To overcome memory barrier of kinetic solvers for non-equilibrium flow study

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For the non-equilibrium flow study, there are very few analytical solutions. Most studies are based on the simulation techniques. At the current stage, there are mainly two type of numerical methods for the study of non-equilibrium gas dynamics. The dominant numerical method for rarefied gas flow, especially for the high speed one, is the Direct Simulation Monte Carlo (DSMC) method [1]. The essential DSMC technique is the direct modeling in its algorithm development, which mimics the physical process in the construction of the Boltzmann equation. More specifically, the DSMC simulates the gas dynamics in small scales, such as time step Δt and cell size Δx being less than the particle collision time τ and mean free path ℓ. Only under such a condition, the decoupling of the particle transport and collision in DSMC will not introduce much numerical error and the physical solution can be faithfully obtained in the rarefied flow regime. Even though the DSMC is a single scale method for capturing flow physics in the kinetic level (τ, ℓ), for rarefied high speed flow, the DSMC is very efficient and is the only reliable method which has been routinely used in aerospace industry.

Another method for rarefied flow is the direct Boltzmann solver [2], which basically follows the numerical partial differential equation methodology, to solve the Boltzmann equation numerically. Instead of following individual pseudo-particles, here the velocity distribution function is the only dependent variable which is a function of space, time, and particle velocity. As a result, the Boltzmann solver needs to follow the evolution of a gas distribution function in a computational space with seven dimensions. If 100 grid points are used in each direction, for a three dimensional unsteady flow calculation

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