LBM-BASED LARGE-EDDY SIMULATION OF WIND TURBINE ROTOR WAKE AERODYNAMICS

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Abstract. Lattice Boltzmann methods are a particularly suitable approach for simulating unsteady wake aerodynamics with high resolution. In this work, we focus on parallel large-eddy simulations of wind turbine wakes imposed by actuator disk and actuator line models. The verification of the turbulence model by a forced isotropic turbulence test case is also discussed. High fidelity is achieved by patch-based structured mesh adaptation provided by our AMROC framework.

1 INTRODUCTION

The rotor of an operating horizontal axis wind turbine creates a large-scale turbulent rotating wake structure. While it is undisputed that upstream wakes have a major influence on the power output of downwind turbines, the understanding of wind turbine wake creation and interaction is still quite poor. High fidelity large eddy simulation (LES) is a promising avenue to improve on this. While the majority of available computational fluid dynamics methods for wind engineering approximate the incompressible or weakly compressible Navier-Stokes equations, we use utilize here the lattice Boltzmann method (LBM) that is explicit in time and easily parallelizable. Being a type of Cartesian immersed boundary method, the LBM is also well suited for modeling fluid-structure interaction. While in previous work [1, 2], we had focused on modeling wind turbines as resolved moving embedded surface mesh structures, we concentrate here on approaches representing rotors as momentum forcing terms.

2 METHODS

The simplified Boltzmann equation with additional force term reads \( \partial_t f + \mathbf{u} \cdot \nabla f = \omega (f^{eq} - f) + F \). Introducing the partial density distribution functions \( f_\alpha(x,t) \), we turn the latter into the discrete lattice Boltzmann equation

\[
f_\alpha(x + e_\alpha \Delta t, t + \Delta t) = f_\alpha(x, t) + \omega_\alpha \Delta t \left( f^{eq}_\alpha(x, t) - f_\alpha(x, t) \right) + \Delta t F_\alpha,
\]

which assumes that a breakdown of \( F \) into a suitable set of \( F_\alpha \) is considered as part of the particle collision process. Note, however, that also different approaches have been proposed for including force terms into the LBM.
3 RESULTS

We have supplemented the LBM with a Smagorinsky-type LES turbulence model, that locally modifies the discrete collision frequency $\omega_L$, in order to enable aerodynamic computations with realistic Reynolds number. For verification, isotropic turbulence with continuous momentum forcing on a uniform periodic lattice has been simulated directly as well as on coarser scales using the LES model. Figure 1a shows energy spectra in equilibrium and it is evident that the results follow the expected theoretical line with $-5/3$ power law in the inertial subrange (middle of plots).

Figure 1b shows an LES computation using actuator line forcing to model the rotation of a three-bladed wind turbine with the adaptive LBM. The configuration corresponds to a Vestas V27 with 27 m rotor diameter and 33 RPM at constant inflow velocity 8 m/s. Verification comparisons with previous structure resolving AMROC-LBM computations [2] will be discussed.

REFERENCES

