Improving Simulation of Flows with Complex Geometries

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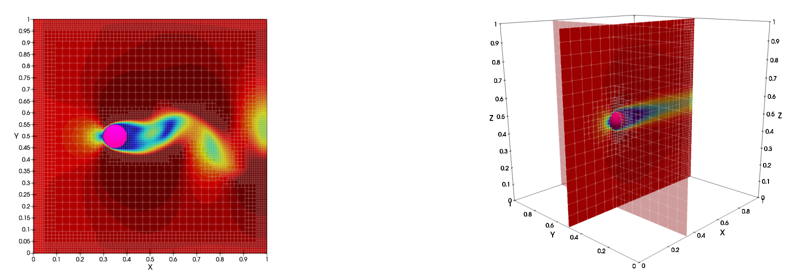
The numerical simulation of airfoils generates data for studying and modeling the physics of flow separation. If equipped devices such as the synthetic jet actuator, the data further enables the development of strategies for active flow control. The underlying computational fluid dynamics (CFD) is complicated by the curvature of the airfoil surface, which generally necessitates the use of unstructured or body-fitted grids. Another factor is the presence of turbulence, which requires a suitable Large Eddy Simulation (LES) eddy-viscosity model to enable the collection of transient data without drastically increasing the required computational cost. We present a framework for parallel numerical simulation of turbulent weakly compressible flow over complex geometries with the Lattice Boltzmann Method (LBM) — a relatively new numerical method that has recently attracted the attention of researchers in the context of aerodynamics and aeroacoustics. Unlike conventional Navier-Stokes CFD methods, the LBM is based an integration along the characteristics of the Boltzmann equation after it has been discretized in particle-velocity space, which results in a method that is fully explicit in time, handles advection exactly, and allows for a straightforward parallelization. However, a major disadvantage of the 'standard' method is that the discretization approach imposes uniformity in the grid such that spatial step sizes in the cardinal Cartesian directions are equal. This also means that the boundaries of complex geometries are approximated with 'staircase' patterns. Uniformity of the grid can be remedied by introducing local grid refinement of the root Cartesian grid. The boundaries of the complex geometries can be accounted for with interpolation that identifies the exact location of a tessellation of the curved surface overlaid on the grid. We provide a brief overview of the challenges in implementing and parallelizing an improved LBM that handles turbulence and complex geometries and describe our particular implementation of this LBM on the GPU within the AGAL software package for GPU-native adaptive mesh refinement. We also present benchmark tests for this implementation such as the 2D and 3D flows past a circle and a sphere as a first step towards simulating 3D airfoils at low Reynolds numbers.



(a) Circle.

(b) Sphere.

Figure 1: Snapshots of the 2D and 3D benchmark tests.

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