

## Lattice Boltzmann Analysis of Fluid-Structure Interaction with Moving Boundaries

Alessandro De Rosis<sup>1,\*</sup>, Giacomo Falcucci<sup>2</sup>, Stefano Ubertini<sup>3</sup>,  
Francesco Ubertini<sup>1</sup> and Sauro Succi<sup>4</sup>

<sup>1</sup> Department of Civil, Environmental and Materials Engineering, University of Bologna, Bologna 40136, Italy.

<sup>2</sup> Department of Technologies, University of Naples "Parthenope", Naples, Italy.

<sup>3</sup> DEIM - Industrial Engineering School, University of Tuscia, Largo dell'Università s.n.c., 01100, Viterbo, Italy.

<sup>4</sup> Istituto per le Applicazioni del Calcolo - CNR, Via dei Taurini, 00100 Roma, Italy.

Received 14 November 2011; Accepted (in revised version) 20 December 2011

Available online 29 August 2012

---

**Abstract.** This work is concerned with the modelling of the interaction of fluid flow with flexibly supported rigid bodies. The fluid flow is modelled by Lattice-Boltzmann Method, coupled to a set of ordinary differential equations describing the dynamics of the solid body in terms its elastic and damping properties. The time discretization of the body dynamics is performed via the Time Discontinuous Galerkin Method. Several numerical examples are presented and highlight the robustness and efficiency of the proposed methodology, by means of comparisons with previously published results. The examples show that the present fluid-structure method is able to capture vortex-induced oscillations of flexibly-supported rigid body.

**PACS:** 62, 47

**Key words:** Lattice-Boltzmann method, fluid-structure interaction.

---

## 1 Introduction

The correct prediction of the interaction between a solid structure and a fluid flow is a problem of great interest both from a theoretical and a practical point of view [1,2]. Several industrial, technological, biological and environmental problems are, in fact, associated with Fluid-Structure Interaction (FSI) and the ability of predicting the fluid and solid behavior in such processes is extremely important for these applications. This, together with the increased computer power of the last two decades, is promoting an enormous

---

\*Corresponding author. *Email addresses:* alessandro.derosis@unibo.it (A. De Rosis), falcucci@uniroma3.it (G. Falcucci), stefano.ubertini@uniparthenope.it (S. Ubertini), francesco.ubertini@unibo.it (F. Ubertini), succi@iac.cnr.it (S. Succi)

research effort in this field of computational mechanics. Being this a typical “coupled field” problem, monolithic (i.e. fluid and solid equations solved simultaneously) or partitioned (i.e. each physical field is separately discretized and numerically solved) approaches can be used, being the latter of simpler implementation and presently the only one applicable to practical problems [3–6]. In this paper the fluid flow is modelled by the Lattice-Boltzmann Method (LBM), which is a numerical approach for fluid dynamic investigation based on Boltzmann’s Kinetic Equation [7,8]. In recent years, the LBM has been successfully adopted for the simulation of phenomena of technical interest, such as multiphase/reacting flows [9–11], cavitation, spray formation and break-up [12] and others. LBM has also been employed in problems of fluid-structure interaction [13–15] and in the framework of immersed boundary approaches [16–19], for the ease and accuracy with which it enables complicated boundary geometries to be processed. In particular, Zhang and his coworkers [11,12] have proposed an immersed boundary-lattice Boltzmann coupling scheme for deformable and moving boundaries and demonstrated it on blood flows with simplified bi-dimensional geometries. A Lattice-Boltzmann based implicit immersed boundary method has been also developed by Hao and Zhu [20] and tested to simulate a flexible and massless filament in a bi-dimensional viscous flow at low Reynolds numbers.

In LBM, a popular scheme for the fluid-structure interaction is based on the 2<sup>nd</sup>-order accurate bounce-back rule enforcing the no-slip condition on the solid surface [21, 22]. Such a scheme is suitable for the rigid-solid case where the motion of the solid obstacle is determined only by the external force. However, for the elastic-body case where the solid motion is determined by the local stress state, a very fine mesh might be required for high accuracy [14]. Recently Kollmannsberger et al. [23] have presented very interesting results for bi-dimensional fluid-structure interaction obtained by coupling fixed-grid Lattice-Boltzmann fluid solver with *p*-refinement finite element solid solver. An interface mesh is used to adapt the two different discretizations and a staggered algorithm with subiteration is chosen for the fluid. Solid time integration is performed by the Newmark method.

The method proposed in this paper can be classified as “non-boundary-fitted”, as the solid boundaries do not lie on the fluid nodes, similarly to immersed boundaries [24]. Therefore, the main advantage of the present method is the absence of moving meshes, which usually require high computational times, combined to the simplicity and the computational efficiency of the Lattice Boltzmann method for fluid flows. Using the LBM as the fluid solver, in fact, allows moving the body in a fixed lattice, given proper boundary conditions (i.e. Mei et al. [25]) and a refill procedure for fluid node initialization after solid obstacle motion [15, 26, 27]. The dynamics of the rigid body is modelled through the Time Discontinuous Galerkin Method, because of its good accuracy and dissipative properties [28, 29]. The computational cost is successfully reduced owing to the implementation proposed in [28, 29]. Different types of constraints, including rigid and elastic joints are considered and the dynamic response of the rigid obstacle is calculated as a coupled function of the fluid-dynamic external field.