A Dynamically Adaptive Lattice Boltzmann Method for Predicting Wake Phenomena in Fully Coupled Wind Engineering Problems

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ABSTRACT

Many aerodynamical wind engineering problems are characterized by a strongly coupled interaction between moving structures and fluid flow. An example of particular technical relevance are wind turbines. Here, the incoming flow drives the motion and elastic deformation of the rotor, which in itself generates large-scale wake structures that can affect downstream turbines considerably. The development of effective, fully coupled computational methods for predictive wind farm simulation is challenging. As an alternative approach to the presently still employed vortex and actuator-based methods, we are currently developing a parallel adaptive lattice Boltzmann method (LBM) for large eddy simulation of turbulent weakly compressible flows with embedded moving structures that shows good potential.

Our LBM is implemented on Cartesian finite volume grids and considers geometrically complex boundaries with a level-set-based ghost-fluid-type approach, making the method well suited for moving structures. Dynamic mesh adaptation is applied in addition in order to increase the local resolution based on the level set function and features detected in the flow field [1]. A specialized algorithm is adopted to compute level set distance functions from triangulated surface meshes of complex geometries; specialized inter-/extrapolation routines are used to evaluate hydrodynamic forces on the embedded structural mesh [2]. Given the time-explicit nature of the LBM, a weak coupling approach is used to exchange embedded surface data with a recently developed six degree-of-freedom rigid body solver as well as previously developed finite element models with elastic-plastic material behavior [3].

Beside the sketched fluid-structure coupling methodology, the paper will discuss typical validation examples, e.g., the rigid-body motion of a two-segment hinged wing with torsion damper and dynamic wind loading on elastically deforming thin panels. Subsequently, first verification computations involving realistic wind turbine geometry under prescribed rotation rate will be considered. The results show that the overall approach can easily handle large structural motion and high coupling frequencies, while the low dissipation properties of the lattice Boltzmann scheme in combination with dynamic mesh adaptation are able to resolve even complex vortex structures at moderate computational costs

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