The Hong Kong University of Science and Technology

Department of Mathematics

PhD THESIS EXAMINATION

Numerical Simulation of Moving Objects Using Gas-kinetic Schemes

By

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ABSTRACT

The computational fluid dynamics (CFD) is an efficient tool for design and analysis. The gas-kinetic scheme (GKS) is a numerical method based on kinetic theory. Because the GKS can provide second-order time-accurate distribution functions at the cell interface, both the flux and pointwise flow variables can be obtained at the cell interface. Thus, the compact gas-kinetic scheme (CGKS) can be designed. This thesis presents an extension of the GKS and CGKS to effectively address moving mesh problems in fluid dynamics. We developed three models: the single rotation frame, the sliding-mesh method, and the arbitrary Lagrangian-Eulerian (ALE) method.

First, we introduce a gas-kinetic scheme that incorporates mesh motion velocity, enabling the calculation of fluxes in moving meshes. This scheme treats mesh velocity as a combination of rigid rotation and arbitrary motion, resulting in a finite volume method that simplifies the rotation frame and ALE formulations. We develop two distinct approaches for calculating fluxes, integrating the distribution function using both absolute and relative velocity moments.

To address steady-state problems involving rigid rotation, such as those in compressor rotors, we propose an implicit gas-kinetic scheme within the rotating frame. This scheme enhances shock-capturing stability through a novel discontinuity feedback factor. The GMRes method is used to solve the implicit equation for computational efficiency and SST turbulence model is used to deal with the high Reynolds number effects. Validation against NASA Rotor 67 and NASA Rotor 37 shows strong agreement with experimental data.

We also develop a sliding-mesh method for unsteady problems with rotational components, implementing the compact third-order gas-kinetic scheme and the two-stage fourth-order time integration approach. The mortar approach using Sutherland-Hodgman algorithm is used to deal the sliding interface. Numerical cases from low Mach numbers to high Mach numbers are tested.

Finally, we adapt the ALE method to handle arbitrary mesh motion problems by subdividing arbitrary meshes into tetrahedrons and triangulating quadrilateral surfaces. This adaptation preserves the geometric conservation law and demonstrates excellent mass conservation in test cases with close boundaries. The compact gas-kinetic scheme and two-stage fourth-order time integration approach are used to increase the accuracy of the method. The method effectively addresses moving boundary problems and shows robustness in scenarios with strong discontinuities, including blast problems, by accurately tracking material interfaces.

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Time : 10:00 am

Venue : Room 5506 (Lifts 25/26)

***Thesis Examination Committee*:**

Chairman	**:**	**Prof. Jiannong WANG, PHYS/HKUST**
Thesis Supervisor	**:**	**Prof. Kun XU, MATH/HKUST**
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(Open to all faculty and students)

The student's thesis is now being displayed on the reception counter in the General Administration Office (Room 3461).