Boltzmann Solver with Adaptive Mesh in Phase Space

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In this lecture, we will start with an overview of the Unified Flow Solver (UFS) and octree Cartesian mesh technologies for simulations of rarefied, transitional and continuum flows for aerospace applications. We will describe details of the Boltzmann solver implementation in UFS and show examples of steady and transient flow simulations in mixed rarefied-continuum regimes. Then, we will introduce a new Adaptive Mesh in Phase Space (AMPS) methodology for solving multi-dimensional kinetic equations by the discrete velocity method [1]. In our AMPS implementation, adaptive Cartesian mesh is generated for both configuration (r) and velocity (v) spaces using a "Tree-of-Trees" data structure. The mesh in r-space handles easily geometric complexity and is dynamically adapted to local flow properties. The mesh in v-space is created on-the-fly for each cell in r-space. Mappings between neighboring v-space trees implemented for the advection operator in configuration space. We will describe new algorithms for solving the full Boltzmann and linear Boltzmann equations with AMPS. Several recent innovations are used to calculate the full Boltzmann collision integral with dynamically adaptive mesh in velocity space: importance sampling, multi-point projection method, and the variance reduction method. We have also developed an efficient algorithm for calculating the linear Boltzmann collision integral for elastic and inelastic collisions of light particles in a Lorentz gas. New AMPS technique will be demonstrated for simulations of hypersonic rarefied gas flows and electron kinetics in weakly ionized plasma. We will discuss how AMPS helps minimizing the number of cells in phase space to reduce computational cost and memory usage for solving challenging kinetic problems.

References

[1] http://arxiv.org/abs/1304.3330