

Wall Resolved Fluid-Structure Interaction Numerical Simulation of a Modern Wind Turbine Blade

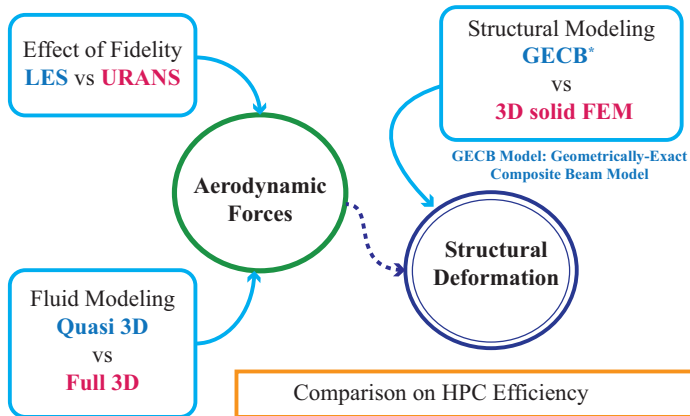
Mohsen Lahooti* **Rodolfo Puraca†** **Bruno Carmo†** **Rafael Palacios***
Spencer J. Sherwin*

*Department of Aeronautics, Imperial College London

[†] Department of Mechanical Engineering, Escola Politécnica, University of São Paulo

COBEM2021-0320

Objectives



Challenges

- **Separated flows**

Thick boundary layer

Leading/Trailing edges separation

Vortex shedding/interactions

- **Anisotropic turbulence**

High-fidelity methods (LES/DNS)

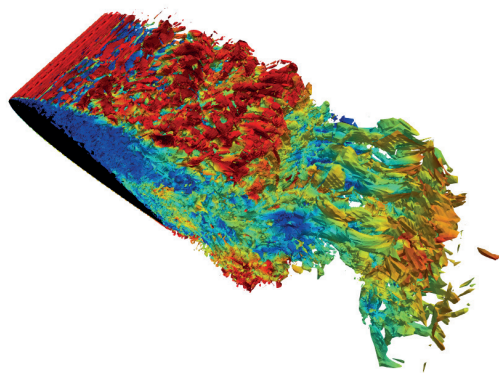
- **High Re flow**

Grid Resolution $h/L \propto Re^{-3/4}$

FLOPS scales as Re^3

Efficient numerical method

Highly scalable



LES simulation of NACA 0012 at

$Re = 1.56 \times 10^5$ $\alpha = 16^\circ$

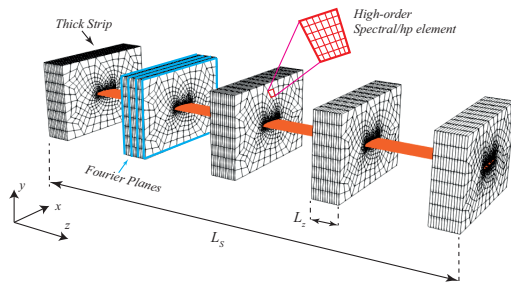
Q-criterion iso-contour colored by velocity

Numerical Method

Thick Strip LES method

3D domain models as separate smaller domains: *Thick Strips*

- Spanwise thickness L_z
- Capturing local 3D turbulence
- Reduces computational expense
- Implicitly connected by structural dynamics
- High order hp elements in xy
- Fourier expansion in spanwise (z) direction



Ref- AIAA SciTech21


Nektar++/SHARPy FSI Solver

Flow Solver

- Transformed Navier-Stokes equations
- Coordinate transformation to avoid remeshing

Inertial Coord. Body-fitted Coord.

$$\bar{\mathbf{X}}(\bar{x}, \bar{y}, \bar{z}) \rightarrow \mathbf{X}(x(t), y(t), z(t))$$

- High-order Spectral/hp element method
- P-order polynomial expansion in xy
- Fourier expansion in z
- High-order stiffly-stable velocity splitting velocity correction scheme
- Nektar++  www.nektar.info

Structural Solver

- Flexible multi-body solver
- Geometrically-Exact Composite Beam model
- Non-linear high deformation
- Static and Dynamic formulation
- Quadratic Finite Element method
- Newmark- β time integration
- **SHARPy**
www.imperial.ac.uk/aeroelastics/sharpy/

OpenFoam/CalculiX FSI Solver

Flow Solver – OpenFoam

- Finite volume method
- OpenFoam solver: pimpleFoam (operating in PISO mode)
- URANS (k- ω SST)
- Backward time scheme (Second Order)
- Simulation dt: 5×10^{-5} s
- **OpenFoam**
www.openfoam.com

Structural Solver - CalculiX

- FEM with solid elements
- CalculiX solver: Nonlinear Dynamic Direct solver using Spooles
- Solid Section structure
- Orthotropic Elastic Material
- Simulation dt: 5×10^{-5} s
- **CalculiX**
calculix.de

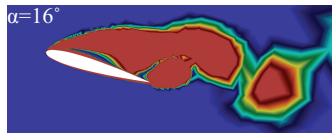
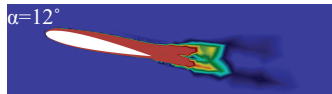
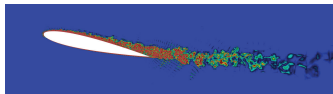
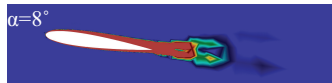
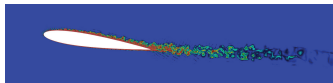
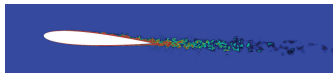
Coupling through preCICE (precice.org)

Flow over *NACA0012* section

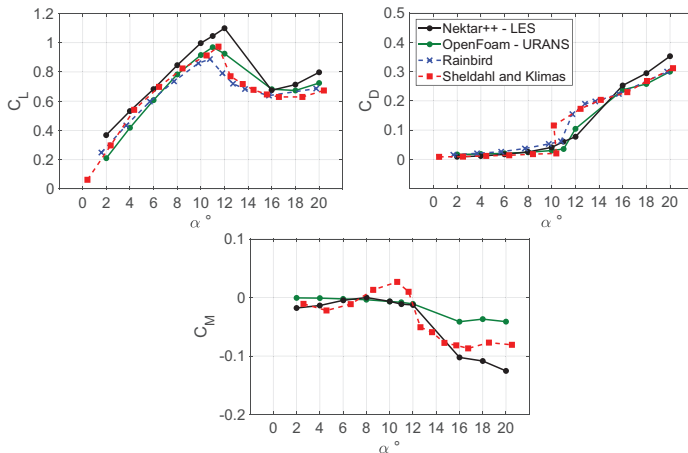
Vorticity contours $Re = 1.56 \times 10^5$

Large Eddy Simulation

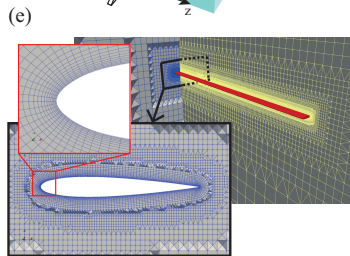
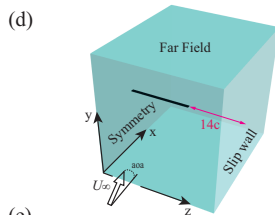
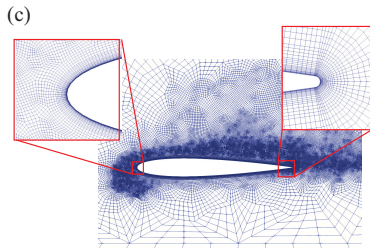
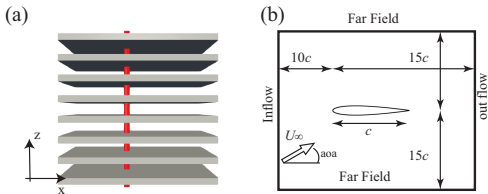
URANS



NACA0012 Aerodynamics coefficients

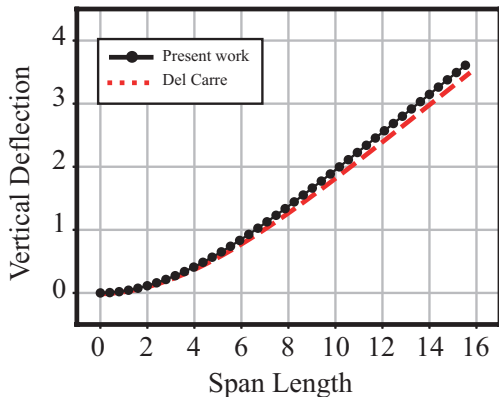


FSI of Cantilever blade



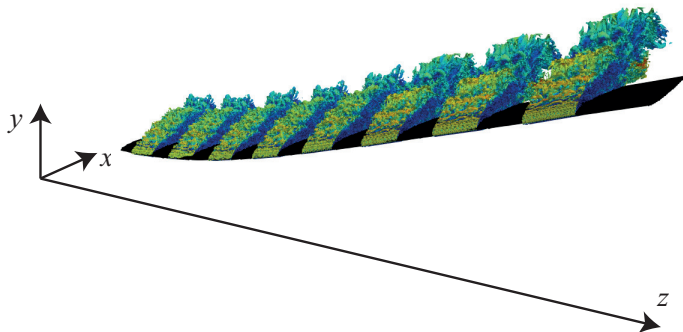
Cantilever Blade: Equilibrium before stall

- $Re = 1.56 \times 10^5$
- Angle of attack $\alpha_0 = 4^\circ$
- $g = 9.754 \text{ m/s}^2$
- Del Care: beam + UVLM
- Number of Strips $N_s = 4, 8, 12$ tested, $N_s = 8$ selected

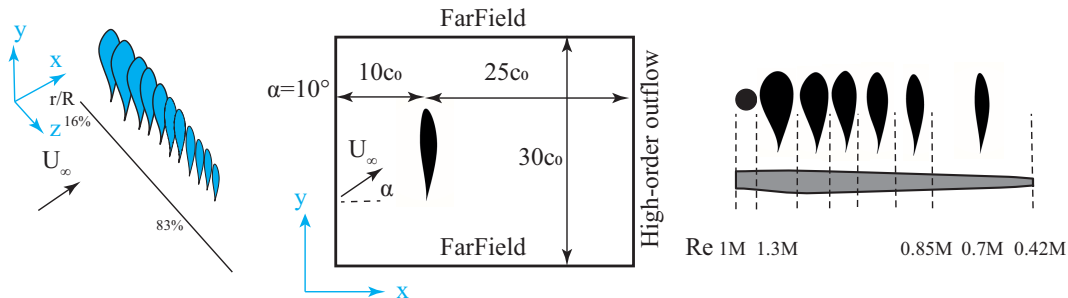


Cantilever Blade at stall

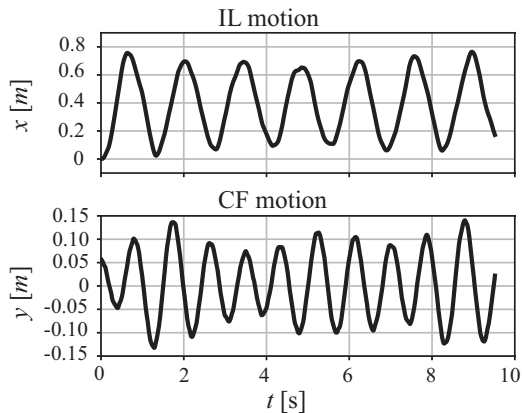
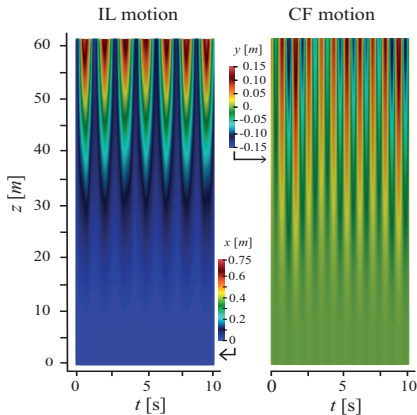
- $Re = 1.56 \times 10^5$
- $\alpha_0 = 16^\circ$
- $g = 9.754 \text{ m/s}^2$
- 8 Strips
- Iso-contour $Q = 10$
- Color $|\mathbf{V}^*| = [0 - 2]$



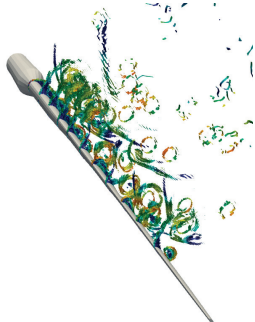
VIV of NREL5MW blade in parked condition



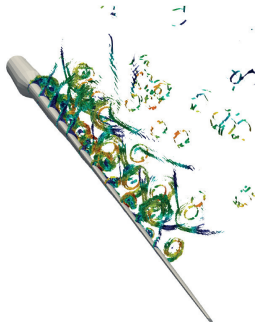
NREL5MW Blade VIV



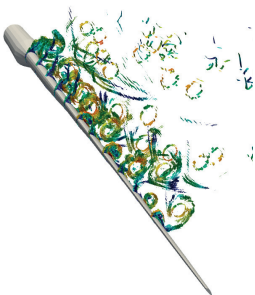
A



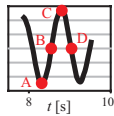
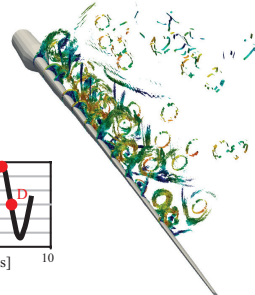
B



C



D



Wall-Resolved FSI Simulation of Modern Turbine Blades

Dr. Mohsen Lahooti*

MSc. Rodolfo Puraca†

Dr. Bruno Carmo†

Prof. Rafael Palacios*

Prof. Spencer J. Sherwin*

* Department of Aeronautics,
Imperial College London

† Department of Mechanical
Engineering, Escola Politécnica,
University of São Paulo



This project has received funding from European Union's Horizon 2020 research and innovation programme under grant agreement No 828799.



High Performance Computing in Wind Energy
(<https://www.hpcwe-project.eu/>)

Thanks from ICL to Dr. David Scott and EPCC for helping on the scaling test for Nektar++/SHARPy solver

Thanks to EPSRC for the computational time made available on the UK supercomputing facility ARCHER via the UK Turbulence Consortium (EP/R029326/1)

Thanks to Imperial College HPC for the computational time made available