**Application of the Immersed Boundary Method to particle-laden and bubbly flows**

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**ABSTRACT**

The numerical simulation of turbulent flows laden with solid particles is of specific importance for a wide range of situations relevant for engineering as well as fundamental research. If particles are smaller than the smallest scales of turbulence, i.e. the Kolmogorov scales, they are usually modelled as mass points without spatial extension. If, in contrast, the particles are larger than the smallest scales, a spatial resolution of the particle geometry is required. The same applies to non-spherical particles with more complex shapes. In the recent years, the Immersed Boundary Method (IBM) has proven to be an efficient method for the fully coupled, three-dimensional simulation of many mobile particles in viscous flows with interface resolution [1,2]. The result of the application of an IBM to the flow around a single sphere which moves towards a wall is displayed in Figure 1. The idea of the talk is to give an overview of the recent extensions and improvements of the basic method of Uhlmann [1] and their use for various physical configurations.

![Figure 1](image1.jpg)

**Figure 1: Numerical and experimental determination of the flow around a sphere impacting on a wall for three instants of time. The left-hand images were obtained with an IBM [2] while the right-hand images contain the experimental data of [Eames & Dalziel, JFM, 2000]. Pictures are taken from [3].**

In many flows with moving particles collisions may occur. Even for low volume fractions, collisions need to be represented accurately to yield realistic simulation results. The accurate and efficient modelling of collisions is challenging due to the strongly different time scales of fluid and solid material as well as the small gaps between the surfaces of approaching or rebounding particles. A conclusion from the available literature as well as from our own experiments is that the collision models which have been developed in the framework of the discrete element method cannot simply be transferred to approaches with interface resolution. Despite the rapid increase of available computer power not all scales of the flow and the collision process itself can be resolved entirely, since these commonly span more than two orders of magnitude. To handle this situation, multiscale modelling approaches are often introduced in order to avoid excessive time step reduction and local grid refinement. Such an approach is the Adaptive Collision Model (ACM) proposed in [3]. The talk briefly presents the different components of the model for the normal and the tangential interaction of spherical particles.

In the following part of the talk, large scale highly-resolved simulations of an open channel flow laden with spherical particles are presented [4]. The physical processes occurring in mobile sediment beds with bed load transport of particles are of particular importance for environmental flows as well as for many industrial processes. The structures created by the interaction between the fixed bed, the mobile particles and the turbulent flow are manifold and influenced by a number of factors. The transport of mobile particles over a rough bed consisting of fixed spherical particles in a hexagonal packing was computed (Figure 2a). The particles are resolved with 22 points per diameter ($D$). Flow depth is $H = 9 \, D$, the stream-wise extent of the domain is $24 \, H$, and the span-wise extent $6 \, H$. The bulk Reynolds number is 2941. Four different runs were conducted: A reference run with just as many fixed as mobile particles having a specific...
density slightly above the threshold of incipient motion. Secondly, the amount of mobile particles was increased by 50\%, and thirdly the specific density ratio was decreased by 55\%. Further comparison is provided by a simulation with immobile particles. The variation of the parameters defining the mobile sediment yields a strong modification of the interaction between the fluid and the disperse phase. The formation of particle structures differs entirely by their scales in space and time depending on mass loading and specific density ratio. The results obtained in this respect are in agreement with experimental observations. The talk provides a discussion of the key mechanisms governing this interaction.

![Figure 2](image.png)

**Figure 2:** Application of the IBM to different configurations. a) Instantaneous particle distribution in an open channel flow. Contour plot of $u/U_0$ on the sides of the domain, 3d-iso-surfaces of fluid fluctuations with $u'/U_b = -0.3$ inside the domain. Particle colours: grey = fixed, white = $|u_p| < 1.5u_c$, black = $|u_p| > 1.5u_c$. b) Light ellipsoidal particles in a vertical channel flow. Snapshot of particle position and slice of fluid velocity (streamwise component) for an instant in time during the simulation.

In the last part of the talk, some extensions of the IBM to other physical configurations are presented which have been developed recently in our group. These are, for example, the computation of light particles with ellipsoidal shape in a vertical turbulent channel flow (Figure 2b) or the simulation of deformable bubbles [6].

**REFERENCES**


