tec21
the engineering
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Summer School

"Multi-scale modeling and multi-physics coupling in solid and fluids mechanics"

Grenoble 14-18 September 2015

http://www.tec21.fr/summer-school/

Objectives:

Important societal issues require to solve problems in mechanical and process engineering of increasing complexity. A key vector of progress relies on multi-scale and multi-physics approaches. The aim of this summer school is to make an overview of the different approaches, advanced numerical and experimental techniques allowing to tackle this complexity. All the courses will be illustrated through various recent examples. One day will be dedicated to practical exercises on « high tec demonstrators » based on the most up-to-date techniques and methods developed by partner laboratories of Tec21. Finally, a focus on the « fluid-solid transition » topic is proposed.

Programme overview:

	Monday	Tuesday	Wednesday	Thursday	Friday
	Multiscale approaches in mechanics	Numerical and experimental tools and methods	Advanced multi-scale and multi-physics problems	High-tech lab-courses (6 parallel sessions)	Focus on « fluid-solid transition »
9:00	Turbulent flows	Turbulence metrology	FEM x DEM approach in geomechanics	Turbulence and particle transport Behaviour of granular materials	Invited Lectures D. Bonn (Univ. Amsterdam)
10:50	Multiphase flows	Numerical prediction of turbulent flows	Suspensions of soft particles	Red blood cells in a model network	A. Mangeney (IPGP, France)
	Buffet lunch served from 12:30 to 14:00 every day in the lobby of the laboratory LEGI				
14:00	Rheology of suspensions	Advanced experimental solid mechanics	Solidification of metallic alloys	Dense gravitational flow 3D imaging of woven fabric	P. Claudin (PMMH, ESPCI, Paris)
15:50	Homogenisation of heterogeneous materials	Advanced numerical solid mechanics	Presentation of the high-tech lab - courses	Biobased polymers and composites	B. Metzger (IUSTI, Marseille)

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Monday 14th September 2015
« Multiscale approaches in mechanics »

8h15 -8h45: *Coffee*

8h45 -9h00: Introduction

9h00 -10h30: A brief introduction to fluid turbulence

Lecturer: Mickaël Bourgoin (LEGI)
Abstract: In spite of centuries of active research Turbulence remains one of the deepest mysteries of fluid mechanics. The complexity relies on the random and multi-scale nature of the phenomenon. This lecture will review the origin and the characteristics of fluid Turbulence, as well as the phenomenological framework and statistical tools commonly used to describe the phenomenon. These rely on the concept of energy cascade, introduced by L. Richardson in the 1920's, later refined by A. Kolmogorov, who's ideas still dominate the Turbulence research community.


"Turbulenza" (L. Da Vinci)

10h30 -10h50: *Coffee break*

10h50-12h20: Multiphase flow

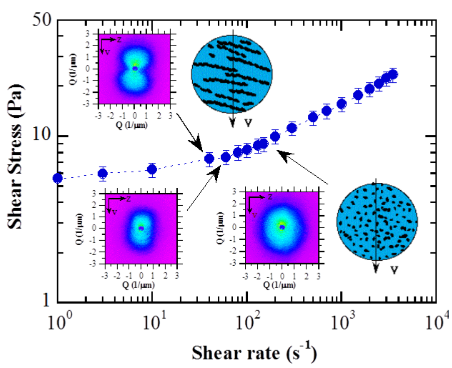
Lecturer: Daniele Marchisio (Politecnico di Torino)
Abstract: The lecture will concern some aspects of the dynamics of dispersed flows and of their modelling. Following the dusty gas approach, various two-fluid models have been developped since the 70's in a variety of frameworks (namely Euler-Euler, Euler-Lagrange, Kinetic theory) for connecting the dynamics at a microscopic scale (i.e. at the scale of a particle) with the macroscopic behaviour. Today, such models are extensively exploited by engineers when dealing with flows charged with solid particles, droplets or bubbles. The current prediction capability of such approaches will be reviewed, and important open issues, such as the representation of collective effects, will be debatted in connection with experiments.


Bubbly flows at low (1.6%, left) and high (45%, right) void fractions.

12h20 -14h00: *Lunch*

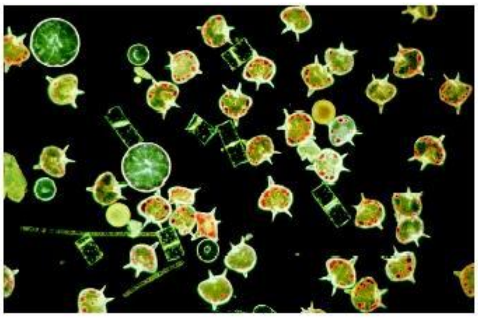
14h00 -15h30: Structure and flow properties of colloidal suspensions: combination of in-situ scattering and rheometric techniques

Lecturer: Frédéric Pignon (LRP)
Abstract: courses objectives are the characterization of the link between the flow mechanical properties (flow field, shear or extensional stresses, viscoelasticity moduli) and the structural organizations (aggregation, orientation, phase changes). The goal is to bring an understanding of the mechanisms controlling the flows properties of colloidal dispersions used in several processes (membrane separation, extrusion, film casting) involved in several industrial applications (chemical, bio- and agro-industries, pharmaceutical, water treatment,…).



Hydrodynamics of suspensions - when particles come to life

Lecturer: Philippe Peyla (LIPhy)

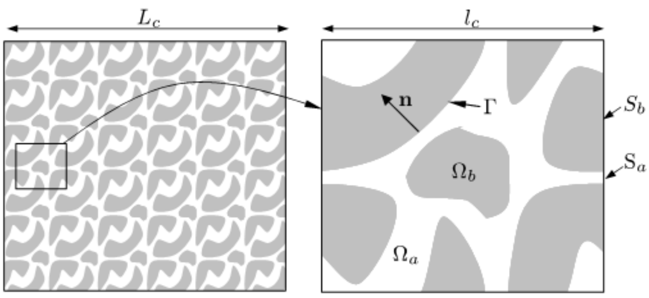


Abstract: Suspensions are encountered in nature as well as in various industrial processes. Suspensions refer to particles immersed in a liquid like mud, fresh concrete, blood, paints or ink to site but a few examples. A very recent interest with an exponential growing number of publications concerns active suspensions where particles can actively swim in the liquid phase like planktonic suspensions. Usually, the small size of the particles often means that the surrounding flow is dominated by viscous effects, and therefore that inertial forces can be neglected relative to viscous forces. This means that the Reynolds number associated with the particles is small and the flow can be considered as a Stokes flow. The present course aims at providing a physically based introduction to the dynamics of particulate suspensions and focuses on hydrodynamical aspects. We will also briefly summarize recent researches concerning active suspensions.

15h30 -15h50: *Coffee break*

15h50 -17h20: Homogenization of coupled phenomena in heterogeneous materials

Lecturer: Christian Geindreau (3SR)



Abstract: The macroscopic mechanical behaviour of heterogeneous material strongly depends on the arrangement of the constituents according to various microstructures (granular or porous media, fibrous network) and the physical phenomena involved at the microscale (heterogeneity scale). A fine scale description of such material is often impossible due to the large number of heterogeneities. In practice, a macroscopic equivalent modelling is more efficient. An overview of the different methods that can be used to derived such equivalent macroscopic behaviour is given.

17h30 - 20h00: *Poster session / Apéro*

--------- List of the posters ---------

- Étude de schémas numériques semi-implicites pour le couplage fluide-structure eulérien, Sengers A, *et al.*
- Reflection of internal waves from a slope, Raja K, *et al.*
- Numerical Modelling of Mechanical Behaviour of Cellulose Microfibrils in a Fluid Flow, Kunhappan D, *et al.*
- Pore-scale modeling of two-phase flow in deformable porous media, Yuan C, et al.
- Melt extrusion of Tempo oxidised cnc with hydropobic polymers, Nagalakshmaiah M, *et al.*
- Continuum elasto-plastic modeling of amorphous solids under steady shear, Karimi K, *et al.*
- A rheological study of Lignosulfonate and its mixed suspensions with microfibrillated cellulose for 3D impression, Shao Y, *et al.*
- Effect of TTAB cationic surfactant on foaming and stability of illite clay micro-aggregates foams, Chapelain J, *et al.*
- Joint investigation of settling and preferential concentration of inertial particles in turbulence, Sumbekova S, *et al.*
- Forces experienced by the walls of a lid-driven cavity, Kneib F, *et al.*
- Occlusion dynamics in sickle cell disease, Audemar V, *et al.*
- A micro-mechanically based multi-scale model for granular materials, Veylon G, *et al.*
- On the 3D Extension of the Micromechanically-based H-model, Xiong H, *et al.*
- Internal dynamics of a free surface viscoplastic flow, experimental results through PIV measurments, Freydier P, *et al.*
- CELLDIFF: Stimuli Responsive Nanocellulose Based Matrices for Differentiating Cell Growth, Smyth M, et al.
- Heat and mass transfer modelling for gypsum board exposed to fire, Dauti D, *et al.*
- Couplage Fluide-Structure pour la simulation numérique de l'écoulement d'un fluide dans une conduite

à parois élastique, Achab L, *et al.*

- Study of the role of concentration and molecular weight on fiber morphology, Aljaber K G J, *et al.*
- Description of the mechanical response of soils subjected to a process of internal erosion by suffusion, Aboul Hosn R, *et al.*
- Fibrinogen purification impacts fibrin ultrastructure, *Garcia X, et al.*
- Caractérisation des conditions hydrodynamique et de l'organisation structurale dans le dépôt créé lors d'ultraifiltration tangentielle assistée par ultrasons, Rey C, *et al.*
- Amoeboid swimming in confined geometry, Wu H, *et al.*
- Hydrodynamic dispersion of microswimmers in suspension, Martin M, *et al.*
- A non-linear flow rheology study of tissues, Matoz D, *et al.*
- Dynamic properties of soft fibrous biomaterials for the design of biomimetic oscillators: application to vocal tissue, Cochereau T, *et al.*
- An inversion method to extract basal friction law of granular flows and snow avalanches, Pulfer G, *et al.*
- Vibro cpt, Hosseini Sadr Abadi H, *et al.*
- Observation 3D et in situ par microtomographie à rayons X de la rhéologie de composites polymères renforcés par des fibres courtes, Laurencin T, *et al.*
- Investigation of the multi-scale interactions between an offshore wind turbine wake and the ocean-sediment dynamics in an idealized framework, Nagel T, *et al.*
- Microstructure and rheology of SMC, Ferré Sentis D, *et al.*
- Fluid-Structure Interaction in Cavitation Erosion, Paquette Y, *et al.*
- The influence of wave breaking depth on longshore sediment transport modelling on a macrotidal beach, Oudart T, *et al.*
- An experimental lagrangian study of inhomogeneous turbulence, Stelzenmuller N, *et al.*

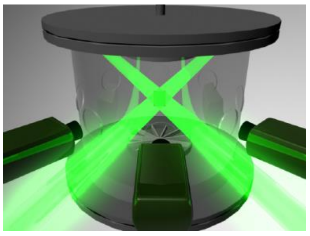
Tuesday 15th September 2015
« Numerical and experimental tools and methods »

8h30 -9h00: *Coffee*

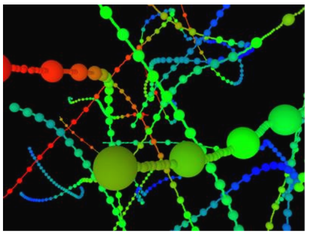
9h00 -10h30: A brief review of turbulence metrology

Lecturer : Mickaël Bourgoin (LEGI)

Abstract : Because of its intrinsic multi-scale nature, the experimental characterization of turbulence requires dedicated metrological tools, capable to resolve (simultaneously if possible) the whole range of relevant involved scales (both in time and space). The present lecture will review the main contemporary instruments used by the scientific community for such high resolution and multi-scale diagnosis. These include Eulerian methods (such as hot-wire anemometry, laser-Doppler velocimetry and Particle Image Velocimetry) as well as new Lagrangian methods, based on acoustical and optical 3D particle tracking.



High resolution 3D Lagrangian particle tracking system



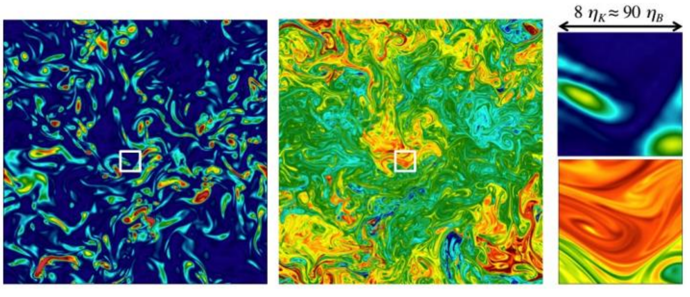
Experimental reconstruction of particles trajectories

10h30 -10h50: *Coffee break*

10h50 -12h20: Numerical prediction of turbulent flows

Lecturer: Guillaume Balarac (LEGI)

Abstract: Turbulent flows are characterized by a large range of motion scales. When turbulent flows are studied by numerical simulations, the explicit discretization of the overall range of scales is still an issue, even with the exponential rise in computational capability over the last few decades. In this presentation, some methods to overcome this limitation will be presented. The methods can consist to model a part of the turbulent fields (RANS and LES approaches), but the methods can also consist to develop numerical algorithm to allow direct numerical simulation with a lower computational cost (hybrid method for turbulent mixing).

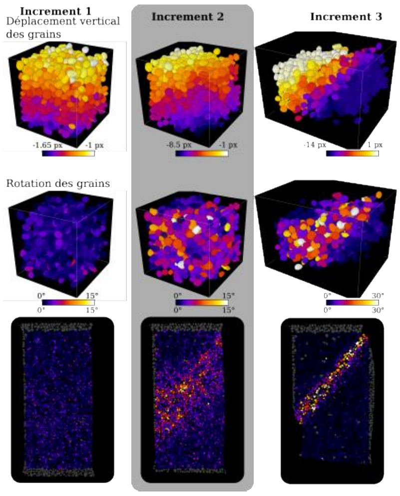


12h20 -14h00: *Lunch*

14h00 -15h30: Full-field methods and multi-scale approaches in experimental solid mechanics

Lecturer: Cino Viggiani (3SR)

Abstract: Various advanced modeling approaches have been proposed to describe intriguing phenomena in solid mechanics, including: higher-order continuum approaches to characterize, for example, strain localization; multi-scale approaches involving homogenization of explicitly modeled micro-scale mechanics; discrete element models that attempt to model granular systems from the grain-scale upwards. However, such models require experimental results, at the appropriate scales, with the appropriate sensitivities and under the appropriate loading conditions, to identify and characterize the important mechanisms controlling the material responses, to provide ground truth and to identify model input parameters. Unfortunately, traditional experimental methods often fall short of providing the necessary data for the increasingly ambitious modeling approaches. To address such shortcomings, new (advanced) experimental methods have been under development in recent years. This lecture summarizes some of the key developments in this area, with specific examples mostly (but not only) from geomechanics.

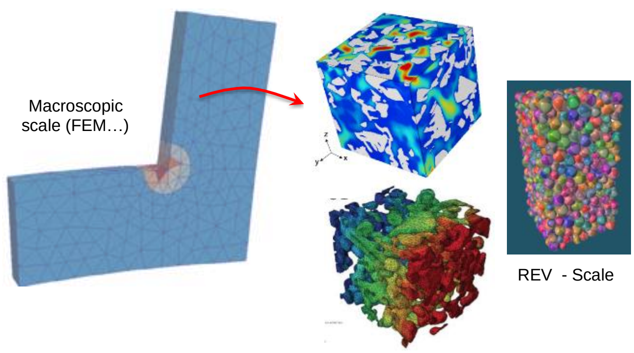


15h30-15h50: *Coffee break*

15h50 -17h20: Numerical investigations of macroscopic behaviour of heterogeneous materials

Lecturer: Bruno Chareyre (3SR)

Abstract: The macroscopic effective properties or behaviour of heterogeneous materials are commonly invstigated by solving specific boundary value problem on Representative Elementary Volume (i.e. at the microscale) arising from the homogenization process. Nowadays, these boundary value problems (BVP) are commonly solved on 3D images of the material obtained by microtomography or idealized microstructure. Different numerical methods (Finite volume differences, Finite Element method, Discret Element method…) can used to solved the BVP. An overview of these methods is presented and illustrated.



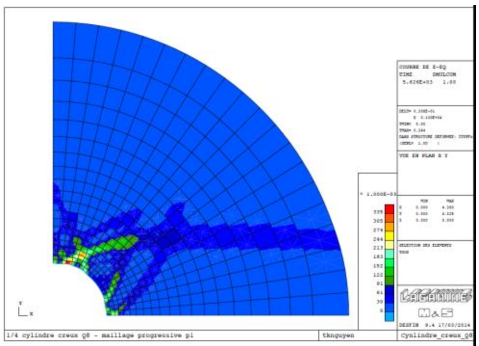
Wednesday 16th September 2015
« Advanced multi-scale and multiphysics problems»

8h30 -9h00: *Coffee*

9h00 -10h30: FEMxDEM double scale integrated approach in Geomechanics

Lecturer : Jacques Desrues (3SR)

Abstract : Recently, multi-scale analysis using a numerical approach of the homogenisation of the microstructural behaviour of materials to derive the constitutive response at the macro scale has become a new trend in numerical modelling in geomechanics. Considering rocks as granular media with cohesion between grains, a two-scale fully coupled approach can be defined using FEM at the macroscale, together with DEM at the microscale [1,2,3]. In this approach, the micro-scale DEM boundary value problem attached to every Gauss point in the FEM mesh, can be seen as a constitutive model, the answer of which is used by the



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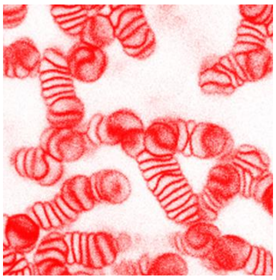
FEM method in the usual way. A first major advantage of two-scale FEM-DEM approach is to allow one to perform real-grain-size micro-structure modelling on real-structure-size macroscopic problems, without facing the intractable problem of dealing with trillions of grains in a fully DEM mapped full-field problem. A second one is that using this approach, microscale related features such as the inherent and induced anisotropy of the material, or material softening/hardening with strain, naturally flow from the microscale DEM model to the macroscale FEM model. Arguably, multi-scale numerical approaches may suffer from computational cost penalty with respect to mono-scale one. However, high performance computing using parallel computation schemes offers solutions to mitigate the computational cost issue. An implementation of the FEM-DEM method in a well-established, finite strain FEM code is presented, and representative results are discussed, including aspects related to strain localisation in this context. High Performance Computing implementation and performances are illustrated.

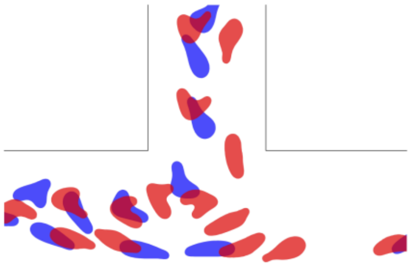
[1] Nitka M., Combe G., Dascalu C., Desrues J. Two-scale modeling of granular materials: a DEM-FEM approach, Granular Matter vol.13 No 3, pp. 277-281, (2011)
[2] Nguyen T.K., Combe G., Caillerie D., Desrues J. FEM x DEM modelling of cohesive granular materials: numerical homogenisation and multi-scale simulation, Acta Geophysica vol.62 No 5, pp. 1109-1126, (2014)
[3] Guo Ning and Zhao Jidong. A coupled FEM/DEM approach for hierarchical multiscale modelling of granular media. International Journal for Numerical Methods in Engineering 99.11, 789-818 (2014)

10h30 -10h50: *Coffee break*

10h50 -12h20: Suspensions of soft particles

Lecturer: Thomas Podgorski (LIPhy)



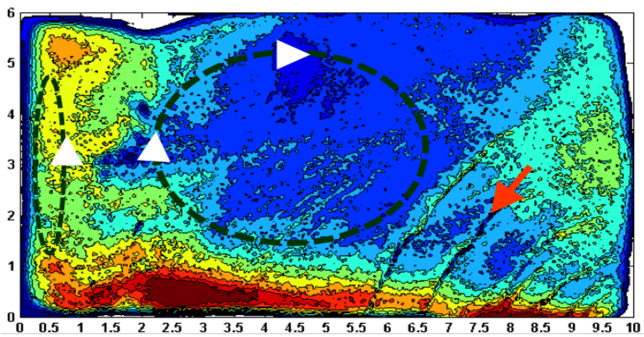


Abstract: Many complex media of biological or industrial interest are composed of soft particles embedded in a fluid (droplet emulsions, bubbly fluids, blood – a suspension of red blood cells). The mechanical properties of these particles and their interactions lead to complex rheological properties (shear thinning, shear thickening, yield stresses, viscoelasticity) as well as rich microscopic dynamics involving migration or segregation for instance. At the modelling and simulation level, specific challenges arise from the deformability of particles which involves solving solving fluid and solid mechanics equations in multiple coupled domains with moving boundaries. We will review the hydrodynamic and rheological properties of these suspensions through several examples, as well as the principle of a few modelling methods that have emerged to investigate these questions.

12h20 -14h00: *Lunch*

14h00 -15h30: Solidification of metallic alloys: a multiscale multiphysic phenomenon

Lecturer: Yves Fautrelle (SIMAP)



Solute composition map in a Tin-Lead alloy ingot solidified from the lateral sides. Digitalized X-ray image. Dimensions of the ingot 10×6×1cm³. The red color corresponds to the positive segregations.

Abstract: Mastering solidification is one of the main targets in process metallurgy. Mastering encompasses elimination of the various defects as well as the control of the solidified structures. Solidification involves multiphysics aspects like heat transfer, solute transport, phase change, thermodynamics, fluid flow, sometimes electromagnetism. The phase change may occur with several morphologies such as dendritic columnar structures or/and equiaxed grains moving in the liquid, a transition zone analogous to a porous medium between the liquid bulk and the solid, the so-called mushy zone. Liquid metal flows existing both in the bulk and in the mushy zone are one of the key parameters. Another major complexity originates from the multiscale nature of the phenomenon. The length scales may vary from the scale of the device, typically several meters, to the microscales, a few microns. Finally, natural convection is transitional even turbulent (especially when electromagnetic stirrers are used in the process). Numerical modeling is a mandatory tool in order to understand and master the solidification processes. They will be briefly discussed. However, only partial modelling can be performed in a given range of scale. As far as macro/meso-scales are concerned, numerical models based on

spatial/ensemble averaging methods have been developed so far. They have proved to be quite efficient, but the parametrization of small scales still remains an issue. As for the small scales, i.e., dendrites, phase field models are well developed, but the results are still somewhat qualitative. All those aspects will be discussed. Examples of numerical modelling achieved with various methods will be presented.

15h30 -15h50: *Coffee break*

15h30 -17h00: **Introduction of the practical works that will be held on Thrusday**

Tuesday 17th September 2015
« High-tech lab-courses »

8h30 - 9h00: *Coffee*

9h00 - 12h20: **Practical works**

12h20 -14h00: *Lunch*

14h00 -18h00: **Practical works**

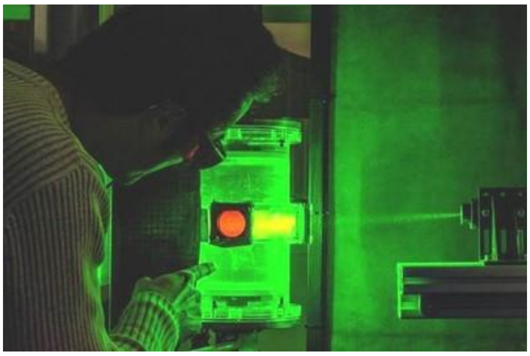
19h30: *Gala dinner*

--------- List of the different practical works ---------

Practical Work 1: Initiation to fluid turbulence

Lecturer: Henda Djeridi / Nicolas Mordant / Guillaume Balarac (LEGI)

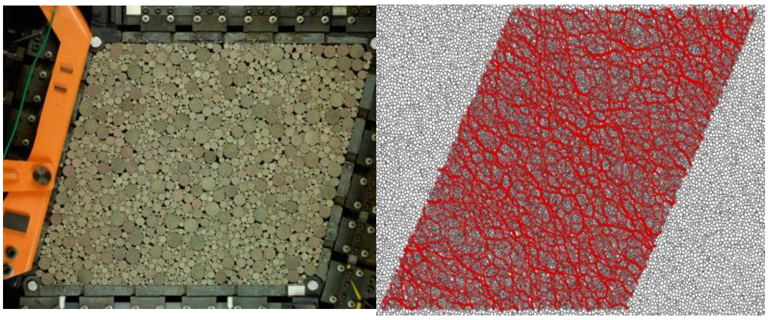
Abstract: Turbulence is a canonical example of multi scale phenomenon. This multi scale character is actually at the very center of the phenomenological theory of turbulence by Kolmogorov. During this lab course, the trainees will be initiated to the PIV (Particle Image Velocimetry) measurement technique that provides 2D spatial maps of a flow or to hot wire anemometry. We will focus on the wake behind a simple object like a cylinder. This introduction to major experimental techniques in fluid mechanics (and to their limitations) will be augmented by an initiation to numerical techniques (and the issues associated to them) such as direct numerical simulations, RANS method, or Large Eddy Simulations.



Practical Work 2: Experimental and numerical behavior of granular media – multiscales analyses

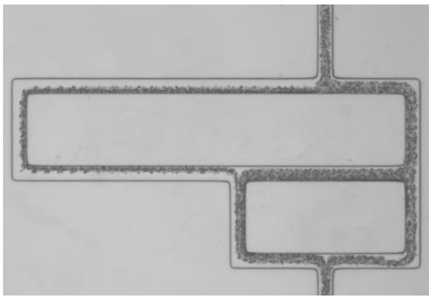
Lecturer: Gael Combe (3SR)

Abstract: In this practical session, we will perform shear tests on a 2D granular media with the help of the device called 1γ2ε. This unique apparatus allows to apply various loading paths on granular assemblies made of rods. By means of a 80 MPixels camera, discrete kinematics field will be assessed and analyzed. Comparisons between experimental and numerical simulations by means of Discrete Element Modeling will also be performed. The multiscale kinematic behavior will then be discussed.



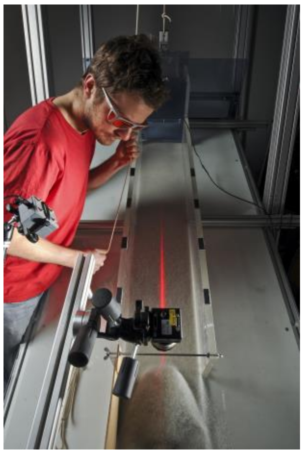
Sheared granular assembly of 2D grains – 1γ2ε device (left). Sheared granular assembly of 2D grains and contact forces – DEM (right)

Practical Work 3: **Red blood cells distribution in a model network**



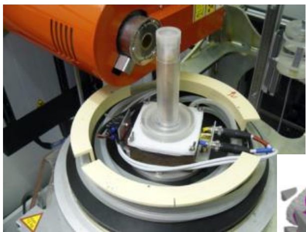
Lecturer: Gwennou Coupier (LIPhy)
Abstract: One of the functions of the vascular system is to bring oxygen to the body via the red blood cells. The vascular system consists of a large number of vessels subdividing themselves in increasingly small vessels, where the distribution in cells is highly heterogeneous. The purpose of this practical work is to measure these heterogeneities in a simplified artificial network, where real blood samples will be injected. The results will then allow comparison with existing models from the literature.

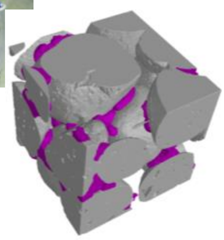
Practical Work 4: **Dense gravitational flows**



Lecturers: Thierry Faug, Mohamed Naaim, Guillaume Chambon (Irstea)
Abstract: The aim of this TP is to tackle the problem of the modeling of dense gravitational flows dynamics. Dense avalanches of granular materials will be produced and analyzed with the help of a laboratory inclined plane equipped with advanced instrumentation: granular PIV, fringe projection, etc. The experimental granular avalanche-flows will then be reproduced by numerical simulations based on shallow-flow (Saint-Venant) equations. Emphasis will be placed on comparing the propagation and final stopping of laboratory and numerical avalanche-flows, with the objective to infer the relevant rheological parameters of the studied granular fluid. (crédit photo: H. Raguet)

Practical Work 5: **3D imaging of a woven fabric under deformation using X ray tomography**





Lecturers: Sabine Rolland du Roscoat / Laurent Orgéas (3SR)
Abstract: The aim of this module is to emphasize the interest of coupling 3D imaging and fine scale fluid flow simulation to estimate the both the microstructures and the permeability of fibrous reinforcements commonly used in fiber reinforced composites or geotextiles . A woven fabric will be subjected to a tensile loading with a mechanical testing machine placed inside a X-ray microtomograph, allowing the 3D in situ observations of the fibrous microstructure of the textile during its deforrmation. The microstructure will be then finely characterized using 3D image analysis subroutines provided by the freeware ImageJ (Fiji). Therefrom, the permeability of the initial and deformed fibrous reinforcements will be estimated from fluid flow simulation inside the imaged fibrous microstructures using a finite volume CFD software (GeoDict).

Practical Work 6: **Preparation and thermo-mechanical characterization of thermoplastic bio-based polymers and composites**

Lecturer: Julien Bras (LGP2)
Abstract: This practical course is organized in 2 parts. The first one deals with processing of different bio-based materials using different techniques like twin-screw extrusion or thermopressing. Biodegradable polymers and natural fiber will be performed. A 3D converting using thermopressing might be expected. The second part of the practical work will focus onto biocomposites characterization using DMA and DSC in order to check the influence of fibre addition onto end-use materials properties.

Friday 18th September 2015
Focus « Solid-fluid transition»

8h30 - 9h00: *Coffee*

9h00 - 9h45: Yield stress and jamming
Speaker: Daniel Bonn (University of Amsterdam)

9h45 - 10h10: Dynamical transition from fluid to gel of anisotropic colloids under simultaneous shear flow, pressure and ultrasound during cross-flow ultrafiltration
Speaker: Frédéric Pignon (LRP)

10h10 -10h40: *Coffee Break*

10h40 - 11h25: Static/mobile transition and erosion processes in dry granular flows : laboratory experiments and modelling
Speaker: Anne Mangeney (IPGP, Paris)

11h25 - 11h50: Acoustic and electrical proxys for monitoring solid-fluid transition in clayey landslides
Speaker: Guillaume Chambon (IRSTEA)

12h00 -13h30: *Lunch*

13h30 -14h15: Rheology and jamming of granular systems and suspensions
Speaker: Philippe Claudin (PMMH, ESPCI, Paris)

14h15 - 14h40: Continuous modeling of solid fluid transition: finite element applications to landslide
Speaker: Frederic Dufour (3SR)

14h40 -15h00: *Coffee Break*

15h00 - 15h45: Physical origin of the shear-thickenning transition
Speaker: Bloen Metzger (IUSTI, CNRS, Marseille)

15h45 - 16h10: Grain-fluid mixtures: the solid-fluid non-transition
Speaker: Bruno Chareyre (3SR)

16h10: Closing remarks

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--------- List of the participants ---------

Speakers and lecturers

Second name	First name	email address
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