Central Moment based Lattice Boltzmann Methods for Complex Flows: Models with Improved Accuracy and Efficient Solution Strategies

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Abstract:
Lattice Boltzmann (LB) Method is one of the more recent promising developments in computational fluid dynamics for based on a local kinetic approach flow simulations. Its success stems from its inherent parallelism, ease of implementation of the boundary conditions and natural framework to incorporate kinetic models for complex flows. As such, during the last two decades, the method has seen remarkable success in a variety of complex fluid flow applications. There is still considerable scope for further improvements to the method, in terms of both accuracy and efficiency, some of which are addressed in our research. First, existing LB models are not Galilean invariant due to the degeneracy of the resulting third-order longitudinal moments, which leads to cubic velocity truncation errors. We have derived new collision models based on central moments involving extended equilibria to overcome this limitation for the solution of the generalized Navier-Stokes equations. Second, like other classical explicit time-marching methods, the LBM can suffer from slow convergence rate to steady state, especially at low Mach numbers. This is due to the relatively large disparity between the acoustic wave and fluid convection speeds, i.e. high eigenvalue stiffness. In this regard, we developed preconditioned central moment LB method to provide convergence acceleration. Third, for the first time, we combined our preconditioned LB scheme with the nonlinear multigrid method to provide further improvements in efficiency by one or more orders of magnitude. Fourth, three-dimensional flows with axial symmetry can be solved more efficiently on a quasi, two-dimensional Cartesian coordinate system with appropriate source terms. We developed a new radius-weighted LB model for axisymmetric flows using a non-orthogonal moment basis. Finally, we constructed new pressure-based LB model in 3D including a capability to accommodate variable body forces to improve accuracy for incompressible flow simulations. In this talk, we will first present the basic features of the LBM and then discuss the above new developments with various numerical examples.

Biography:
Farzaneh Hajabdollahi is a Ph.D. student in the Department of Mechanical Engineering at the University of Colorado Denver. She received her B.S. and M.S. degrees in Mechanical Engineering from the University of Kerman and Ferdowsi University of Mashhad, respectively, in Iran. She is conducting her research on developing advanced lattice Boltzmann models and efficient numerical methods for various complex fluid flows.