Banff International Research Station
for Mathematical Innovation and Discovery

Mathematical Modelling of Particles in Fluid Flow
August 18 - 22, 2014

MEALS

*Breakfast (Buffet): Sally Borden Building, Monday – Friday
*Lunch (Buffet): Sally Borden Building, Monday – Friday
*Dinner (Buffet): Sally Borden Building, Sunday – Thursday
Coffee Breaks: As per daily schedule, in the foyer of the TransCanada Pipeline Pavillion (TCPL)

***Please remember to scan your meal card at the host/hostess station in the dining room for each meal.**

MEETING ROOMS

All lectures will be held in the lecture theatre in the TransCanada Pipelines Pavilion (TCPL). An LCD projector, a laptop, a document camera, and blackboards are available for presentations.

SCHEDULE

Sunday

16:00	Check-in begins (Front Desk – Professional Development Centre - open 24 hours)
17:30-19:30	Buffet Dinner, Sally Borden Building
20:00	Informal gathering in 2nd floor lounge, Corbett Hall
	** Beverages and small assortment of snacks are available on a cash honour system. **

Monday

7:00-8:45	Breakfast
8:45-9:00	Introduction and Welcome by BIRS Station Manager, TCPL. Organizers' Opening remarks
	Session Chair: Jim McElwaine
9:00-10:00	**Eckart Meiburg**: *Double-diffusive sedimentation*
10:00-10:30	Coffee Break
10:30-10:50	**Ian Frigaard**: *Particulate flows in oil and gas well construction and stimulation*
10:50-11:10	**Bruce Sutherland**: *Turbidity Currents in Stratified Ambients*
11:10-11:30	**Jos Derksen**: *Particle-resolved simulations of solid-liquid systems including mass transfer*
11:30-11:50	**Andrew Woods**: *Particle transport in volcanic flows*
12:00-13:00	Lunch
	Session Chair: Nathalie Vriend
13:00-14:00	Guided Tour of The Banff Centre; meet in the 2nd floor lounge, Corbett Hall
14:00-15:00	**Andrew Hogg**: *The flow of fluidised particles*
15:00-15:30	Coffee Break
15:30-15:50	**Angelo Iollo**: *Numerical modelling of particles in fluid flow on Cartesian meshes*
15:50-16:10	**Eric Climent**: *Numerical modelling of particulate flows (passive and active suspensions)*
16:10-16:30	**Nicola Mingotti**: *Steady-state particle transport in a displacement-ventilated enclosure*
16:30-17:30	Discussions ("Questions from a hat")
17:30-19:30	Dinner

Tuesday

7:00-9:00 Breakfast

Session Chair: Ian Frigaard
9:00-10:00 **Rama Govindarajan**: *Droplets: sinking/rising under gravity; clustering; imparting buoyancy*
10:00-10:30 Group Photo and Coffee Break
10:30-10:50 **Eric Shaqfeh**: *Viscoelastic fluid suspension problems in fracking and drilling*
10:50-11:10 **David Rival**: *Characterizing the turbulence modification from red blood cells in free shear layers using Particle Tracking Velocimetry*
11:10-11:30 **Kai Schneider**: *Spectral analysis of penalized Laplace and Stokes operators*
11:30-11:50 **Gautier Verhille**: *Flexible fibers in turbulent flows*

12:00-14:00 Lunch
14:00-17:30 Informal discussions and free time
17:30-19:30 Dinner

Wednesday

7:00-9:00 Breakfast
Session Chair: Eckart Meiburg
9:00-10:00 **Jim McElwaine**: *Particle sedimentation and resuspension in geophysical flows*
10:00-10:30 Coffee Break
10:30-10:50 **Francois Blanchette**: *Simulating a moving interface between porous media and pure fluid*
10:50-11:10 **Georges-Henri Cottet**: *Fluid-structure and solid-solid interactions by level set methods*
11:10-11:30 **Sarah Hormozi**: *Shear-induced particle migration in yield stress fluids*
11:30-11:50 **Anthony Wachs**: *Fully-resolved simulation of particulate flows: so close yet so far?*

12:00-14:00 Lunch
Session Chair: Rama Govindarajan
14:00-15:00 **Anne-Virginie Salsac**: *Fluid structure interaction of a microcapsule in flow*
15:00-15:30 Coffee Break
15:30-15:50 **Kumbakonam Rajagopal**: *Modeling the flows of fluids infused with particles within the context of the theory of interacting continua*
15:50-16:10 **Barbara Turnbull**: *Powder snow avalanches: fed by pore pressures?*
16:10-16:30 **Jeff Peakall**: *The critical role of stratification in long run-out particulate gravity currents*
16:30-17:30 Discussions ("Questions from a hat")

18:00-21:00 Informal gathering at the *Bison Lounge* in the village of Banff for dinner and drinks, for those who want to participate. Dinner is still provided as usual at BIRS.

Thursday

7:00-9:00 Breakfast
Session Chair: Stuart Dalziel
9:00-10:00 **Joseph Monaghan**: *How to simulate several liquids and species of particles using SPH*
10:00-10:30 Coffee Break
10:30-10:50 **Nathalie Vriend**: *Granular segregation in nature*
10:50-11:10 **Ravichandran Sivaramakrishnan**: *Inertial particle caustics in vortical flows*
11:10-11:30 **Stefan Turek**: *Finite element-fictitious boundary methods for the numerical simulation of complex particulate flows*
11:30-11:50 **Howard Hu**: *Magnetically tuned porous electrode formation in electrochemical flow capacitor*

12:00-14:00 Lunch
14:00-17:30 Informal discussions and free time
17:30-19:30 Dinner

Friday

7:00-9:00 Breakfast

Session Chair: Bruce Sutherland

9:00-10:00 **Stuart Dalziel**: *The impact of a droplet on a bed of particles*
10:00-10:30 Coffee Break
10:30-10:50 **Krishnaswamy Nandakumar**: *Enabling process innovation through computation of multiphase particulate flows*
10:50-11:10 **Mijanur Chowdhury**: *Propagation dynamics of mud slurry underflows*
11:10-11:30 **Mona Rahmani**: *Fully resolved simulations of suspension of spherical particles in shear flows*
11:30-12:00 Discussion and concluding remarks by organizers
12:00-13:30 Check-out and Lunch

Checkout by 12 noon.

** Participants are welcome to use BIRS facilities (BIRS Coffee Lounge, TCPL and Reading Room) until 3 pm Friday, although participants are still required to checkout of the guest rooms by noon. **

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Mathematical Modelling of Particles in Fluid Flow
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ABSTRACTS

(in alphabetic order by speaker surname)

Francois Blanchette
Simulating a moving interface between porous media and pure fluid

We present a new numerical method to simulate flows in a domain that is partially filled with a porous medium. This method allows for simulations of systems where the interface between an unimpeded fluid and a porous medium evolves in space and time, such as when a suspension flows over a sandy deposit. Flow in our domain is partially governed by the Navier-Stokes equations, and partially by the Brinkman equations. The stress jump boundary condition at the interface is enforced by a localized forcing term for efficient implementation. We validate our method against known results in simple systems (pipe flow, drag on a porous sphere or cylinder). We then outline how this method will be applied to study erosion patterns and mechanisms in arbitrary geometries, while including flow through the deposit. To address this multi-scale problem, we develop an adaptive approach, where most of the domain considers the fluid velocity through the porous medium to be zero, but a mixed solver resolves flow within the deposit in regions where erosion is likely.

Mijanur Chowdhury
Propagation Dynamics of Mud Slurry Underflows

Flows of slurries with different compositions and rheological properties occur in many geophysical, environmental, and industrial settings. This presentation elucidates the propagation dynamics of subaqueous mud slurry underflows based on a series of large scale experimental investigations that simulates the hydraulic dredge disposal operations. Laboratory experiments were conducted by discharging mud slurry at a constant volume flowrate from a submerged vertical pipe into a pool of water. The discharged fluid mud descended as vertical buoyant jets and flowed away as axisymmetric underflows after impinging on the bottom. The underflows exhibited three well-documented propagation phases: i) a radial momentum-driven wall jet phase near the impingement region, ii) an inertial gravity current phase after the completion of the wall jet phase, and iii) a viscous propagation phase. In this presentation, I will focus on the distinctive differences of the propagation dynamics of mud slurry underflows with the previously observed saline underflows. In particular, I will explain how the viscous propagations phase of mud slurry underflows are influenced by the non-Newtonian rheology of the slurry. An interesting abrupt settling phenomenon in which suspended particles abruptly settle en masse from the slurry underflows with the occurrence of the lutocline will be discussed.

Eric Climent
Numerical modelling of particulate flows (passive and active suspensions)

The talk will be focused on the modelling and numerical simulations of finite-size particles in shear and turbulent flows. The Force coupling (Climent and Maxey, 2009) method will be described in details. This method is based on a low order multipole expansion of finite size forcing terms added to Stokes or Navier-Stokes equations. Particles in turbulence are experiencing shear flows at different scales. The method has been validated on low Reynolds number shear flows (Abbas et al., 2006) and extension to finite Reynolds will be commented in this communication.

For neutrally buoyant particles seeded in transitional pipe flows, Matas et al. (2003) observed changes in the values of the critical Reynolds numbers depending on both the solid volume fraction and the particle-to-pipe size-ratio. Typically, the transition occurs at lower Reynolds numbers when the flow carries macro-sized particles at dilute to moderate concentrations (up to 25%). On the contrary, the critical Reynolds numbers of the onset of transition is shifted towards greater values when particles are micro-sized and their concentration is higher. In this communication, we aim at understanding the mechanisms lying behind the shift of the laminar-turbulent transition regime down to lower critical Reynolds numbers in suspension flows of macro-sized particles.

At the end of the talk, I will show how this method can be extended to active suspensions (such as micro-swimmers).

Georges-Henri Cottet
Fluid-Structure and Solid-Solid interactions by level set methods

In this talk we will first review a general Eulerian framework that has been developed in our grou to dela with the interaction of elastic or rigid bodies in an incompressible flows. In this framework, fluids and objects are part of a single fluid, modeled by the incompressible Navier-Stokes equations, with time and space dependent rheology. The interface between the bodies and the fluids are captured by level sets functions. These level set functions are also used to compute stresses in elastic bodies and contact forces between bodies. We will show some illustrations of this framework for biological, rigid or deforming objects. The talk will then discuss efficient ways to compute contacts in the case of a large number of objects.

Stuart Dalziel
The impact of a droplet on a bed of particles

The impact of a droplet on a granular bed reveals a number of interesting phenomena. Looking from afar, it produces a `splash' that is superficially similar to that of a solid particle, but that raises somewhat more material than might have been anticipated. Closer examination reveals complex dynamics whereby the distortion of the droplet and the coating of its surface by particles play a significant role. This talk presents the results of an experimental study of the impact process alongside various musings on the dynamics.

Jos Derksen

Particle-resolved simulations of solid-liquid systems including mass transfer

Many engineered processes rely on mass transfer between a solids phase and a liquid phase. Agitation and fluidization of dense solid-liquid suspensions are common ways of enhancing transfer rates. Suspensions have large interfacial area and the slip velocities between the phases help in transporting chemical species towards and away from the interfaces. We present detailed simulations of flow dynamics coupled to mass transfer in dense suspensions with explicit resolution of the solid-liquid interfaces. Solid and liquid dynamics are directly coupled through no-slip conditions at the solid particle surfaces and the (resolved) hydrodynamic forces and torques that translate and rotate the particles. The simulations are based on a lattice-Boltzmann scheme equipped with an immersed boundary method (the latter for imposing no-slip at solid surfaces) that captures the two-phase flow dynamics, and a finite-volume scheme on coupled overlapping domains (COD) for mass transfer. In COD, fine â(inner) grids around the particles resolve the thin scalar boundary layers that are the result of high Schmidt numbers in the liquid. They are coupled to a courser background grid. We show - amongst more - the intimate relation between flow conditions and local and overall mass transfer rates in fixed and fluidized beds.

Ian Frigaard

Particulate flows in oil and gas well construction and stimulation

Many different particulate flows arise during oil & gas well construction and stimulation. Here we survey what are some of the main operations of interest industrially, the regimes that are found and other characteristics of the flow. These flows span the range from stationary, through laminar to fully turbulent flows, may involve Newtonian and non-Newtonian fluids and volume fractions that range from dilute to concentrated suspensions. It is a playground. We pick out some particular problems that we are addressing.

Rama Govindarajan

Droplets: sinking/rising under gravity; clustering; imparting buoyancy

The talk is in two parts. The first part is about three-dimensional simulations of an initially spherical single drop of fluid rising under gravity through another fluid. A comprehensive phase diagram of symmetry-breaking and bubble-breaking will be discussed and the connection made to dynamics. We will also ask how a rising bubble rising is fundamentally different from a sinking drop. The second part is about dynamics of droplets in the vicinity of vortices, when the droplets are allowed to grow and shrink. Inertia and thermodynamics are important in the resulting clustering and dynamics. We show that particles can cluster in unexpected regions, and that buoyancy due to phase change can modify the dynamics a lot. The relevance of this work to clouds will be discussed.

Andrew Hogg
The flow of fluidised particles

A gas flow through an ensemble of relatively heavy particles has a significant effect on their collective properties. When the vertical gas flow is sufficiently strong, it is possible for the weight of the particles to be supported fully and the granular material is fluidised. At this transition, there is a reduction in frictional effects generated by collisions and longer sustained contacts between the particles as the drag between the solids and the gas becomes the dominant physical process. Although there has been much recent progress in understanding aspects of dry granular flows down slopes, little attention has been paid to the interactions between the grains and the interstitial gas, but in the scenario investigated by this study, this process dominates the dynamics.

We present new experimental results for the propagation of relatively fine glass particles along a sloping, rigid, but porous surface, through which gas flows and fluidises the particles. We introduce the particles at a constant rate and measure their propagation through the apparatus. Typically they flow as a relatively thin, but highly mobile layer. For a range of angles of inclination, we measure the bulk characteristics of the motion, such as the temporal development of the depth of the layer and the flow speed, and from high-speed videography and particle tracking, we determine the mean velocity of the grains and the velocity fluctuations about the mean. The velocity profiles feature slip at the base, a region of shear and then a plug-flow throughout the rest of the layer, while the level of agitation is quite small.

We analyse these results in terms of a two-phase mathematical model. A key component of this model is the inter-phase drag that leads to the support of the excess weight of the granular layer. However the results indicate that there is also a drag that balances the gravitationally-related force driving the motion parallel to the underlying boundary. We analyse a mathematical model for this force, which is due to granular interactions, and demonstrate that it may account for both the fully-developed velocity profiles and the temporally evolving behaviour measured in the experiments.

Sarah Hormozi
Shear-induced particle migration in yield stress fluids

Dense suspensions are materials with broad application both in industrial processes (e.g. waste disposal, concrete, drilling muds and cuttings transport, food processing, etc) and in natural phenomena (e.g. flows of slurries, debris and lava). These suspensions may consist of solid particles with a broad range of sizes. Often the fine colloidal particles interact to form a shear thinning yield stress carrier fluid, i.e., visco-plastic fluid, which itself transports the coarser solid particles. It is therefore of interest to understand how particles distribute in sheared flows of these non-Newtonian suspensions. We have followed the suspension balance framework of Nott and Brady (J. Fluid Mech. 1994) to develop a model for visco-plastic suspension flows. We show the effect of shear-induced migration on the dispersion dynamics of the particles in both channel flow and circular Couette flow. Moreover, we present results of an experimental study of this type of flow in a circular Couette geometry. We have used a system of non-Brownian spherical hard particles suspended in a concentrated emulsion with yield stress. The transient distribution of particles under shear is measured by an X-ray microtomography and radiography imaging technique.

Howard Hu
Magnetically Tuned Porous Electrode Formation in Electrochemical Flow Capacitor

In our electrochemical flow capacitors (EFCs), high surface area, conducting, magnetizable porous particles suspended in an electrolyte solution flow from one storage tank to another through a charging/discharging device between collecting electrodes (collector). In the collector, the particles quickly aggregate to form percolated, electrically conducting networks that facilitate electron flow. To achieve a highly conductive and rapidly assembling network, a high concentration suspension is needed. To facilitate easy pumping, a low concentration suspension is desired. To speed up the network formation process and overcome these conflicting requirements, we use magnetizable colloids. The particles will acquire a magnetic moment in the presence of an external magnetic field. The magnetic moment will reversibly disappear as soon as the magnetic field is removed. The magnetic field will be applied during the charge and discharge phases to accelerate the formation of electrically connected networks when desired and will be removed when it is time to flow the slurry and refresh the contents in the collector. In this presentation, I will present the study of the network assembly process, and the estimate for the network connectivity and electric properties.

Angelo Iollo
Numerical Modelling of Particles in Fluid Flow on Cartesian Meshes

I will discuss the numerical methods available to model the dynamics and the interaction of particles, passive or active. Precise predictive models of flow of such complex fluids are crucial in many applications ranging from food to aeronautical industry. The paradigm described is based on cartesian meshes, level-sets, accurate treatment of the boundary conditions and massively parallel simulations. Preliminary examples relative to simple particle flows in compressible and incompressible configurations will be presented. In particular I will present numerical models of interacting particles in a Couette flow and in sprays of rarefied flows. This work is in collaboration with Michel Bergmann and Lisl Weynans also present at this workshop.

Hubert Klahr
Particle laden Flows, Streaming Instability and the Formation of Planets

A key process in the formation of planets is the accumulation of gravel sized dusty and icy material in the gaseous nebula around the young sun. Magneto-Hydrodynamical as well as classical Hydrodynamical instabilities create zonal flows and vortices that locally concentrate solid material from initial dust to gas ratio of 1:100 to 1:1, at which point the dynamics of the gas are dominated by the frictional feedback from the dust grains and a streaming instability is triggered. That instability leads to local densities in the solids that are above the Roche density, at which the self-gravity of the dust and ice mixture forms 100 km planetesimals, the building bricks for a solar system.

Jim McElwaine
Particle Sedimentation and Resuspension in Geophysical Flows

Avalanches, turbidity currents, debris flows and pyroclastic flows are all gravity currents driven by the weight of solid particles. How these particles move vertically within the flow, including their entrainment and deposition, critically effects the flow dynamics. For example a debris flow where the solid particles are fully suspended is much more mobile than one where granular friction is dominant. In other flows a two layer structure often occurs with a dilute particle cloud above a shallow dense layer. We formulate a simple model that can reproduce this behaviour and show the results of direct numerical simulations. We give a comparison with lab experiments and field data and show how these effects can be incorporated in shallow water models.

Eckart Meiburg
Double-diffusive Sedimentation

When a layer of particle-laden fresh water is placed above clear, saline water, both double-diffusive and Rayleigh-Taylor instabilities may arise. We explore the nonlinear regime of such processes by means of two- and three-dimensional direct numerical simulations (DNS). The presence of settling particles modifies the traditional double-diffusive fingering by creating an unstable 'nose region' containing both salt and sediment. When the ratio of the unstable layer thickness to the diffusive interface thickness of the salinity profile is small, double-diffusive fingering dominates, while for larger values the sediment and salinity interfaces become increasingly decoupled and the dominant instability mode becomes Rayleigh-Taylor-like.

The vigorous growth of individual fingers is followed by their collective instability, and eventually by the formation of intense plumes that become detached from the interfacial region. For Rayleigh-Taylor-dominated situations, the flow exhibits a phase-locked fingering mode, corresponding to the 'leaking mode' observations by earlier authors. While this mode has the same spectral content as the traditional fingering mode, the large-scale convective overturning generated by the Rayleigh-Taylor mode creates a phase-locking that results in very thin, wisp-like plumes released from the base of the unstable layer.

Nicola Mingotti
Steady-state particle transport in a displacement-ventilated enclosure

In low-energy buildings, displacement ventilation is frequently used to extract warm exhaust air through a vent located at a high level in a room, while fresh air is supplied at a lower level. As a result of such a ventilation scheme, the room becomes thermally stratified. There has recently been considerable interest in the transport of particulate through the ventilation system of healthcare buildings, as a mechanism to spread infection. In this talk a series of new experiments are presented which explore the transport of heavy particles by such displacement ventilation flow. Using an image processing technique, the evolution of the particle concentration through the space is explored under conditions of large and small ventilation flow rate. The results of the experiments are compared with a series of new models based on the dynamics of turbulent buoyant plumes in confined environments.

Joseph Monaghan

How to simulate several liquids and species of particles using SPH

SPH (smoothed particle hydrodynamics) is a particle method that replaces a fluid by a set of particles that interact according to the equations of fluid dynamics. In this talk I will describe how SPH can be used for problems involving liquids containing particulate matter which I refer to as dust. The dust particles are considered sufficiently numerous to allow them to be treated collectively as a fluid which is represented by a set of SPH particles which interact with the fluid SPH particles by drag terms. Solid bodies (stirrers) can also be handled by replacing them by SPH particles in a straightforward way.

Krishnaswamy Nandakumar

Enabling process innvoation through computation of multiphase particulate flows

Multiphase flows are ubiquitous in chemical, mineral processing, food processing and materials processing industries. Our traditional approach has been to ignore fluid dynamical effects by invoking simplifying assumptions of homogeneity, but pay the price during scale-up of processes through pilot scale experiments. The questions that I address in this presentation are "Can Multiphase flow modeling come to our rescue in minimizing the need for pilot scale experiments? Can it lead to process innovation similar to what has happened in aerospace and automotive industries?" I will present an overview of our research in using computational fluid dynamics to explore multiphase flows. On the fundamental side, we have developed advanced algorithms for direct numerical simulation (DNS) and Discrete Particle Modelling (DPM) of multiphase flows. For dispersed rigid particles as in suspension flows, sedimentation etc, we couple the Navier-Stokes equations with the rigid body dynamics in a rigorous fashion to track the particle motion in a fluid. For deformable bubbles/droplets dispersed in another fluid, we also track their motion in an Eulerian grid. These classes of algorithms show great promise in attempting to shed light on multiphase flows with many particles or droplets, from which we can extract statistically meaningful average behaviour of suspensions or bubbly flows.

On the other hand, there is an immediate need to study flow of complex fluids of industrial importance. Such cases include the recent oil spill modelling, polymer blending processes involving melting, deformation and break-up, corrosion-erosion in pipelines and process vessels, mass transfer in packed beds with random and structured packing or in Sieve trays. In such studies we use volume averaged equations as the basis of flow models coupled with experimental validation of such predictions in an effort to develop scale invariant closure models that are needed as part of the volume averaged flow models. We will discuss the merit of this approach and the synergy between these two approaches.

Jeff Peakall

The critical role of stratification in long run-out particulate gravity currents

Submarine particulate gravity currents are able to travel remarkable distances, transporting sediment hundreds or even thousands of kilometres. However, the mechanisms by which flows can be sustained over these distances remain enigmatic. Two shallow water models of submarine channel flows are considered: the first assumes the flow is unstratified whilst the second uses empirical models to describe vertical stratification, which effects depth averaged mass and momentum transfer. The importance of stratification is elucidated through comparison of modelled flow dynamics. It is found that the vertically stratified model shows the best fit to field data from a channelised field-scale gravity current in the Black Sea. Moreover, the stratified flow is confined by the channel to a much greater degree than the flow in the unstratified model. However, even the stratified model fails to accurately represent the flow dynamics, suggesting current empirical stratification models require improvement. It also highlights the limitations of particulate gravity currents at the laboratory scale in describing stratification, and in turn field-scale processes. The results suggest that in real-world channels stratification is critical in enabling maintenance of velocity and sediment suspension, thus explaining how flows can transport sediment remarkable distances.

Mona Rahmani

Fully resolved simulations of suspension of spherical particles in shear flows

Fully resolved simulations of particulate flows give an exact account of fluid and solid phase properties. This is highly desirable when the intention is to study the exact fluid-solid interactions or local stresses and strain rates. Here, we use a Distributed Lagrangian Multiplier/ Fictitious Domain (DLM/FD) method to study the non-Brownian suspension of spherical particles in a plane Couette shear flow in a Newtonian fluid. Such flows have application in many industrial and natural flows, including slurry flows in pipes, sedimentation in channels, mud and concrete flows, and processes of production of cosmetics and food. Here, we consider a plane Couette flow generated by two oppositely moving horizontal planes. The range of particle Reynolds numbers studied is Re_p=0.002 to 20, where Re_p=2 rho U d^2/mu H, with `rho' being the fluid density, and `mu' the fluid viscosity. The range of volume fractions studied here is between phi=0.05 and 0.4. For the suspension as a whole, the total normal and shear stresses are the result of contributions of the fluid and solid phases. The particle stresses, on the microscopic sacale, are the result of hydrodynamic and particle contact stresses. While the local stresses, which can be much higher than global scale ones, govern the dynamics of the flow, for practical reasons it has always been of interest to find a constitutive model that describes the stresses at the macroscopic level. The most well-known model that serves this purpose is the suspension balance model (SBM), e.g. see Nott & Brady, 1994 . Our results show a good agreement with the momentum balance in SBM. We also compare our results for the shear and normal stresses of the whole suspension to previous experimental findings and the Krieger-Dougherty model. Our numerical simulations give us the capability of examining the microscopic features of the flow that contribute to the total stresses, and also to the particle migration.

Kumbakonam Rajagopal

Modeling the flows of fluids infused with particles within the context of the theory of interacting continua

In this talk I will discuss the flow of fluids infused with particles within the context of the theory of interacting continua. The theory provides a basis for studying mixtures wherein balance laws are provided for each constituent of the mixture and wherein a variety of interactions amongst the constituents as well as the possibility of interconversion of the constituents can be taken into account.

David Rival

Characterizing the Turbulence Modification from Red Blood Cells in Free Shear Layers using Particle Tracking Velocimetry

In modeling hemodynamics in large vessels where turbulence may be present, blood is most often assumed to act as a homogenous Newtonian fluid. However, blood presents as a non-homogenous, two-phase viscoelastic suspension on account of the presence of red blood cells (RBC) that comprise approximately 50% of the total blood volume. Past work has demonstrated that viscoelastic flows display turbulence modification through the presence of suspended particles that act to either augment or attenuate turbulent kinetic energy. Specifically, it has been speculated that blood displays prolonged laminar-like behaviour due to RBC presence. However, how RBCs specifically modify turbulence in blood remains unclear. Given this uncertainty, the purpose of the present study is to quantify how RBCs modify the generation of turbulent behaviour in blood. In order to tackle this problem, a novel free shear-layer experiment has been developed in which optically-matched, spherical and deformable beads are used. Glycerine and water are used to scale up the experiment such that Particle Tracking Velocimetry can be performed on tracer particles in between the optically-matched beads. Here the contribution of the deformable beads on the development of the unsteady free shear layer will be quantified and a physical mechanism will be proposed.

Anne-Virginie Salsac

Fluid structure interaction of a microcapsule in flow

A capsule consists of an internal medium enclosed by a semi-permeable membrane that controls exchanges between the environment and the internal contents and has a protection role. Natural capsules are cells, bacteria or eggs. Artificial capsules are widely used in industry (pharmaceutical, cosmetic, food industry, etc) for the protection of active substances, aromas or flavours and the control of their release. They are also used in bioengineering applications, such as drug targeting and artificial organ fabrication.

In most situations, capsules are suspended into another liquid and are thus subjected to hydrodynamic forces when the suspension is flowing. The motion of the suspending and internal liquids creates viscous stresses on the membrane, which lead to its deformation and possible breakup. The three-dimensional fluid-structure interactions may be modelled coupling a boundary integral method (for the internal and external fluid motion) with a finite element method (for the membrane deformation), which we have shown to be a stable and accurate coupling strategy. We will concentrate on the case of ellipsoidal capsules and explore their motion and deformation when subjected to a simple shear flow.

When designing artificial capsules, it is also necessary to control and tune the capsule deformation, so that it has the desired behaviour. We will see how the mechanical properties of microcapsules can be obtained from a microfluidic experiment.

Kai Schneider
Spectral analysis of penalized Laplace and Stokes operators

We report the results of a detailed study of the spectral properties of Laplace and Stokes operators, modified with a volume penalization term to approximate Dirichlet conditions in the limit when a penalization parameter, *eta*, tends to zero. The eigenvalues and eigenfunctions are determined either analytically or numerically as functions of *eta*, both in the continuous case and after applying Fourier or finite difference discretization schemes. For fixed *eta*, we find that only the part of the spectrum corresponding to eigenvalues *lambda* <= eta^{-1} approaches Dirichlet boundary conditions, while the remainder of the spectrum is made of uncontrolled, spurious wall modes. The penalization error for the controlled eigenfunctions is estimated as a function of *eta* and *lambda*. Surprisingly, in the Stokes case, we show that the eigenfunctions approximately satisfy, with a precision O(*eta*), Navier slip boundary conditions with slip length equal to $eta^{1/2}$. Moreover, for a given discretization, we show that there exists a value of *eta,* corresponding to a balance between penalization and discretization errors, below which no further gain in precision is achieved. These results shed light on the behavior of volume penalization schemes when solving the Navier-Stokes equations, outline the limitations of the method, and give indications on how to choose the penalization parameter in practical cases.

R. Nguyen van yen, D. Kolomenskiy and K. Schneider. Approximation of the Laplace and Stokes operators with Dirichlet boundary conditions through volume penalization: a spectral viewpoint. Numer. Math., dx.doi.org/10.1007/s00211-014-0610-8, 2014

D. Kolomenskiy, R. Nguyen van yen and K. Schneider. Analysis and discretization of the volume penalized Laplace operator with Neumann boundary conditions. Appl. Num. Math., dx.doi.org/10.1016/j.apnum.2014.02.003, 2014

Eric Shaqfeh
Viscoelastic Fluid Suspension Problems in Fracking and Drilling

Suspensions of rigid particles in viscoelastic fluids play key roles in many energy applications. For example, in oil drilling the `drilling mud' is a very viscous, viscoelastic fluid designed to shear-thin during drilling, but thicken at stoppage so that the `cuttings' can remain suspended. In a related application known as hydraulic fracturing suspensions of solids called â`proppant' are used to prop open the fracture by pumping them into the well. It is well-known that particle settling in a viscoelastic fluid can be quite different from that which is observed in Newtonian fluids. For example, in a non-Newtonian liquid, the complex rheological properties induce a nonlinear coupling between the sedimentation and shear flow. In the present work, we use (a) simulations of viscoelastic flow past a single, torque-free sphere and (b) immersed boundary simulations of multiparticle suspensions including sedimentation with a cross shear flow to study the effect of carrier fluid elasticity on the drag experienced by a given sphere and thus on its settling rate.

Ravichandran Sivaramakrishnan
Inertial particle caustics in vortical flows

Fluid flows containing inertial particles are commonly found. Inertial particles can change the nature of the fluid flows which carry them. They can do this because of the phenomena of clustering and caustics. We study inertial particle caustics in vortical flows. We study analytically the simplest possible vortical flow containing particles: a single vortex. We find the existence of a critical value for the Stokes number of particles beyond which caustics cannot occur. We then apply this idea to flows with many vortices, and comment about possible implications for the flows of mixtures of water vapour, air, and droplets of water that are clouds.

Bruce Sutherland
Turbidity Currents in Stratified Ambients

Lock-release laboratory experiments are performed to examine particle-laden flows down a slope in salt-stratified ambient fluid. Depending upon the particle size and concentration as well as the ambient stratification and bottom slope, the turbidity current runs down the slope entraining ambient fluid while particles rain out. Eventually the current reaches its level of neutral buoyancy and separates from the slope. Using a box-model, we develop a simple theory predicting the point of separation from the slope, which depends upon the ratio of the entrainment velocity to the particle-settling velocity.

Stefan Turek

Finite Element-Fictitious Boundary Methods for the Numerical Simulation of Complex Particulate Flows

This contribution presents new numerical simulation techniques using a Finite Element approach coupled with the Fictitious Boundary Method (FEM-FBM) for non-stationary multiphase flow configurations in 3D, allowing additionally non-newtonian fluid behaviour. The fluid solution is computed by a FEM Newton-multigrid solver, which has been realized in the open source CFD package FEATFLOW (www.featflow.de), while complex dynamic or static geometrical features of the flow domain as well as solid particles, which interact with the surrounding fluid, are treated by the FBM [1]. This approach allows for the use of structured and unstructured computational meshes which can be static or adaptively aligned by dynamic grid deformation methods. We explain the details of how we can use the FBM to simulate flows with complex geometries that are hard to describe analytically. Stationary and time-dependent numerical examples, demonstrating the use of such geometries are provided. Numerical results for benchmark cases involving a well-known settling sphere benchmark [2] are shown for validation purposes. The results show that the presented method can accurately handle the 3D particulate flow situations, reproduce the experimentally determined values and resolve the associated flow features. We show how our approach can be applied to the numerical simulation of complex particulate flows where a large number of particles is immersed in the fluid domain, including also (swarms of) microswimmers. In applications involving multiple solid particles contact forces between the particles have to be considered. We demonstrate how these contact forces can be determined in a FBM framework and how their calculation can be accelerated using GPU hardware.

[1] R. Muenster, O. Mierka and S. Turek. Finite element-fictitious boundary methods (FEM-FBM) for 3D particulate flow. Int. J. Numer. Meth. Fluids., vol. 69, pp. 294-313, 2012.

[2] A. t. Cate, C. H. Nieuwstad, J. J. Derksen and H. E. A. V. d. Akker. Particle imaging velocimetry experiments and lattice-Boltzmann simulations on a single sphere settling under gravity. Phys. Fluids, vol. 14, no. 4012, 2002.

Barbara Turnbull

Powder snow avalanches: fed by pore pressures?

Recent work has explored the possibility of bed erosion and subsequent particle entrainment into a powder snow avalanche being driven by pore pressures induced within the bed by the avalanche. The avalanche is modelled as potential flow with a source of density that moves at the front speed, with the strength of the source dictated by the rate at which pore pressures overcome the strength of the bed. This approach can predict the bed conditions able to ignite and sustain a powder snow avalanche and the speeds and flow heights that the avalanche can achieve. Some interesting questions remain, in particular linking this 'eruption current' model to classical gravity current models and also in the behaviour of the density-perturbed potential flow field. This presentation introduces this `eruption currentâ€™ model and discusses recent progress in two areas. A) Uncovering the unsteady characteristics of the powder snow avalanche using a free boundary method and B) experimentally identifying the conditions where pore pressures succeed shear as the dominant mechanism to mobilise particles.

Gautier Verhille

Flexible fibers in turbulent flows

Most fundamental works on particle laden flows focused on flows with spherical particles and only a few investigations have been done on anisotropic particles such as spheroids, fibers, etc. Moreover, these investigations were mainly concerned with rigid bodies and focused on particle orientation dynamics or on its statistical distribution for particles smaller or of the order of the Kolmogorov length. However, for an anisotropic particle with high aspect ratio, its flexibility may strongly affect its motion as the bending energy scales as Ed^4/L, where d and L are the diameter and the length of the particle. To understand the particle dynamics, we need not only to study the evolution of its orientation and its center of mass but also analyze and model its spatial conformation. To quantify the influence of particle flexibility, we have designed an experiment devoted to the study of the spatial conformation of a flexible fiber in a turbulent flow. We propose a model for the transition from rigid to flexible regimes as the intensity of turbulence is increased or the elastic energy of the fiber is decreased. Then, intrigued by the posidonia fiber seaballs found on Mediterranean beaches, we will focus on the characterization of fiber aggregates which can form in turbulent flows in concentrated regimes. I will present some recent results obtained on the formation of fiber aggregates in our setup.

Nathalie Vriend
Granular segregation in nature

In this talk, I will present very recent (April 2014) geophysical measurements on the structure of a desert dune. Using Ground Penetrating Radar and sand pit analysis, we image the internal structure of a small (h = 5 m) mobile dune. The layering displays a regular fine pattern of cross-bedding, resulting from diurnal variations or segregation during avalanches on the slipface. Furthermore, a pattern of thicker, more humid, ""organic layers"" are apparent at irregular intervals and are most likely related to large rainfall events. I will continue with some results from laboratory experiments on avalanches that highlight and clarify the segregation phenomena we observe in nature.

Anthony Wachs
Fully-resolved simulation of particulate flows: so close yet so far?

Fully-resolved simulation (FRS) of particulate flows has become rather popular over the past fifteen years for two primary reasons: (i) access to a detailed knowledge in the core of the flow that is usually unattainable experimentally, and (ii) constant growth of computational resources. Various sophisticated simulation methods have been suggested in the past literature, all containing intrinsic assets and drawbacks. FRS represents a promising research direction but is still far from being the ultimate panacea. After a short review of the field, current limits in FRS will be illustrated on various flow configurations, as very concentrated suspensions where lubrication prevails and mass & thermal boundary layer thickness at high Pr and Sc numbers in flows with heat & mass transfer. Two different though complementary worthwhile remedies will be suggested: (i) to go one step further in highly parallel and advanced numerical approaches, and (ii) to integrate this type of numerical method into a multi-scale analysis that allows to transfer the physical comprehension gained at the lowest scale, i.e., the scale of FRS, to the upper ones.

Andrew Woods
Particle transport in volcanic flows

In this presentation we report on a series of new experiments relating to particle transport in volcanic flows, including (a) the impact of the particles on mixing in magma chambers; (b) on magma flow through volcanic conduits and (c) in the control of particle sedimentation on eruption style at the surface, and the morphology of the ensuing deposits.