Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

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

# PROGRAMME 2018

Udine, Italy

Centre International des Sciences Mécaniques
International Centre for Mechanical Sciences

*Rectors:*

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

# PROGRAMME 2018

Udine, Italy

**CONTENTS** Page

**CONTENTS** Page

**CONTENTS** Page

# The Stephen C. Cowin Session

## Fluid Mechanics of Planets and Stars

*April 16 - 20, 2018*

Understanding the dynamics of planetary and stellar fluid layers, including atmospheres, oceans, iron cores, convective and radiative zones in stars... remains a tremendous interdisciplinary challenge. Beyond the challenge in fundamental fluid mechanics to understand these flows involving rotation, buoyancy, waves, instabilities, turbulence, at typical scales well beyond our day-to-day experience, a global knowledge of the involved processes is fundamental to a better understanding of the dynamics of celestial bodies. Among the numerous open questions, one can for instance mention:

- How and where does the energy of the general ocean circulation cascade from the large climatic scales, where most of it is generated, to the smaller scales, where all of it is dissipated?
- What are the relevant driving forces and flow regimes in planetary cores for explaining the generation of a large variety of magnetic fields by dynamo processes?
- What are the prevalent force balances and physical mechanisms behind the large-scale features such as Jupiter's Great Red Spot and Jupiter's bands?
- How are the various types of waves propagating in stellar interiors generated, and how can they be understood via asteroseismology?

Interdisciplinary research in geo- and astrophysical fluid dynamics is also intrinsically multi-method. Indeed, the main obstacle to quantitative modeling and understanding of planetary flows stands in the extreme character of the involved dimensionless parameters. Relevant studies thus rely on the principle of dynamical similitude and scaling laws, sustained by theory, experiments and numerical simulations.

Much effort has been devoted to understanding planetary and stellar flows within the various communities of Mechanics, Applied Mathematics, Engineering, Physics, Planetary and Earth Sciences, Astrophysics... While open questions actually rely on the same fundamental concepts and phenomena, lots of progress has been made within each enclosed domain, with only marginal cross-fertilizations. The objective of this CISM School is to go beyond this state, by providing participants with a global introduction and an up-to-date overview of all relevant studies, fully addressing the wide range of involved disciplines and methods.

The course will be organized in two parts, each consisting of three chapters. The first part will focus on fundamental aspects of fluid mechanics, including introductory material and current research. Its three chapters will be devoted to waves, instabilities, and turbulence. The second part will focus on applications to topical geo- and astrophysical problems. Its three chapters will be devoted to planetary cores, atmospheres and oceans, and stars. All chapters will be pursued in parallel during the whole week, in order to highlight the close link between the models and their various applications.

The target audience for this School is PhD students, postdoctoral and young researchers, in departments of Mechanics, Applied Mathematics, Engineering, Physics, Planetary and

Earth Sciences, and Astrophysics. A background in fluid dynamics will be assumed, but no specific knowledge in any of the application domains will be requested.
This school takes place within the research project FLUDYCO, supported by the European Research Council (ERC) under the European Union's Horizon 2020 research and innovation program (grant agreement No. 681835-FLUDYCO-ERC-2015-CoG).

*Invited Lecturers:*
Renaud Deguen (Université Claude Bernard Lyon 1, Villeurbanne Cedex, France), Benjamin Favier (CNRS, Marseille, France), Michael Le Bars (CNRS, Marseille, France), Daniel Lecoanet (Princeton University, USA), Gordon Ogilvie (University of Cambridge, UK), Bruce Sutherland (University of Alberta, Edmonton, Canada).

*Coordinator:* M. Le Bars (France), D. Lecoanet (USA).

## Transport Phenomena in Complex Fluids

*May 7 - 11, 2018*

The term "complex fluids" refers to a broad class of liquids and soft materials with complex microstructure; examples are polymer melts or solutions, gels, colloidal pastes, foams, emulsions, surfactant solutions, slurries, and many others. Depending on their microscopic structure, the macroscopic behaviour of these fluids can exhibit significant differences with respect to simple fluids such as water or air. From the macroscopic point of view of continuum mechanics, their behaviour is usually described using non-Newtonian constitutive models, where the stress tensor is a generic function of the velocity gradient tensor and its derivatives, although in several cases the continuum approach is not sufficient to capture its phenomenology, and molecular models must be used.
The recent decades witnessed a fast-growing interest in complex fluids, largely driven by their relevance in a multitude of practical applications, such as painting, advanced manufacturing, food processing, cosmetics and personal care products, and many others. Moreover, with a better understanding of the microscopic structure of complex liquids, industries have realized that working fluids can be tailored specifically to optimize existing industrial processes, by altering their formulation (e.g., by means of chemical additives) in such a way as to change one or more physical properties. An example of industrial optimization is the use of polymer additives in agrochemical formulations, which improves the application efficiency of agrochemical sprays and reduces the environmental impact from ground contamination. In this context, a detailed understanding of the mass, momentum, and energy transport mechanisms in complex fluids is very important and has a significant impact on everyday practical applications.
The aim of this course is to provide a thorough overview of transport phenomena in complex fluids, based on the most recent research results and the most updated methods for their analytical prediction and numerical simulation. Lectures will cover several topics, including: a description the structural features of the most common complex fluids (polymer and surfactant solutions, colloidal suspensions); an introduction to the most common non- Newtonian constitutive models and their relationship with the fluid microstructure; a detailed overview of the experimental methods to characterise the

thermophysical properties, the bulk rheology, and the surface properties of complex fluids; a comprehensive introduction to heat, mass, and momentum transport, and to hydrodynamic instabilities in complex fluids; an introduction to state-of-the-art numerical methods to simulate complex fluid flows, with focus on the Smoothed Particle Hydrodynamics (SPH) and the Dissipative Particle Dynamics (DPD) techniques. A number of lectures will be dedicated to an in-depth description of phenomena such as thermal convection, elastic turbulence, mixing of complex fluids, thermophoresis, sedimentation, non-Newtonian drops and sprays. The course is addressed to research scientists and professionals, engineers, R&D managers and graduate students in the fields of Engineering, Chemistry, Biology, Medicine, Applied and Fundamental Sciences. Participants will be given the opportunity to present their own research, and discuss their individual challenges and results with the instructors during a round table at the end of the course.

*Invited Lecturers:*
Volfango Bertola (University of Liverpool, UK), Günter Brenn (Graz University of Technology, Austria), Teodor Burghelea (CNRS, Nantes, France), Marco Ellero (Swansea University, UK), Roberto Piazza (Polytechnic University of Milan, Italy).

*Coordinator:* V. Bertola (UK), T. Burghelea (France).

**Mechanics of Strain Gradient Materials**

*May 14 - 18, 2018*

Many materials show a different elastic or plastic behavior if tested on large or on small samples. Such size effects can be ascribed to internal length scales related to the micro-structure. This behavior is for instance observed in indenter tests, torsion, bending, and shear banding. Such effects cannot be simulated by classical constitutive models in which the stresses depend locally on the (dimensionless) strains. One possible extension of the classical models relies on the constitutive inclusion of higher strain gradients, which involve the dimension of length. This allows for an introduction of internal length scales in the constitutive model.

Strain gradient models can further be employed for the regularization of singularities in the classical solutions, which make them also advantageous from a numerical point of view. Moreover, they allow for the conceptually sound introduction of line and point forces into continuum mechanics.

The balance laws and boundary conditions for such materials can be derived by resorting to variational principles. For each primal higher strain gradient a conjugate stress tensor of the same tensorial order has to be introduced, for which a constitutive law is needed. Material modeling becomes a challenging task for such materials.

In the elastic case, all stress tensors may depend on all of the corresponding strain tensors. Even in the linear case, this leads to an enormous amount of material constants. This can, however, be drastically reduced by the assumption of symmetry properties like isotropy or centro-symmetry. In the non-linear case of finite deformations, one has to satisfy invariance principles, which is not trivial.

In the case of plastically deforming metals, primal higher strain gradients are chosen with the aim of describing the behavior of geometrically necessary dislocations.
In the course, the following topics will be considered

- experimental findings for size effects
- balance laws and boundary conditions for strain gradient materials
- the linear theory of elasticity and plasticity of strain gradient materials of arbitrary order
- the application to crystal plasticity
- the finite strain gradient theory for large deformations
- the application of strain gradient models to fracture and damage and to micro-to-macro transitions (media with microstructure).

*Invited Lecturers:*
Lorenzo Bardella (University of Brescia, Italy), Albrecht Bertram (University of Magdeburg, Germany) assisted by Rainer Glüge (University of Magdeburg, Germany), Samuel Forest (Mines ParisTech, Evry, France), Wolfgang H. Mueller (Technical University of Berlin, Germany), Christian Niordson (Technical University of Denmark, Lyngby, Denmark), Pierre Seppecher (University of Toulon, France).

*Coordinator:* A. Bertram (Germany), S. Forest (France).

**High-performance Computing of Big Data for Turbulence and Combustion**

*May 21 - 25, 2018*

The main aim of this course is to acquaint the participants with present state of art of high accuracy scientific computing and its future prospects, as applicable to the broad areas of fluid mechanics and thermal analysis, across all speed regimes. Beginning with the concepts of space-time discretization and dispersion relation in numerical computing, the foundation will be laid for the solution of Navier-Stokes equation and its solution strategies for RANS (Reynolds-averaged Navier-Stokes), LES, DES (detached eddy simulation) and DNS using classical discretization techniques. Also, newer, approaches to cope with geometrical complexity like immersed boundary methods will be used not only for high accuracy computing, emplyoing high performance computing, but also for futuristic exascale computing.
Basics of high accuracy computing is rooted to the concept of stability, dispersion and phase errors, which require global spectral analysis (GSA) of discrete computing by rigorously following error dynamics. In this context we present high-order methods from finite difference, finite volume and finite element (including spectral element). We will specifically discuss compact schemes, which promise very high accuracy computing for DNS/LES of incompressible and compressible flows. Naturally, discussion would involve high performance computing (HPC) with various concepts of parallel computing. With the added help of multi-dimensional filtering, results have been produced for turbulence starting from receptivity stage without any modeling from first principle. This will be one case that will be discussed for simulating transitional and turbulent flows.
Another interesting case is the simulation of wall bounded turbulence for both incompressible and compressible flows, which will be described in all essential details.

With growth of available computer power, DNS has recently got to the stage of simulating high Reynolds number flows, where comparison with experiments is a distinct possibility. It is now even conceivable to solve for even higher values of Reynolds number. We plan to discuss about complex fluid-structure interaction problems involving moving bodies and heat transfer.

This course aims to raise the bar above the pedagogical usage of high- accuracy computing in addressing more complex physical scenarios, like discussing turbulent combustion. This will span from modeling level to investigation of complex combustion instabilities in gas turbines, which may also incorporate acoustically coupled causes. The participants would also gain insights into the industry practices in the areas of turbomachines via the usage of hybrid-RANS, LES modeling. Such advanced industrial simulations using LES also require innovative hybrid turbulence models. The pre- and post-processing of LES data is another challenge that is faced in present day industrial practices.

Obtained results of Navier-Stokes equation in time-accurate manner constitute huge data bases, whose analysis poses significant challenges already to researchers. In the near future one would aim at peta and exascale computing.

To visualize and analyze such big data arising from models in industrial scale simulations, LES and DNS of canonical problems one needs to familiarize oneself with various pre- and post-processing tools. We specifically present tools like proper orthogonal decomposition (POD), proper generalized decomposition (PGD), singular value decomposition (SVD), recursive POD, high order SVD in multi-parameter spaces. Special attention would be paid to bivariate and multivariate data sets in the course, with respect to various canonical flow and heat transfer cases.

The course is mainly addressed to doctoral students in mechanical, aerospace engineering and all applied disciplines including applied mathematics. We believe that the covered materials would also significantly benefit post-doctoral fellows and young professional working in related fields. The course will be offered with enough scope of interaction between the lecturers and the participants. As we expect that some of the participants would be already involved in similar activities, an afternoon would be set aside for participants to discuss their specific problems orally via informal and/or poster presentations.

*Invited Lecturers:*

Mejdi Azaïez (University of Bordeaux, France), Gianluca Iaccarino (Stanford University, USA), Sergio Pirozzoli (“La Sapienza” University of Rome, Italy), Thierry Poinsot (CERFACS, Toulouse, France), Tapan K. Sengupta (Indian Institute of Technology, Kanpur, India), Paul G. Tucker (University of Cambridge, UK).

*Coordinator:* S. Pirozzoli (Italy), T. K. Sengupta (India).

**Modelling and Simulation of Tribological Problems in Technology**

*May 28 - June 1, 2018*

Significant advances in contact mechanics have been achieved since the first theoretical derivations a few centuries ago, primarily associated with contact problems in statics and dynamics involving friction, adhesion, wear, roughness, heat or electric conduction, and also with materials not only linear elastic. Principles of contacts mechanics can be applied in many traditional mechanical engineering areas such as locomotive wheel-rail contact, coupling devices, braking systems, tires, bearings, combustion engines, mechanical linkages, gasket seals, metal forming, ultrasonic welding, electrical contacts, and many others. Current challenges in the field regard the extension of contact mechanics methodologies to the micro- and the nano-scales, to coupled multi-field problems, and the application to finite elasticity.

The main objective of this course is to convey, in a self-contained manner, the fundamental concepts for the classification of the types of contact, the mathematical methods for the formulation of the contact problems, and the numerical procedures required for their solution. In addition to the methodologies, a wide class of applications will be covered, including contact problems in mechanical engineering, microelectronics and nanomechanics.

A taxonomy of contacts and the half-space solutions for linear elastic problems will be provided. For the class of complete contacts, asymptotic methods are formulated and applied to mechanical engineering problems. Further concepts for modelling contact problems with friction and partial slip will also be provided. Methods to formulate contact problems in the presence of coupled fields, such as thermo-elastic and electro-elastic contact problems, are then presented together with applications to mechanical engineering and microelectronics. An overview on numerical methods for the approximate solution of contact problems will also be provided (boundary element method, finite element method, molecular dynamics) with attention to complex problems characterized by multi-scale roughness, emphasizing the advantages and disadvantages of each technique. Finally, advanced contact problems involving lubrication, roughness and interaction between bodies undergoing finite deformation will complete the course.

Each set of lectures will be designed to convey a strong background on theory and numerical methods, with also in-depth treatment of cutting-edge research topics and applications. The final aim of this intensive course is to provide a compact yet comprehensive overview of contact mechanics in technology and its current challenges.

The lectures are primarily tailored for doctoral students of applied mathematics, mechanics, engineering and physics with a strong research interest in theoretical modeling, numerical simulation and experimental characterization of contact problems in technology. They are also suited for young and senior researchers in the above-mentioned and neighboring fields working in academia or in private research and development centers, interested in gaining a compact yet comprehensive overview of contact mechanics from its fundamental mathematical background, to the computational methods and the experimental techniques available for the solution of contact problems.

*Invited Lecturers:*
Andreas Almqvist (Luleå University of Technology, Sweden), James R. Barber (University of Michigan, Ann Arbor , USA), Daniele Dini (Imperial College London, UK), David A. Hills (University of Oxford, UK), Marco Paggi (IMT School for Advanced Studies Lucca, Italy).
*Coordinator:* M. Paggi (Italy), D. A. Hills (UK).

**Advanced Topics in MHD**

*June 11 - 15, 2018*

Magnetohydrodynamics (MHD) is a union of fluid mechanics and electromagnetism and describes the macroscopic interaction of electrically conducting fluids and magnetic fields. Since its initial development in the 1930s, MHD has blossomed into a major area of fluid mechanics, with applications ranging from industry to astrophysics. The original development of MHD lay mainly in dynamo theory, which describes how fluid motions within stars and planets can act to generate and sustain a global magnetic field. Later, MHD became popular in the fusion community as the language that could describe the stability of magnetic fields containing plasma.
MHD continues to grow and is an area of intensive research. In recent times, the phenomenon of ‘space weather’ has drawn much attention as solar storms that hit the Earth can have a major technological and economic impact. In order to understand the origin of space weather, we need to study the formation and eruption of storms on the Sun. To model the large-scale mechanics of solar storms, we require MHD. In particular, three key areas of MHD are important for the formation of solar storms: MHD stability theory, magnetic topology and magnetic reconnection. These three fields are active areas of research and have each already undergone significant development.
Often, these three topics are treated separately. However, for many applications, including the formation and eruption of solar storms in space weather, the three topics are inseparable. The application of these three topics is not only restricted to space weather but is also becoming essential in understanding plasma physics experiments, tokamaks and spheromaks, and many astrophysical applications. The purpose of this school is to focus on the above three areas and present a unified view, revealing how they connect intimately with each other and the role they play in space weather, astrophysical systems and plasma experiments. We shall go beyond the standard theory, as commonly found in textbooks and undergraduate and postgraduate courses. The lectures will describe many recent developments. For MHD stability theory, classical theory will be reviewed and new mathematics required for important extensions of this theory will be developed. Models of plasmas which require physics that goes beyond standard MHD will be discussed. Magnetic topology will be presented from both theoretical and applied standpoints. The modelling of magnetic reconnection, with connections to helicity and turbulence, will be described. Throughout the school, the links between all the above topics will be emphasized and demonstrated.
This school would be ideal for PhD students and postdoctoral researchers working in MHD, both in astrophysical and experimental applications. The lectures would give

students not only valuable information but an appreciation of how the various disciplines described above, which they may have encountered separately, fit together to give a more accurate picture of the evolution of magnetic fields in electrically conducting fluids and plasmas.

*Invited Lecturers:*
Andrew Hillier (University of Exeter, UK), Elena Khomenko (Institute of Astrophysics of the Canaries, Spain), David MacTaggart (University of Glasgow, UK), Etienne Pariat (LESIA, Observatoire de Paris, CNRS, France), Anthony Yeates (Durham University, UK), Nobumitsu Yokoi (University of Tokyo, Japan).

*Coordinators:* A. Hillier (UK), D. MacTaggart (UK).

**Wave Turbulence and Extreme Events**

*June 18 - 22, 2018*

When the number of degrees of freedom of a wave system is very large, a deterministic description is not feasible anymore and a statistical one is required. Wave turbulence (WT) can be generally defined as the out-of-equilibrium statistical mechanics of random dispersive nonlinear waves. It has been applied to a variety of fields from quantum to astrophysical scales. WT finds its application in the description of ocean waves: the nonlinear interactions provided by the WT theory are an important ingredient in the operational ocean wave forecasting models. WT concepts have also been applied to internal waves that are responsible for the turbulent mixing in the ocean; quantized vortex lines which are important for understanding superfluids turbulence; Alfvén waves in astrophysical application; planetary Rossby waves, relevant in weather and climate studies; waves in Bose–Einstein condensates and in nonlinear optics; a great variety of waves in plasmas of fusion devices; waves on vibrating elastic plates, capillary waves, and many other physical systems.

After introducing the general concepts of turbulence in fluids, the purpose of the course is to give a general and compact introduction to WT and make it accessible for graduate students and non-specialist researchers who are willing to master it and possibly to apply it in their own field of research.

The course will be as self-consistent as possible, trying to insist on conceptual issues, but giving all the mathematical details needed to tackle properly the problem. The aim will be to propose a formal but yet simplified picture of the key aspects and properties of the Wave Turbulence theory and to provide insights into physical situations and practical problems. Specifically, the course will propose a general presentation of the mathematical background suitable for physicists and engineers. The different lecturers will propose examples extracted from their research fields with particular attention to surface gravity waves, elastic waves, optical waves and quantum turbulence. Differences between fluid turbulence (Navier-Stokes) and WT will be examined.

The limits and failure of the Wave Turbulence theory, including the observation of the phenomenon of intermittency observed in many incoherent wave systems, will be reviewed. Finally, some interesting and new perspectives to be pursued in the future will

be presented. With respect to this scope, an illustration of the more general framework of extreme events (like rogue waves in the ocean) and large deviations will be given.
The course is addressed to master students, doctoral students, young and senior researchers interested in general physics, fluid mechanics, geophysics, nonlinear optics, turbulence, statistical mechanics and condensed-matter.

*Invited Lecturers:*
Sergio Chibbaro (Sorbonne Université, UPMC, France), Gregory Falkovich (Weizmann Institute of Science, Rehovot, Israel), Christophe Josserand (Sorbonne Université, UPMC, France), Sergey Nazarenko (University of Warwick, Coventry, UK), Miguel Onorato (University of Turin, Italy), Davide Proment (University of East Anglia, Norwich, UK), Pierre Suret (Université de Lille, France).

*Coordinators:* S. Chibbaro (France), M. Onorato (Italy).

## Turbulent Mixing in Stratified Flows

*June 25 - 29, 2018*

The world's oceans, lakes and atmospheres and many astrophysical bodies are stably stratified, in that the density of the fluid increases in the direction of the gravitational force. A fluid particle displaced from its equilibrium position is then subject to a restoring buoyancy force that tends to return it to its equilibrium position. On Earth, this means that vertical motions are inhibited by the stratification, providing an impediment to vertical exchanges of mass. However, these vertical exchanges and any consequent mixing are critical determinants of the structure of these natural fluid bodies. For example, the uptake of heat and carbon dioxide into the ocean from the surface depends critically on how these quantities are mixed down into the ocean interior, an essential aspect of the climate system. This mixing is caused predominantly by turbulent motions generated by shear flows, breaking internal waves and other forcing mechanisms interacting with large scale motions.
Over the past ten years or so there have been major advances in our understanding of stratified turbulence. This has been largely brought about by improved computational capabilities that allow direct numerical and large eddy simulations of stratified flows, coupled with significantly improved experimental diagnostics. In addition field measurements have provided new data at geophysical scales that have caused a re-evaluation of the extrapolations of data from numerical and laboratory studies. There has also been significant progress in understanding transitions from stratified laminar to turbulent flows through the application of modal as well as non-modal analysis.
This course brings together six leading researchers specializing in stratified turbulence and mixing to teach focused and highly original courses in this area. They will present the latest findings from stability theory on the laminar to turbulent transition, and discuss the recent progress in scaling stratified turbulent flows. The latest laboratory experiments will be presented and the impact of new highly-resolved three dimensional fields of velocity and density and the relation to the latest numerical simulations. Important quantities such as mixing efficiency and the relation to the underlying

non- dimensional parameters and the molecular properties of the fluid involved will be highlighted. Lectures will also cover the role of stratified turbulence in the oceans, atmosphere and in astrophysics.
Learning skills in this interdisciplinary environment is challenging and rarely addressed to a sufficient level in standard graduate programs. The integrated presentation of theoretical, experimental and numerical research coupled with applications in geophysical and astrophysical fluid dynamics, provides a valuable opportunity to learn about this important field of fluid dynamics. The course is intended for doctoral and postdoctoral scholars in physics, applied mathematics, engineering, oceanography and meteorology.

*Invited Lecturers:*
Jean-Marc Chomaz (Ecole Polytechnique, Paris, France), Stuart Dalziel (Cambridge University, UK), Sonya Legg (Princeton University, USA), Paul F. Linden (Cambridge University, UK), Michel Rieutord (Université Paul Sabatier et Observatoire Midi-Pyrénées, Toulouse, France), Chantal Staquet (LEGI, Grenoble, France) .

*Coordinators:* J-M. Chomaz (France), P. F. Linden (UK).

**Fluid Dynamics Effects on Particle Formation in Crystallization Processes**

*July 2 - 6, 2018*

The aim of the course is to survey and discuss the role of fluid dynamics and turbulence on particle formation processes in crystallization and precipitation with a particular focus on primary nucleation, growth and aggregation. Crystallization is a separation process, widely applied in the chemical and pharmaceutical industries, that exploits the limited solubility of a compound in a solvent under certain conditions.
A change of these conditions to a state of lower solubility leads to the formation of a crystalline solid. Precipitation is instead defined as the rapid formation through a chemical reaction of insoluble solid particles from a liquid solution, often under high supersaturation conditions. Both processes involve the occurrence of primary nucleation (solute molecules or atoms dispersed in the solvent start to gather into clusters, which constitute the nuclei) and subsequent growth (size increase of the nuclei that become stable by achieving the critical cluster size) of particles, together with secondary processes, such as aggregation. Crystallization and precipitation have been long applied to generate a solid from a supersaturated solution. The final product quality is determined by many factors, the particle size distribution and particle morphology being among the most important. In turn, these properties are influenced by parameters such as the operating pressure and temperature that control supersaturation and, therefore, nucleation and growth rates. The competition between these phenomena dictates the final particle morphology and size: if nucleation is favored over growth, small particles are produced and viceversa. Aggregation has a strong influence on the final product quality at moderate to high particle loadings (typically from 1 to 10% in terms of the solid volume fraction) that correspond to the standard operating conditions of industrial crystallization equipment.

The role of fluid dynamics and turbulence in crystallization and precipitation processes is crucial as it affects the creation and redistribution of supersaturation through mixing, it influences the local nucleation rate and gives an important contribution in determining the final nucleation and growth rates. Secondary processes are also strongly influenced by fluid dynamics. In fact, the driving force for secondary processes is the shear rate, which is of course determined by the flow and turbulence fields in the vessel of the crystallization/precipitation reactor. Due to the practical importance of such effects, efforts have been made to understand how fluid flow and mixing impact on the overall crystallization/precipitation process (considering, for instance, reactive crystallisation/ precipitation and antisolvent crystallization/ precipitation with supercritical fluids applied as the antisolvents). In particular, mechanistic models, computational fluid dynamics and population balances (including the method of classes and the method of moments) have been widely applied to investigate the elementary subprocesses (macro-, meso-, micro-mixing, chemical reaction, nucleation, growth and aggregation of particles), trying to characterize the corresponding time constants (which must be known to provide proper modeling and scale- up of the overall process).

Lectures will provide an overview of the current state of the research in the field, including both experimental and computational studies. Particular emphasis, however, will be given to modelling and numerical simulation approaches: Different approaches, characterized by a different level of accuracy and computational costs, will be presented and discussed. In particular, homogeneous models will be compared with computational fluid dynamics models, highlighting potentials and limitations. Lectures will also show, in the context of industrially- relevant practical applications, to what extent the approaches discussed in this course can be applied to “design” particles.

The course delivers a comprehensive overview of mixing and fluid mechanics effects on particle primary nucleation and aggregation for crystallization processes and hence 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 in this very active field will also be of considerable interest to many senior researchers, as well as industrial practitioners having a strong research interest in understanding the multiscale complex behavior of such processes, with particular emphasis on their modelling and simulation.

*Invited Lecturers:*

Matthaus Babler (Royal Institute of Technology KTH, Stockholm, Sweden), Richard D. Braatz (MIT, Cambridge, USA), Jos Derksen (University of Aberdeen, UK), Cristian Marchioli (University of Udine, Italy), Daniele Marchisio (Polytechnic of Turin, Italy), Jan Sefcik (University of Strathclyde, Glasgow, UK).

*Coordinators:* D. Marchisio (Italy), C. Marchioli (Italy).

**Mechanics of Fibrous Materials and Application: Physical and Modelling Aspects**

*July 9 - 13, 2018*

Fibrous media are present in a large variety of systems and applications due to their high mechanical performances at low weight. Such systems include complex yarns used as reinforcement for rubber tires, 3D woven structures used in cutting-edge areas such as aeronautics, composite engineering for transportation (aerospace, maritime, automotive industry), biological tissues, scaffolds for tissue growth and some biomaterials, such as ligament biosubstitutes or vascular endoprostheses. Some man-made fibrous structures have a regular, periodic architecture, e.g. woven networks for composite applications, while others have random microstructure, such as in paper and various types of insulation materials. Rubber and gels are random molecular networks. Many biological materials have a random complex fibrilar structure which plays the central role in their mechanics. Examples include soft connective tissue, such as tendons and ligaments, the arterial walls, and the cellular cytoskeleton. Damage accumulation, fracture and the related non-linear behavior under large deformations are important considerations in all these materials.

The scientific problems raised by the complexity of fibrous media include the following aspects:

- The development of methods to characterize the multiscale structure, including imaging techniques and image-to-model conversion;
- The identification of the relation between the fiber properties and network architecture, and the overall mechanical behavior of the fibrous assembly;
- The description and prediction of the onset of damage and overall structural failure, including occurrence of global scale instabilities;
- Accounting for time-dependent behavior under small and large deformations, including the rheology of wet fibrilar structures and fibrilar structures embedded in matrix;
- Understanding the mechanical behavior of active networks such as the cellular cytoskeleton;
- The development of homogenization methods for constructing an equivalent homogeneous medium;
- The consideration of scale effects, which may require the consideration of generalized continua (Cosserat, second gradient, microstretch or micromorphic media);
- The design of experimental procedures for identifying specific mechanical properties and in particular non-conventional properties of networks;
- The design of metamaterials with a fibrous architecture for acoustic or other applications;
- The development of efficient numerical methods to handle fibrous microstructures incorporating multiscale aspects (discrete elements, multi-domain approaches, finite element techniques).

The aim of the course is to bring together researchers in the field of fibrous media, to foster interactions between experts with different background and to educate the next generation of researchers. The course is mostly intended for Master students, PHD students, post-doctoral researchers, industrial researchers and engineers and scientists interested in the more practical use of such materials. More established researchers interested in an overview of the field are also welcome.

*Invited Lecturers:*
Philippe Boisse (LaMCoS, INSA de Lyon, France), Francesco Dell'Isola (University of Rome "La Sapienza, Italy), Jean-François Ganghoffer (LEMTA, Université de Lorraine, Vandoeuvre, France), Edoardo Mazza (ETH Zurich, Switzerland), Mohammad Mofrad (Molecular Cell Biomechanics Laboratory, University of California at Berkeley, USA), Catalin Picu (Rensselaer Polytechnic Institute, Troy, USA).

*Coordinators:* J-F. Ganghoffer (France), C. Picu (USA).

**Efficient High-order Discretizations for Computational Fluid Dynamics**
CISM-ECCOMAS Summer School

*July 16 - 20, 2018*

This course introduces modern high-order methods for computational fluid dynamics.
As compared to low order finite volumes predominant in today's production codes, higher order discretizations significantly reduce dispersion errors, the main source of error in long-time simulations of flows at higher Reynolds numbers. Thus, they make previously intractable problems accessible to simulation in an increasingly wide range of applications. However, a careful selection of algorithms and implementations is fundamental to fully unleash the potential of high order schemes, in particular for emerging high-performance computer architectures that approach the exascale threshold. A major goal of this course is to teach the basics of the discontinuous Galerkin (DG) method in terms of its finite volume and finite element ingredients. Consistent numerical fluxes over the element boundaries take directionality of flow into account and introduce some numerical dissipation. High-order shape functions inside the element provide accurate approximations and geometric flexibility. This special combination makes DG not only high-order convergent but also robust for transport-dominated problems.
In the presentation of the method, favorable numerical fluxes and recent developments regarding the particular arrangement of the weak form for turbulent flows are discussed. Furthermore, implementation techniques that have their origin in the spectral element community will be presented. These so-called sum factorization kernels avoid building a global Jacobian matrix and instead evaluate differential operators by particular fast integration schemes for tensor product shape functions and quadrature formulas. The complexity of the resulting DG operator evaluation is competitive with finite differences without compromising the geometric flexibility and robustness, as showcased by a compressible flow solver with explicit time integration. Sum factorization is also increasingly used in implicit scenarios, for example for solving the pressure Poisson equation in splitting schemes for the incompressible Navier-Stokes equations with multigrid solvers. An alternative technique that makes matrix-based DG competitive is the hybridizable discontinuous Galerkin (HDG), where the numerical fluxes are

expressed in terms of a new variable on all faces, the mesh skeleton. The particular construction allows HDG to eliminate all the degrees of freedom inside the elements in favor of the variables on the mesh skeleton by a static-condensation-like approach, considerably reducing the final linear system size. Together with improved convergence rates, efficiency gets a significant boost. The course also discusses the computational efficiency of high- order methods versus state-of- the-art low order methods in the finite difference context, given that accuracy requirements in engineering are often not overly strict. Thus, the faster convergence rates of high-order methods in the asymptotic regime must be put in a quantitative context, in particular with respect to the nonlinear interaction between scales typical for fluid dynamics. This comparative setup enables the participants to obtain a broader perspective on high-order methods and identify major challenges in the field for the next decade.

*Invited Lecturers:*
Sonia Fernández-Méndez (Universitat Politècnica de Catalunya, Barcelona, Spain), Gregor Gassner (Köln University, Germany), Martin Kronbichler (Technical University of Munich, Germany), Rainald Löhner (George Mason University, Fairfax, VA, USA), Per-Olof Persson (University of California, Berkeley, USA), Stefano Rebay (University of Brescia, Italy).

*Coordinators:* M. Kronbichler (Germany), P-O. Persson (USA).

## Substructuring in Engineering Dynamics: Emerging Numerical and Experimental Techniques

*July 23 - 27, 2018*

One fundamental paradigm in engineering is to break a structure into simpler components in order to simplify test and analysis. In the numerical world this concept is the basis for Finite Element discretization and is also used in model reduction through substructuring. In experimental dynamics, substructuring approaches are commonly used (for instance for Transfer Path Analysis) , although the subtleties involved are perhaps not always adequately appreciated. Recently there has been renewed interest in using measurements alone to create dynamic models for certain components and then assembling them with numerical models to predict the behavior of an assembly. Substructured models are also highly versatile; when one component is modified it can be readily assembled with the unchanged parts to predict the global dynamical behavior. Substructuring concepts are critical to engineering practice in many disciplines, and they hold the potential to solve pressing problems in testing and modeling structures where nonlinearities cannot be neglected.
In this short course we will review a general framework which can be used to describe a multitude of methods and the fundamental concepts underlying substructuring. The course is aimed at explaining the main concepts as well as specific techniques needed to successfully apply substructuring both numerically (i.e. using finite element models) and experimentally. Therefore, hands-on exercises will be included to illustrate the concepts using routines written in Matlab® and real-life applications will be presented.

The course is centered around the following topics, which range from classical substructuring methods to topics of current research such as substructuring for nonlinear systems.

- Primal and dual assembly of structures and applications to parallel computing.
- Model reduction and substructuring for linear systems including Guyan and Hurty/ Craig-Bamtpon reduction, McNeal, Rubin, Craig-Chang, etc… Recently developed interface reduction methods will also be reviewed.
- Experimental-Analytical substructuring including modal substructuring methods such as the transmission simulator method and frequency domain methods such as impedance coupling.
- Model reduction and substructuring methods for non-linear systems: Overview of traditional nonlinear FEA including geometric nonlinearity. Nonlinear Normal Modes and other analytical techniques for nonlinear systems will be reviewed to demystify nonlinearity and its effect on structural response. The special case of weakly nonlinear systems will also be treated including experimental identification methods and experimental substructuring.

The course is designed to provide practicing engineers or researchers such as PhD students with a firm grasp of the fundamentals as well as a thorough review of current research in emerging areas. Attendees are expected to have a solid foundation in structural dynamics and some exposure to finite element analysis. The course material will be of interest to those who primarily perform finite element simulations of dynamic structures, to those who primarily focus on modal test, and to those who work at the interface between test and analysis.

*Invited Lecturers:*

Thomas Abrahamsson (Chalmers University, Gothenburg, Sweden), Matthew Allen (University of Wisconsin-Madison, USA), Randall L. Mayes (Sandia National Labs, Albuquerque, USA), Daniel Rixen (Technische Universität München, Germany), Paolo Tiso (ETH Zurich, Switzerland), Maarten van der Seijs (VIBES Technology, Delft, The Netherlands).

*Coordinators:* M. Allen (USA), D. Rixen (Germany).

# The Bruno A. Boley Session

## Electromechanical Transducers: Principles and Technologies

*September 3 - 7, 2018*

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.
Prof. Reinhard Lerch will address the Finite Element (FE) modeling of piezoelectric, electrostatic and magnetomechanical transducers, the characterization of material data for piezoelectric and magnetic materials using inverse methods, the modeling and measurement of hysteresis properties, ultrasound transducer technologies (air coupled transducers for distance measurement and object identification, sonar Transducers, and imaging transducers), transducers for energy harvesting and associated electronic circuits. The design of audio electrodynamic loudspeakers will serve as an example for a particular application treating the FE-modeling of the devices, their verification by prototypes, and their application as loudspeakers in cars.
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), Reinhard Lerch (University of Erlangen, Germany), Pasqualina M. Sarro (TU Delft, The Netherlands), Michiel Vellekoop (University of Bremen, Germany).

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

**Thermodynamics of Irreversible Processes in Material Systems**

*September 10 - 14, 2018*

Thermodynamics is an efficient tool for the description of the development of the microstructure of a solid material system as well as the motion of defects.
Within the framework of continuum mechanics a proper thermodynamic potential depending on external and internal state variables can be found to describe the state of a system. Internal state variables are assigned to properties, e.g., as concentrations of components, but can also be assigned to defects, e.g., cracks or dislocations. As a proper thermodynamic potential the Gibbs energy of a material system is introduced, relevant for systems under constant temperature and stresses.
A central role plays the dissipation and the associated dissipation function. The dissipation is derived from the rate of the Gibbs energy. Correspondingly, a dissipation func-

tion is introduced, in terms of thermodynamic fluxes (fluxes of matter, of heat, etc.). Finally, the dissipation and the dissipation function are used to derive evolution equations for the internal variables by applying an extremum principle for irreversible processes.
The Thermodynamic Extremal Principle (TEP) is demonstrated (related to prominent names such as Onsager, Prigogine, H. Ziegler et al.) yielding a variational formulation, which allows an explicit derivation of evolution equations for the internal variables. The according thermodynamic forces lead to the so-called configurational forces driving physico-chemical processes and defects. Applications to various fields of materials science are presented. For example, one can treat the development of the surface of a solid consisting of grains and interacting with the environment as grooving, together with its numerical realization. Systems characterized by distinct parameters, such as effective grain radii, as evolving quantities are dealt with, too. Particular emphasis is laid on phase transformations as diffusive transformations controlled by the interaction of chemical and mechanical processes. Martensitic (i.e. displacive) phase transformations are also investigated, based on the minimization of the mechanical energy contribution to the total energy of the system.
Also the Phase Field Method (PFM) is outlined for multiphysics problems (chemistry, diffusion, electricity, magnetism, mechanics) with respect to its mathematical foundation and demonstrated for practical applications.
A successful validation of the procedures, introduced for simulations, by numerical methods, applied in a wide field of actual problems, is a necessary condition for their practical usability. Therefore, also this topic will be dealt with in this course. Particularly, the implementation of the physical and mathematical framework into actual numerical codes shall be discussed in detail. Within this context also the concept of configurational forces is explained allowing an efficient numerical calculation of the driving forces on defects, such as cracks, dislocations and other objects.
In conclusion, this course shall offer an overall view on the subject of thermodynamics of irreversible processes in materials starting from physical principles and proceeding via their mathematical formulations and numerical solutions on the way to their application.

*Invited Lecturers:*
Thomas Antretter (Montanuniversität Leoben, Austria), Georges Cailletaud (School of Mines/Paris Materials Centre, France), Franz Dieter Fischer (Montanuniversität Leoben, Austria), Klaus Hackl (Ruhr Universität Bochum, Germany), Ralf Müller (Technische Universität Kaiserslautern, Germany), Jiri Svoboda (Institute of Physics of Materials, Brno, Czech Republic).

*Coordinator:* F. D. *Fischer* (Austria).

**Stability and Serviceability of Controlled Structures**

*September 17 - 21, 2018*

The aim of this course is to discuss fundamental and practical concepts for assessing the stability and the serviceability of controlled engineering structures.

Pioneering works in applying control strategies to large-scale complex structures such as buildings and bridges have been mainly motivated by the protection of the built environment from earthquakes. Therefore, the uncontrolled structural systems are likely to have either approached or already entered the inelastic limit state. Recent advances in new material technologies enable to design highly flexible large-scale structures for which the limit states of stability and serviceability become of critical importance. It would be desirable that control solutions are developed in the design stage of these structures. Alternatively, retrofitting measures to introduce affordable control strategies together with their maintenance planning are typically required.

Structural stability is, in all cases, a key criterion in the design and service of most systems and structures where safety is paramount. Hence, there is a need to carefully assess the effects of the control devices on the global structural behaviour with respect to the stability limit state.

Vibration mitigation is often implemented to meet the serviceability requirement. Different solutions ranging from active to passive and semi-active control strategies are available but their feasibility and maintenance may be prohibitive. For these reasons, there is a need to preliminarily estimate their effects by investigating the serviceability of the controlled structures. In these studies, the testing of real-world large-scale structures is essential to support the validity of the approach.

The course will be structured into two series of three modules. Each module will consist of six one-hour lectures. The specific contents of the modules are summarized as follows. In the first module, a two-sided damping constraint control strategy for a quasi-zero-stiffness isolators is shown to improve the system stability. The second module is dedicated to the stability of passively controlled structures using either nonlinear energy sinks or piezoelectric devices. In the third module, thin plates and shells made of either piezoelectric materials or dielectric elastomers are embodied into smart structures as eigenstrain actuators to control stress and structural stability. In the fourth module, the serviceability assessment of controlled footbridges is discussed. The fifth module is dedicated to the recently developed control strategies for improving the vibration performance of floor structures. In the sixth module, the emerging trends in the vibration control of both onshore and offshore wind turbines are presented.

The course is addressed to doctoral students and postdocs in the fields of Civil and Mechanical Engineering, as well as Mechatronics, scientists, industrial researchers, and practicing engineers interested in the research areas of linear and nonlinear dynamics, stability and control.

*Invited Lecturers:*

Biswajit Basu (Dublin Trinity College, Ireland), Sara Casciati (University of Catania, Italy), Michael Krommer (TU Wien, Austria), Paul Reynolds (University of Exeter, UK), Marian Wiercigroch (University of Aberdeen, UK), Daniele Zulli (University of L'Aquila, Italy).

*Coordinators:* S. Casciati (Italy), M. Wiercigroch (UK).

**Cell Mechanobiology: Theory and Experiments on the Mechanics of Life**
CISM-AIMETA Advanced School

*September 24 - 28, 2018*

The role of Mechanics in governing key biological processes at the cell scale is becoming increasingly apparent. At the interface between biology, biophysics, and mechanics, Mechanobiology is emerging as a new, thriving research field, that is attempting to understand Biology from the perspective of Mechanics. And while the key role played by biochemical regulation in molecular cell biology is undisputed, the importance of forces and stresses in determining how cells function is becoming more and more widely recognised. Forces control shape and motion of the cells. But also how cells decide when and how much to differentiate, and where cells migrate to (e.g., durotaxis). Unveiling the details of this mechano-transduction opens the way to understanding key biological process at the cell scale first, and then at the tissue and organ scale.
Cell motility provides one concrete example where Mechanics is shaping our understanding of key biological processes. More generally, Mechanics is providing us with a conceptual framework to go beyond the identification of the molecular components and their individual function, by integrating them into a comprehensive understanding of cell motion and migration, of cell and tissue morphogenesis. The course will survey recent advances in the fields of cell motility and Mechanobiology of cells and tissues, emphasising such an integrative approach.
The topics of this Advanced School, which builds upon a previous one organised in 2014 by M. Arroyo and A. DeSimone, will include cell migration on solid substrates, adhesion and control of shape and migration, scaffold design in tissue engineering, mechanics of neural network growth, statistical mechanics and energetics of single cells, and mechanics of the cytoskeleton with an emphasis on its role in detecting and responding to mechanical, topological, and chemical cues. Both theoretical aspects (mathematical and computational modelling) and experimental techniques will be surveyed.
The Course will consist of 7 introductory lectures by the organisers, of 23 lectures on more specialised topics given by four eminent experts in the field, and of 4 “perspectives” lectures that will open and close the Course. In addition, a poster session will be organised, together with a social evening, to allow participants to discuss topics related to their research or professional interests. The financial support from the European Research Council, through the ERC Advanced Grant 340685-MicroMotility, and the endorsement by the Italian Association for Theoretical and Applied Mechanics (AIMETA) are gratefully acknowledged.

*Invited Lecturers:*
Carlijn Bouten (TU Eindhoven, The Netherlands), Antonio De Simone (SISSA, Trieste, Italy), Vikram Deshpande (University of Cambridge, UK), Dennis E. Discher (University of Pennsylvania, USA), Josè Manuel Garcia-Aznar (University of Zaragoza, Spain), Robert M. Mcmeeking (University of California at Santa Barbara, USA), Pierre Recho (LIPhy, Grenoble, France), Ulrich Schwarz (University of Heidelberg, Germany).

*Coordinators:* A. De Simone (Italy), V. Deshpande (UK).

**Modeling in Engineering using Innovative Numerical Methods for Solids and Fluids**

*October 15 - 19, 2018*

The development of reliable and efficient discretization methods for solids and fluids supports the modeling process in engineering and enables the understanding of complex physical phenomena. In this way the design and optimization of products and processes can be accelerated in almost all fields of engineering. Based on numerical simulations, the number of time-consuming and expensive experiments can be significantly reduced. So engineering decisions can be supported by computed data, which might be very difficult if not impossible to obtain experimentally.

The fast growing performance of available computers itself, however, is not sufficient to satisfy the increasing requirements for the simulation of complex problems arising in fluid and solid mechanics. To this end, innovative numerical methods need to be further developed in order to enable modeling of complex engineering problems. In response to the requirement for improved numerical methods, in Germany a Priority Program has been established entitled "Reliable Simulation Techniques in Solid Mechanics. Development of Non-standard Discretization Methods, Mechanical and Mathematical Analysis".

Inspired by the above mentioned challenges and stemming from the context of this Priority Program, the present CISM course focuses on innovative numerical methods for solid and fluid mechanics in order to support the modeling process in engineering. The objective is to present new and emerging simulation methods to young scientists and engineers from academia and industry.

The topics to be focused on are

- Particle methods addressing particle-based materials and numerical methods that are based on discrete element formulations and include fluid particle interaction as well as coupling with finite element methods. These methods are of importance in natural and engineering sciences.
- Phase field models, which have become very popular to model and simulate problems with surfaces and interfaces that are described implicitly.
- Fictitious domain methods, which allow for efficient discretization of very complex problems for which meshing with finite elements is very difficult.
- High-order continuous and discontinuous Galerkin methods, which offer high convergence rates and overcome many problems related to standard finite element approaches.
- Computational Fluid Dynamics based on modern finite volume schemes to efficiently discretize the Navier-Stokes equations.
- Nonintrusive coupling methods for structural models that allow to perform model adaptive simulations based on existing well developed solvers.

The course is addressed to scientists and engineers from both academia and industry working in the broad field of civil and mechanical engineering or applied physics and mathematics. The intention is to give a sound introduction into innovative numerical methods for solids and fluids which can be used to model complex problems in engineering.

*Invited Lecturers:*
Olivier Allix (École normale supérieure Paris-Saclay, France), Laura De Lorenzis (TU Braunschweig, Germany), Alexander Düster (Hamburg University of Technology, Germany), Antonio Huerta (Universitat Politècnica de Catalunya, Spain), Hrvoje Jasak (University of Zagreb, Croatia), Peter Wriggers (Leibniz Universität Hannover, Germany).

*Coordinators:* L. De Lorenzis (Germany), A. Düster (Germany).

## International Advanced Professional Training

### Advanced After-treatment Technologies for Automotive Applications

*June 4 - 8, 2018*

The Course on "Advanced after-treatment technologies for automotive applications" gathers worldwide renowned scientists and technologists, in order to provide a comprehensive picture of current challenges and solutions related to automotive-related air pollution. Moreover, the Course delivers fundamental knowledge on the involved complex phenomena, from the aftertreatment line scale down to the catalyst scale. The Course starts with an introduction having an engine-directed perspective, in order to describe the mechanisms of pollutant generation, the control of the engine to minimize them, and the developments driven by law regulations. Subsequently, the catalytic converters are individually considered: firstly, the oxidation of gaseous pollutants from either gasoline (TWC) or diesel (DOC) engines exhausts in structured reactors is described. Then, the abatement of soot within Particulate Filters is tackled from an experimental and modeling point view, with a multi-scale approach: soot-catalyst interactions are specifically addressed, with a focus on mechanisms and rational catalyst design. NOx abatement, which constitutes a tremendous problem nowadays given the gap between bench and on-road performance of catalyst converters, is presented through concurrent technologies: NSR (and specifically the Di-Air technology), SCR, NSR+SCR, and ammonia slip catalysts (ASC). The mechanisms, the catalysts, and the reactor-scale management from reaction engineering perspective, are widely described. The possible combination of these different technologies will be proposed too.

Finally, the perspective of a major manufacturer of catalytic converters and diesel engines is given, aiming at understanding the practical trade-offs that have to be optimized in terms of reliability, durability, cost and customer acceptance of the available technologies.

*Invited Lecturers:*
Samir Bensaid (Polytechnic University of Turin, Italy), Agustin Bueno-Lopez (University of Alicante, Spain), Michael Harold (University of Houston, USA), Athanasios G. Konstando-poulos (Chemical Process & Energy Resources Institute , Thessaloniki, Greece), Michiel Makkee (Technical University of Delft, The Netherlands), Federico Millo (Polytechnic

University of Turin, Italy), Aleksey Yezerets (Cummins Inc., USA).
*Coordinators:* S. Bensaid (Italy), M. Makkee (The Netherlands).

## Joint Advanced School

**Marie Curie – ITN ANTARES School on "Smart Systems for Vibration Control, Energy Harvesting, Tactile Feedback, Measurement and Monitoring"**

*January 29 - February 1, 2018*

*Coordinators:* M. Ghandchi Tehrani (University of Southampton, UK), Paolo Gardonio (University of Udine, Italy).

**Marie Curie - ITN School on "Damage and Failure of Materials under Extreme Conditions"**

*October 1 - 5, 2018*

*Coordinators:* S. Mercier (Université de Lorraine, Metz, France), J. A. Rodríguez-Martínez (University Carlos III of Madrid, Spain).

## Meetings and Events

**IUTAM Symposium on "Motile Cells in Complex Environments"**

*May 14 -18, 2018*

*Coordinators:* Eric Climent (Institut de Mécanique des Fluides de Toulouse, France), C. Marchioli (University of Udine, Italy).

## National Advanced Professional Training

National APT courses in the fields of Structural and Geotechnical Engineering, Surveying, Environmental, Bioengineering and Industrial Engineering will be given in Italian.
For all activities and meetings, please refer to our website.

## Admission to Courses

Applications should reach CISM Secretariat no later than one month before the course. Name, degree, current address and course to be attended should be specified.
A limited number of academic participants, not supported by their own institutions, can be granted board and/or lodging upon application. Application for support must reach CISM Secretariat no later than two months before the course.
Detailed programmes, admission rules and on-line forms are available from the website.

CISM, Palazzo del Torso, Piazza G. Garibaldi 18, 33100 Udine, Italy
Ph. +39 0432 248511 (6 lines) - Fax +39 0432 248550
cism@cism.it - http://www.cism.it

**Professor Bernhard A. Schrefler**
**Secretary General**

**Dr Mario Pezzetta**
**President**
**of the Board of Directors**

*" ...The purpose of the Centre is to promote, on a non-profit basis, research in the Mechanical Sciences and related multidisciplinary sciences, favour the exchange, diffusion, and application of the most advanced knowledge in this field, establish active relations with similar national, or international institutions, enlist the cooperation of the most qualified scientists and researchers throughout the world, set up research laboratories and libraries, organize courses and seminars of a high scientific level ..."*

**from the Statute of the "International Centre for Mechanical Sciences".**
**CISM, Chap. I, Art. 1.**

Printed by CISM, Udine - December 2017

International Centre for Mechanical Sciences I Palazzo del Torso I Piazza Garibaldi 18 I 33100 Udine I Italy
Ph. +39 0432 248511 (6 lines) I Fax +39 0432 248550 I cism@cism.it I www.cism.it