The 9th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2024
3 – 7 June 2024, Lisbon, Portugal

A general formulation for the slip velocity boundary condition in lattice Boltzmann methods

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Key Words: *Lattice Boltzmann Methods, Two-Relaxation-Time Collision Operator, Wall Boundary Schemes, Slip Velocity Boundary Conditions, Rarefied Gas Flows*

Numerous fluid flow problems employ the slip velocity boundary condition, which due to their complexity are often only accessible through CFD. While the lattice Boltzmann method (LBM) [1] has been credited as a natural CFD strategy to model the wall slip phenomenon, it is now recognized that numerical artefacts affect the LBM solution [2] if the LBM slip boundary scheme is not properly calibrated. Unfortunately, this calibration uses an ad hoc procedure, and it does not work in general [2].

Currently, the development of consistent LBM slip boundary schemes tends to relate the slip velocity boundary condition with the closure relation of the LBM boundary scheme [2, 3, 4]. In this context, both linkwise or wet-node operation principles can be explored, though none is optimal. In linkwise philosophy [2, 3], boundary populations are constructed along lattice links, making it difficult to handle directional information, like simultaneous satisfaction of the slip (Robin-type) condition for the velocity tangential component and the no-penetration (Dirichlet-type) condition for the velocity normal component. In wet-node philosophy [4], the directional information is naturally handled, but the construction of the boundary populations is more evolving and harder to cope with.

This work proposes a scheme that combines these two philosophies. Here, any standard linkwise scheme, e.g. a multireflection scheme [5], can be used to prescribe the no-slip condition over normal and tangential directions, which is amended with a correction term to enforce the conditions for the velocity slip only along the wall tangential direction(s). This correction brings in the information from the first- and second-order velocity derivatives along the pertinent wall directions, which are found in a simple and local way through the LSOB wet-node operation principle [4]. Our theoretical analysis shows that, the proposed mixed linkwise/wet-node scheme, reaches parabolic accuracy for both no-penetration and slip velocity conditions. This high level of accuracy is also confirmed through a series of numerical simulations performed in well-established benchmark test cases of slip flow over planar and curved walls. The comparison of the numerical results here obtained against previously published ones [2, 3, 4] pinpoints the superiority of the present strategy in modelling the slip velocity boundary condition in LBM offering supremacy both in terms of accuracy and simplicity of implementation.

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