Application of Lattice Boltzmann Models based on Laguerre Quadratures in Complex flows

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Abstract. The Gauss-Laguerre Lattice Boltzmann (LLB) models are constructed to exactly recover integrals of the equilibrium distribution function over octants of the momentum space. In the mesoscopic formulation of the Boltzmann equation, such integrals are necessary for the implementation of diffuse reflection boundary conditions. Furthermore, the separation of the octants in the momentum space allows for the distribution function to relax to discontinuous solutions, e.g., the ballistic regime. The corner transport upwind scheme is used for the implementation of the convection term in the Boltzmann equation, thereby reducing numerical errors. The capabilities of our models are investigated through simulations of Couette and force-driven flows at various values of the Knudsen number Kn. Two implementations of the force term are considered for the investigation of force-driven flows: firstly, by approximating the distribution function with a truncation of its Chapman-Enskog expansion; secondly, by projecting the distribution function on the space of Laguerre polynomials, through a more computationally expensive procedure.
We report LLB simulation results where the Knudsen number varies from 0.1 to infinity. For Couette flow at Kn $<$ 0.5, the LLB simulation results are in excellent agreement to Direct Simulation Monte Carlo (DSMC) results and specific microfluidics effects are well captured. For higher values of Kn, the LLB results (and especially the temperature profile) no longer agree to DSMC results, especially on the temperature profile, due to the employment in our models of the Shakhov single relaxation time collision term. However, in the ballistic regime the LLB results are in excellent agreement to the analytic solution. When compared to Gauss-Hermite Lattice Boltzmann models (HLB), we conclude that the LLB models are more appropriate for conducting gas flow simulations at large values of Kn in the presence of solid walls.

Keywords: rarefied gas, Lattice Boltzmann modeling, diffuse reflection, ballistic regime, Couette flow, Poiseuille flow.