

# **Development of fictitious-domain simulations of bedload sediment transport over a movable bed in a minimal channel flow**

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"Bedload transport", defined as the flow-induced motion of larger sediment particles in or near contact with the bottom boundary, is a fundamental process shaping rivers and the seabed. However, it remains only partially understood due to its complicated mechanisms involving turbulence, two-phase momentum coupling, and interparticle contacts/collisions. To contribute to analysis and modeling of this important phenomenon, the objective of the present study is to achieve "direct numerical simulation" of bed-load transport, wherein the particle and fluid flow equations are solved simultaneously without any models or simplifying assumptions on particle and flow type. For this purpose, I have developed fictitious-domain methods for "particle-dynamics" simulation of dense-phase particulate flow in liquid with nearly complete resolution of the turbulence. The thesis first presents several possible fictitious-domain methods, classified according to the use of variable-density versus constant-density flow solvers, and according to the artificial forcing method used to recover rigid-body motion within particles; volumetric forcing, "marker" forcing, or a new hybrid thereof. The relative merits of these schemes are investigated by various simple test cases with one or two particles. Next, more complicated test cases on dense-phase granular flow in liquid are considered; in particular, we check against experiments with a cylindrical drum rotating about a horizontal axis and partially filled with spherical glass beads. Two configurations have been implemented: 1) a closed drum containing beads and completely immersed with sunflower oil (or alternatively, air); 2) an "open" drum whose circumference of wire mesh confines the particles while permitting a free-surface flow of oil, inducing a bedload layer, to be maintained over the particle bed. Overall agreement between experimental and simulated values is found to be quite satisfactory for both configurations. Finally, simulations of bedload sediment transport in a minimal channel are presented; doubly-periodic "quasi-2D" and doubly-periodic 3D open channels have been simulated and investigated. To our knowledge, the present dissertation is the first to achieve DNS of bedload transport.