AN IMPROVED IMMERSED-BOUNDARY ALGORITHM FOR FLUID-SOLID INTERACTION IN LATTICE-BOLTZMANN SIMULATIONS

G. BORONI[†], J. DOTTORI[†], D. DALPONTE[‡], P. RINALDI[†] and A. CLAUSSE[†‡]

†CONICET and Universidad Nacional del Centro, Tandil, Argentina.
‡Comisión Nacional de Energía Atómica, Argentina.
gboroni@conicet.gov.ar, jdottori@exa.unicen.edu.ar, diego.dalponte@gmail.com, rinaldipablo@gmail.com and clausse@exa.unicen.edu.ar.

***Abstract* – An improved algorithm combining the features of the lattice-Boltzmann and the immersed-boundary methods is presented. Following previous formulations, the method represents a fluid constrained by flexible boundaries by means of a force term acting on the cells adjacent to the boundary, which in turn is moved by the fluid. The present algorithm introduces a more efficient iteration procedure to calculate the fluid-boundary interaction, which facilitates the implementation and improves performance. The simulations were validated against experimental and analytical data showing good agreement and demonstrating the performance of the method to simulate different kind of fluid-solid interaction.**

***Keywords*— Immersed boundary method, Lattice Boltzmann method, fluid–structure interaction.**

I. INTRODUCTION

The lattice-Boltzmann method (LBM) is an evolution of the lattice-gas automata, a discrete particle kinetics method originated from Boltzmann's kinetic theory of gases. In the method, time and space are discretized to solve the Boltzmann equation for particle velocity distribution functions on a regular grid. The LBM is an alternative to traditional numerical methods to obtain the flow solution. The LBM is rather simpler and more suitable to add mesoscopic kernels to simulate new phenomena as compared to conventional approaches that solve the flow problem directly discretizing the partial differential equations of the flow.

In the past few decades LBM has achieved great success in simulating various incompressible flow problems with simple bounce-back rules to represent solid walls. However, it is not a straightforward task to simulate complex geometries over a regular grid with simple streaming-collision rules.

On the other hand, the simulation of flows in flexible channels is very important in some applications, like hemodynamics. Among various numerical solvers, the development of Cartesian mesh solvers is an active research area due to their simplicity to simulate flows interacting with moving boundaries (Fadlun *et al.*, 2000; Ge and Sotiropoulos, 2007; Gilmanov and Sotiropoulos, 2005; Johansen and Colella, 1998; Mittal and Iaccarino, 2005; Peskin, 1977; Udaykumar *et al.*, 2001). These problems involve complicated interaction between a viscous fluid, deformable body, and free moving boundary, making them difficult to discern. Consequently, analytic solutions are few and almost nonexistent, but a computational approach is a viable possibility. Nowadays there exist a variety of methods developed to handle this kind of problems. Traditionally solving a fluid interacting with complex geometry relies on the unstructured grid method or the overset grid method (Zhang, 2002 and 2008).

For solid wall representation in LBM, the classic idea consists in treating the lattice cells as fluid or solid. When the bounce-back rule is applied to the solid cells, the incoming distribution particles are returned back to the fluid. Some subsequent works present evolutions of this basic concept, Zou and He (1997) generalized a second order bounce-back scheme to simulate rigid straight walls. Other approaches, like Guo *et al.* (2007), use extrapolation techniques to implement rigid curved walls in LBM.

Recently, Cheng and Zhang (2010) successfully coupled LBM with the Immersed Boundary method (IB) to simulate moving curved walls in a mitral heart valve. IB (Peskin, 2002) was originally proposed to solve the fluid–flexible-structure interaction problem. This method decouples the solutions of governing equations and boundary conditions. The boundary effect into the surrounding fluid is replaced by adding forces to the fluid equations.

The solution proposed by Cheng and Zhang (2010) uses a regular grid contained in the flow field. The fluid-particles velocity field is solved by adding a force density term into the LBM equation. This method preserves the advantages of LBM in tracking particles and offers an alternative to handling the solid–fluid boundary conditions. The method also solves the problems of forces and velocities fluctuations on the particles when boundary conditions are applied.

In the present article, the Cheng and Zhang's algorithm has been redesigned with a more efficient iteration scheme for calculation of forces at the boundary points. Furthermore, different object-fluid interactions were tested including straight and curved immersed walls and flexible curved walls. The simulations were validated against experimental or analytical data showing good agreement and demonstrating the performance of the method to efficiently simulate different kind of fluid-solid interaction.