Wind turbine wake analysis and investigation of rotor-wake interactions using high fidelity simulation.

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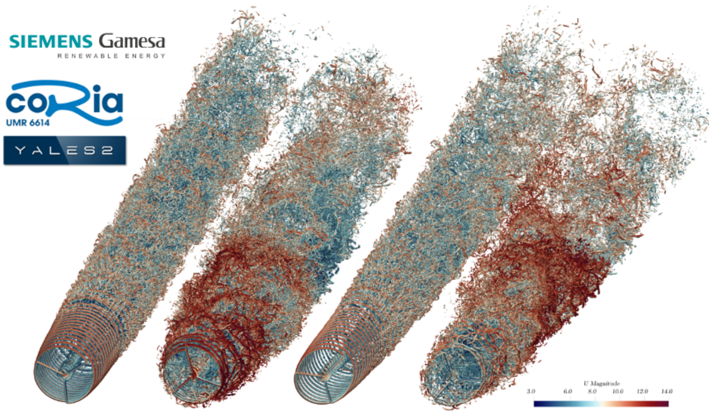
Over the past few decades, wind energy has grown in importance to become one of the leading sources of sustainable electricity. Offshore solutions are more and more implemented to extract power, as the wind resources are higher and more stable. In order to maintain a reasonable levelized cost of energy (LCOE), the main harvesting strategies rely on increasing the rated power and rotor size of a wind turbine. Such new designs require both addressing technical challenges of a rising complexity, and gaining a better understanding of the multi-physics phenomena involved during the power collection. Typical issues to consider are the wind-blade interactions as blades remain flexible and can deform considerably as a result of the unsteady aerodynamic loads they undergo. When a rotor is receiving a misaligned incident wind coming from upstream rotor wakes, the resulting fluid-structure interactions are even more critical. Low order and affordable engineering models are limited to correctly describe such flows in some wind scenarios and need the help of Computational Fluid Dynamics (CFD) to calibrate and validate these models. Especially, Large-Eddy Simulation (LES) appears as a valuable tool to predict unsteady wind and wakes [1]. Simulations of very refined wakes and multi-rotor configurations proposed in this work are still very expensive and require High-Performance Computing solutions.

Using this LES framework, coupled to the actuator line method to model the blades of a wind turbine, studies were conducted along three main axes within the PRACE project called WIMPY. First, the validity of the so-called 1D momentum theory was assessed by performing highly resolved simulations. Mean kinetic energy and momentum budgets were computed from streamtubes data in several configurations, including yaw misalignment. From these budgets, four wake regions showing similar flow dynamics were defined and correlated to local flow structures [2]. Second, an adaptive mesh refinement (AMR) technique was elaborated to automatically refine the mesh within wakes. A methodology based on the transport of a progress variable was developed to capture their envelope. Third, a new aero-servo-elastic solver was designed to investigate more deeply the wind-blade interactions, especially in the case of wake-induced interferences. For validation purposes, the solver was applied to study an isolated turbine and a 7-turbine row of the Westermost Rough wind farm, for which field data were available. The obtained results were very promising, especially for the isolated turbine given the necessary assumptions on the operating conditions for the 7-turbine row.

All the above activities were parts of the WIMPY PRACE project 20200255444. More than 20 millions of CPU hours were necessary to complete this study.



[1] Bénard et al., *Computers and Fluids*, 2018
[2] Houtin-Mongrolle et al., *Journal of Physics: Conference Series*, 2021