Postdoctoral position

Modeling and numerical simulations of granular flows. Application to pyroclastic density currents.

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Location : Laboratoire de Mathématiques Blaise Pascal (http ://recherche.math.univ-bpclermont.fr/)
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Salary : the gross salary is 2589.88 € (net income 2085.58 €).

Starting date : between october 1st 2018 and january 1st 2019.

Duration : 16 months.

Required qualifications : applicants should have a PhD either in Applied Mathematics (numerical analysis, scientific computing), Fluid Mechanics (numerical simulations) or Computer Science. Experience in High Performance Computing (parallel programming with MPI) will be welcome. The candidate must be interested both in numerical analysis and programming aspects (efficient implementation of numerical schemes).

The scientific context. Pyroclastic density currents occuring during volcanic eruptions, when for instance the volcanic plume collapse on the ground under the effect of gravity, are complex by nature and the physical mechanisms involved are not well understood. These gravity flows, which are mixtures of gaz (air), rocks and dusts, are dense as the volume fraction of solid matters is closed to the packing limit. Nevertheless, they behave like fluids and have the ability to carry out heavy pieces of rocks over large distances, of the order of one or several (up to fifty) kilometers. A possible explanation to describe this phenomenon relies on the role played by the fluidization of the mixture during the eruption process, namely the pore pressure (due to the presence of air) could, combined with gravity, reduce the strength of the particle interactions and then decrease the energy dissipation. In order to assess the role of the fluidization, collapse of granular columns were experimentally studied in the *Laboratoire Magmas et Volcans* (see [1]). The results show indeed that an initially fluidized columm of granular matter flows over a distance about twice longer than a non-fluidized column.

A dense granular flow seems to behave like a fluid. However, unlike fluids, granular flows stop in finite time. It is therefore reasonable to use visco-plastic models of Bingham type. In [2], a mathematical model based on the incompressible Navier-Stokes equations for homogeneous fluids, *i.e.* with both constants viscosity and density, with a visco-plastic rheology has been proposed and studied. Unlike for classical Bingham fluids, the yield stress here depends on the hydrostatic pressure, which is computed as a function of the density of the granular material, the heigth of the column and a pore pressure obtained as the solution of an advection-diffusion equation. Iverson in [3] introduced a similar pore pressure in a depth averaged one-dimensional model. The pore pressure aims to control the fluidization level during the column collapse and hence acts on the energy dissipation. The diffusion coefficient depends on the physical properties of the studied granular material and has been estimated by Roche in [1] using experimental measurements.

The model studied in [2] has then been extended in order to account for the presence of the ambiant air, *i.e.* we have two non-miscible phases : the air and the granular column. They have completely different physical properties and behaviours : the density of the granular flow is 2500 times larger than the air density and the plastic viscosity of the granular matter is about 10 000 times bigger than the air viscosity.

The aim of this project is to develop a robust and efficient code and to perform numerical simulations of the collapse of dense fluidized as well as non-fluidized granular columns. The numerical results will be compared with experimental ones provided by the *Laboratoire Magmas et Volcans*.

Research project. A parallel code, written in Fortran 90 and using the PETSC and MPI libraries, has been developped at the *Laboratoire de Mathématiques Blaise Pascal* in order to solve incompressible two-phase flows, one phase being an incompressible newtonian flow while the other one is an incompressible visco-plastic of Bingham type flow. The spatial discretization is achieved with second-order centred finite difference schemes on staggered grids and a projection method is employed to enforce the incompressiblity condition. The constitutive equation for the visco-plastic medium is solved with the bi-projection scheme recently proposed and studied in [4, 5]. The interface between the two phases is tracked with a level set method (see [6] for a review). The transport equation for the level set function is discretized in space with a 5th order finite difference WENO scheme combined with a third order TVD Runge-Kutta scheme for the time discretization (see [6]). A friction law, *i.e.* a slip-stick boundary condition, is applied at the bottom of the computational domain.

The postdoctoral fellow will focus on the development and implementation of a model for fluidized granular flow. The approach used in [2], which consists in modeling this effect by adding a pore pressure, solution of an advection-diffusion equation, in the definition of the yield stress of the granular medium, will first be implemented and tested. The main objective is to validate the numerical simulations by reproducing experimental results.

Related questions will also be investigated. For instance, the friction law allows the granular material to slide on the ground surface. However, no boundary conditions are applied to the level set function and extrapolations are commonly used at boundaries which may be a source of numerical instabilities in the reinitialization step. Therefore an improved boundary condition for the level set function, compatible with the friction law applied to the granular flow, should be developped and tested.

Bibliography

[1] O. Roche, Depositional processes and gas pore pressure in pyroclastic flows : an experimental perspective, Bulletin of Volcanology, 74(8), 1807-1820, 2012.

[2] L. Chupin et J. Mathé, Existence theorem for homogneous incompressible Navier-Stokes equation with variable rheology, European Journal of Mechanics - B/Fluids, 61(1), 135-143, 2017.

[3] R.M. Iverson et R.P. Denlinger, Flow of variably fluidized granular masses across three-dimensional terrain 1. Coulomb mixture theory, Journal of Geophysical Research, 106(B1), 537-552, 2001.

[4] L. Chupin et T. Dubois, A bi-projection method for Bingham type flows, Computers and Mathematics with Applications, 72, 1263-1286, 2016.

[5] R. Chalayer, L. Chupin et T. Dubois, A bi-projection method for incompressible Bingham flows with variable density, viscosity and yield stress, SIAM Journal on Numerical Analysis, 2018.

[6] S. Osher et R.P. Fedkiw, Level Set Methods and Dynamic Implicit Surfaces, Applied Mathematical Sciences, Springer-Verlag, New-York, 153, 2003.