Commun. Comput. Phys.
doi: 10.4208/cicp.OA-2022-0058

Vol. **33**, No. 1, pp. 349-366
January 2023

Effective Force Stabilising Technique for the Immersed Boundary Method

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Received 21 February 2022; Accepted (in revised version) 5 November 2022

Abstract. The immersed boundary method has emerged as an efficient approach for the simulation of finite-sized solid particles in complex fluid flows. However, one of the well known shortcomings of the method is the limited support for the simulation of light particles, *i.e.* particles with a density lower than that of the surrounding fluid, both in terms of accuracy and numerical stability.

Although a broad literature exists, with several authors reporting different approaches for improving the stability of the method, most of these attempts introduce extra complexities and are very costly from a computational point of view.

In this work, we introduce an effective force stabilizing technique, allowing to extend the stability range of the method by filtering spurious oscillations arising when dealing with light-particles, pushing down the particle-to-fluid density ratio as low as 0.04. We thoroughly validate the method comparing with both experimental and numerical data available in literature.

AMS subject classifications: 65D10, 76M28

Key words: Immersed boundary method, lattice Boltzmann method, light particle, force stabilization, added mass effect.

1 Introduction

The transportation of rigid particles, droplets and bubbles in multiphase and multicomponent fluid flows are ubiquitous to several fields of science and technology [1]. Many

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examples can be cited, for example in connection with environmental research (erosion of sediments in sea shores and bubble generation in thee ocean), power engineering (to enhance heat and mass transfer inside of the boiler of power-plants), chemical engineering (reaction between a gas and a liquid phase relies on the increased surface area of small bubbles), bio-medical industry (air bubble formation in transported blood samples through pneumatic tube systems) and many others.

The motion of particulate matter, as well as the numerical techniques required for an accurate and reliable description of its dynamic, may vary significantly depending on whether one deals with bubbles, droplets or particles. For example, for heavy particles, with densities larger than that of the dispersed phase, the dynamics is mostly governed by the inertia of the particles. On the other hand, when dealing with light particles (e.g. small bubbles) the governing force comes mostly from the inertia of the fluid inside the immersed body which gets accelerated along with the particle; this phenomena is commonly referred as "added mass effect" (and seldom as "internal mass effect" [2]).

Although a significant effort has been invested through the years on the experimental side for the study of the motion of bubbles in complex fluid flows [3–5], there is not as much literature available in terms of numerical works, due to the lack of efficient techniques for the simulation of light particles in fluid flows.

A standard approach for the simulation of interactions between fluids and particles is given by the Immersed Boundary Method (IBM), which simulates the boundary of the particles using a Lagrangian grid. The method, originally introduced by Peskin [6, 7], and successively refined over the years by a number of researchers [8–11], has proven successful in the simulation of several types of complex fluid-particle interactions. However, a well known shortcoming of the method is the restricted support, both in terms of accuracy and numerical stability, for the simulation of light particles [10].

Although several methods have been reported for extending the stability range of IBM (e.g. [12–14]), they are often very expensive from a computational point of view, and for this reason one usually relies on other numerical approaches for the simulation of light particles, such as for example the interface tracking method [15, 16].

In this work, we present a lightweight solution for filtering-out spurious oscillations arising in the force term acting on the particle, which occur when simulating light particles in fluid flows.

We couple the IBM with a Lattice Boltzmann Method (LBM) [17] for the solution of the governing equations of the fluid, and perform numerical simulations for heavy and light particles, comparing and validating against both numerical and experimental data.

Our results show that we are able to solve particle to fluid density ratios as low as 0.04, improving of about one order of magnitude over a standard IBM implementation.

This article is organized as follows: in Section 2 we introduce the numerical methods used in the simulation of the fluid dynamics and of the fluid-particle interactions, respectively the LBM and the IBM. Besides, we also provide a description of the shortcoming of the IBM in the simulation of light particles, as well as a stabilization technique for smoothing out oscillations from the particle force and torque. In Section 3 we report