PARALLEL DIRECT SIMULATION MONTE CARLO METHOD USING GRAPHICS PROCESSING UNITS

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The Direct Simulation Monte Carlo (DSMC) method [1] is a computational tool for simulating flows in which effects at the molecular scale become significant. The Boltzmann equation, which is appropriate for modeling these rarefied flows, is extremely difficult to solve numerically due to its high dimensionality and the complexity of the collision integral term. DSMC provides a particle-based alternative for obtaining realistic numerical solutions of the Boltzmann equation. In DSMC, the movement and collision behavior of a large number of simulation particles within the flow field are decoupled over a time step which is a small fraction of the local mean collision time. The method has been shown to provide a solution to the Boltzmann equation statistically when the number of simulated particles is large enough [2]. However, high computational cost has hindered further applications of DSMC to some practical problems, especially in the near-continuum (collision-dominated) regime, while the non-equilibrium effect may be important. Hence, it is important to increase the computational efficiency to extend the applicability of the DSMC method.

In this study, we have proposed a two-dimensional DSMC method using MPI-CUDA paradigm on Graphics Processing Units (GPUs) cluster and using a cut-cell Cartesian grid for treating objects with complex geometry. Parallel performance study is presented by a two-dimensional subsonic lid driven cavity problem. The simulation domain is a square cavity (1m×1m) with diffusely reflecting walls of fixed temperature (300K) and the upper wall which is moving at Mach Number M=0.2. The argon gas is initially at rest with a temperature of 300 K. Various Knudsen numbers are investigated through the manipulation of gas density, computed using a characteristic length equal to the wall length. There are nine cases ranging from Kn=0.01 to Kn=0.002 with various number of particles (10M-30M). In Fig. 1a, the result shows that up to 185 times of speedup can be reached using 16 GPUs for the most dense case with 30M particles as compared to single core of a CPU. When compared to the performance using a single M2070 GPU, the ratio of speedup of 12 times (see Fig. 1b) demonstrates approximately 75% parallelization efficiency. Fig. 2a shows the spatial distributions of density and streamline of a hypersonic flow over a compression ramp [3, 4]. Fig. 2b and 2c illustrates the distributions of pressure and skin friction coefficients along the solid wall at three different ramp angles. The results are in excellent agreement with the previous published data [3, 4]. Detailed implementation strategies, study of parallel performance and some its applications will be presented in the meeting to further demonstrate the potential of the proposed DSMC method.

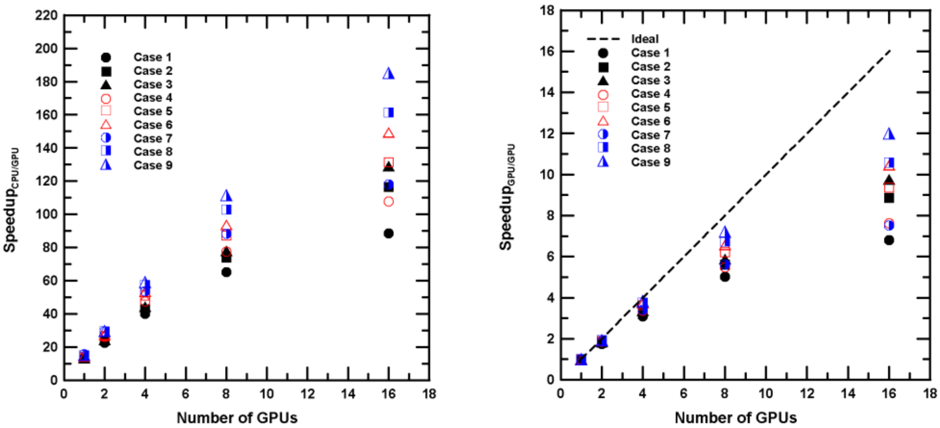

Fig. 1. Speedup ratio as a function of GPU (NVIDIA Tesla M2070) number for subsonic lid-driven cavity problem: (a) (left) compared to a core of the CPU (Intel Xeon X5670), and (b) (right) compared to a single GPU (NVIDIA Tesla M2070).

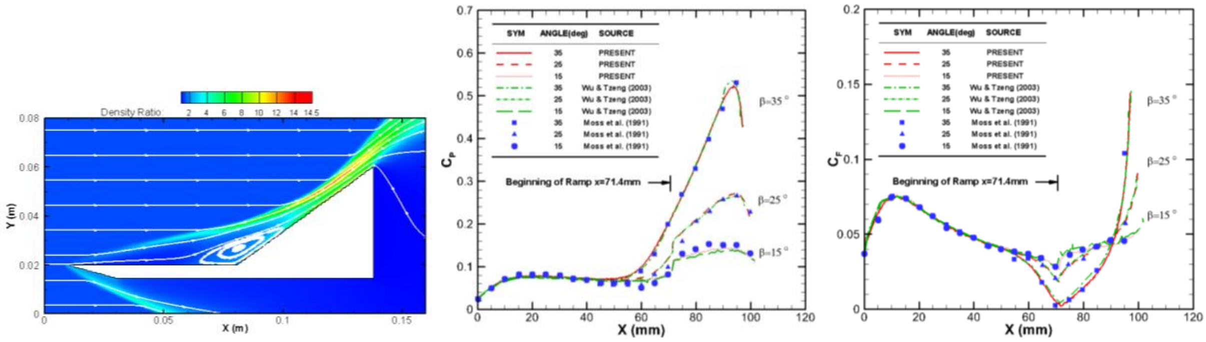

Fig. 2. (a) (left) density distribution; (b) (middle) comparison of pressure coefficient; (c) (right) skin friction coefficient.

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