Intermediate Lattice Boltzmann-BGK method and its application to micro-flows

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The Lattice Boltzmann method is supposed to be an adequate approach for the modeling of non-equilibrium flows and kinetic effects beyond the Navier-Stokes level [1]. Nevertheless, when the flow is rarefied and the role of high-order moments of the velocity distribution in a rarefied media increases the precision of conventional LB models go down. In real world, the large values of the rarefaction parameter - the Knudsen number can be observed in the micro, nano-flows, in shale gas flow inside porous media, water transport inside nano-graphene membranes [2]. The present research is aimed to develop a new LB based velocity discretization method which is able to cope with the kinetic high-order moments in the rarefied flow.

I will consider a new conservative discretization method for BGK kinetic model based on the application of the Central Limit Theorem (CLT) to the conventional LB model. In the presented discrete velocity kinetic theory we consider 1D discrete velocity local equilibrium state in a such form that this equilibrium describes the probability distribution for a sum of **N** independent and identically distributed random variables. For **N=1** case we obtain the well-known 3-velocity D1Q3 model [3], in general case we have **2N+1** velocity model. The proposed method is somewhat intermediate between the difference schemes for the Boltzmann BGK equation and the canonical LB method.

This construction has several very attractive properties. Firstly, the method is conservative. Second, according CLT the increase of **N** for this method guarantees that all the moments of the local equilibrium state will converge to local Maxwell moments. This property is important since allows us to construct the conservative difference scheme for BGK equation adjusting the precision of the highest moment by the choice of **N.** Next, the velocity grids for the method are Cartesian by the construction. Finally, some analytical properties of the equilibrium state like the moment generating function can be obtained in a nice concise form since the equilibrium distribution corresponds to the probability density for a sum of random variables.

It is shown that 5-velocity (N=2) and 7-velocity (N=3) models applied to the classical Sod shock tube problem have good stability for moderate viscosities while the conventional 3-velocity D1Q3 model (N=1) is unstable for the considered conditions. Next, the gas microflow between the parallel walls under the pressure gradient (plane Poiseuille flow) is considered for various values of the rarefaction number (Knudsen number). It is shown that the models are able to reproduce the non-equilibrium kinetic effects like the Knudsen paradox, slip velocities with excellent precision in slip and transitional regimes. The accuracy is comparable and sometimes even better than for high-order LB models with additional regularization [4]-[6]

REFFERENCES

[1] S. Succi,, Lattice Boltzmann 2038, *Europhys. Lett.*, **109**, 50001 (2015)

[2] A. Montessori, G. Falcucci, Lattice Boltzmann Modeling of complex Flows for Engeneering Applications, Morgan & Claypool publishers, 2018

[3] S. Succi, The Lattice Boltzmann Equation: For Complex States of Flowing Matter, OUP Oxford, 2018

[4] R. Zhang , X. Shan, and H. Chen, Efficient kinetic method for fluid simulation beyond the Navier-Stokes equation. Phys. Rev. E 74 046703 (2006)

[5] X-D Niu, S-A Hyodo, T. Munekata and K. Suga, Kinetic lattice Boltzmann method for microscale gas flows: Issues on boundary condition, relaxation time, and regularization. Phys. Rev. E 76 036711 (2007)

[6] A. Montessori, P. Prestininzi, M. La Rocca and S. Succi , Lattice Boltzmann approach for complex nonequilibrium flows. Phys. Rev. E 92, 043308 (2015)