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Numerical modelling of particle-fluid interaction in fluvial sediment transport

Abstract

Numerical simulations for the transport of coarse sediment particles in turbulent flows are performed, with particular emphasis on the energy and momentum exchange [1, 2, 3] between the two phases at the particle scale. The solid particles positions and velocities are solved through the Discrete Element Method (DEM), coupled with a Computational Fluid Dynamics (CFD) model which updates the dynamically evolving flow field through the numerical solution of the Reynolds Averaged of Navier-Stokes equations (RANS).At the core of this work, the coupling of these two models (DEM-CFD) based on the Fictitious Boundary Method, is analysed. The models have a high mesh resolution, by adopting a meshing strategy which aims at sufficiently discretising the flow field surrounding each particle. Smooth and rough bed cases are simulated, under a wide range of Reynolds numbers covering applications from particle entrainment, up to bulk bedload transport through rolling and saltation. The numerical results are benchmarked against experimental data obtained from controlled laboratory experiments [4, 5, 6]. The implementation of coupled CFD-DEM models provides a very powerful tool for improving the understanding of fluid and particle physics in sediment transport. Particularly, the potential to perform a large number of validated numerical that robustly predict geomorphological changes in aquatic environments and fluvial systems.

1. Forces on a particle next to a smooth bed

The entrainment of sediment particles in natural flows is generated by forces of impermanent nature generated by the fluid dynamics surrounding the particle, through the pressure field and the viscosity effects.

A series of numerical experiments are run to extract the series of drag and lift forces due to pressure and viscosity effects. Results show that:

- A good resolution of the vortex structures is achieved and visualization is clear through the Q-criterion;
- Viscosity forces become more relevant under lower Re numbers (Re<100);
- The forces exerted on the particle fluctuate around an average value;

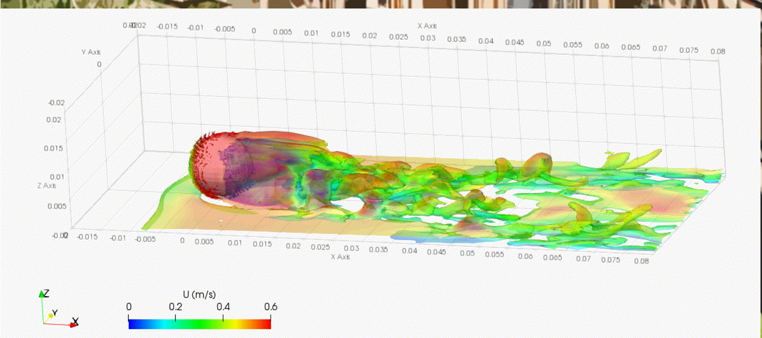

Figure 1. Vortex structures behind a sphere on a smooth bed; Re=5000; Q-criterion = 100

1.1 Drag and lift forces

From the numerical experiments carried out at Reynolds numbers ranging 10 to 5000, the drag and lift forces are integrated around the sphere face (Figure 2).

The analysis of these series permits to translate the bulk flow conditions into probability of particle entrainment.

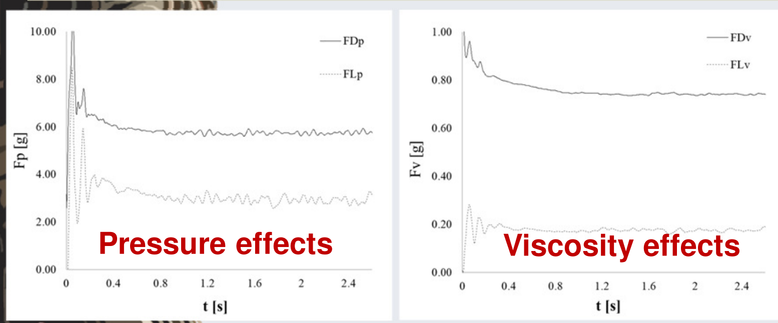

Figure 2. Integrated pressure and viscosity forces (grouped as drag and lift, in accordance to traditional convention) as a function of time, for Re=5000

2. Moving particle

CFD-DEM four-way coupled numerical experiments are developed. Four-way coupling denotes a full interaction and momentum transfer from fluid to the particles and vice versa.

The models implemented are resolved, this is dp>Δx and therefore the full representation of the fluid flow onto the particle is achieved.

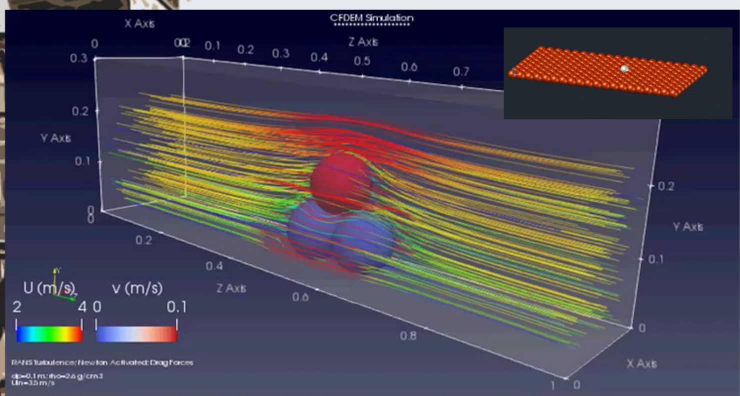

Figure 3. Coupled CFD-DEM simulation with moving particle; future set up with rough-bed conditions (inset)

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