Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

Rectors:

E. Guazzelli (Marseille) - F.G. Rammerstorfer (Vienna) - W. A. Wall (Munich)

PROGRAMME 2019

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Udine, Italy

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The Christian Miehe Session

Dynamics of Machining: Prediction and Suppression of Undesired Vibrations

May 6 - 10, 2019

Dynamics of metal cutting is a relevant research topic that has an essential theoretical background both in mechanics of solids and in dynamics of rigid bodies. The basic difficulty was summarized as early as 1907 by F. W. Taylor, the 3rd president of ASME: "… Chatter is the most obscure and delicate of all problems facing the machinist – probably no rules or formulae can be devised which will accurately guide the machinist in taking maximum cuts and speeds possible without producing chatter…"

Chatter refers to the vibrations that may arise during cutting processes. This specific self-excited oscillation is mainly caused by the so-called regenerative effect. The undesired relative vibrations between the tool and the work-piece deteriorate the quality of machined surfaces. If the modal parameters, like natural frequencies, damping, vibration modes, are identified on a machine tool, and if the cutting force is estimated by means of well-established cutting mechanics models, then there is a chance to predict and to prevent chatter by selecting appropriate cutting parameters (feed rate, depth of cut and cutting speed) and achieve maximal material removal rates. During the last 100 years, the research methodology has developed parallel to the theoretical and numerical methods in mathematics, informatics, vibration theory, measurement techniques and nonlinear dynamics including chaos.

The advanced course provides a full spectrum of the research results in machining dynamics from the theoretical background of nonlinear delayed oscillators to the practical issues of modal testing. Mechanical and mathematical models are presented both in frequency domain and in time domain. Introduction is given to advanced numerical and software solutions to carry out virtual machining to optimize cutting parameters. The hardware-in-the-loop technique is introduced for enhanced design of improved tool geometries. Optimization of milling tool geometry (pitch and helix angles) is discussed. Methods involving partial modification of the machine tool structure are also presented, like the various dynamic vibration absorbers. Up-to-date experimental modal testing methods and their future development strategies are overviewed together with the sophisticated construction of the stability charts that are relevant for industrial applications. Research and commercial solutions for real-time chatter detection and process regulation are discussed. An industrial panel will bridge the state-of-the-art research results and actual industrial needs in machining dynamics.

The school is addressed to doctoral students, post-docs, early career researchers and engineers working at R&D departments of companies with interest in improving machining efficiency. The course is designed for participants working in the field of dynamics of machining and related topics like deep drilling, also to those interested in vibration measurement techniques, hardware-in-the-loop applications and/or in other fields of dynamics of delayed oscillators from traffic dynamics to human-machine systems in general.

Invited Lecturers:
Yusuf Altintas (University of British Columbia, Vancouver, Canada), Erhan Budak (Sabanci University, Istanbul, Turkey), Zoltan Dombovari (Budapest University of Technology and Economics, Hungary), Jokin Munoa (IK4-IDEKO, Elgoibar, Spain), Gabor Stepan (Budapest University of Technology and Economics, Hungary), Giovanni Totis (University of Udine, Italy).
Coordinator: G. Stepan (Hungary).

Micromechanics of Internal Stresses in Multiphase Materials

May 20 - 24, 2019

Advanced materials (e.g., composites) are subject to stresses and strains at the microscopic, mesoscopic, and macroscopic level. This extends to components, especially if manufactured with complex methods, such as additive manufacturing. The determination of mechanical properties of such materials and of the life duration of such components is particularly important, but also extremely challenging, in view of their microstructural complexity. Typical examples are composite materials (especially multi-phase) and functional materials such as those for filter applications. For components it is of great interest to determine (and possibly measure) internal stresses in a non-destructive manner, in order to connect the internal stresses with their performance and lifetime.

One aspect of relevance is the multi-scale character of the problem. For example, in composite materials internal stresses do not only appear at macro level (due to machining, heat treatments, operating conditions, etc.) but also at micro-level, i.e., among the different constituent phases. Those stresses are a consequence of the microstructure; they also evolve under applied loads (thermal, mechanical chemical, etc.), and need to be monitored. Diffraction methods are particularly suited to tackle the non-destructive determination of internal stresses, and micromechanical methods are available to calculate them analytically. Both methods can cast further light onto the mechanisms of load partition among the different constituents.

The present course is targeted at systematically rationalizing the experimental and theoretical aspects of stress analysis in complex materials such as multi-phase composites (thereby including pores as a phase).

Classic experimental determination of mechanical and thermal properties through uniaxial, bending, instrumented indentation tests, impulse excitation, and thermal conductivity will also be treated. It will be shown how thermal properties are connected to mechanical behavior, and which additional information they can yield, especially under the light of the so-called cross property connections in materials.

Several micromechanical schemes will be treated, and advanced applications of those micromechanical methods will be made by calculation of stress partition in multiphase materials and non-linearity in porous ceramics and rocks, as well as by determination of equivalent elastic constants in multi-phase materials.

In parallel, different numerical approaches will be covered, the main emphasis being put on Finite Element based methods, with special attention being given to issues connected

to evaluating local stress and strain fields.

Both analytical and numerical methods will be merged into the so-called Inverse Analysis (IA), which aims at extracting information from experimental data through simulation and modeling (i.e. minimization of discrepancy between experimentally measured quantities and their computed counterpart).

It will be pointed out how models give a framework to assess quantities that are not directly measurable within the experiment by measuring something else, which is more accessible.

The target audience are mainly Mechanical Engineers and Materials Scientists, but Physicists and Geologists may well use the material dealt with.

Invited Lecturers:

Helmut J. Böhm (Technical University of Vienna, Austria), Giovanni Bruno (BAM, Berlin and University of Potsdam, Germany), Vladimir Buljak (University of Belgrade, Serbia), Mark L. Kachanov (Tufts University, Medford, MA, USA), Jaroslav Kováčik (Slovak Academy of Sciences, Slovakia), Igor Sevostianov (New Mexico State University, Las Cruces, USA).

Coordinator: G. Bruno (Germany).

Cohesive Granular Materials, Description and Flowing Properties

May 27 - 31, 2019

Granular matter and powders are widely used in the manufacturing of numerous products and in many industries. Despite this intense utilization, their behavior and rheological properties are non-trivial. One major difficulty is that powders and their ability to flow are strongly affected by cohesive effects. In worst cases, the flow may stop and is somehow difficult to start again. The main objective of this course is to provide an overview of the knowledges on cohesive powders from the academic and industrial point of view. The course will cover three different scales.

At the particle scale, the particle motion is mainly governed by friction, particle-to-particle cohesion, interaction with walls. The physical origins of the cohesion (Van der Waals, electrostatic or magnetic forces, capillary forces, chemical forces, polymer layers) will be presented in detail. Two courses will be devoted to this topic. The effects of the cohesion driven by humidity on powders will be discussed in detail in one course, both from an experimental and numerical point of views. Physico-chemical aspects and adhesion mediated by soft media will also be covered by a specific series of lectures.

At a larger scale, where many particles interact, discrete or continuous models may be depicted. A numerical technique such as the DEM may be very useful to have a close insight on coarse-grained particle volume fraction, velocity, forces and stresses in a lab-scale volume containing cohesive particles. On the other hand, experiments with rheometers, inclined planes, rotating drums, hoppers, piles can provide useful elements to build an elementary continuous model. Three series of lectures will develop the techniques to prepare a cohesive granular material and the principal ways to study the static properties and the flow behavior of cohesive material.

At last, at an even larger scale, the course will present issues and solutions occurring in large volume systems such as silos, hoppers, transporting ducts, and other industrial equipment dealing with a large quantity of material. A series of lectures will focus on handling operations and will discuss how the powder rheology may bring useful facts about the industrial processes.

One of the key feature of this course is to propose to attendees a wide scope on the subject, from contact interaction theory to commercially available apparatus (powder rheometers).

The lectures are mainly designed for doctoral students of applied physics, mechanics, engineering and chemical engineering with a strong research interest in theoretical modeling, numerical simulation and experimental. They are also suited for young and senior researchers working in academia or in private research and development centers, interested in gaining a compact yet comprehensive overview of cohesive powders from its fundamental physical background, to the computational methods and the experimental techniques available for measuring the flow properties of such powders.

Invited Lecturers:
Jamie Clayton (Freeman Technology, Tewkesbury, UK), Blanche Dalloz (Aix-Marseille University, France), Cyprien Gay (University Paris Diderot, France), Pierre Jop (CNRS-Saint-Gobain, Aubervilliers, France), Geoffroy Lumay (University of Liege, Belgium), Maxime Nicolas (Aix-Marseille University, France), Marco Ramaioli (University of Surrey, UK).

Coordinators: B. Dalloz (France), P. Jop (France), M. Nicolas (France).

Coherent Structures in Unsteady Flows: Mathematical and Computational Methods
CISM-ECCOMAS International Summer School

June 3 - 7, 2019

Turbulence is sometimes described as the last unsolved problem of classical physics. While significant advances have been made towards solving this problem, the available results are largely confined to asymptotic scaling laws for non-dimensional descriptors of homogeneous, isotropic turbulence. In contrast, turbulent flows observed in nature and technology tend to display coherent structures, rendering the hypotheses of homogeneity and isotropy invalid. Coherence in unsteady flows has been studied in four main contexts:
 - Eulerian coherent vortices (ECV): spatial patterns in the instantaneous velocity field.
 - Lagrangian coherent structures (LCS): persistent spatial patterns in tracer distributions.
 - Objective Eulerian coherent structures (OECS): the instantaneous limits of LCSs.
 - Exact Coherent States (ECS): persistent temporal patterns in the velocity field.
ECV are well studied in fluid dynamics but have no universally accepted definition or detection algorithm. This is largely due to the inherent dependence of this concept on the observers and to the lack of an experimentally verifiable ground truth. In contrast, LCSs, OECSs and ECS have observer-independent features, and hence definitions and algorithms aimed at their identification are experimentally verifiable. Going beyond

a popular-level understanding of these three coherence notions, however, requires a solid command of higher mathematical and computational concepts.

The objective of this course is to provide an opportunity for junior researches to obtain a first-hand introduction to contemporary coherent structure detection techniques and computational algorithms. The lectures will be delivered by recognized experts who have participated directly in the development and applications of these methods. The list of speakers is intentionally broad, ranging from mathematicians through engineers to physical oceanographers. The scope of the course is similarly broad, covering necessary fundamentals from dynamical systems, continuum mechanics, fluid mechanics, probability, operator theory, stability theory for the Navier-Stokes equations, as well as related computational algorithms. Of the specific coherence concepts, the lectures will cover Lagrangian and Eulerian coherent structures, coherent diffusion barriers, coherent sets and exact coherent states in turbulence.

This course is addressed to doctoral students, postdocs, and young scientists wishing to learn the basics of the field. Given the diversity in the expertise of the speakers and the broad range of the applications, the participants are expected to gain substantial insight into this exciting and quickly involving area of research. They will also have access to Matlab and high-performance Fortran codes implementing the main techniques. Finally, participants will have a chance to briefly introduce a poster summarizing their own related research..

Invited Lecturers:

Marc Avila (University of Bremen, ZARM, Germany), Francisco Beron-Vera (University of Miami, FL, USA), George Haller (ETH Zürich, Switzerland), Oliver Junge (Technical University of Munich, Germany), Rich Kerswell (University of Cambridge, UK).

Coordinator: George Haller (Switzerland).

Coupled Processes in Fracture Propagation in Geo-Materials: from Hydraulic Fractures to Earthquakes

June 10 - 14, 2019

The propagation of fractures in geological media either due to natural or man-made forcing share common similarities related to the coupling of fluid and temperature variations with mechanical deformation. Earthquakes are shear mode cracks dominated by frictional weakening with thermal pressurization, flash heating of asperities playing an important role. Hydraulic fractures on the other hand are opening mode cracks propagating under the injection of viscous fluid. In both cases, the energy budget of the process (and the overall evolution of the system) may widely differ depending on the dominant physical process: e.g. fracture surface creation versus viscous flow dissipation, fluid storage versus leak-off in hydraulic fractures.

During this summer school, we will focus on recent advances in the mechanical modeling of both fluid-driven fractures and earthquakes. Our aim is to review the physical modeling of these problems, which combines fracture mechanics, thermo-hydro-mechanical deformation and complex friction laws. We will cover in-depth the solution of a number of

model problems that allow for a deeper understanding of the complex interplay between the different physical processes on the evolution of fracture.

The theory of fracture mechanics and the use of boundary integrals equations for the solution of fracture problems will be discussed in details in order to give a basis for its applications to both earthquakes nucleation and hydraulic fracture growth.

After a presentation of the coupling between fluid flow and fracture deformation, the tip behavior of a propagating hydraulic fracture will be discussed in details as well as semi-analytical solutions for the growth of finite hydraulic fracture of simple geometries (radial, plane-strain) in limiting propagation regimes (Storage/viscosity & toughness -- leak-off/viscosity & toughness). Insights revealed by dimensional analysis and scaling will be highlighted. Different numerical schemes for hydraulic fracture propagation will be discussed and a particular emphasis will be given to numerical scheme incorporating the multiscale tip behavior. Hands on examples with an open-source code will demonstrate a number of important points for the resolution of such moving boundary problem. The necessity of proper code verifications will be highlighted. A number of laboratory and field experiments on hydraulic fracture growth will be given and compared to theoretical predictions. Current research topics related to rock anisotropy, heterogeneity and non-linearity will also be discussed.

On the subject of earthquake source physics, the theory of fracture mechanics will be revisited in the context of Mode II and Mode III fractures. Insights into solutions for cohesive zone fractures will be given along with the reasoning for their applicability in earthquake source physics. Both analytical and numerical treatment through Boundary Integral Equation Methods will be given. The students will then be given insights into these fracture solutions through laboratory experiments. At the next stage we will talk about elaborate friction laws used in earthquake physics and how they are coupled to classical fracture mechanics problems. Insights from laboratory experiments on friction and dynamic shear rupture will also be given. As a final step a short introduction to field geology would be given where these modeled phenomena can be observed.

Invited Lecturers:

Harsha Bhat (Ecole Normale Superieure, Paris, France), Dmitry Garagash (Dalhousie University, Halifax, Canada), Leonid Germanovich (Clemson University, SC, USA), Brice Lecampion (Ecole Polytechnique Fédérale de Lausanne, Switzerland), Alexandre Schubnel (Ecole Normale Superieure, Paris, France), Robert Viesca (Tufts University, Medford, MA, USA).

Coordinators: H. Bhat (France), B. Lecampion (Switzerland).

Mechanobiology and Tribology of the Skin - from Experimental Characterisation to Modelling

June 24 - 28, 2019

The skin is the first line of defence of our body against the external environment and acts as a complex multi-functional physical interface. It controls many types of exchanges between our inner and outside worlds which take the form of mechanical,

thermal, biological, chemical and electromagnetic processes.

The complexity of skin mechanobiology and tribology can only be unravelled by adopting interdisciplinary research approaches which integrate physical experiments, imaging and modelling. As a consequence, researchers, must be trained in a wide range of topics from experimental physics, skin biology, continuum mechanics, soft matter physics, mathematical modelling and data analysis, through multiscale imaging protocols and image processing to finite element methods and computational procedures. Often, researchers in mechanobiology/biomechanics lack fundamental knowledge about surface physics and soft matter tribology while scientists/engineers focussing on tribology do not appreciate the inherent complex interplay between biological processes associated with cell activity, skin microstructure, material properties of its elemental constituents and the resulting surface effects associated with contact and friction.

The ambition of the course is therefore to provide a consistent and holistic introduction to modern research focussed on skin mechanobiology and biotribology whilst also covering advanced topics at the experimental and modelling levels. The aim of the course is to present the current state of the art as well as basic associated methods and theories.

The lectures will address in particular the fundamental aspects of skin mechanobiology (biology, physiology, structural organisation, damage and wound healing), characterisation techniques (mechanical properties, tribological properties, acoustic wave propagation techniques, experimental testing devices, numerically-based inverse identification techniques) as well as mathematical and numerical modelling approaches (basic foundations of non-linear continuum mechanics, constitutive modelling and associated finite element techniques, image-based modelling and analysis of skin surface instabilities).

Throughout the course the lecturers will point to future directions and challenges in research in the broad area of skin biophysics and also illustrate how the presented theories and techniques are used to solve practical problems of fundamental and industrial relevance.

This course is not only addressed to doctoral students and postdoctoral researchers in biomedical/mechanical/civil engineering, biophysics and applied mathematics but also to more senior scientists and engineers in academia and industry, with a special interest in skin mechanobiology and tribology. The summer school will also be an excellent opportunity to foster discussions between young and more established researchers in a very conducive atmosphere, to encourage interactions between experts with different background and to educate the next generation of researchers.

Invited Lecturers:

A Michel Destrade (NUI Galway, Ireland), Amit Gefen (Tel Aviv University, Ramat Aviv, Israel), Jakub Lengiewicz (Polish Academy of Sciences, Warsaw, Poland), Georges Limbert (University of Southampton, UK and University of Cape Town, South Africa), Marc Masen (Imperial College London, UK), Edoardo Mazza (ETH Zürich, Switzerland).

Coordinators: G. Limbert (UK and South Africa), M. Masen (UK).

Anisotropic Particles in Viscous and Turbulent Flows
CISM-AIMETA Advanced School

July 1 - 5, 2019

Dynamics of anisotropic particles in fluid flow are encountered both in nature and in industrial applications. Examples include airborne solid particles or aerosols, sediment-laden flows, fiber suspensions, but also carbon nanotubes, macromolecules, swimming microorganisms, biopolymers. In these processes, particle shape departs from spherical, and particle size ranges from nano- to centi-meters, with loadings that can substantially change the macroscopic properties of the suspension. In addition, transport and interaction of particles in complex (e.g. turbulent) flows is governed by a number of physical processes occurring at a wide range of length and time scales. The rapidly increasing computational power has made feasible three-dimensional, time-dependent, fully-resolved simulations of non-spherical particles in fluid flows, producing an entire branch of literature that is fostering research in dispersed multiphase flow. Progress has been substantial also from an experimental point of view, thanks to the improvement of measurement techniques. In view of these developments, it is now useful to provide a general and unified frame of the current state of research and put future research paths in perspective.

Lectures will survey the most up-to-date modeling approaches, numerical simulations and/or experiments used to study the dynamics and properties of flows involving particles suspended in and interacting with a viscous or turbulent flow. In particular, several complex fluid flow problems will be addressed. The complexity may arise from: multi physics phenomena coupling various interaction types (mechanical, chemical, or thermal) that lead to complex dynamics; the effects of short-range or long-range hydrodynamic interactions on pattern formation. Many of these problems are motivated by biological phenomena, environmental processes or engineering applications, and their solutions involve applied mathematics, large-scale computations and comparisons to experimental data. Issues related to modeling and physical understanding of non-ideal particle at all various length scales will be covered: from the scale resolving the complex flow around individual non-spherical particles, to modulation of turbulence induced by particles; from particle dynamics in free and wall-bounded turbulence to fluid-particle interactions, collisions, breakup and agglomeration; from advances in measurement and simulation techniques to rheological characterization of deformable and non-deformable particle suspensions. A comprehensive ensemble of applications, extracted from the lecturers' own research field and covering areas of applied physics and engineering, will also be provided.

The course will be particularly attractive to graduate students, PhD candidates, young researchers and faculty members in applied physics and chemical/mechanical engineering. The advanced topics and the presentation of current progress will also be of considerable interest to many senior researchers, as well as industrial practitioners having a strong interest in understanding the multi-scale complex behavior of

such multiphase flows, with particular emphasis on their modeling, simulation and experimentation.

Invited Lecturers:
Jason Butler (University of Florida, Gainesville, USA), Elisabeth Guazzelli (Laboratoire Matière et Systèmes Complexes, Université de Paris, France), Cristian Marchioli (University of Udine, Italy), Francesco Picano (University of Padova, Italy), Alain Pumir (ENS de Lyon, France), Gautier Verhille (IRPHE, Aix-Marseille University, CNRS, France), Greg Voth (Wesleyan University, Middletown, CT, USA).

Coordinators: C. Marchioli (Italy), G. Verhille (France).

Plant Biomechanics
24th CISM-IUTAM International Summer School

July 8 - 12, 2019

Plants offer some of the most elegant applications of Mechanics to be found in Nature. Wind-induced leaf fluttering, waves on wheat crops or seed dispersal by the wind are well-known illustrations of the interaction of plants with an external flow. Mechanics play also a central role in the physiology of plants. Terrestrial plants and trees are hydraulic machines that take water deep into the soil to raise it to the leaves through osmosis and evaporation. The motor of plant growth and movement results from a balance between the mechanical stresses in the cell wall and the water pressure inside. All these external and internal forces are perceived by plants and participate in their development and their morphogenesis. Understanding these functions is of crucial importance for a better management of agriculture or to forecast plants behavior in this period of rapid environmental changes.

The objective of this CISM International Summer School is to provide an introduction to Plant Biomechanics at all scales, from the cellular and tissue level to the whole plant and ecosystem level. Lectures will combine concepts from plant biology (anatomy, physiology) and continuum mechanics (elasticity, plasticity, fluid mechanics, rheology, instabilities, modeling). Due to the interdisciplinary nature of the course topic, and, consequently, of the expected audience, a great attention will be paid on introducing biological and mathematical concepts at the basic level first, before going deeper in the description and eventually reach research topics.

The school will be composed of 6 lectures given by world-renowned experts covering all the main aspects of plant biomechanics. Time will be allocated during the week for attendees to present their own research work through short talks. The first two lectures will deal with the mechanics of plant growth and morphogenesis. Anja Geitmann (McGill, Canada) will focus on the cellular level and give the basic notion of biology needed for the rest of the course, while Oliver Jensen (Manchester University, UK) will describe different aspects of the modeling of growing plant tissues.

Two lectures will then address plant fluid mechanics. Missy Holbrook (Harvard University, USA) will be in charge of describing internal flows (sap ascent, sugar transport) and Emmanuel de Langre (Polytechnique, France) will discuss the interaction

of plants with an external flow.

The last two lectures will discuss plant biomechanics in the broader perspective of plant ecophysiology and evolution. Bruno Moulia (INRA, France) will give a lecture on how plants respond and adapt to their environment, with a focus on tree biomechanics, while Karl Niklas (Cornell University) will address the global biomechanical constraints that shaped plant structure and function through evolution.

The targeted audience for this Summer School will be PhD students, postdoctoral, and young researchers in departments of Physics, Biophysics, Biology, Applied Mathematics, Engineering and Agricultural Sciences.

Invited Lecturers:

Emmanuel de Langre (Ecole Polytechnique, Palaiseau, France), Anja Geitmann (McGill University, Ste-Anne-de-Bellevue, QC, Canada), Noel Michele Holbrook (Harvard University, Cambridge, MA, USA), Oliver Jensen (University of Manchester, UK), Bruno Moulia (PIAF-INRA, Clermont-Ferrand, France), Karl Niklas (Cornell University, Ithaca, NY, USA).

Coordinators: C. Eloy (France), Y. Forterre (France).

Advances in Dispersed Multi-Phase Flows: from Measuring to Modeling

July 15 - 19, 2019

Multi-phase flows where a dispersed phase interacts with a carrier fluid are ubiquitous in nature and industry, but the description of their dynamics has challenged scientists and engineers for decades. Difficulties arise due to the interface between the continuous and dispersed phases, the opacity of the media, and the vast range of spatial and temporal scales at play. However, recent developments in both measurement techniques and predictive capabilities bear the promise of a rapid progress in the near future. In this course, we will review existing theories that describe the behavior of this class of flows, and introduce a variety of measurement and simulation strategies that capture and reproduce the key phenomena.

Even in the idealized scenario of dilute suspensions of point-like particles, inertia leads to non-trivial behaviors, especially in the turbulent regime. Classic results on single-phase and particle-laden turbulence will be reviewed, as well as recent findings on multi-scale clustering and gravitational settling, especially relevant to natural phenomena. With increasing levels of concentration, we will illustrate how the two-way coupling between the phases becomes manifest, for both momentum and energy. Recent insight on the behavior of finite size particles of different shape and their interaction with the fluid will be also discussed. Bubbly flows display distinctive features due to the bubbles being often large and deformable, with gas-liquid interfacial dynamics and compressibility effects contributing to a rich phenomenology. We will review the fluid dynamics around individual and swarming bubbles, emphasizing the different types of agitation induced in the carrier liquid. Considering dense suspensions of particles or droplets in a liquid phase, we will introduce the fundamentals of rheology, highlighting the relation between the suspension structure and the macroscopic properties. We will also explore exciting

developments on active dispersions, at the intersection of fluid mechanics and biology. Throughout this course, we will critically assess modern numerical and experimental strategies. The former will include Eulerian methods with sharp and diffuse interfaces, and Lagrangian-Eulerian methods for rigid and deformable particles. Kinetic-based moment methods will also be addressed, stressing their connection with two-fluid methods and illustrating their versatility in technological applications such as polydisperse sprays. On the experimental side, we will address optics-based methods relying on particle imaging, but also powerful medical imaging modalities that can overcome the medium opacity.

The course is mainly directed to doctoral and postdoctoral students in engineering and physics, with strong interests in numerical simulations and experimental methods. It is also suited for researchers working in academia or R&D, interested in rapidly gaining a comprehensive overview of multiphase dispersed flows. The attendees will be encouraged to actively participate in the scientific conversation, also through a poster session in which they will present and discuss their own research. Matlab implementations of selected methodologies will be available for hands-on exercises.

Invited Lecturers:
Luca Brandt (KTH Royal Institute of Technology, Stockholm, Sweden), Xiang Cheng (University of Minnesota, Minneapolis, USA), Filippo Coletti (University of Minnesota, Minneapolis, USA), Marc Massot (École Polytechnique, Palaiseau, France), Frédéric Risso (Institut de Mécanique des Fluides de Toulouse, France), Remi Zamansky (Institut de Mécanique des Fluides de Toulouse, France).

Coordinators: F. Coletti (USA), R. Zamansky (France).

Pattern Formation in Advanced Materials: Energetics and Evolution

July 22 - 26, 2019

In the past decades a wealth of new solid materials has emerged, designed to have very specific properties in order to offer optimal solutions to engineering problems. This evolution would not have been possible without fundamental contributions from the theoretical sciences, in particular solid mechanics and mathematics. Within this general framework, mathematical concepts from the broad context of variational analysis have proven to be successful. This spectrum of methods includes, but is not limited to, the theories of homogenization, relaxation, Gamma convergence and variational time evolution. Classical application areas involve models in the framework of nonlinear elasticity, finite plasticity and phase transformations in general and the analysis of fracture, damage, motion of dislocations, formation of microstructure and the impact of these effects on material behavior in particular.

The role of pattern formation and microstructures becomes more and more noticeable with a decreasing size of the material specimen considered. These scale effects play a major role in modern micromechanical applications. Microstructure is indeed crucial, since material behavior typically is the result of the interaction of complex substructures on several length scales. The macroscopic behavior is then determined by appropriate

averages over the (evolving) microstructure. Effects controlling the lifetime and deterioration of specimens, too, depend strongly on the microstructure. What is needed are models which are more closely related to physics and material science and which are able to take into account the microstructural behavior of the material.

Mathematics and especially the calculus of variations are essential in the understanding of microstructural pattern formation in the presence of nonconvex potentials (i.e., potential energy functionals lacking weakly lower semi-continuity). Solutions to macroscopic boundary value problems become infimizing sequences whose description requires the identification of the quasiconvex envelope of the non(quasi)convex energy density, whose infimizers are interpreted as the associated microstructural patterns.

The mechanics of materials side of this course aims to exploit the above mathematical concepts towards formulating and validating constitutive theories and associated numerical tools for the prediction of complex material behavior. Since exact solutions of quasiconvex hulls are a rare find, approximate solutions from the theory of relaxation via, e.g., rank-one-convexification and sequential lamination, via convexification, via polyconvex envelopes, or via time-incremental variational formulations have served to describe the intricate micromechanical processes leading to the well-documented macroscopic inelastic material behavior.

The course is addressed particularly at doctoral students and young researchers (postdoctoral scholars, research associates and assistant faculty). The lectures will target an audience that has a proficient background in graduate-level mathematics and solid mechanics (typical of Master's graduates in, e.g., mechanical and civil engineering, applied mechanics, applied physics, applied mathematics, and related disciplines).

Invited Lecturers:

Kaushik Bhattacharya (California Institute of Technology, Pasadena, USA), Georg Dolzmann (Universität Regensburg, Germany), Klaus Hackl (Ruhr-Universität Bochum, Germany), Richard D. James (University of Minnesota, Minneapolis, USA), Dennis M. Kochmann (ETH Zürich, Switzerland), Annie Raoult (Université Paris Descartes/CNRS, Paris, France).

Coordinators: K. Hackl (Germany), D. M. Kochmann (Switzerland).

The Olga Ladyzhenskaya Session

Electromechanical Transducers: Principles and Technologies

September 9 - 13, 2019

Current developments in mechatronics lead to (and often require) the integration of sensors and actuators in mechanical structures. This trend is represented by research topics as for instance "smart structures" and "structural health monitoring". The associated technologies connect mechanics with neighboring disciplines such as electrical engineering and microtechnology.

For the realization of embedded transducers, microtechnologies are particularly useful which will be introduced by Prof. Lina Sarro. Microsystems or MicroElectroMechanical Systems (MEMS) technology covers design, technology and fabrication efforts aimed at combining electronic functions with mechanical, optical, thermal and others and that employ miniaturization in order to achieve high complexity in a small space. The core technologies, silicon bulk micromachining and surface micromachining, will be introduced to illustrate the potential of 3D micro structuring in the development of Microsystems. Advances in dry etching technology and thin films deposition and the added value the introduction of other materials in silicon-based technology offer, will be discussed as well.

When implementing autonomous sensor nodes, energy harvesting technologies are essential to power these nodes, which will be discussed by Prof. Vittorio Ferrari. Energy harvesting to power sensors from the surroundings, making them autonomous nodes, or passive sensors with energy supplied on demand from an external interrogation module, are two attractive options, each with specific features. Both options can be enabled by piezoelectric elements embedded in miniaturized devices. The lectures will introduce the piezoelectric effect as a cross-domain energy conversion mechanism and offer an overview of principles and applications in stand-alone sensors.

Prof. Michiel Vellekoop will discuss microfluidic components and systems. The investigation and analysis of fluids in microchips should, compared to macro devices, yield advantages such as very small sample volumes, high speed testing, integration of multiple functions, and monitoring of fast reaction dynamics. In the course, some fundamentals of fluid behavior are used to discuss basic design considerations for microfluidic devices. Technologies for the realization of microfluidic devices, which are partly very different from standard sensor technology will be presented.

In addition, some attention will be given to the "chip to world" connection, as it is an important aspect that is often underexposed. Finally, a series of examples of Lab on a Chip devices will be conferred. Prof. Bernhard Jakoby will provide general considerations when considering interaction of vibrating systems with liquids. First, some fundamental principles regarding microacoustic devices will be reviewed and selected microacoustic sensors will be discussed as examples. Many of these devices require

special analysis approaches to allow for efficient modeling. To understand and model the interaction with fluids, the behavior of potentially non-Newtonian fluids will be considered including a discussion on the first and second coefficient of viscosity. The interaction with fluids will be considered for piezoelectrically and electromagnetically actuated devices and device performance and modeling will be discussed for selected examples.

Finally, the sensing and control of deformations and stresses in structures will be addressed by Prof. Hans Irschik. Particular emphasis will be given to dense, specially weighted piezoelectric sensor networks that can measure, e.g., discrete displacements or slopes. The use of so called nil-potent sensor networks for structural health monitoring will be discussed. Complementary to the discussion on sensors, weighted piezoelectric actuator networks that can track desired displacement fields, as well as nil- potent actuator networks and their usage for minimizing the actuator input energy will be presented. As a quite new research field, structural control of stresses by dense piezoelectric sensor and actuator networks will be systematically addressed also in the lectures.

Invited Lecturers:

Vittorio Ferrari (University of Brescia, Italy), Hans Irschik (Johannes Kepler University Linz, Austria), Bernhard Jakoby (Johannes Kepler University, Linz, Austria), Pasqualina M. Sarro (TU Delft, The Netherlands), Michiel Vellekoop (University of Bremen, Germany).

Coordinators: H. Irschik (Austria), B. Jakoby (Austria).

Transport Phenomena on Textured Surfaces: Fundamentals and Applications

September 23 - 27, 2019

In the past two decades numerous laboratories have microfabricated surfaces with the chemical and textural properties to mimic superhydrophobic surfaces (SHs) found in nature, the most well-known being the self-cleaning properties of the lotus leaf. This has been made possible by the continuing advances in nano/micro fabrication technology. This Advanced School will bring together engineers, physicists, chemists and applied mathematicians in a multi-physics framework.

Adopting a holistic approach coupling momentum, heat, mass and charge transport phenomena the lecturers comprise 2 applied mathematicians, 2 mechanical engineers, a physicist and a chemist: together they bring theoretical and experimental perspectives to the topic.

The fundamentals of the physical and chemical phenomena exploited to suspend liquids in the Cassie (unwetted) state on SHs will be covered. We address the conditions required, and technologies developed, to maintain the Cassie state and those which cause transition to the (sometimes desirable) Wenzel (wetted) state. Transport phenomena physics related to droplets on SHs and flows of liquids over them will be emphasized.

For droplets on SHs, the fundamental microfabrication principles including those

based on polymer processing technology will be surveyed. Ice prevention and enhancing boiling and condensation heat transfer will be points of emphasis, as will electrowettability-based dynamic control and enhancement of general phase change phenomena. Various approaches to suppress or exploit Leidenfrost phenomena to, e.g., suppress critical heat flux or pump droplets, will be studied. SHs with multifunctional properties such as photo-catalytic activity, anti-reflectivity, abrasion resistance and antisoiling characteristics will be treated.

In studying external/internal flows over SHs, the course will include a rigorous derivation of the governing equations and boundary conditions, resolution of surfactant, Marangoni, thermocapillary and molecular phenomena and possible meniscus deformations. Comparison of theoretical models to experiments will be made with implications for key engineering parameters.

The course is suitable for graduate students, academics, engineers in industry. The techniques used will span mathematical modelling ideas and numerical schemes, through to experimental procedures and understanding the fundamental physical principles. Applications will be emphasised throughout.

Invited Lecturers:

Vaibhav Bahadur (University of Texas at Austin, USA), Darren Crowdy (Imperial College London, UK), Marc Hodes (Tufts University, Medford, MA, USA), Alan Lyons (City University of New York Graduate Center and College of Staten Island, USA), Demetrios Papageorgiou (Imperial College London, UK), David Quéré (Physique et Mécanique des Milieux Hétérogènes, ESPCI, Paris, France).

Coordinators: D. Crowdy (UK), M. Hodes (USA).

The Art of Modeling in Computational Solid Mechanics

October 7 - 11, 2019

Modeling is one of the main challenges in engineering science for the predictive description and simulation of the responses of systems and processes under complex actions in solid mechanics. This includes mechanical and mathematical modeling of single- and multi-phase materials as well as coupled problems, scale-bridging of micro-heterogenous materials, multiscale design of tailored materials, characterization of soft biological tissues and the tremendous development of data driven science in engineering using concepts of artificial intelligence, machine and manifold learning. All systems related to engineering need predictions of the behavior, durability and efficiency and hence models have to be developed that can be solved by analytical or numerical methods.

Therefore we focus on mechanical and mathematical modeling in single-phase solid mechanics, discussing theoretical models as well as simulation models associated with engineering applications in solid mechanics. Within the lectures examples will be considered in which different models and discretization schemes are compared.

Another challenging problem is the modeling and characterization of soft biological tissues. Some properties of a biological system, might be directly measurable, others,

and especially in-vivo properties, can only be explored with proper models at hand. In addition, prospective events, i.e. questions such as 'What would be the outcome from a certain clinical intervention?' can only been explored through modeling. Soft biological tissues are non-man-made highly complex systems, and the first main task of the modeler is to decide what properties are important for the Intended Model Application. A variety of engineering applications exhibit a coupling between individual thermodynamical fields, (e.g. thermoelasticity), electro-mechanical coupling, multiphase-systems. Hence in this course we discuss the general formulation of thermoelasticity and their solution using finite elements, the coordinate-invariant modeling of piezo-electricity within the framework of the invariant-theory and a macroscopic model of a saturated porous solids consisting of ice and water, presented within the theory of mixtures.

Computational homogenization schemes and multi-scale modeling can be seen as one of the driving forces in virtual material design. This field requires modeling and simulation at the scale of heterogeneous microstructures with an implicit or explicit connection to other scales. Particular emphasis is given to nonlinear and multiphysics phenomena at a micro-scale to incorporate related simulation challenges. We discuss numerical or virtual material testing across the scales to realize two-scale analyses equivalent to FE2 methods.

Modern advances in small-scale fabrication techniques have enabled the creation of a wide range of engineered meta-materials with tailored mechanical properties, whose design calls for theoretical and computational techniques that link microscale and nanoscale architectures to macroscale properties. We will discuss a number of state-of-the-art computational approaches and associated architected materials systems.

A tremendous development of Artificial Intelligence techniques took place in the last decades. Machine learning and manifold learning, and, notably, deep learning techniques, have assisted to an unprecedented growth in the wide range of applications they can be envisaged for. With the irruption of data-enabled science and engineering, applied science is today a symbiosis of theory, experiments and simulation. This lecture covers some of the most outstanding applications of AI and data-science in engineering sciences.

The course is intended for doctoral and postdoctoral researchers in civil and mechanical engineering, applied mathematics and physics as well as industrial researchers, who are interested in conducting research in the topic. A problem for young scientists trying to do high level research in this area is the number of topics one has to be familiar with: Advanced constitutive modeling, homogenization, data driven science in engineering as well as numerical discretization schemes and applications of these methods to coupled problems, biomechanics and tailored materials. Furthermore, there are neither adequate textbooks nor advanced courses at research/university level available. The aim of this CISM course is to fill this gap.

Invited Lecturers:

Francisco Chinesta (University of Nantes, France), Christian Gasser (KTH Stockholm, Sweden), Dennis M. Kochmann (ETH Zurich, Switzerland), Jörg Schröder (Universität Essen-Duisburg, Germany), Ken Terada (Tohuku University, Sendai, Japan), Peter

Wriggers (Leibniz Universität Hannover, Germany).

Coordinators: J. Schröder (Germany), P. Wriggers (Germany).

Controlling Delayed Dynamics: Advances in Theory, Methods and Applications

November 25 - 29, 2019

Delays are ubiquitous in engineering and natural sciences, e.g., communication delays in control devices and complex networks or maturation and gestation delays in population dynamics. The inclusion of past history in the time evolution adds nontrivial complexities with respect to ordinary systems, balancing the advantage of dealing with more realistic models. Equations involving delays generate dynamical systems of infinite dimension, asking for advanced tools and methods in the background mathematical analysis, the numerical treatment, the development, design and optimization of control strategies. Eventually, the comprehension of fundamental issues like stability of equilibria and other invariants is crucial, especially for varying or uncertain parameters. The school brings together strong and up-to-date contributions in the field of time delay systems, concerning analytical, numerical and application aspects, under the paradigm of control theory. It aims at discussing the most recent advances in these different contexts, focusing also on their interdisciplinary connections. Analysis, methods, control strategies and applications will be illustrated, starting from rapid introductions of the basics, reaching a state-of-the-art level by evolving the classic approaches into modern perspectives.

Attention will be devoted to the framework of semigroups, leading to a proper theory of linearized stability, where characteristic equations and Laplace transforms will be discussed for the sake of asymptotic analysis. An overview will thus be offered on efficient discretization schemes to reduce the dimension of the stability question, focusing on reliable and fast converging techniques. In parallel, the influence of model and control parameters on delayed dynamics will be investigated and characterized efficiently via continuation methods.

Moreover, the design problem for time-delay plants will be adequately addressed. Indeed, delays are crucial elements of engineering systems, e.g., regenerative delays in machine tool vibrations, leading often to unpredictable dynamics. Stabilization in the presence of feedback delay and sensory uncertainties is a challenging task and different control concepts will be discussed, together with an overview of limitations induced by delays in control loops. Recent control methodologies will be introduced, such as direct optimization approaches for synthesizing controllers. Concerning parameters, studying bifurcations of linear systems requires attention to the location of the rightmost roots, for which Weierstrass-based algorithms and frequency-sweeping tests will be proposed. Besides the design of controllers, considered the detrimental effects of delays in the plant model or in the feedback loops, the "dual problem" of intentionally using the delays in control law in order to improve the system behavior will be addressed. Also model reduction for large-scale systems will be discussed.

The school is primarily addressed to PhD students and post-docs in the fields connect-

ed to dynamical systems involving time delays and their control theory and numerical analysis, ranging from mathematics to engineering and physics. The lectures are also suited for young and senior researchers in the above or neighboring fields, from academia or private R&D centers, interested in gaining a compact yet comprehensive overview of dynamical systems with delay, from their mathematical background to control and computation.

Invited Lecturers:
Dimitri Breda (CDLab - Computational Dynamics Laboratory, University of Udine, Italy), Tamás Insperger (Budapest University of Technology and Economics and MTA-BME Lendület Human Balancing Research Group, Hungary), Bernd Krauskopf (University of Auckland, New Zealand), Wim Michiels (KU Leuven, Heverlee, Belgium), Silviu Iulian Niculescu (CNRS-CentraleSupélec-University Paris-Sud, Gif sur Yvette, France), Sjoerd Verduyn Lunel (Utrecht University, The Netherlands).

Coordinator: D. Breda (Italy).

International Advanced Professional Training

Vehicle Dynamics: Fundamentals and Ultimate Trends

September 2 - 6, 2019

Since the invention of the world's first motor vehicle, more than 100 years ago, automobiles have been widely accepted in our society with the progress of modern industry. The study and understanding of vehicle dynamics has always played a crucial role in the design of vehicles, with the aim of guaranteeing safety and stability as well as good performance. The recent advent of electric vehicles and the future perspective of widespread autonomous cars have posed further interesting challenges for the vehicle dynamicist, both in industry and academia. Nonetheless, the importance of the basics should never be underestimated - after all, essentially a vehicle behavior is described by second Newton's law, F=ma.

Therefore, the aim of this course is to recall the fundamentals of vehicle dynamics, as well as to present and discuss the state-of-the-art of ultimate trends in the field, including torque vectoring control, vehicle parameter estimation, and autonomous vehicles. The 6 lecturers include 2 eminent academics, 2 experienced researchers, and 2 industrial representatives.

The course will begin with a discussion of vehicle dynamics fundamentals. It will introduce classic hypotheses of vehicle dynamics theory, vehicle models for handling and performance, with a critical and often questioning approach. The handling of road cars will be also covered, with particular attention to the handling diagram and to the critical analysis of classical concepts such as understeer and oversteer. Since the vehicle performance and cornering depends strongly on the basic geometric properties of roads and suspensions, the lectures will then focus on suspension kinematics and compliance, engineering and measurement, as well as steering design and

development. Another aspect of paramount importance which will be discussed is tire modeling and testing. Indeed tires allow the generation of the contact forces which rule the vehicle dynamics. A good representation of tire behavior is therefore a necessity, but is not a simple task. Furthermore, often thermal effects have a significant impact on tire behavior.

The second part of the course, dedicated to ultimate trends, will begin with the discussion of a relatively recent technology: torque vectoring, i.e. the ability to allocate desired amounts of torque to specific axles/wheels of a vehicle, aimed at the enhancement of vehicle safety and handling qualities, as well as battery life. Advanced vehicle control techniques, including torque vectoring, may require parameters such as tire-road friction coefficient or vehicle sideslip angle, which are difficult to obtain. Hence the lectures will discuss advanced techniques for their estimation. The last part of the course will be devoted to the autonomous driving. As well-known, advances in computational capabilities, communication architectures, as well as sensing and navigation devices have led to the development of autonomous vehicles with increasing level of automation. They must be able to construct a proper representation of the environment and of their own state, and to make timely decisions in order to act with the external environment in an optimal and safe way.

Invited Lecturers:

Massimo Guiggiani (University of Pisa, Italy), Basilio Lenzo (Sheffield Hallam University, UK), Gene Lukianov (VRAD Engineering LLC, Beverly Hills, MI, USA), Frank Naets (Katholieke Universiteit Leuven, Belgium), Francesco Timpone (Megaride srl, Naples, Italy), Kyong Su Yi (Seoul National University, Seoul, Korea).

Coordinator: B. Lenzo (UK).

Joint Advanced School

CISM-JMBC Course on Complex Flows and Complex Fluids

Udine, May 13 - 17, 2019

Coordinator: Federico Toschi (TU Eindhoven, NL)
JMBC Representative: Gert-Jan van Heijst (TU Delft, NL)
CISM Representative: Alfredo Soldati (TU Wien, A)

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