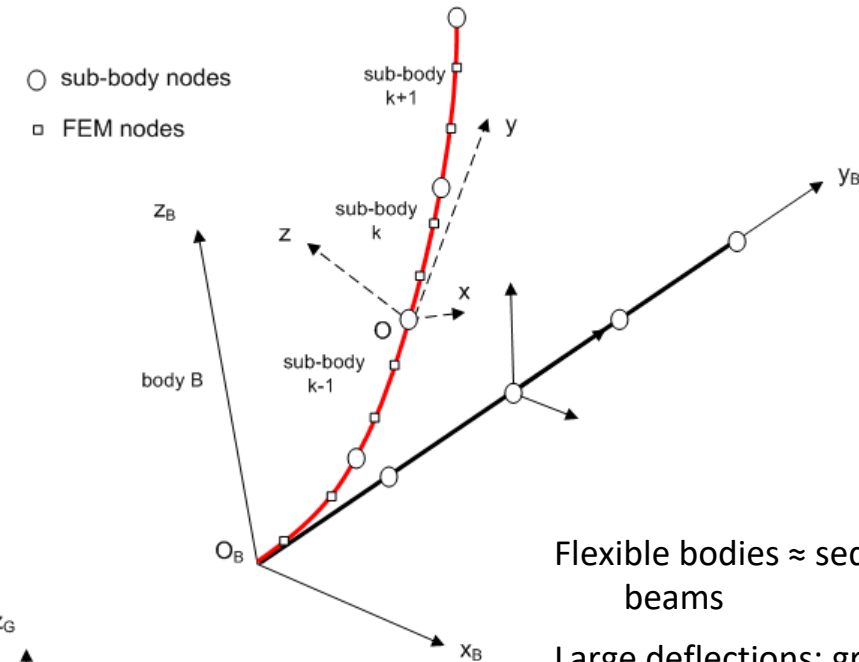


Hybrid Eulerian Lagrangian



+

structural module



Flexible bodies $\approx$ sequence of linear beams

Large deflections: gradually built

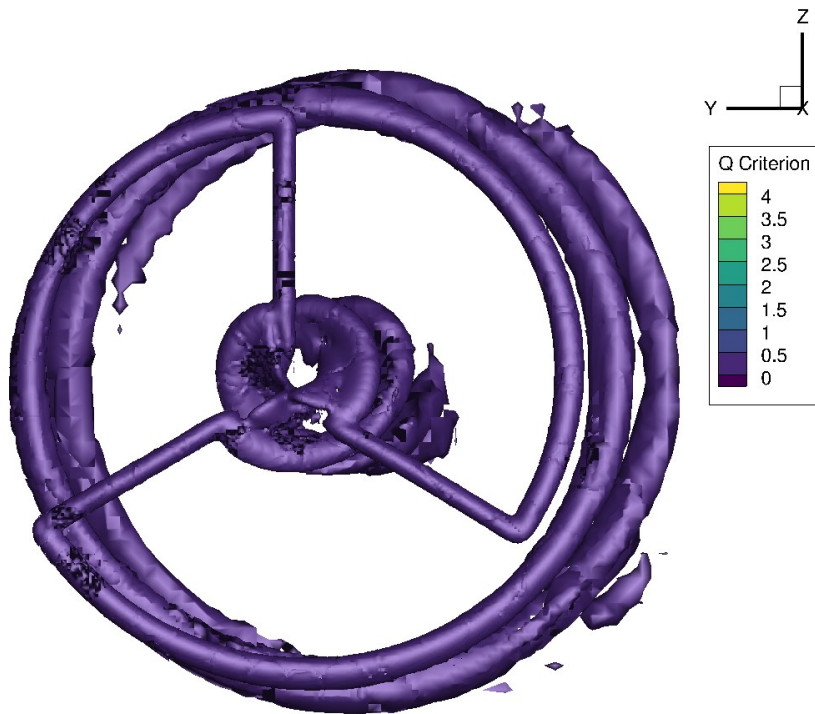
Geometric non-linear effects ✓

- Linear beam theory
- +
- non-linear connections

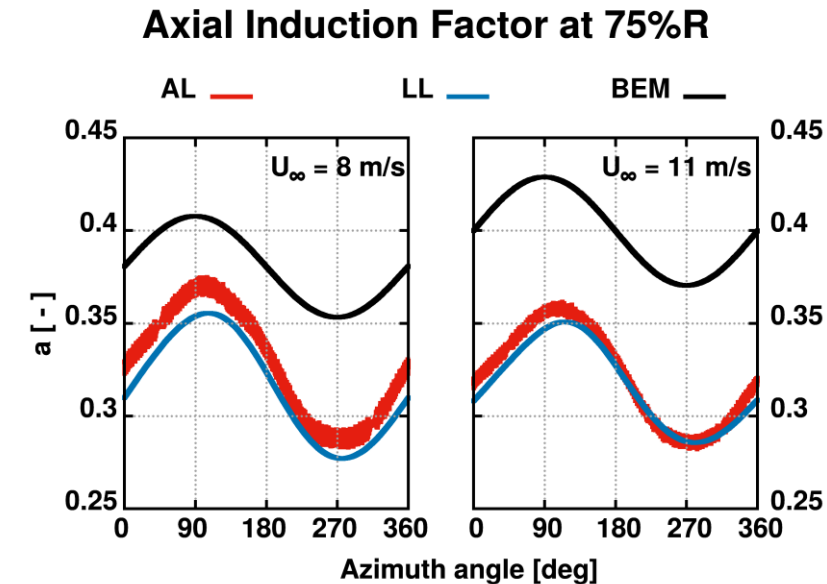
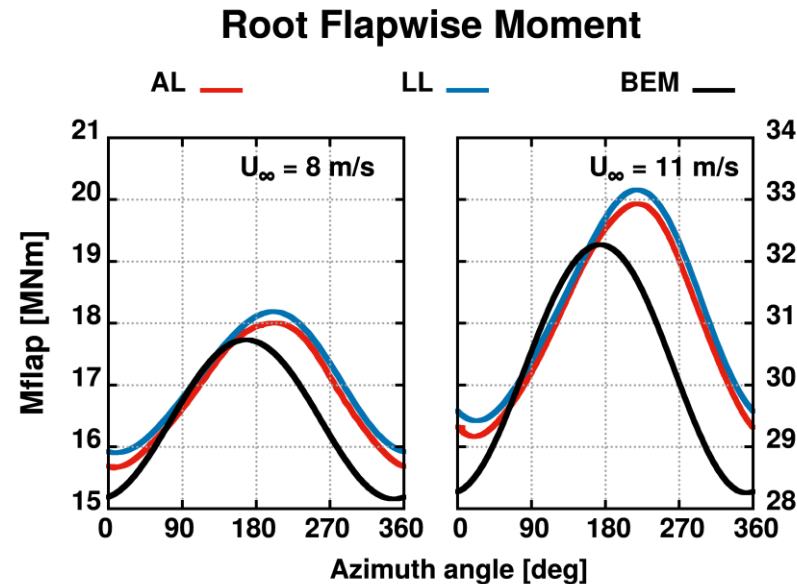


Aeroelastic modelling of wind turbine rotors in yawed flow conditions

Spyropoulos, N., Papadakis, G., Prospathopoulos, J., Riziotis, V.A., "Investigating the Level of Fidelity of an Actuator Line Model in Predicting Loads and Deflections of Rotating Blades under Uniform Free-Stream Flow," Appl. Sci. 2021, 2021, 11, 12097

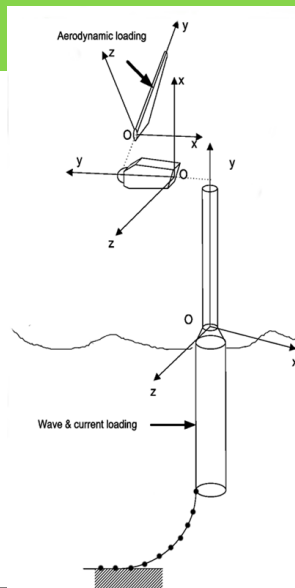
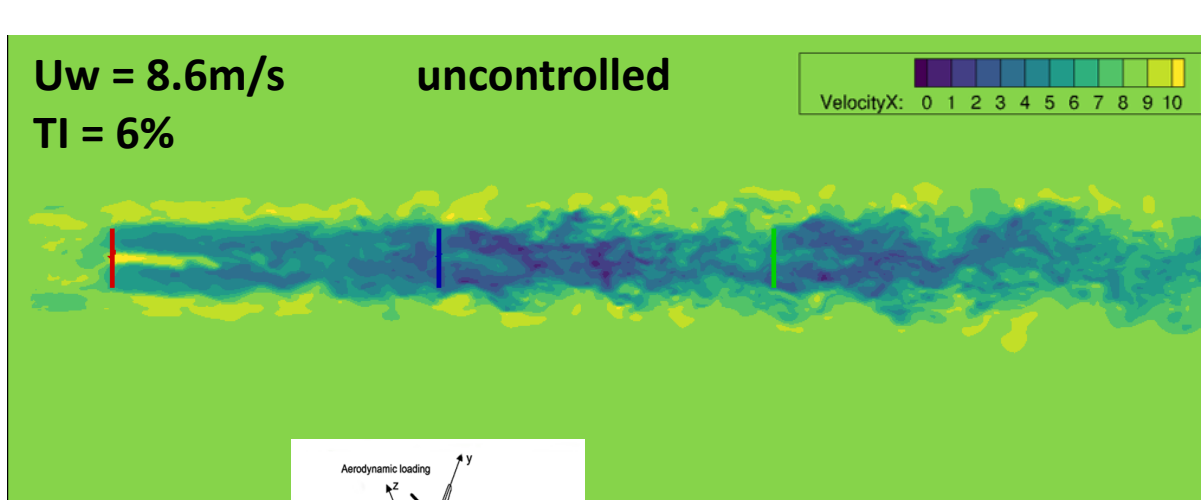


Yaw 15°



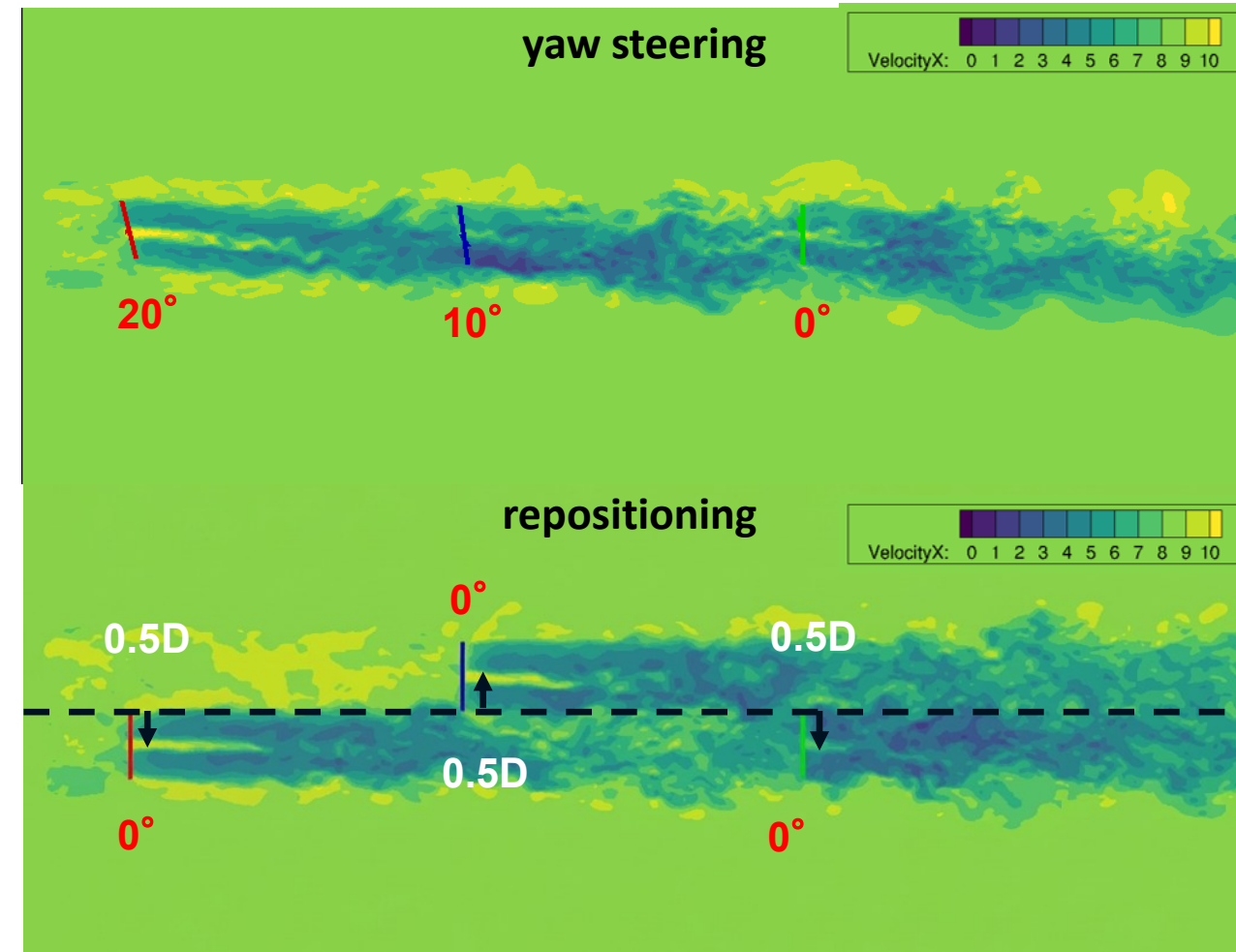


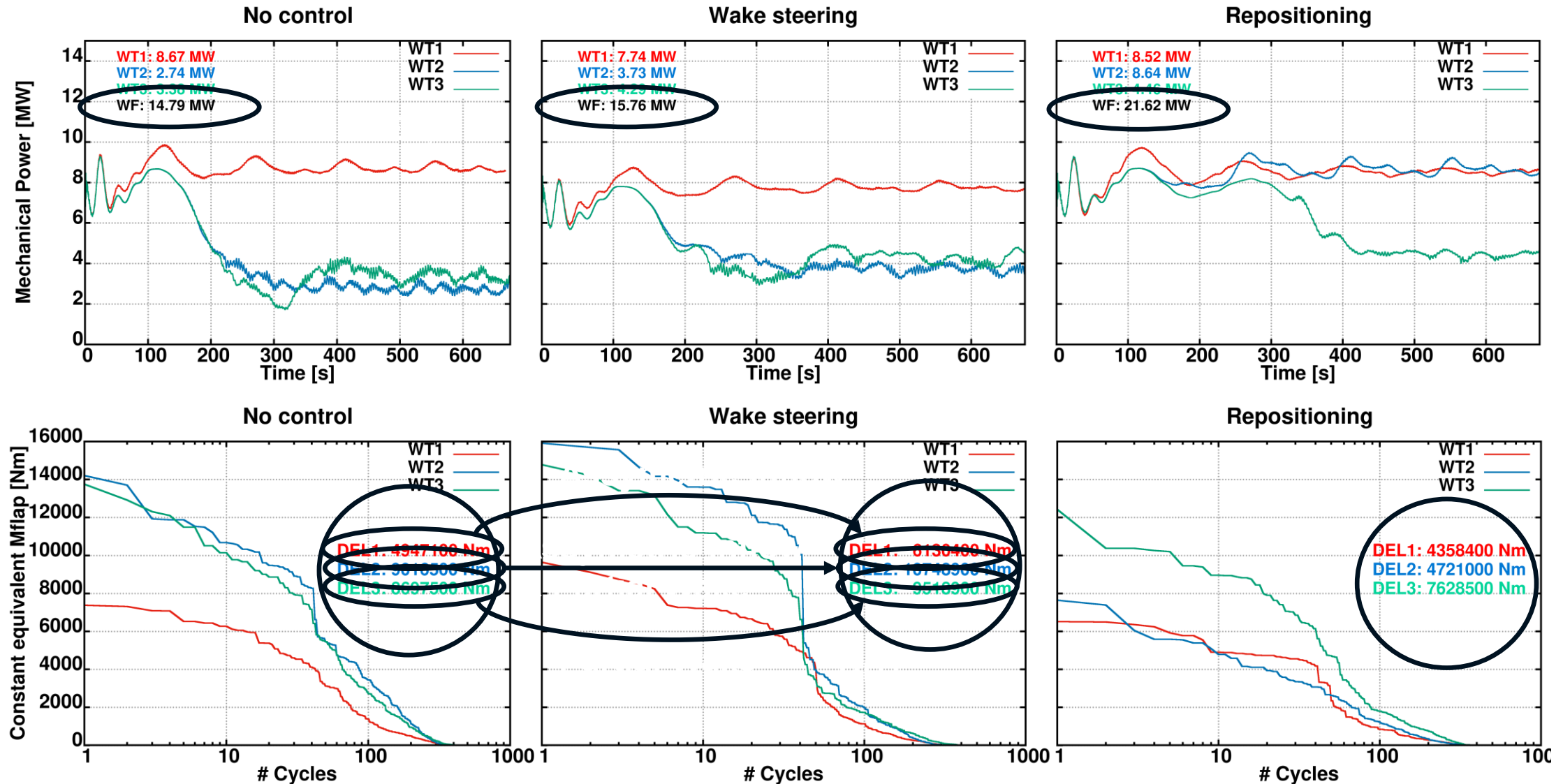
Aeroelastic modelling of Wind Farms configurations – Wind Farm control techniques



S U
D O
C O

Aeroelastic modelling of
the complete wind
turbine configuration
within the computational
domain

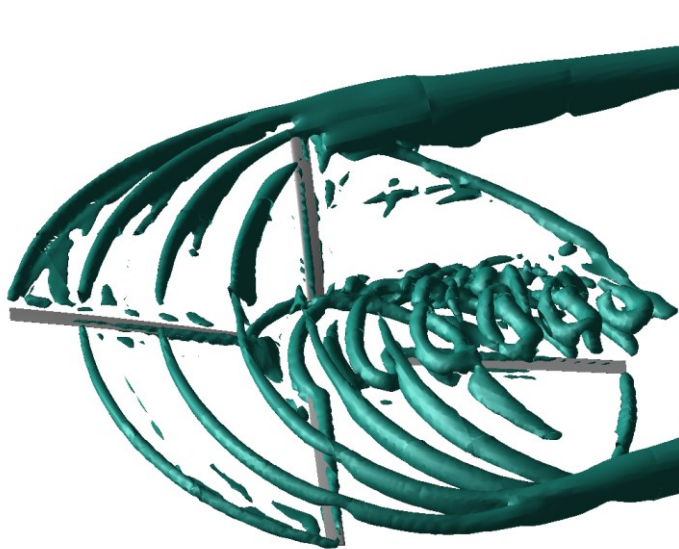
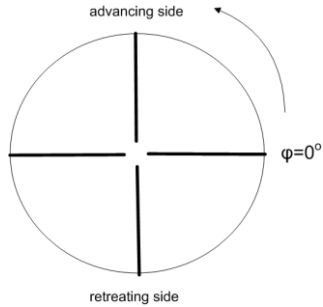




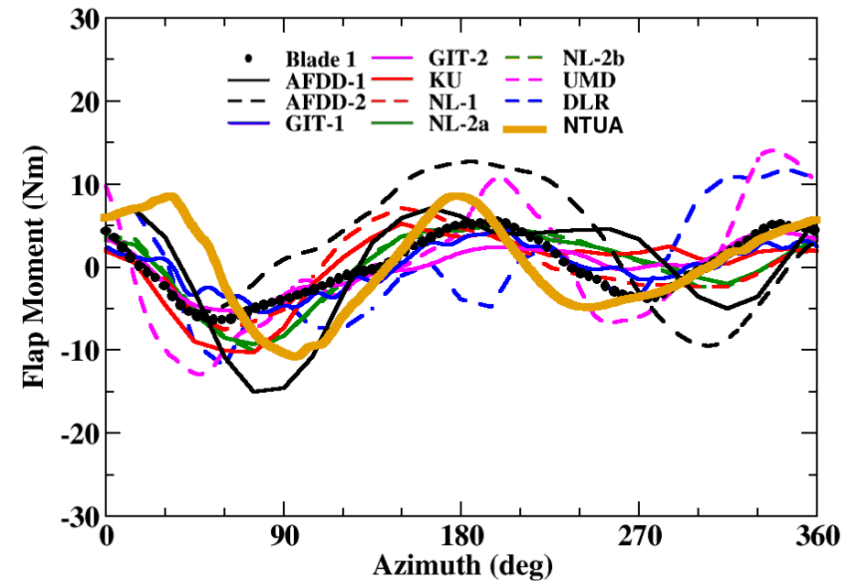


Aeroelastic modelling of helicopter rotors

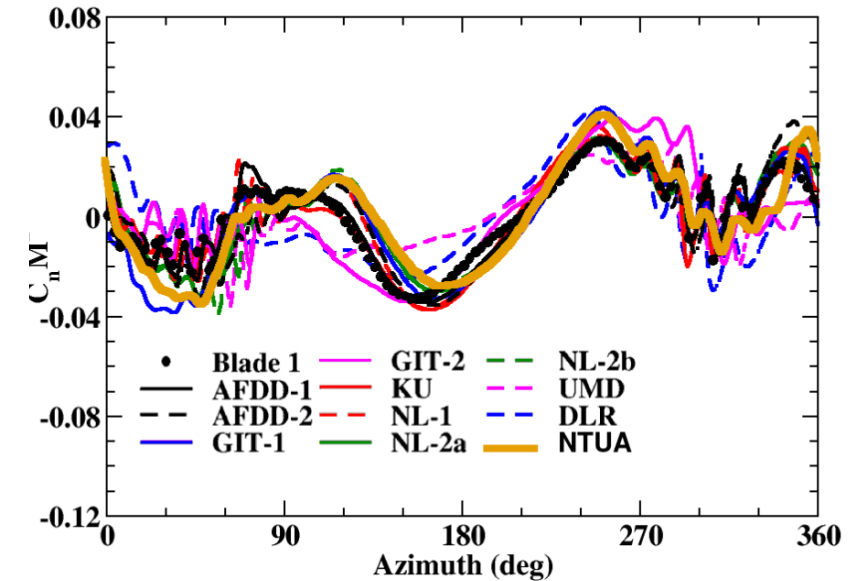
N.Spyropoulos, "Development of Computational Methods for the Aeroelastic Analysis of Rotors using Grid Based and/or Particles Techniques. Application to Wind Turbine and Helicopter Rotors", PhD Thesis



Flapwise Moment 17%R



$C_N M^2$ 87%R



- Weaker BVI in 1st quadrant ← Tip vortices position ✕
- Strong BVI in 4th quadrant ← Tip vortices position ✓
- Overall good agreement with exp.
- Where diffs occur, agree with other CFD

Comparison against data sets from HeliNovi experimental campaign



CFD aeroelastic analysis of Vortex Induced Vibrations on Wind Turbine towers

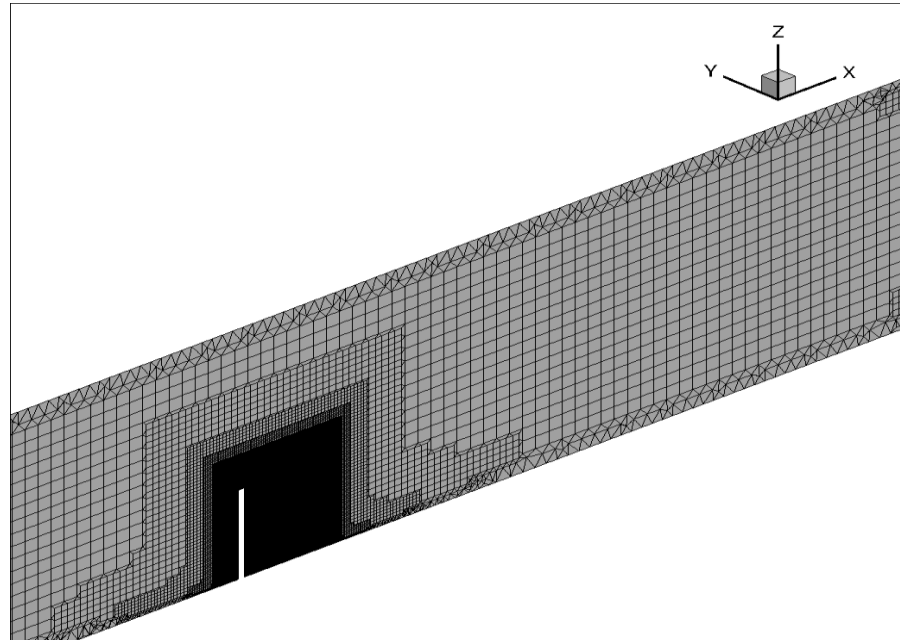
- Unstructured grids with wake refinement
- Refinement area size critical for resource management
- Cantilever cylinder based on the experimental setup of Lupi et al. (2021) (*)
- Fully resolved boundary layer modeling.
- Tunnel walls modelled as inviscid walls

(*) Lupi, F., Rüdiger Höffer, R. Niemann, H.,J.: Aerodynamic damping in vortex resonance from aeroelastic wind tunnel tests on a stack, Journal of Wind Engineering & Industrial Aerodynamics 208 (2021) 104438

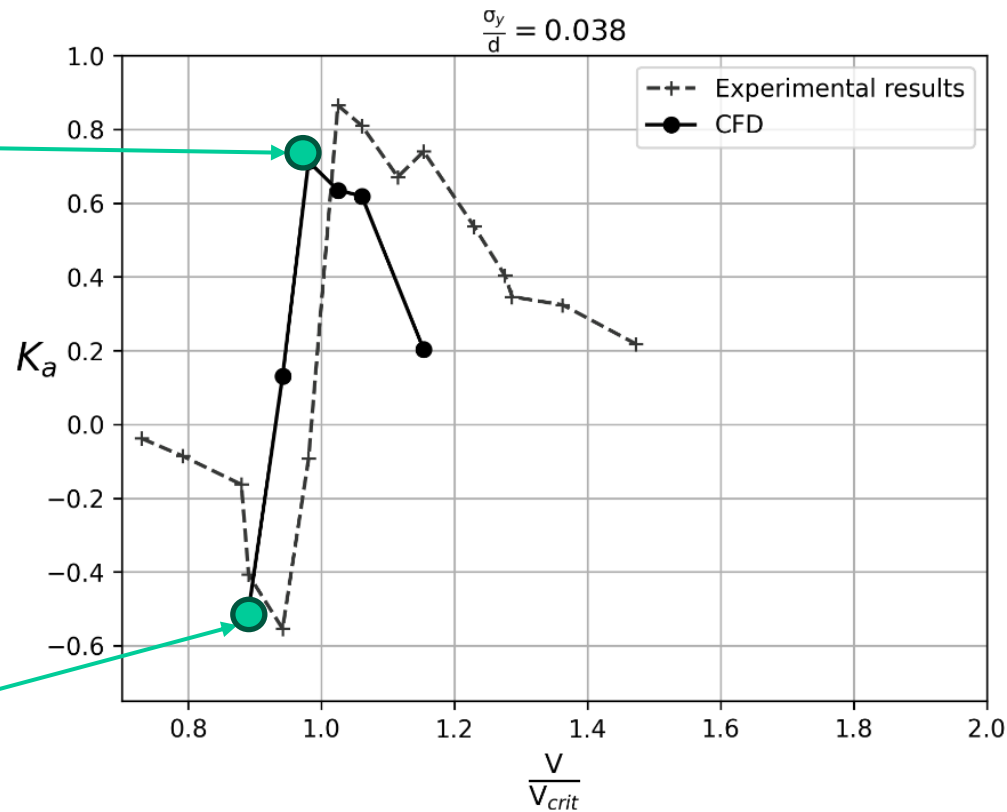
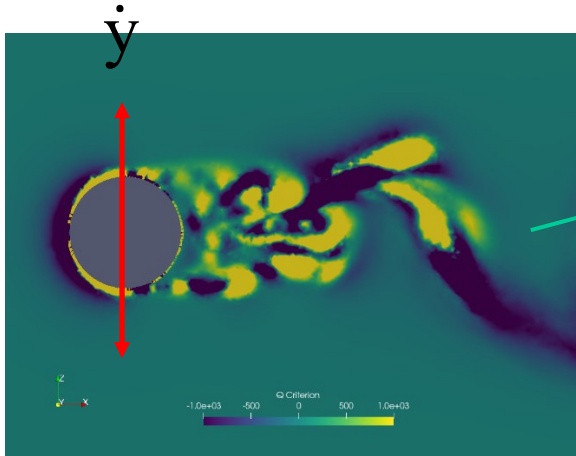
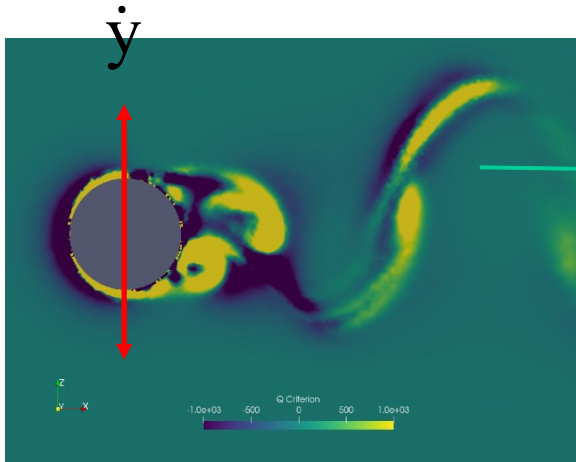
$$L = 775 \text{ mm} \quad d = 50 \text{ mm}$$

$$f_n = 20 \text{ Hz}$$

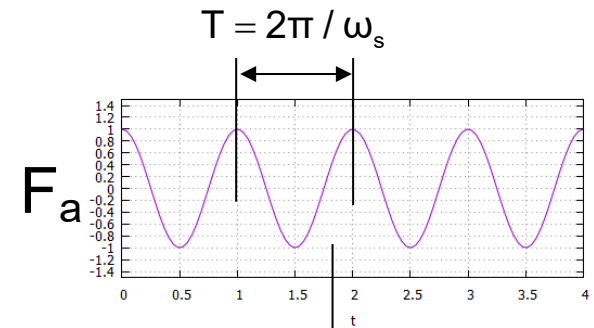
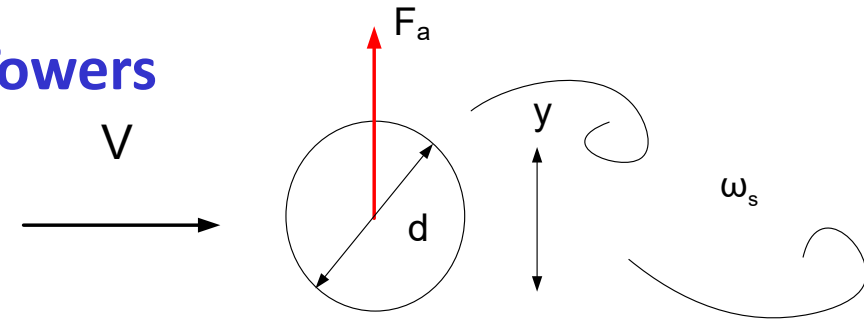
$$\text{Re} \approx 2 \times 10^4$$



Prediction of Vortex Induced Vibrations on Wind Turbine Towers



Vlastos, D., Riziotis, V.A., Papadakis, G., Manolas, D.I., Chaviaropoulos, P.K. (2024), "Numerical investigation of vortex induced vibrations on cylinders," Journal of Physics: Conference Series 2767 (2024) 022034.



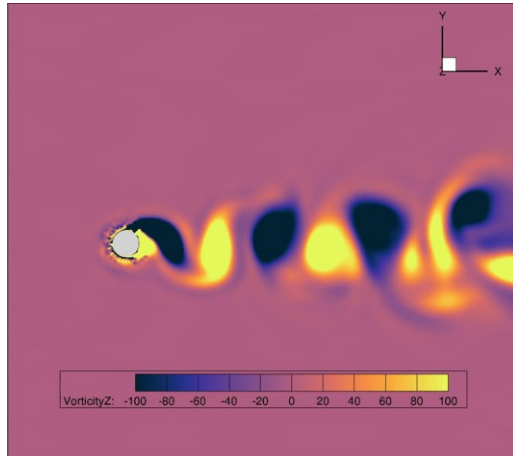
$$P = \int_0^T F_a(t) \dot{y}(t) dt$$

$$2\pi\zeta = \frac{P}{m\omega_n^2 A^2} \rightarrow K_a = -\zeta \frac{m}{\rho d^2}$$

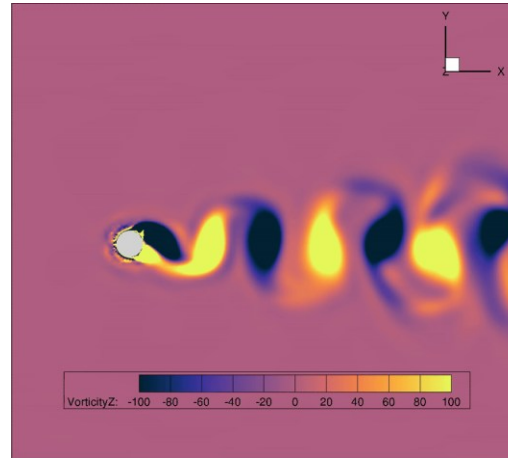


CFD aeroelastic analysis of Vortex Induced Vibrations on Wind Turbine towers

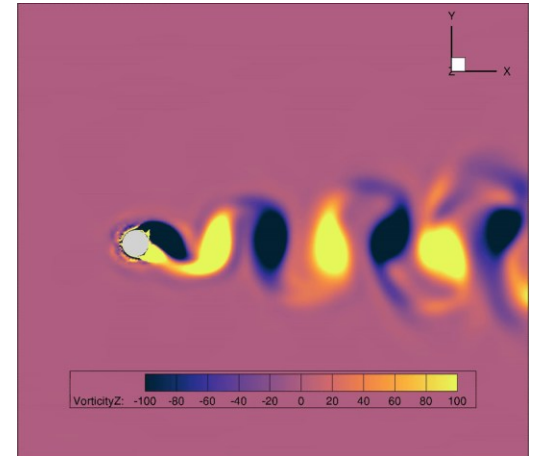
$h/H = 0.1$



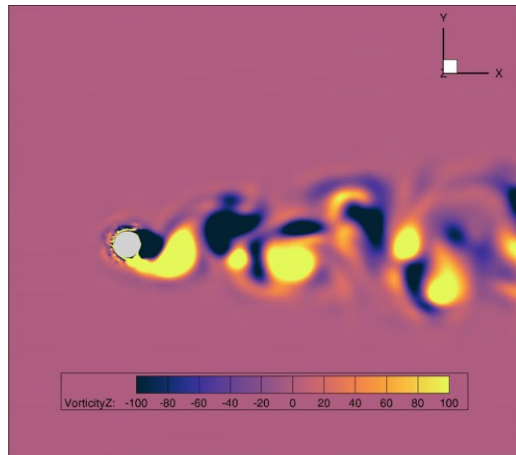
$h/H = 0.25$



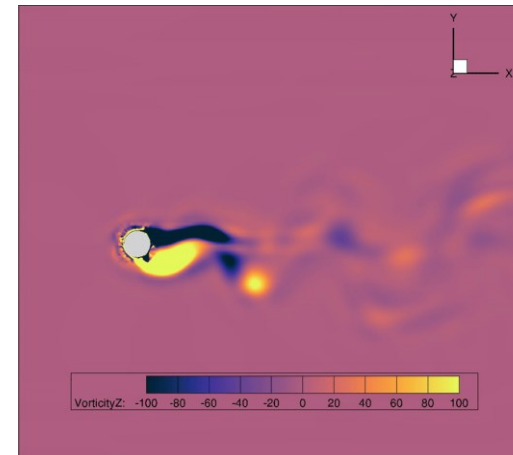
$h/H = 0.5$



$h/H = 0.75$

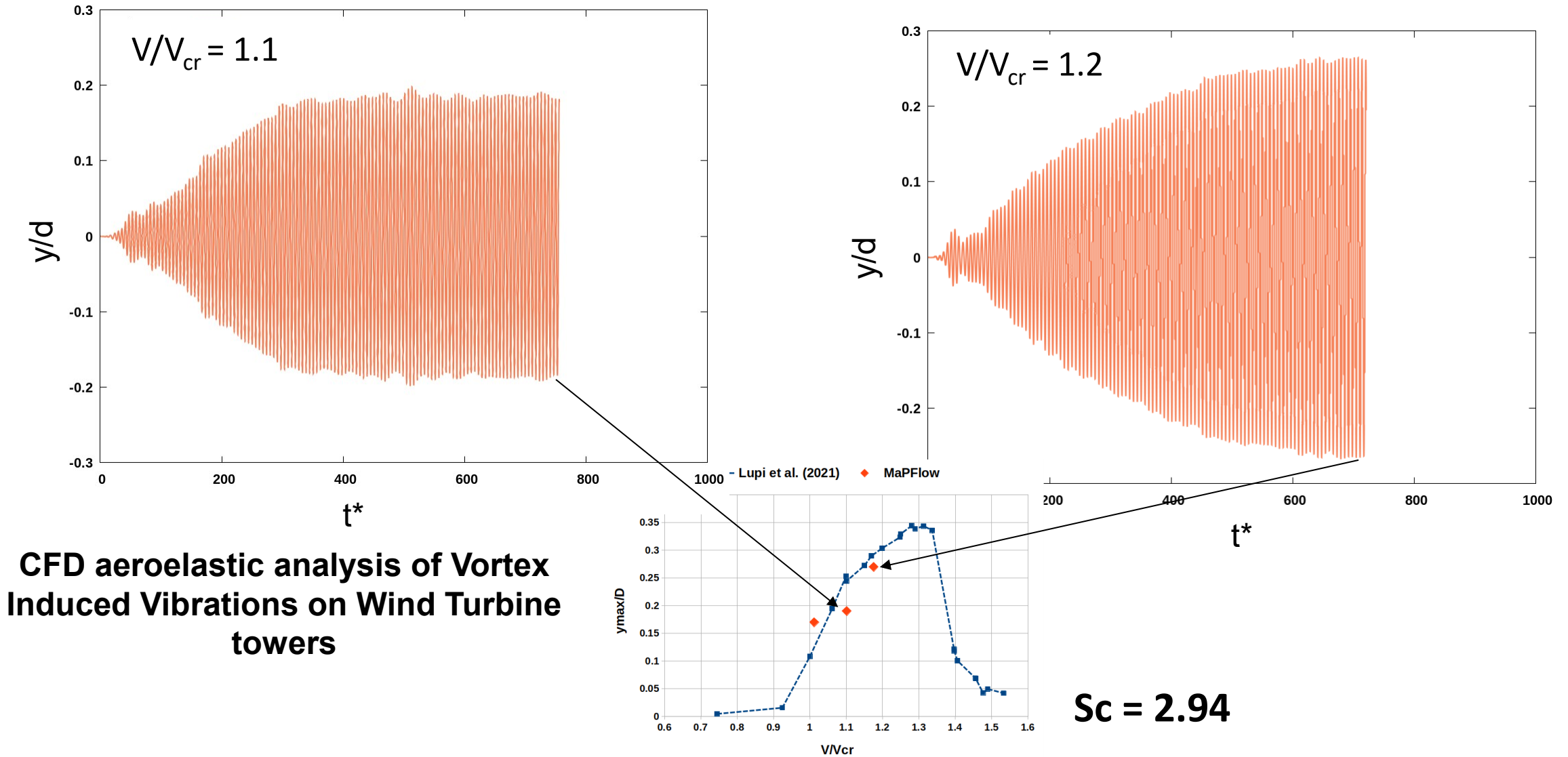


$h/H = 0.9$



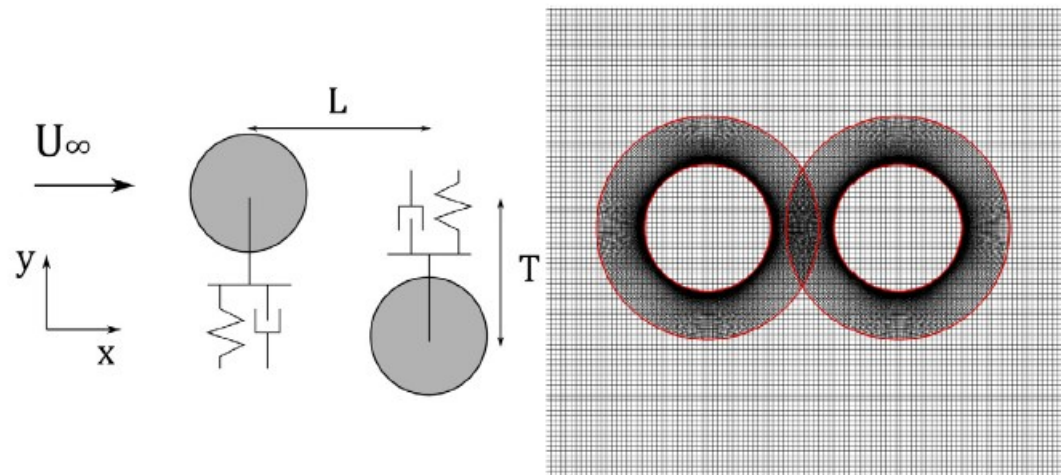
$$\frac{V}{V_{cr}} = 1.2$$

Work Supervised by
Profs V. Riziotis & G.
Papadakis

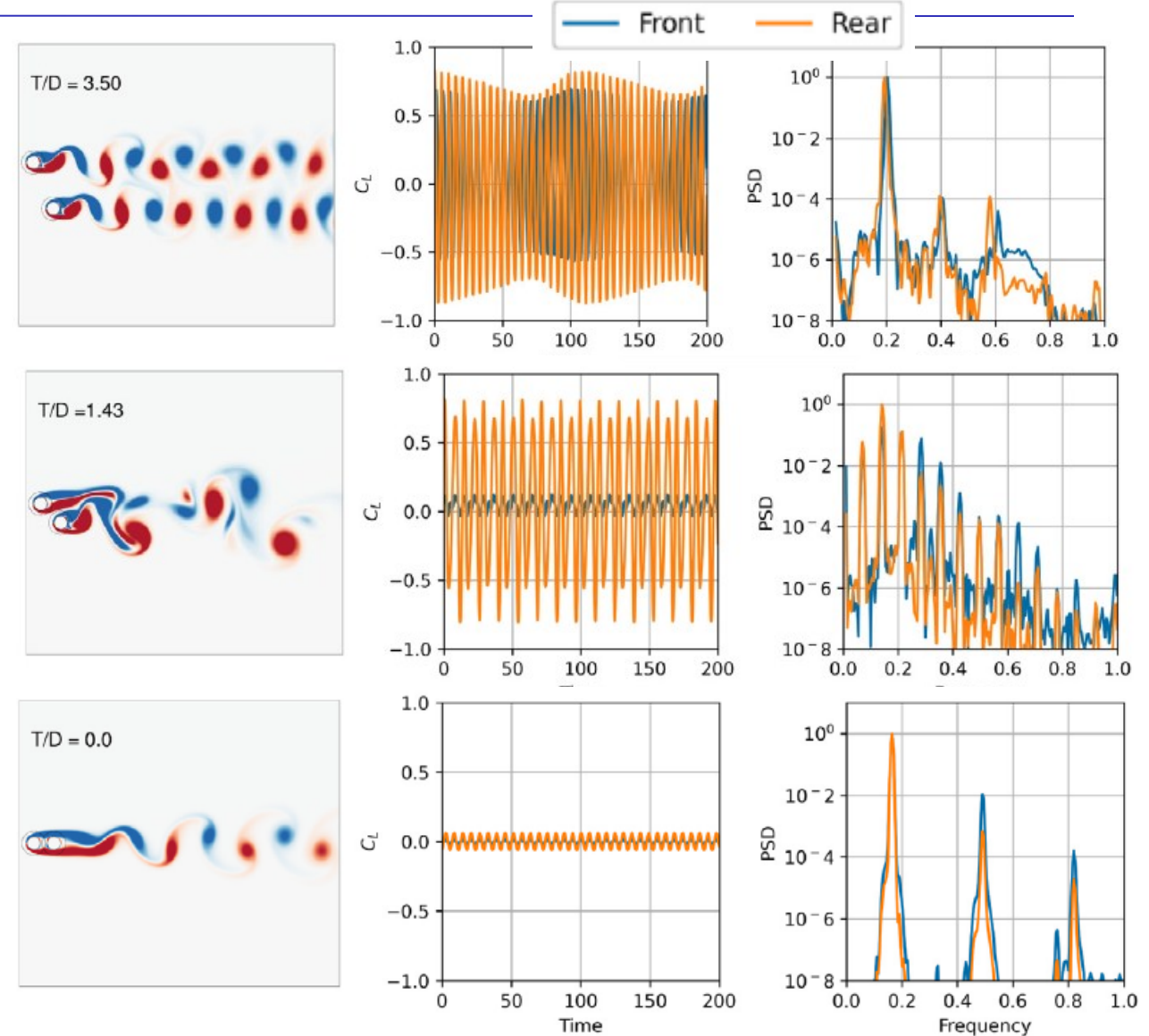


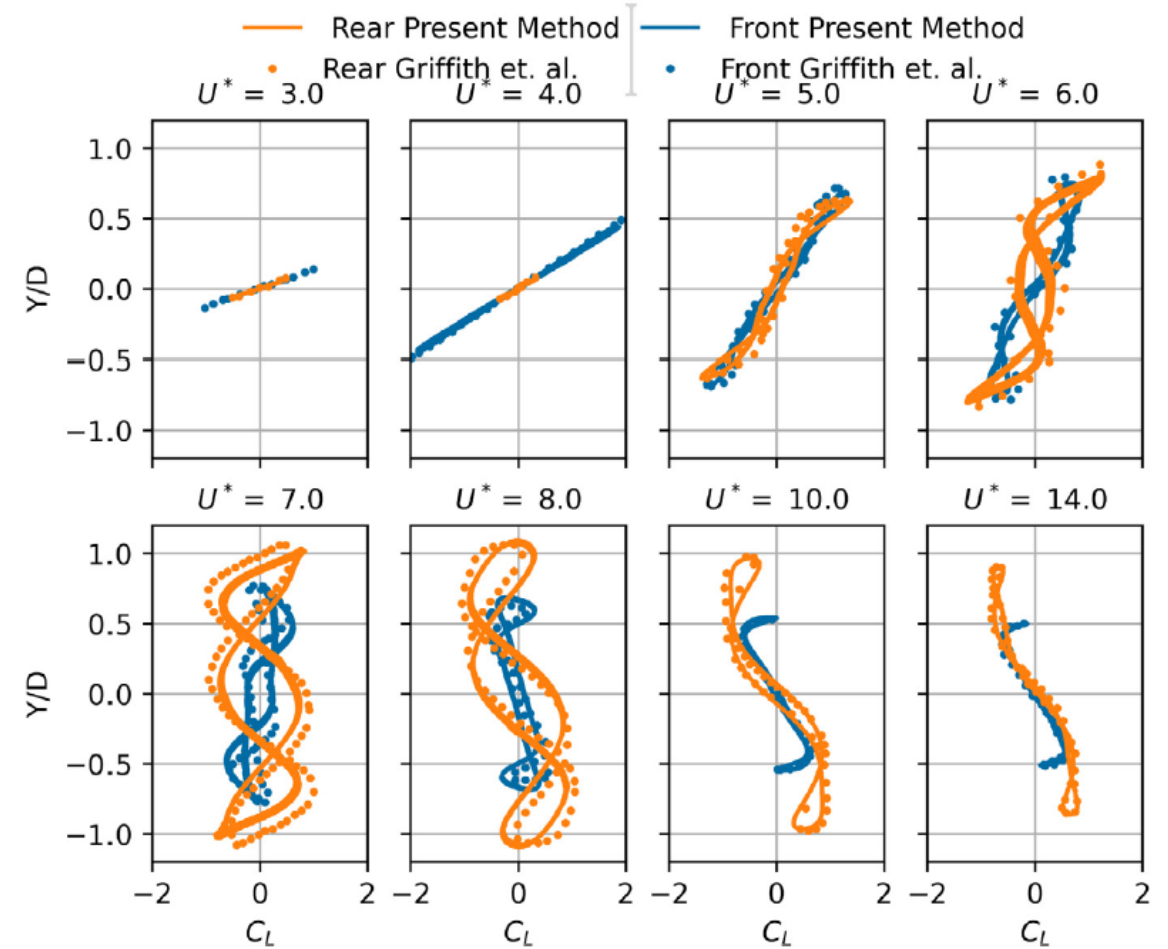
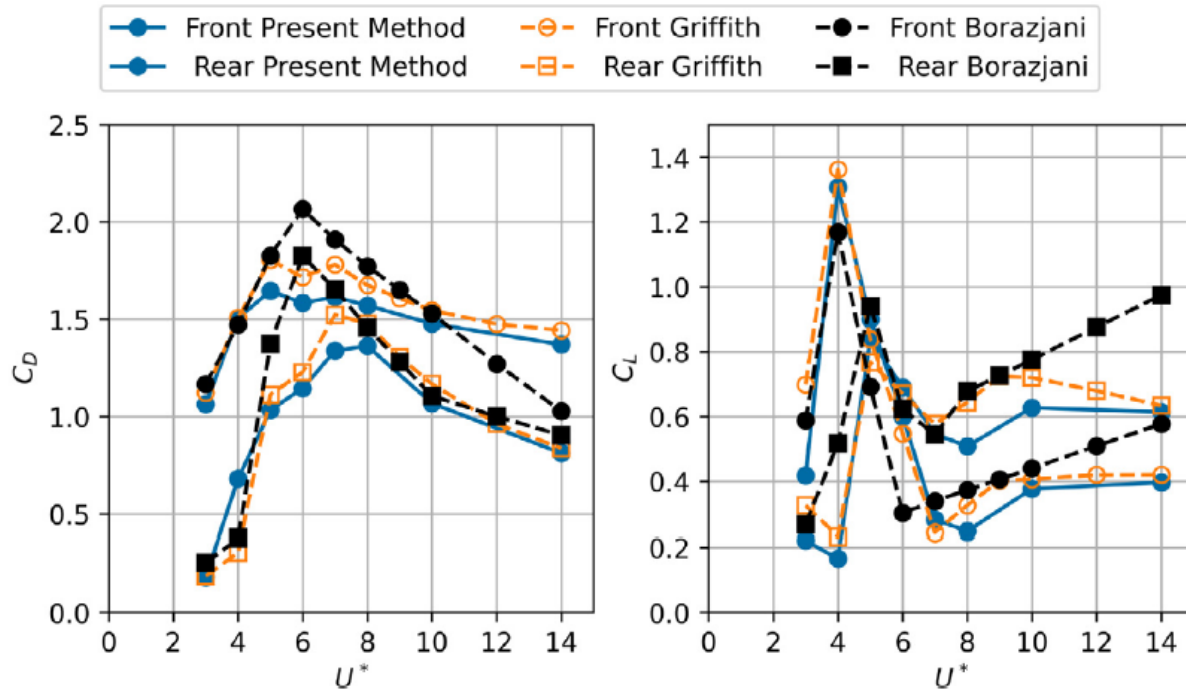


Tandem cylinder applications



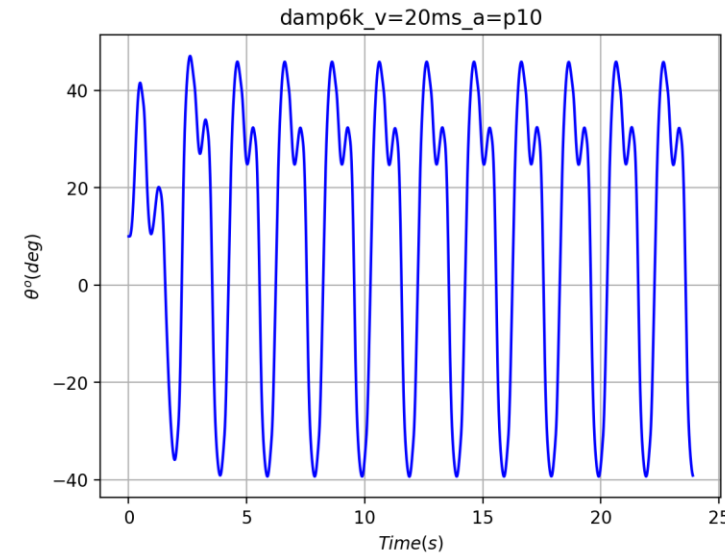
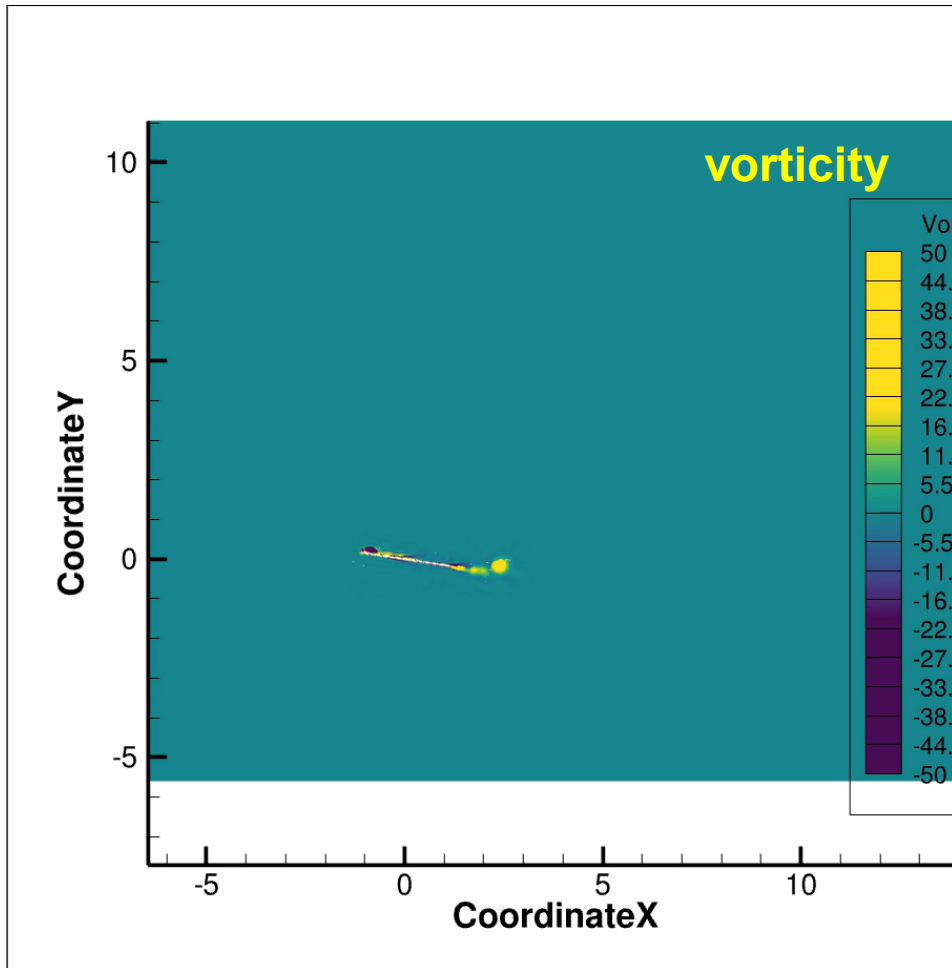
Papadakis, G., Riziotis, V.A., Voutsinas, S.G., "A hybrid Lagrangian-Eulerian flow solver applied to cylinders in tandem arrangement," *Journal of Fluids and Structures* 113 (2022) 103686.







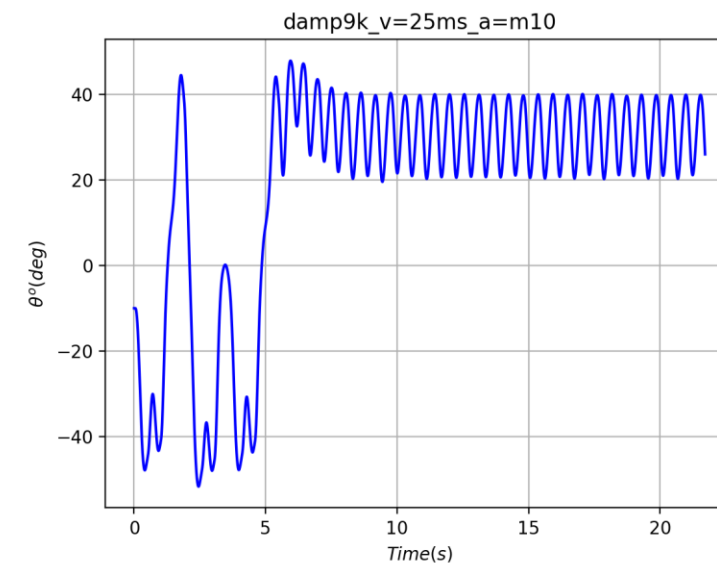
CFD analysis of PV vortex induced vibrations



$U = 20 \text{ m/s}$

$\theta_{\text{initial}} = +10 \text{ deg}$

low damping



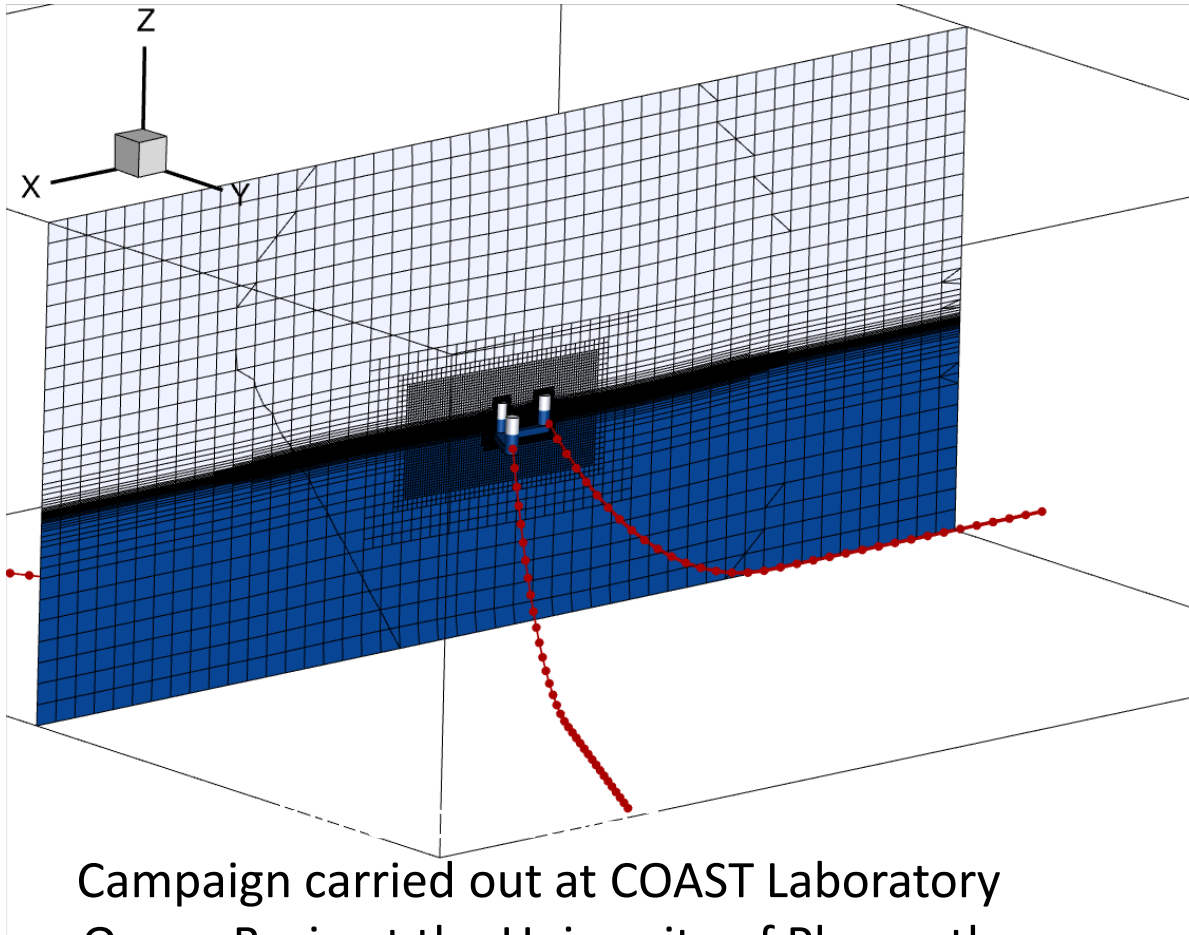
$U = 25 \text{ m/s}$

$\theta_{\text{initial}} = -10 \text{ deg}$

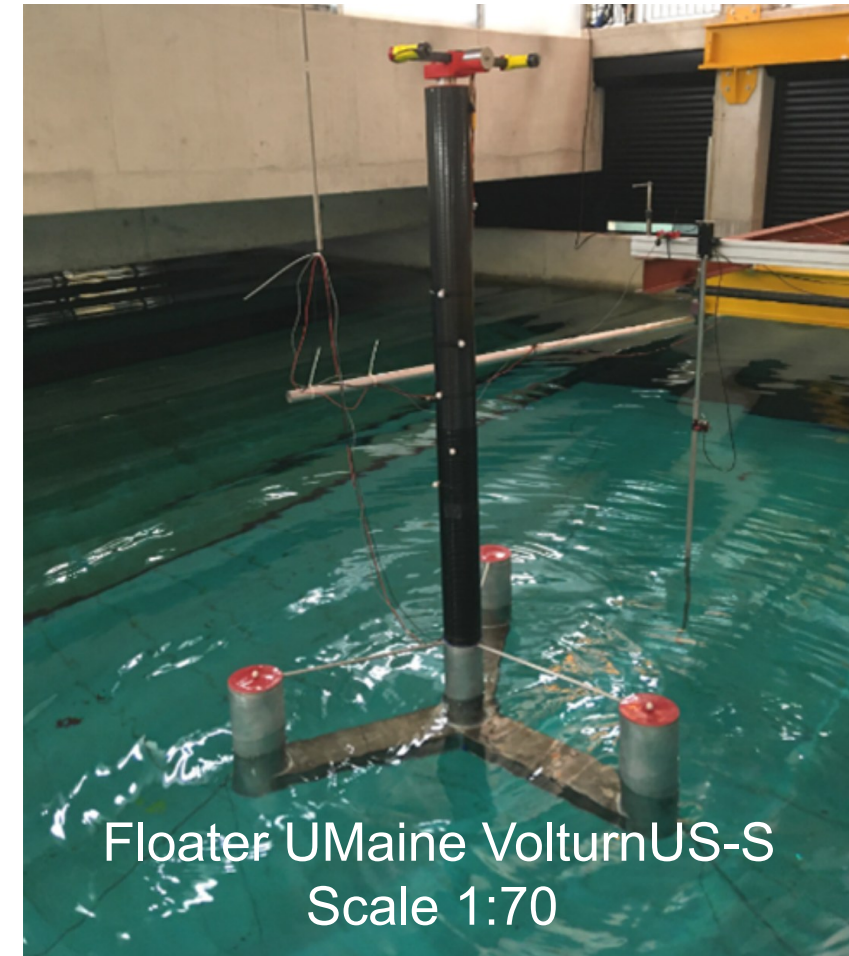
high damping



Modeling of the hydrodynamics of a WT floater



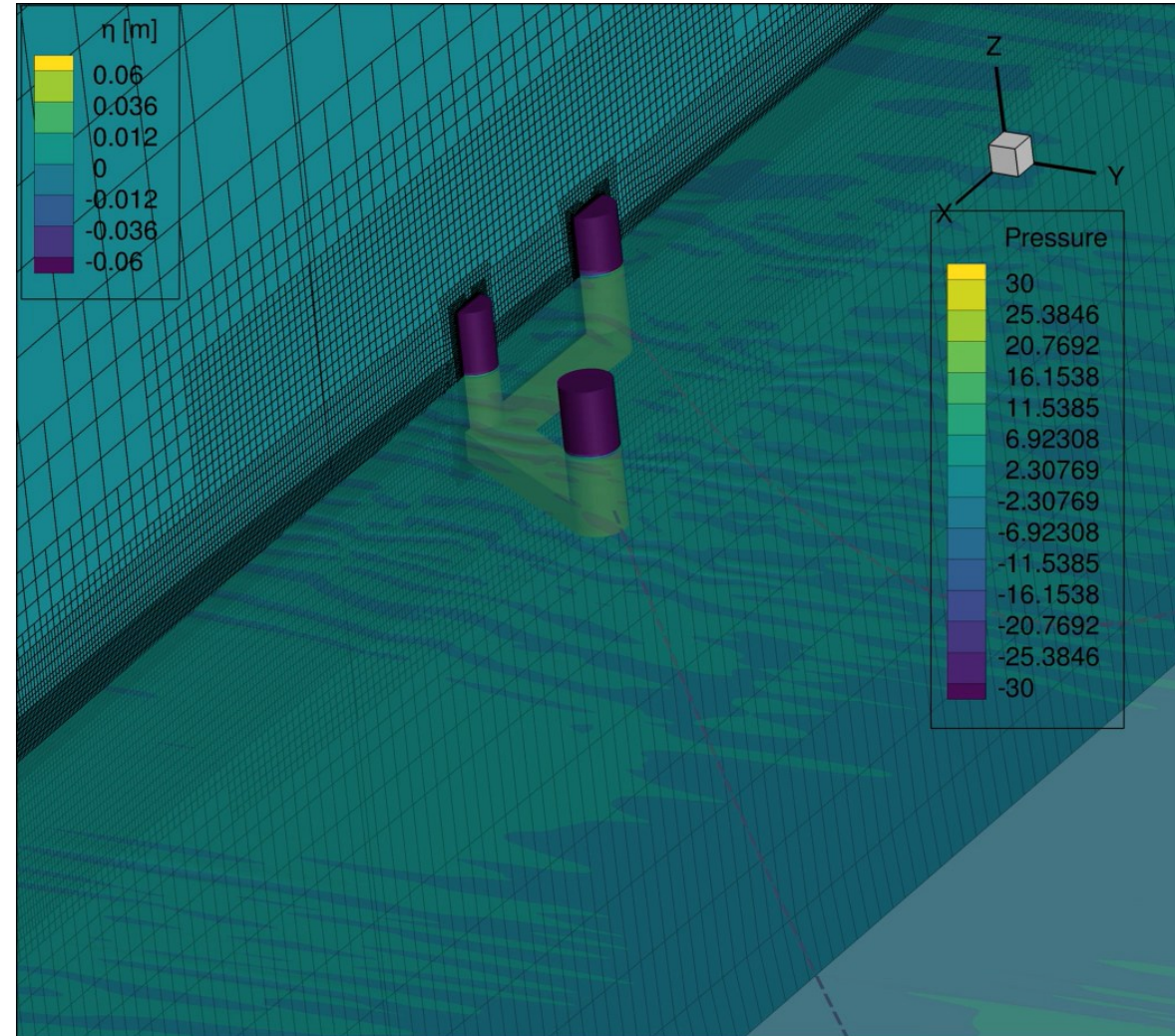
Campaign carried out at COAST Laboratory
Ocean Basin at the University of Plymouth





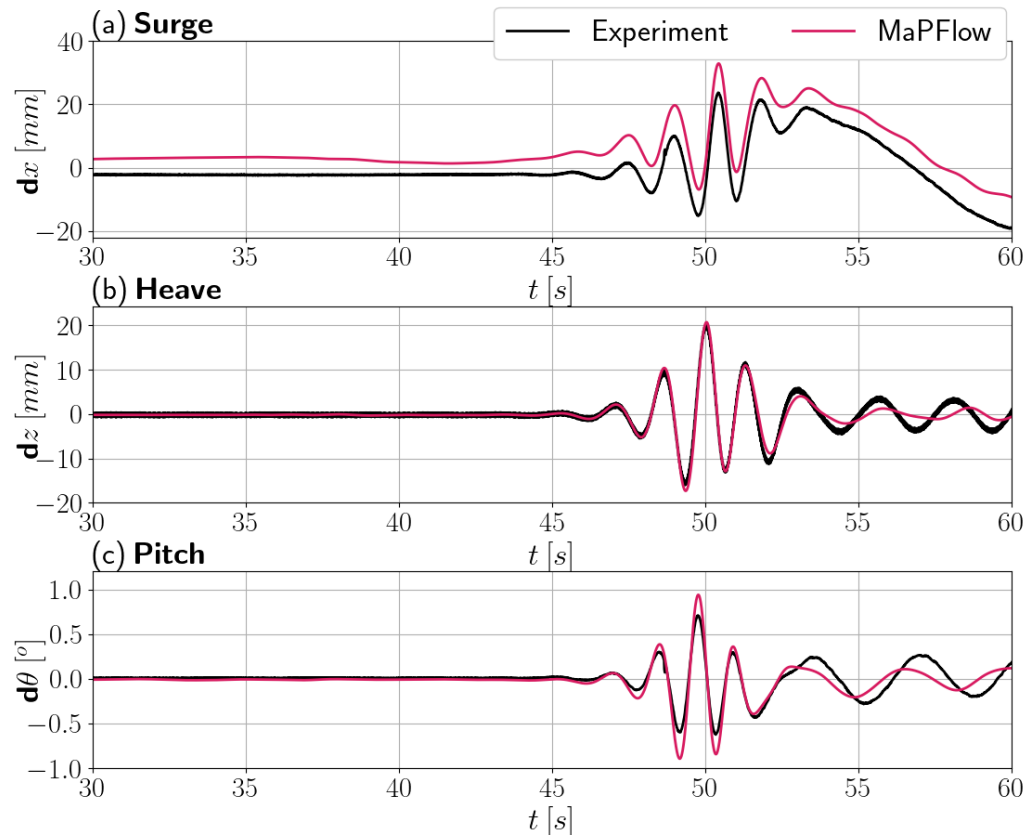
Floater motion excited by irregular incident wave

“Modelling the Hydrodynamic Response of a Floating Offshore Wind Turbine - a Comparative Study,”
Applied Ocean Research 155 (2025) 104441.

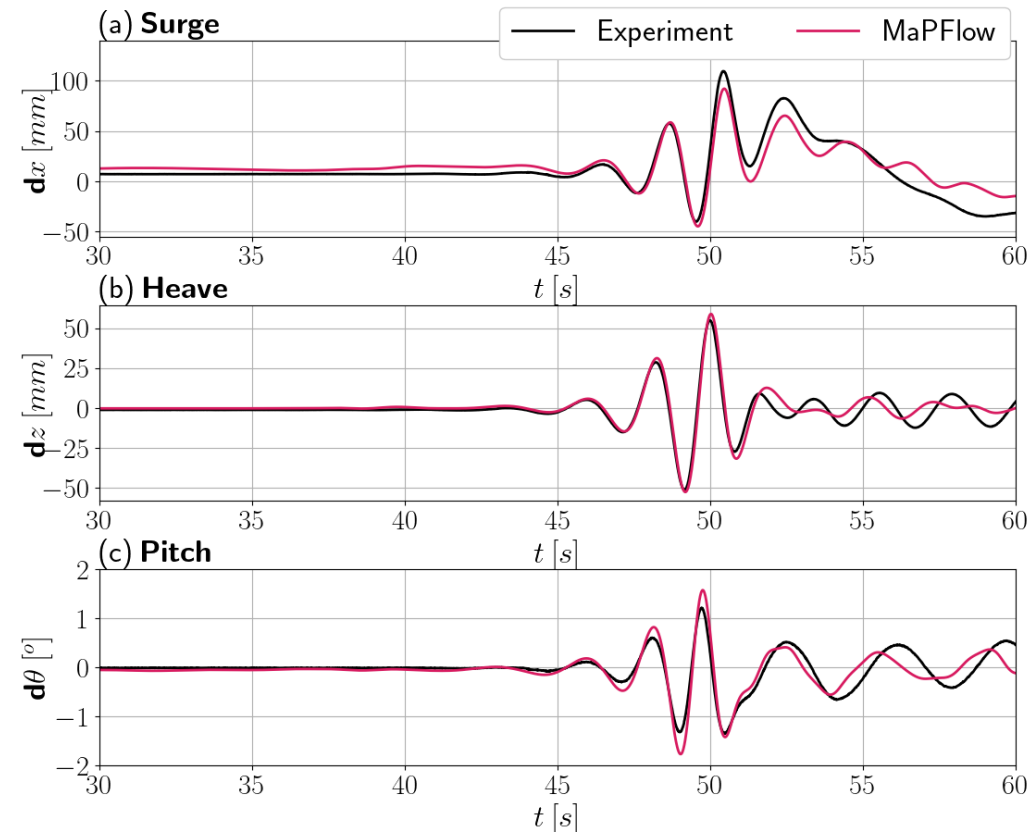


Modeling of the hydrodynamics of a WT floater

Benign wavetrain



Extreme wavetrain





- Several Low and Medium Fidelity options can be employed in wind energy and aeronautical applications, as they generally provide satisfactory performance under design and near design conditions.
- However, High-Fidelity (HiFi) aerodynamic models can offer deeper physical insight under conditions dominated by complex aerodynamic phenomena, such as deep stall and vortex shedding, which can significantly influence the aeroelastic response.
- Time-domain FSI analyses using HiFi aerodynamic options are extremely computationally demanding and, in practice, require substantial HPC resources.
- Surrogate models can help mitigate the computational burden, enabling the indirect integration of high-accuracy, physics-based models into the design loop of aeroelastic systems.