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論 文 要 旨

THESIS SUMMARY

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要旨（英文 800 語程度）
Thesis Summary（approx.800 English Words ）

A wide spectrum of engineering applications are highly related to multi-material fluid flows or flows with sharp interfaces, including contact discontinuities in compressible flows, moving boundaries of fluid-structure interaction (FSI), free surfaces in two-phase flow, etc. However, accurately simulating these flows is very difficult due to the moving interfaces where a variety of boundary conditions or jump conditions may be enforced. In this work, we want to track the moving interfaces as far as possible by using moving grids in order to ensure the accurate solutions at interfaces while leaving extremely flexible interfaces, e.g. free surfaces in two-phase flows, to be captured.

However, development of numerical model for tracking interface is rather challenging since it is always associated with moving unstructured grids which results in the difficulties for achieving adequate solution accuracy, superior numerical stability and robustness. In this thesis, we proposed a moving mesh framework for fluid flows based on multi-moment finite volume method. The characteristics of this framework are presented as follows: (1)The motion of fluid flows is described in Arbitrary Lagrangian Eulerian (ALE) viewpoint. (2)Both Volume Integrated Average (VIA) and Point Value (PV) are treated as computational variables and used for high order polynomial reconstruction. (3) Multi-moments, namely, VIA and PV, are solved separately on arbitrarily moving mesh.

Based on above framework, we developed numerical models for both compressible flows and incompressible flows on moving grids. For applications, we also constructed a practical and reliable numerical solver for Fluid-Structure Interaction (FSI) problems. The details and our major efforts are divided into following four parts:

1). Numerical model for compressible Euler equations was firstly proposed based on multi-moment finite volume method on moving grids, which interprets the core idea of this moving mesh framework. Governing equations are cast into ALE integral form and differential form for updating VIA and PV respectively. The VIAs are computed by a finite volume method (FVM) that ensures the rigorous numerical conservativeness, while the PVs are defined at cell vertices and updated efficiently by a point-wise finite difference formulation. By employing both VIA and PV as computational variables, it

becomes convenient for generating quadratic or high order polynomials within a compact stencil. An uniformly third-order accuracy is achieved on arbitrarily moving grids for 1D and 2D smooth solutions and geometrical conservation law is well satisfied. Moreover, numerical tests reveal that it has superior capability for resolving moving discontinuities in a Lagrangian way.

2). We extended the numerical model to viscous compressible flows and solved a simple one-way coupling FSI problem where the fluid state is affected by a prescribed varying boundary. Due to the moving boundary of fluid domain, we implemented the radial basis function (RBF) interpolation to transfer the movement of boundary to internal mesh points, which is of great significance for putting our moving mesh numerical model to practical use. In addition to several basic benchmark tests with high Mach number, we also investigate the phenomenon of flows past over an oscillating cylinder, which verifies the feasibility of present model for FSI application.

3). Multi-moment finite volume method for incompressible flows on unstructured moving grids was developed, where incompressible Navier-Stokes equations are solved by the pressure projection procedure. We then built a fluid-structure interaction solver by integrating the fluid model with an elastically mounted rigid-body. Two coupling schemes, i.e. an explicit weak coupling scheme and a semi-implicit strong coupling scheme, have been devised to formulate the interactions between fluid and moving solid with a wide range of mass ratios. By employing PVs at cell vertices as additional variables updated at each time step, the present multi-moment finite volume method shows great advantage when applied to the ALE framework for interactions among multiple materials, since the solution points can always coincide with the interfaces between different materials.

4). We presented a preliminary numerical model for moving body in free surface flow. In view of the extreme flexibility of free surface of two-phase flow as well as breakup and coalescence phenomena, the gas and liquid are described by one-fluid model where the free surface is captured by an algebraic interface capturing method, THINC-QQ scheme. Governing equations for two-phase flow are solved on moving grids by multi-moment finite volume method and coupled with the movement of solid body. Numerical tests, such as wave generation by a moving paddle, water exit of a circular cylinder and free falling of a wedge, show that the present solver is capable for simulating fluid flows with three-phase material interaction (i.e. gas, liquid and solid).

As mentioned above, the proposed numerical model has been verified by a wide range of benchmark tests and analyzed from many aspects including numerical error, convergence rate, conservativeness, computational cost, as well as reliability for practical applications. Numerical results demonstrate the appealing performance and feasibility of present framework for FSI application.