Study of wetting phenomena at small scales in microgravity
In collaboration with Centre National d'Etudes Spatiales (CNES)

The main goal of this PhD is to study, in microgravity conditions, the behavior of capillary bridges, with focusing on the instabilities and the (very fast) dynamic behavior associated with the evolution close to the rupture, and on the coalescence (merging) of several capillary bridges.

This work takes place in a fundamental topic in Mechanics and Physics, *the capillarity*, with a direct link to the mathematical theories of minimization under constraints. The applications are numerous and may concern among others Geomechanics (stability of granular soils under hydric loadings, avalanches, landslides…), or life science (rising of sap in fine capillaries, soil root interaction).

During this PhD, we propose to focus on an accurate description and on the modelling of capillary bridges between three phases (solid grains, liquid and gas phases). The capillary bridges that are created between solid grains, result in attractive capillary forces that provide a cohesion of the partially saturated granular assembly. It is recognized that complex Geomechanics processes at large scales originate at the scale of elementary particles. It is therefore deemed necessary to better understand the physics of capillary bridges at grain scales, as well as the associated resulting capillary forces.

Even if there exists abundant literature on capillary bridges, some fundamental questions still remain open:

- How to solve Young-Laplace equation when the right hand side involving the capillary pressure (pressure deficiency between liquid and air) is unknown, in particular in gravity conditions?
- What are the more stable geometric configurations among the possible solutions of Young-Laplace equation?
- There is no consistent mathematical criterion of instability of Young-Laplace equation, characterizing the loss of stability (in a geometric sense) of the associated capillary bridge.
- The transition between a quasi-static configuration and a dynamical one just before the rupture of capillary bridges is still unexplained.
- How to calculate very accurately the capillary forces associated to a capillary bridge and how they evolve when some capillary bridges merge to form a cluster? This is a main point to compute the forces at the scale of a partially saturated granular assembly to predict a possible loss a stability.

Some recent mathematical results obtained in LaSIE-CNRS enable us to determine rigorously, in microgravity conditions, the exact geometry of the capillary bridges, as an axisymmetric surface of revolution with a constant mean curvature, and to calculate explicitly the associated characteristics (volume, surface, capillary force, pressure). This approach is based on an original resolution of Young–Laplace equation for capillary doublets using an inverse problem. We established a simple explicit criterion based on the observation of the contact point, the wetting angle and the gorge radius, to classify in an exhaustive way the nature of the surface of revolution.

The first experiments performed during two previous parabolic flight campaigns enabled us to validate the theoretical results obtained in LaSIE for capillary doublets, when the gravity effects can be neglected (for very small separation distances between solid particles or very small liquid volumes). The gravity induces a distortion (loss of symmetry) of the capillary bridges and it is fundamental to decouple the phenomena involved (at least in a first time), to better understand the physics at small scales.

Fig. 1. Specific rack used in a parabolic flight in microgravity in *zero G Airbus* of the CNES.

These results constitute a strong basis to tackle the open questions raised previously in the framework of the PhD. The recruited student will take advantage of the experimental set-up existing in LaSIE to measure very accurately the geometric properties of capillary bridges between different solid materials, and the associated capillary forces. In order to validate the new modelling that will be carried out, a new parabolic flight campaign will be proposed.

A possible promising innovative extension of the proposed work could be to generalize the study using an improved Young-Laplace equation involving the Gauss curvature characterizing the bending effects. Using the Gauss-Bonnet theorem for smooth surfaces with boundaries, it is possible to link the Gaussian curvature to the wetting angles of a capillary bridge, and to study the link between these two physical quantities resulting from a complex thermodynamical equilibrium. A recent work performed at LaSIE has been initiated on this point. A generalization of these theoretical results including gravity could be also performed.

Embedding and facilities

The PhD student will join the International Research Network (IRN GeoMech) on Multi-Physics and Multi-scale Couplings in Geo-environmental Mechanics, whose director is Olivier Millet (LaSIE-CNRS). Many opportunities of academic positions will result from this after the dissertation defense.
The PhD student will also take advantage of the numerous contributions of LaSIE on the subject (see references on the subject).
Moreover, the student will benefit from an opportunity of collaboration with the Centre National des Etudes Spatiales (CNES) in the framework of a parabolic flight campaign.

Supervisor:
Olivier Millet, University of La Rochelle, France

Collaboration:
Marc Médale, University of Aix-Marseille, France

Student requirements

The applicants for the position should have a master's degree in engineering or applied mathematics complemented by a strong background in continuum mechanics, coupled phenomena in physics, applied and computational mechanics.

Contact :

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Deadline for application : 30 May 2023

Some references on the subject

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G. Gagneux, O. Millet: Analytical calculations for quantifying capillary bridges distortions from experimental data, 2021. ⟨hal-03363070⟩

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