The 18th International Conference on Finite Elements in Flow Problems (FEF2015)
16-18 March 2015, Taipei, Taiwan

A GAS-KINETIC SCHEME FOR CONTINUUM AND RAREFIED FLOWS

Juan-Chen Huang

Department of Merchant Marine,
National Taiwan Ocean University, Keelung 20224, Taiwan
jchuang@ntou.edu.tw

Key words: *unified scheme; non-equilibrium flow; thermo-driven flow; Knudsen force.*

With discretized particle velocity space, a unified gas-kinetic scheme (UGKS) for entire Knudsen number flows has been constructed based on the Bhatnagar-Gross-Krook (BGK) model [1]. In comparison with many existing kinetic schemes for the Boltzmann equation, besides accurate capturing of non-equilibrium flows, the unified method has no difficulty to get accurate solution in the continuum flow regime as well, such as the solution of the NavierStokes equations. Instead of particle-based modeling for the rarefied flow, such as the direct simulation Monte Carlo (DSMC) method, the philosophical principle underlying the current study is a partial-differential-equation (PDE)-based modeling. Since the valid scale of the kinetic equation and the scale of mesh size and time step may be different significantly, the gas evolution in a discretized space is modeled with the help of kinetic equation, instead of directly solving the partial differential equation. Due to the use of both hydrodynamic and kinetic scales flow physics in a gas evolution model at the cell interface, the unified scheme can basically present accurate solution in all flow regimes from the free molecule to the Navier-Stokes solutions. The unified scheme is a multiscale method, where the macroscopic flow variables and microscopic gas distribution function are updated simultaneously.

Beside the unified scheme with BGK model, the heat flux in the BGK model is modified through the update of macroscopic flow variables, then this modification feeds back into the update of non-equilibrium gas distribution function. Then, the unified scheme based on Shakhov model was also developed [2], where the heat flux is corrected directly through the modification of gas distribution function. It was shown that current unified scheme with Shakhov model is more consistent than the unified scheme of BGK for the highly non-equilibrium flow computations. The multidimensional UGKS scheme was proposed in [3, 4], where we extensively evaluated the performance of the unified scheme from free molecule to continuum NS solution, and from low speed micro-flow to high speed non-equilibrium aerodynamics. In comparison with the DSMC and Navier-Stokes flow solvers, the current method is much more efficient than DSMC in low speed transition and continuum flow regimes, and it has better capability than NS solver in the capturing of non-equilibrium flow physics in the transition and rarefied flow regimes.

In current study, we are going to study the non-equilibrium flow phenomena of thermo-driven flow which Zhu & Ye [5] investigated the origin of Knudsen force by using direct simulation Monte Carlo (DSMC) based on fully diffuse surfaces, and pointed out that thermally induced bulk flows are the main driven force for creation of such a mechanical force and the configuration of the problem domain plays a critical role in the flow generation and the formation of the Knudsen force. Zhu & Ye [6], also using DSMC and gas kinetic theory to numerically and theoretically justify the existence of the negative Knudsen force at high Knudsen numbers. Despite the above studies with numerical, experimental or even theoretical approaches on the modeling of the Knudsen force, a more detailed and accurate analysis in entire flow regime is under needed. In this paper a systematic study of Knudsen force by means of the UGKS is presented. Of particular interest in this study are the validation of the scheme and the Knudsen forces at very low Knudsen numbers.

REFERENCES

[1] K. Xu, J.-C. Huang (2010) A Unified Gas-kinetic Scheme for Continuum and Rarefied Flows. *Journal of Computational Physics* **229(20)**:7747-7764.

[2] K. Xu, J.-C. Huang (2011) An improved unified gas-kinetic scheme and the study of shock structures. *IMA Journal of Applied Mathematics* **76(5)**:698-711.

[3] J.-C. Huang, Kun Xu, Pubing Yu (2012) A Unified Gas-kinetic Scheme for Continuum and Rarefied Flows II: Multi-dimensional Cases. *Communications in Computational Physics* **12(3)**:662-690.

[4] J.-C. Huang, Kun Xu, Pubing Yu (2013) A Unified Gas-kinetic Scheme for Continuum and Rarefied Flows III: Microflow Simulations. *Communications in Computational Physics* **14(5)**:1147-1173.

[5] T. Zhu, W. Ye (2010) Origin of Knudsen forces on heated microbeams. *Phys. Rev. E* **82** 036308.

[6] T. Zhu, W. Ye (2011) Negative Knudsen force on heated microbeams. *Phys. Rev. E* **84** 056316.