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Review Article

A Review on Contact and Collision Methods for Multi-Body Hydrodynamic Problems in Complex Flows

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Abstract. Modeling and direct numerical simulation of particle-laden flows have a tremendous variety of applications in science and engineering across a vast spectrum of scales from pollution dispersion in the atmosphere, to fluidization in the combustion process, to aerosol deposition in spray medication, along with many others. Due to their strongly nonlinear and multiscale nature, the above complex phenomena still raise a very steep challenge to the most computational methods. In this review, we provide comprehensive coverage of multibody hydrodynamic (MBH) problems focusing on particulate suspensions in complex fluidic systems that have been simulated using hybrid Eulerian-Lagrangian particulate flow models. Among these hybrid models, the Immersed Boundary-Lattice Boltzmann Method (IB-LBM) provides mathematically simple and computationally-efficient algorithms for solid-fluid hydrodynamic interactions in MBH simulations. This paper elaborates on the mathematical framework,

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applicability, and limitations of various 'simple to complex' representations of close-contact interparticle interactions and collision methods, including short-range interparticle and particle-wall steric interactions, spring and lubrication forces, normal and oblique collisions, and mesoscale molecular models for deformable particle collisions based on hard-sphere and soft-sphere models in MBH models to simulate settling or flow of nonuniform particles of different geometric shapes and sizes in diverse fluidic systems.

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1 Introduction

Theoretical physics has a long and distinguished tradition of grasping the essence of complex natural phenomena through the aid of relatively simpler models. Among others, remarkable examples in point include the Ising model for magnetism [1], the Sandpile model for self-organized criticality [2], cellular automata for particle aggregation (DLA model), and lattice gas cellular automata for fluids [3]. To a different extent, they all obey the overarching paradigm of 'simple models for complex phenomena', whereby complexity arises as to the emergent phenomena on top of repeated application of simple microscale rules. The strength of these models is their capability to capture universal features of the phenomena under inspection, regardless of specific details which may differ from system to system in the same so-called universality class.

Modern science and society, however, are increasingly confronted with phenomena whose complexity can no longer be quantitatively captured by the aforementioned 'complex from simple' paradigm, as clearly witnessed by the 2021 Nobel Prize in Physics. The reason is that, due to strong nonlinear interactions extending over multiple decades in space and time, the divide between universality and specificity becomes hazy and dynamic, which means the usual separation between relevant and irrelevant degrees of freedom that powers most of modern theoretical physics is no longer viable. Under such circumstances, simple models must be supplemented with just the right amount of specificity, typically, but not necessarily, in the form of details belonging to a deeper (more microscopic) level of description. In the very act of integrating such details within a simple universal structure, these models lose their 'simplicity', opening up to a new paradigm that we may call 'complex for complex', i.e., complex models for complex phenomena. Modern computational physics offers several examples of this sort, and the subject of this review, particulate flows, inscribes precisely within such conceptual and computational framework.

Particulate suspension flow occurs in diverse scientific and technological applications. In the automotive industry, particle-fluid interactions and flow of particulate matter in thermal multiphase fluidic environments affect the design of combustion chambers and cyclone separators, as nano- to micron-size particles enhance the heat transfer