Given today's energy and environmental challenges, increasing the electrical power generated by wind farms is of paramount importance. To this end, the size of wind turbines has increased significantly over the years, with rotors reaching hundreds of meters in diameter. At this size, they are at the interface between the micro- and meso-scale. The expansion of the scale intro- duces novel phenomena to correctly understand and predict such flows. It is well established that wind turbines performances are significantly influenced by wind shear. Due to the range of the scales involved, accurate analyses of these flows and wind turbines are arduous. Although simulations of the neutral and convective boundary layer have been wildly performed, accu- rate simulation of the stable boundary layer (SBL) remains a challenging task. Their smaller vorticies characteristic size calls for high-fidelity simulations at high resolution. This doctoral thesis aims to study the impact of realistic atmospheric conditions on wind turbines. Special attention is paid to SBL modelling. Large-Eddy Simulations (LES) are performed with the finite-volume, fourth-order central scheme, massively parallel, flow solver, YALES2.

First, an atmospheric solver framework is developed. A constant density incompressible solver has been adapted to include thermal effects, modelled with the Boussinesq approximation for buoyancy-driven flows. In addition, the Coriolis effect is taken into account. At last, since a wall-resolved approach is computationally unfeasible, the Monin-Obukhov Similarity Theory atmospheric wall model has been implemented. Moreover, the developed framework is capable of handling structured and unstructured meshes, necessary to represent complex terrain configurations. Validation of the framework has been performed on neutral, convective and stable cases. In particular, the GABLS1 benchmark has been reproduced using both structured and unstructured grids, showing a good agreement with the literature results and enabling to progress to more complex configurations. Unstructured grids

Wind turbine power production and fatigue loads strongly depend on the incident wind turbulence or wake from upstream turbines. Thus, a critical physical phenomenon to study is the development of the turbulent vortical wake released downstream of a wind turbine. Then a fine enough mesh to capture the wind turbine wake is required. However, a compromise must be found between computational cost and wake accuracy. Adaptive Mesh Refinement strategy has been applied to this end. A methodology to track wind turbines wake has been developed by flagging wake regions based on a transported progress variable. The grid is then adapted with an optimal mesh size in the rotor wake region. This technique has been tested on a row of two wind turbines, giving convincing results.

The whole strategy has been applied on two main applications:

1. The first study has been dedicated to the atmospheric boundary layer impact on a single wind turbine. For that, different atmospheric stabilities have been reproduced, and their impact on a wind turbine has been quantified. This work is based on a SWiFT benchmark.
2. The second is the study of a complex terrain impact on wind turbines wake. More than a comprehensive study, this section is an opening, reviewing the mesh generation methodology.