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Lattice Boltzmann Approach for Local Reference Frames

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Abstract. In this paper we present a generalized lattice Boltzmann based approach for sliding-mesh local reference frame. This scheme exactly conserves hydrodynamic fluxes across local reference frame interface. The accuracy and robustness of our scheme are demonstrated by benchmark validations.

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Key words: LBM, LRF, sliding mesh.

1 Introduction

The fluid flows associated with rotating systems are quite complex and are characterized by a variety of unsteady flow phenomena such as laminar-turbulent transitions, boundary layer separation and reattachment, formation and evolution of vortices and above all, mixing and entrainment processes. Such flows are found in almost every industrial process involving fans, propellers, blowers, pumps, stirred tanks, turbo machinery components etc. Although experiments [1, 2] are commonly conducted to understand the complex physics of rotating systems, they are generally expensive, time consuming and can only provide limited data.

Computational modeling of moving geometry across grids is generally difficult and expensive. However, for certain types of motions, such as rotation, one may come up with substantial simplifications. For simulation of flow with arbitrary geometry that is rotating in time around a fixed axis, a rotating fan for example, the three dimensional computational domain can be divided into an inner domain and outer domain. The inner domain has its grid fixed with the rotating geometry so that the geometry does not have a relative motion with respect to the grid. This forms a local reference frame (LRF) domain "body-fixed" with the rotating geometry. The grid in the outer domain

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The general idea of matching a rotating grid with a non-rotating one is not new. In conventional Navier-Stokes based CFD, an axisymmetric volume mesh near such a sliding mesh interface is usually used on inner and outer sides. This could be an extra constraint on mesh generation. Various numerical interpolations are also needed to match fluid flows across the sliding mesh boundary. The task becomes significantly more difficult if non axisymmetric mesh such as Cartesian mesh is used. It would require expensive computation of time varying weights that link the inner and outer grid points everywhere along the vicinity of the sliding mesh boundary. This could also seriously compromise accuracy of numerical solutions in terms of ensuring conservation laws. Many conventional methods of sliding mesh can be found in literature. One early example is the work of Murthy et al. [3, 4], whereby a sliding mesh technique was developed for time-dependent simulation of the flow in mixing tanks. Later studies by Tabor et al. [5] and Dasakapolous and Harris [6] further explored the applicability of traditional sliding mesh methodology for mixing tanks and Rushton impeller stirred tanks.

The kinetic-theory based lattice Boltzmann method (LBM) is a well-known CFD approach for transient, viscous flow simulation that involves complex fluid phenomena [7]. LBM describes fluid flow in terms of a discrete kinetic equation for particle density distribution functions, namely the lattice Boltzmann equation (LBE). The macroscopic flow properties are direct results of the moments of these particle distribution functions. At the hydrodynamic limit it has been shown that the LBE recovers the Navier-Stokes equation [8, 9]. It has also been demonstrated recently that through a moment expansion procedure, LBE can be extended to describe fluid dynamics beyond Navier-Stokes hydrodynamics [10–12].

LBM has many advantages over traditional CFD [7], particularly, the straightforward boundary condition implementation enables flow simulation on a Cartesian grid system while maintaining exact conservations [13]. This makes LBM very convenient for accurately handling flow that involves complex geometry. Because of its kinetic nature, it is also easy and more physical to model various complex fluid flows [7, 14]. Furthermore, the unsteady Very-Large-Eddy-Simulation (VLES) turbulence model has been incorporated successfully into LBM [15, 16]. Its numerical accuracy and robustness have been