Immersed boundary method for viscous flow with moving rigid boundary

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ABSTRACT

The purpose of present study aims at the establishment of a numerical model to simulate viscous incompressible flows interacting with moving solids using an immersed boundary method. The model based on the Navier-Stokes equations is devised for the solution of the viscous flows in a complex geometry. The governing equation is discretized by local differential quadrature (LDQ) method on a non-uniform Cartesian mesh using a cell-centered collocated arrangement of the primitive variables. An efficient numerical algorithm has been developed with the combination of LDQ and immersed boundary methods to solve the governing equations inside/outside the immersed boundary and the computational flow domain. These help to demonstrate the capability of present model to solve Navier-Stokes equations involving complex geometries.

KEY WORDS: Moving solids; immersed boundary method; local differential quadrature; Cartesian mesh.

1. INTRODUCTION

Solution of viscous flow with moving rigid boundary is an important subject in computational fluid dynamics (CFD) related fields in science and engineering. A series of numerical schemes have been developed and used for the solution of the Navier-Stokes equations. However, CFD is a continuous research going on in the development of new numerical algorithms as modeling tool in other frontiers of science. Nowadays, the Cartesian grid system is in more popular for solving problems with irregular geometries. It is easy to generate the structural Cartesian grid find the niche for this method in comparison with the other methods required by body-fitted or unstructured meshes. Notably, the computational savings of body-fitted or unstructured meshes become a huge challenge when solving problems with a moving boundary. On the other hand, the adoption of the underlying Cartesian mesh constitutes a useful approach for saving computational time.

Various methods have used to handle the flow in complex domains. One approach is Peskin’s (1972) immersed boundary (IB) method that is commonly used in structure grids with Cartesian coordinate system. The IB method becomes more significantly related to CFD because the generation of grids for tackling the flow problems with complex stationary or moving boundaries is an easy work. Many researches paid more attention to the improvement of Peskin’s IB method for retaining the formally second order spatial accuracy (Peskin and Printz, 1993), enforcing the volume conservation enclosed by an immersed boundary (Xu and Wang, 2006), and increasing the resolution across the fluid-solid interface (Ferziger and Peric, 1996; Tseng and Ferziger, 2003; Iaccarino and Verzicco, 2003).

According to the review paper of Mittal and Iaccarino (2005), the IB method used to simulate incompressible viscous flows can be classified into two major categories, namely continuous forcing and discrete forcing (Goldstein et al., 1993; Udaykumar et al., 1999; Ye et al., 1999; Kim et al., 2001). In this paper, we present the results of the LDQ to solve viscous flows in combination with a ghost cell immersed boundary method using an interpolation scheme for tracking the immersed boundaries. The obvious complication in using Cartesian grid methods is in imposition of boundary conditions at the immersed boundary. In particular, since the immersed boundary can cut through the underlying Cartesian mesh in an arbitrary manner, the main challenge is to formulate a boundary treatment which does not adversely affect the accuracy and the conservation property of the underlying numerical solver. This is especially critical for viscous flows with which the inadequate resolution of boundary layers that form on the immersed boundaries can reduce the fidelity of the numerical solution. To comprehend the complexities of the viscous flows including the immersed boundary, we adopt a compact interpolation scheme near the immersed boundaries that allows us to retain the formally second order spatial accuracy and the conservation property of the solver.

As far as the proposed numerical method is concerned, the DQ method is employed to solve the governing equations with higher-order accuracy. The DQ method was first pioneered by...