What Makes Gas Micro Flows So Complicated: Non-classical Physical Laws and their Morphing into Gas-Surface Interaction

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Abstract

A seamless transition between macroscopic and microscopic theory has been a fundamental research subject in gas micro flows. Owing to formidable challenges in theoretical and computational aspects associated with the multi-scale nature of the problem, however, proper model is yet to be developed: the conventional Navier-Stokes-Fourier equations are inappropriate for highly non-equilibrium flows and the *partial differential type* higher-order equations such as the Burnett equations suffer inherent difficulty in handling the boundary condition at the solid wall. There is even no consensus what the proper master kinetic equations would be for describing diatomic gases like nitrogen in thermal non-equilibrium.

Here non-classical physics (governing equations and gas-surface interaction model) behind non-equilibrium micro gases is touched upon from the framework of nonlinear coupled *algebraic* constitutive relations and *nonlinear* boundary conditions. In particular, the effects of non-Navier-Stokes and non-Fourier laws and their morphing into gas-surface interaction are elucidated by solving various benchmark micro-flows: planar Couette (equivalently Knudsen layer), force-driven Poiseuille, and pressure-driven Poiseuille in microchannels. Of particular interests are non-classical physics of abnormal behaviors such as non-zero tangential heat flux and normal stress, pronounced thermal effect, rotational non-equilibrium effect, nonlinear velocity profile and velocity gradient singularity (Couette), Knudsen minimum (Poiseuille), non-uniform pressure and the central temperature minimum (Poiseuille), and cross-stream energy preservation (Poiseuille). In addition, a hybrid slip (jump) model combining well-known Maxwell/Smoluchowski model and recent Langmuir model based on the concept of adsorption isotherm is presented. Finally, the verification and validation issue of the multi-scale methods is discussed. As the first step, issues of micro- and macro- sampling of DSMC and its internal error in conservation laws are considered.