A Lattice Boltzmann Method in Generalized Curvilinear Coordinates

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ABSTRACT

In the Lattice Boltzmann method (LBM), the discretisation of the physical space is coupled with the discretisation of momentum space (He and Luo, 1997). The advantage of this scheme is the exact treatment of the advection term, and there leads to zero numerical diffusion. On the other hand, this condition results in a numerical method that is restricted to Cartesian grids. This aspect of the standard LBM limits its application, and solving problems with curved geometries and thin boundary layers becomes troublesome. It is possible to apply isotropic mesh adaptation to the standard LBM and thereby resolve large laminar boundary layers relatively easily. However, this approach can become remarkably expensive for capturing thin boundary layers, and therefore it is impractical for most technically relevant problems in aerodynamics. Nonetheless, it is possible to implement standard numerical techniques on the LBM to use non-uniform and body-fitted meshes. Therefore, we propose an implementation of the LBM in generalized curvilinear coordinates, so the lattice Boltzmann equation (LBE) can be solved with non-Cartesian grids.

A second-order explicit method was implemented to solve the LBE in the computational domain, and several test cases were used for verification, including a 2D lid-driven cavity and a 2D circular cylinder. The 2D lid-driven cavity is solved for high Reynolds numbers, where a clustering function is employed to stretch the mesh and increase the resolution in the cavity corners. The setup is a classical benchmark test, thanks to its simple geometry and complex flow physics. However, the wall-boundary treatment is relative straightforward since there are no curved walls. Therefore, the 2D circular cylinder is used to demonstrate the capacity of the present method to perform steady and unsteady simulations with curved walls. In addition, proper stretching functions have been implemented to increase resolution in proximity to the wall and in the wake region.

Our results have been compared with the literature available, and the outcomes of our new method are consistent with other computational results, confirming the feasibility of the proposed scheme. In addition, the present method has been compared to our own standard Cartesian LBM solver with adaptive mesh refinement (Deiterding and Wood, 2016) for the 2D circular cylinder problem. These preliminary results show that the method proposed is considerably more accurate for curved-wall problems.

References

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