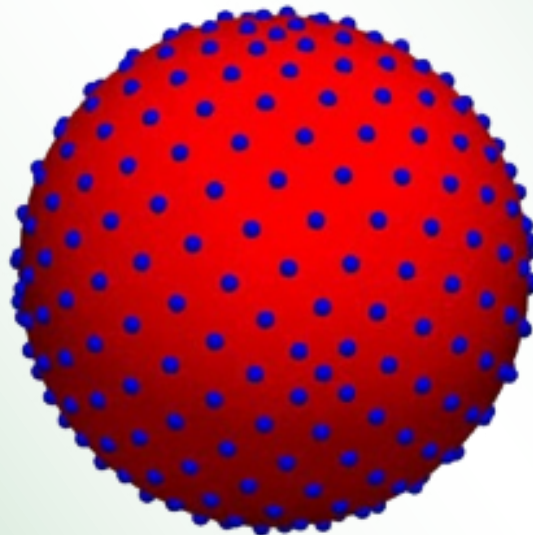
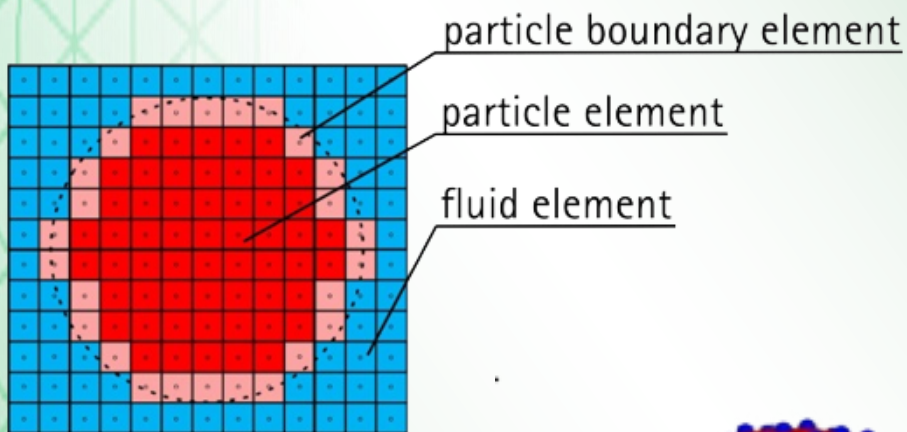


# ECCOMAS NEWSLETTER



**DECEMBER 2014**

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# MESSAGE OF THE PRESIDENT

## WCCM-ECCM-ECFD CONFERENCE

The joint conference of IACM and ECCOMAS in Barcelona in July 2014 was the highlight of the year. Despite its size – by far the largest meeting in our community ever – it was a great success. The organization was perfect, from the technical as well as the social point of view. We from ECCOMAS would like to thank the organizing teams from the Spanish Association for Numerical Methods in Engineering (SEMNI) and the International Center for Numerical Methods in Engineering (CIMNE) at the Universitat Politècnica de Catalunya (Barcelona Tech), headed by the three chairmen Professors Eugenio Oñate, Antonio Huerta and Xavier Oliver as well as the General Manager Cristina Forace for their enormous efforts; they have done a great job. I personally appreciated very much that most of the organization was managed “inhouse”, i.e. within the academic environment of a university, with a very special personal atmosphere.

Does it make sense to hold such a mega-event? 3600 delegates with 218 Minisymposia and up to 48 parallel sessions, meaning that even the most diligent delegate can only attend a very small fraction of the offered talks. Yes, it makes a lot of sense! It followed the arguments which I expressed in my welcome message to the conference: “It is not the size of a conference which matters. Surely it supports what is called “corporate identity”. It may be considered as many small meetings taking place in parallel,

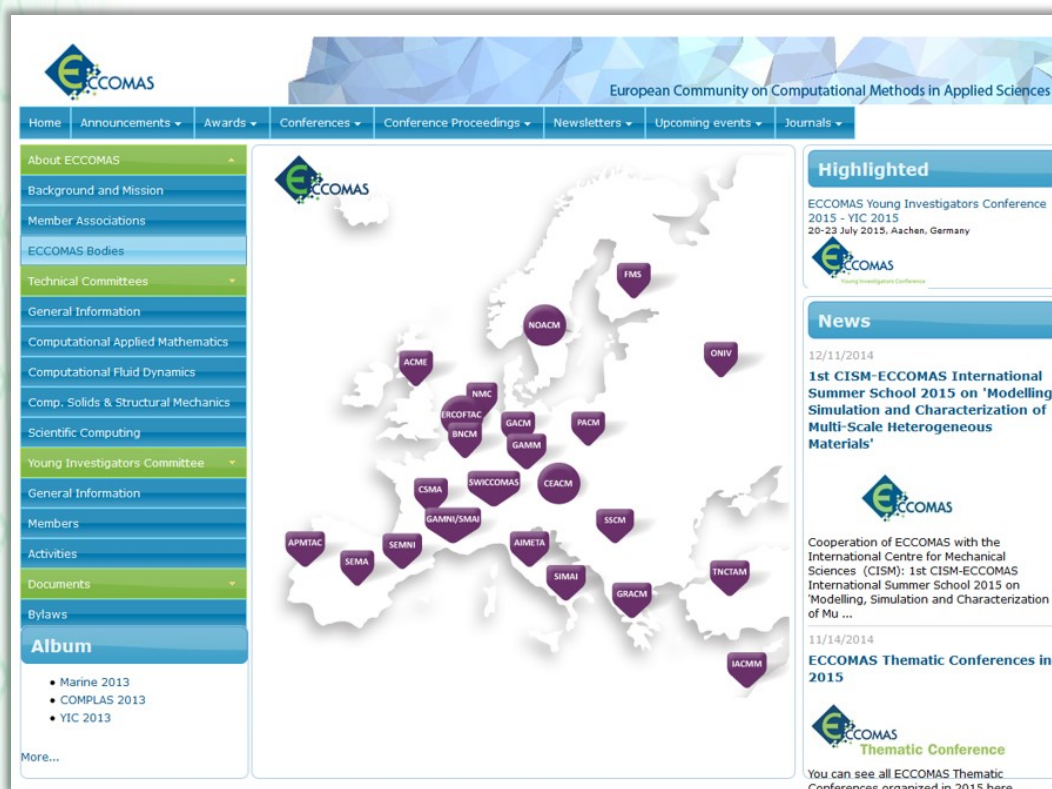
but allowing also getting an insight into other emerging fields. However most importantly it is an indication, maybe a demonstration, for the enormous development of computational methods in Engineering and Applied Sciences in Academia as well as in Practice, with a great influence on our society. Insofar such a mega-event has also a political dimension which should not be underestimated.” The spectrum of the addressed topics was impressive. My own impression and the feed-back from many delegates was exclusively very positive. And in addition it can be

stated that the merge of all three conferences was the right decision.

## AWARDS

During the Barcelona Conference ECCOMAS honored several scientists by a special distinction. The two Awards for the best Ph.D. thesis 2013 were given to Francesc Verdugo (Universitat Politècnica de Catalunya, Barcelona, Spain) for his research in the field of “Computational Solids and Structures” and to Henning Sauerland (RWTH Aachen Universität, Germany) for his work in





ECCOMAS Website

Computational Fluid Dynamics; for a detailed assessment see ECCOMAS Newsletter of July 2014.

The ECCOMAS Awards for young scientists were presented to two excellent young professors, namely the Olgierd Cecil Zienkiewicz Award to Julien Yvonnet (Université Paris-Est, France) in the field of Computational Engineering Sciences and the Jacques Louis Lions Award to Gianluigi Rozza (International School for Advanced Studies, Trieste, Italy) in the field of Computational Mathematics.

Professor Franco Brezzi (Institute for Advanced Study and Institute of Applied Mathematics and Information Technology, Pavia, Italy) was awarded the Leonhard Euler Medal for his outstanding and sustained contributions to the area of computational solid and structural mechanics.

On behalf of all ECCOMAS members I would like to congratulate all awardees for this outstanding distinction; for further information see appraisal in this Newsletter.

## RULES FOR COMMITTEES, CONFERENCES, ADVANCED SCHOOLS

During the Managing Board meeting in Barcelona in July 2014 rules for several activities of ECCOMAS could be approved. They are related to

- Re-installation of the four ECCOMAS Technical Committees (ETC) defining their structure, role and tasks;
- Re-activation of the ECCOMAS Young Investigator Committee (EYIC) nominating its members, establishing its tasks, defining future activities, and guidelines

for ECCOMAS Olympiad;

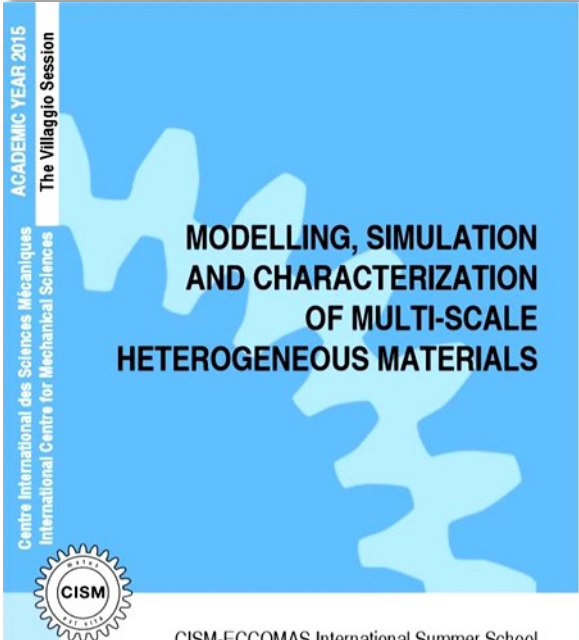
- Rules for nomination and selection of Plenary and Semi-Plenary Lecturers on Congresses and Conferences,
- Rules for ECCOMAS Thematic Conferences (TC), distinguishing between established TC series and new TCs;
- Initiative for ECCOMAS Advanced Schools and Courses defining their objectives and rules.

This information and the related rules can be retrieved from the ECCOMAS website

[www.eccomas.org/](http://www.eccomas.org/).

## CISM – ECCOMAS AGREEMENT OF COOPERATION

The agreement of cooperation between the International Centre for Mechanical Sciences (CISM, [www.cism.it](http://www.cism.it)) and ECCOMAS from



CISM-ECCOMAS International Summer School  
coordinated by

**Daniel Dias-da-Costa**  
The University of Sydney  
Australia  
and  
University of Coimbra  
Portugal

**Stéphane Bordas**  
University of Luxembourg  
and  
Cardiff University, Wales  
UK



**Udine Sept. 28 - Oct. 2 2015**

1999, which was never really applied, has been renewed and in the meantime approved by both institutions. Essential items for cooperation are mutual information for activities on both sides and the installation of one CISM course as ECCOMAS Summer School. Furthermore CISM makes available for adequate costs year-round the infrastructure of its seat in Udine for ECCOMAS events like meetings, small courses etc.

The CISM-ECCOMAS Summer School 2015 and all CISM courses are listed in [www.cism.it/Programme2015](http://www.cism.it/Programme2015).

## NEWSLETTER – WEBSITE – UPCOMING EVENTS

It has been decided that each year two ECCOMAS Newsletters are issued, preferable in June and December as a standard in electronic form. It will be printed though in advance of ECCOMAS Congresses or Conferences allowing to be distributed with the delegates' material.

The ECCOMAS website has been updated with the most recent information.

2015 is a year for the 24 ECCOMAS Thematic Conferences and the Young Investigator Conference in Aachen including the Olympiad. In 2016 the ECCOMAS Congress is taking place on the Crete Island in Greece on 5-10 June 2016 ([www.eccomas2016.org](http://www.eccomas2016.org)). For further information see notes in this Newsletter.

## THANKS

2014 was an intensive year for ECCOMAS, not only due to the Conference in Barcelona, but also because substantial progress for an improved structure and management could be made. I would like to thank the members of all boards, in particular those of the Executive Committee, the Chairmen of the Technical Committees and of the Young Investigator Committee. I am very grateful for the considerable assistance by the Secretary Josef Eberhardsteiner and

by Iztok Potokar from the ECCOMAS Barcelona Secretariat. The ECCOMAS Vicepresidents Ferdinando Auricchio and Pedro Diez served as editor of the present Newsletter and are asked to support also the guest editors of the subsequent issues. This commitment is very much appreciated. Thanks go again to Manolis Papadrakakis and the technical editor Panagiota Kouniaki for the production of this issue.



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# REPORT ON MAIN DECISIONS MADE IN RECENT ECCOMAS MEETINGS IN BARCELONA, JULY 2014

## ECCOMAS NEWSLETTER

The ECCOMAS Newsletter was reactivated in the original time schedule, namely two-times per year. Because of high printing and mailing costs, it was proposed to print only every fourth edition (once every two years), distributing the issue at the ECCOMAS Congress and the ECCM and ECFD Conferences, respectively. The remaining three editions would only be prepared in an electronic version.

## ECCOMAS AWARDS

A report on the rules for the nomination and selection procedure for the ECCOMAS Awards was given. The Award Committee was composed of 14 members, namely the 7 last medalist, the most recent Zienkiewicz and Lions awardees and 5 representatives proposed by the ETCs and the EYIC.

## RE-INSTALLATION OF ECCOMAS TECHNICAL COMMITTEES

It is of utmost importance to get the

four ECCOMAS Technical Committees (ETCs) more involved in the functioning of ECCOMAS because of their expertise in the respective fields. Corresponding rules for the nomination of the members, the structure, role and tasks of the ETCs (see ECCOMAS webpage) have been developed by the Executive Committee (EC) together with the chairpersons of the four ETCs and agreed on by the MB.

Every association can send a person to each committee; however a core group should be constituted in every committee as a managing team, representing a kind of task force. The core group members have to be approved by the MB.

The chairpersons of the four ETCs have been confirmed:

- ETC Computational Applied Mathematics: Harald van Brummelen
- ETC Computational Fluid Dynamics: Wolfgang Wall
- ETC Computational Solids and Structural Mechanics: Olivier Allix
- ETC Scientific Computing: Carsten Carstensen

## IMPLEMENTATION OF ECCOMAS YOUNG INVESTIGATOR COMMITTEE

The ECCOMAS Young Investigators Committee (EYIC) has been restarted. The re-activation of this committee has a high priority. Alessandro Reali was confirmed as chairperson. He informed on the EYIC's activities: They defined some rules and a member committee (40 years age limit). He emphasizes the importance of creating a database and to share information, as well as having regular meetings of the core group.

Already three sections are available on the website, and they have contributed to the recent ECCOMAS Newsletter.

## ECCOMAS SCIENTIFIC EVENTS

### ECCOMAS THEMATIC CONFERENCES

24 Thematic Conferences (TC) for 2015 have been approved by the MB. In addition, following decisions on two supplements have been made:

- i) Organizers will be requested for a

short final report after the TC (template available at the webpage).

- ii) Two different lines for the approval of a TC are distinguished in future. For each established TC series a contact person from the past organizers is nominated by the EC. In case of a new TC (a TC on a new topic or a TC which was not organized more than twice in a series), a timeline for its constitution with several steps has to be followed.

#### **YOUNG INVESTIGATOR CONFERENCE 2015**

The Young Investigator Conference (YIC) 2015 will take place at Aachen University, Germany, 20-23 July 2015, and it will be organized in conjunction with the 6th GACM Colloquium on Computational Mechanics, also organized by and for young investigators.

#### **ECCOMAS CONGRESS 2016**

The Congress Chairman, Manolis Papadrakakis, reported on the ECCOMAS Congress 2016 in Crete, 5-10 June 2016. The website [www.eccomas2016.org](http://www.eccomas2016.org) is already active.

#### **RULES FOR NOMINATION AND SELECTION OF PLENARY AND SEMI-PLENARY LECTURERS ON ECCOMAS CONGRESSES AND CONFERENCES**

The proposal for the rules for nomination and selection of plenary and semi-plenary lecturers on

ECCOMAS Congresses and ECCM & ECFD Conferences, prepared by the EC, was discussed. The information on previous plenary and semi-plenary speakers should be kept in mind for the new selection.

For the ECCOMAS Congress 2016 in Crete, the Congress organizer Manolis Papadrakakis proposed to have 8 plenaries, and 18 semi-plenaries in 3 days, which was accepted by the MB.

One half of the lectures will be determined by the MB with support of the ETCs, the other half by the local organizers (see also ECCOMAS webpage).

#### **ECCOMAS ADVANCED SCHOOLS AND ECCOMAS COURSES**

Following ECCOMAS' objectives to *stimulate and promote education* in its field of operation the EC and the four Chairmen of the ETC decided in their meeting in October 2013 to elaborate a proposal to strengthen this mission. A detailed memorandum regarding these future ECCOMAS activities have been prepared (see ECCOMAS webpage).

An important aspect of these educational activities is the condition of a non-profit objective. The organizers are not paid, only the accrued expenses are reimbursed. Each course pays a support fee to ECCOMAS.

#### **COOPERATION WITH CISM**

An new agreement of cooperation between ECCOMAS and the International Centre for Mechanical Sciences (CISM) in Udine, Italy, was approved by the MB. According to this agreement, each year one CISM course will be declared as ECCOMAS Summer School.

JOSEF EBERHARDSTEINER  
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COMMUNICATED BY OLIVIER ALLIX, CHAIRMAN OF THE ECCOMAS TECHNICAL COMMITTEE "COMPUTATIONAL SOLID AND STRUCTURAL MECHANICS"

# A FICTITIOUS DOMAIN METHOD FOR FULLY RESOLVED SIMULATION OF PARTICLE-LADEN FLOWS

## INTRODUCTION

The characteristics of particulate flows are up to now neither well-investigated nor well-understood, particularly with regard to flow problems with a dispersed phase composed of macroscopic particles. From the side of industry and applied sciences there exists an intense interest in understanding the processes taking place in these kind of multiphase flows in order to predict their behavior. A profound knowledge of the fluid-particle interaction would allow to improve the performance of respective engineering systems; but the conduction of experiments on particulate flow systems is expensive and time-consuming. Performing virtual experiments on models via numerical simulations is, of course, an alternative way to gain deep insight into the flow properties of a multiphase system and then to design better processes. However, due to existing crucial limitations regarding the hardware technology and the scalability of algorithms, simulations often cannot totally replace real laboratory experiments. Thus, they are still required for validation purposes. Additionally the knowledge extracted from representative small-scale virtual experiments can contribute in minimizing the sequence of real

experiments. Consequently, the improvement of existing as well as the development of new frameworks for simulation of particulate flows are significant and demand more effort, as the simulation of problems with large number of particles represents still a great challenging task.

In particle-laden multiphase flow problems the intensity of phase coupling is predominantly determined both, by the local volume fraction of the dispersed phase and by its mass concentration. Hence in case of dense or locally highly concentrated flows the presence of particles in the fluid field can be a determining factor for the main characteristics inherent to an engineering system. To capture the mutual interaction of the phases in such flows, it is crucial to analyze the respective problem at particle scale. This necessity implies

a fully resolved model where the particles are described as objects with a volume, and not just as point-particles, because in dense flows neighboring particles can interact not only via close range effects – like contact forces, adhesion or agglomeration –, but also via long range effects due to particle induced wakes, eddies and other local disturbances (see Fig.1 for an illustration). Those effects can only be captured in the framework of a full 3D direct numerical simulation (DNS). However, a full 3D DNS approach requires very powerful techniques and is nontrivial, even when considering systems with only one immersed particle settling in a fluid, let alone systems with some thousands of dispersed particles in the fluid. This is due to the fact that besides the handling of the evolution of the time varying fluid domain, the motion of the fluid-

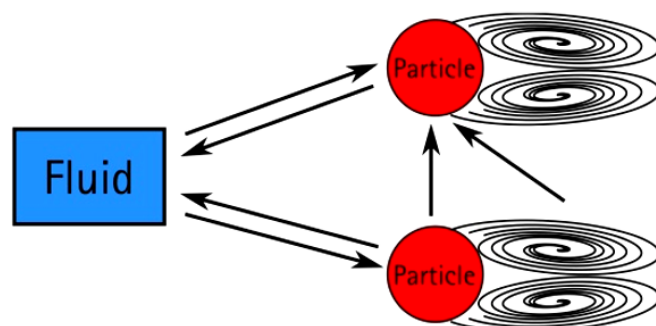


Figure 1: Schematic diagram indicating the different ways of coupling for momentum transfer (four-way coupling).

particle boundaries needs to be continuously tracked during the flow process in order to account for the momentum exchanges taking place at the phase interfaces.

## TECHNIQUES FOR THE DNS OF PARTICULATE FLOWS

In the last two decades, great progress has been made in the development and improvement of DNS methods for particulate flow simulations. Basically, the proposed approaches may be classified into two groups: (i) adaptive grid methods and (ii) fixed grid methods. The first DNS approaches published in the literature are assigned to the category (i). Here, the fluid field is described using a body-fitted moving mesh whose elements locally follow the boundaries of the particles being in motion. Of course, depending on the particles' motion this can lead to large element distortions in a mesh, so that the grid needs to be re-meshed from time to time. Such a procedure is computationally very intensive, and one requires, in fact, very efficient and sophisticated mesh motion and re-meshing algorithms. The first 3D DNS computations of particulate flows

belonging to this category were presented in [1], which can be considered as a pioneering work in this area. In terms of the approaches assigned to the fixed-grid category (ii), one can find in the literature a number of techniques suggested for the DNS analysis of fluid-particle interactions (see the review paper [2] and the references cited therein for an overview). Taken together, the proposed approaches are known under the generic term fictitious domain (FD) method. The most widely-used ones are the immersed boundary method, the distributed Lagrange multiplier/fictitious domain method and the fictitious boundary method. They all have in common that the fluid flow is treated in the framework of an Eulerian setting, where a fixed mesh is employed. Here, a fluid mesh covers, compared to the approaches in group (i), the whole computational domain, also including the space of the particles – that means the solid domain is filled as well with fluid. The main idea on which the FD methods are based on is to uncouple the particles from the mesh and to consider them as fictitious objects having the property to traverse through the grid without causing any element deformation. The crucial point here is to enforce

the fluid enclosed by an embedded particle to adopt its solid body motion. In general, this is realized by imposing additional implicit constraints to the fluid momentum equations.

In this paper, a computational model for the fully resolved simulation of particulate flows is presented. The proposed model is based on the FD approach and is able to compute the fluid-particle interactions at the particle scale, with a fully resolved flow around the particles. All details of the method can be found in [3] and [4].

## THE FICTITIOUS DOMAIN ALGORITHM

The numerical techniques used in this work are the finite element method (FEM) and the discrete element method (DEM), which are applied for the computation of the fluid phase and particle phase, respectively. The flow of the fluid field is modeled by the non-stationary incompressible Navier-Stokes equations, and the resulting nonlinear algebraic equations are solved within the framework of a geometric multigrid FEM. As for the modelling and DEM computation of the particle phase, the motion of the individual particles is obtained by solving a set of Newton-Euler equations at each time-step. The overall computation procedure of the particulate flow is based on a staggered algorithm approach. The algorithm flowchart with the main modules of the multiphysics solver is illustrated in Fig. 2.

Coupling of both physical fields, or rather their mutual momentum transfer, is achieved by the first and third module of the FEM fluid solver.

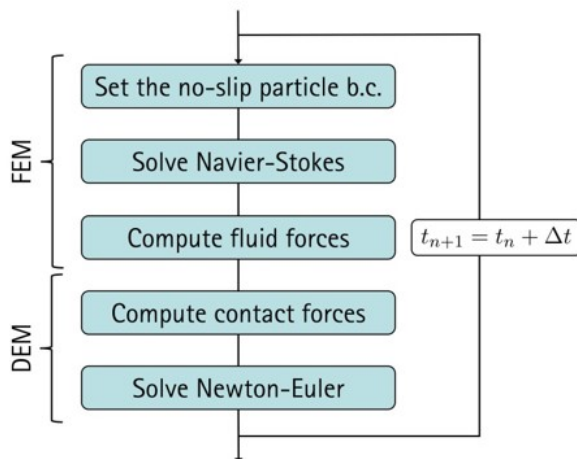


Figure 2: Flowchart of the DNS scheme for the fully resolved simulation of particulate flows.

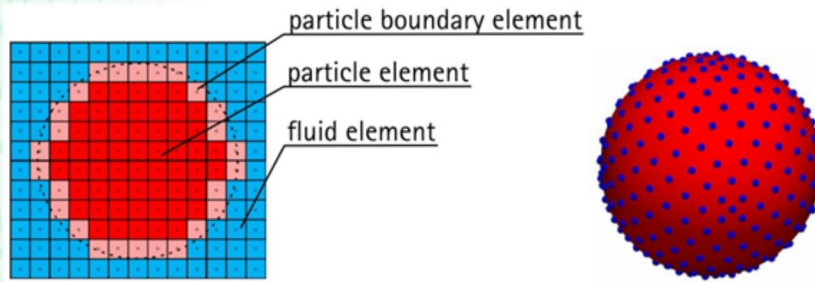


Figure 3: (left) Classification of the computational elements and (right) distribution of the quadrature points on a particle surface for the fluid force computation.

The first FEM module is responsible for the information transfer between the Eulerian fluid description and the Lagrangian particle description. As in the fixed grid approach the mesh of the flow field does not coincide with the boundaries of the particles, see Fig. 3 (left), a suitable linear velocity interpolation is used in this work at the interfaces for the no-slip boundary conditions (see [3,4] for details). A further challenging issue concerning the coupling of the phases is the computation of the fluid forces acting on the particle surfaces. This way of momentum transfer is arranged by the third FEM module. For the integration of the fluid forces acting on the surface of a particle a quadrature rule is used that was developed in [5]. In Fig. 3 (right), the distribution of the integration points, which can also be seen as Lagrangian force points, is displayed for the case of 302 points. With the presented approach, fluid-particle interaction

problems can be described by taking a four-way coupling as a basis for the momentum transfer (cf. Fig. 1).

The momentum contributions due to particle-particle and particle-wall interactions are handled within the framework of the DEM. In a DEM setting, usually a soft sphere approach based on repulsive force models is applied in order to describe the contact among the solid bodies, which are at the same time assumed being quasi-rigid. The implemented DEM solver considers four different interaction modes; these are the normal contact, tangential contact, rolling resistance and twisting resistance. Fig. 4 depicts the interaction modes with the corresponding rheological systems.

An aspect that has also to be considered in the framework of developing a FEM-DEM coupling scheme is the widely differing computational time scale between the both numerical methods. Due to

the displacement driven character of the DEM concerning the force computation, one usually has to use much smaller time-step sizes in the DEM than in the FEM. To handle this problem of unequal time scales, a sub cycling strategy is used in this work.

## NUMERICAL EXAMPLES

In the following, the numerical results of some computed particulate flow test problems are presented. The first benchmark is carried out to reproduce the drafting-kissing-tumbling effect of two particles sedimenting in a row. In Fig. 5, the evolution of this phenomenon is displayed at eight different points in time. One observes that once the trailing particle is located within the gradually growing wake region of the leading particle, it experiences a lower drag force. Consequently, this results in a higher fall velocity for the trailing particle compared to the leading one (drafting). With increasing time, the gap between both particles decreases due to their velocity difference, and thus the particles get – after a while – into contact (kissing). Clearly, this configuration is unstable. The particles tumble as a consequence and start to separate (tumbling).

The second example considers a particle-laden flow through a tube

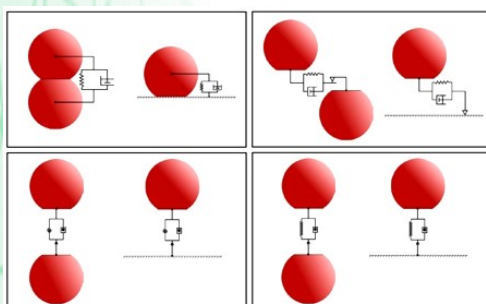


Figure 4: Different modes of particle interaction.

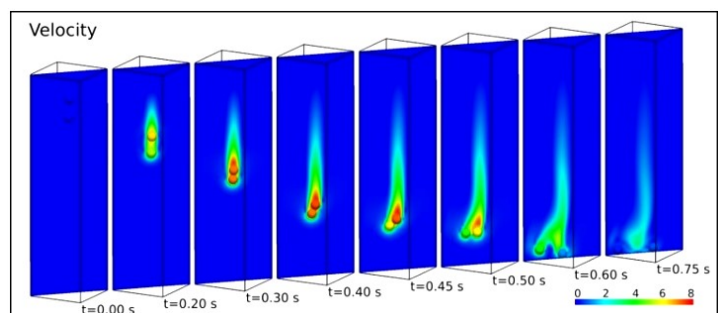


Figure 5: Numerical results of the drafting-kissing-tumbling simulation at eight points in time.

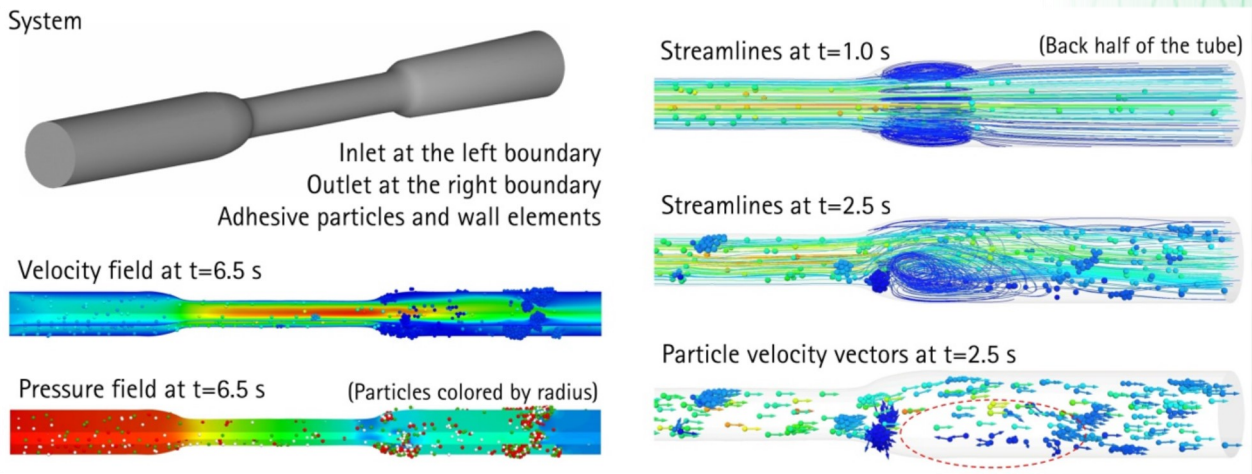


Figure 6: DNS of an adhesive particulate flow through a tube with different cross sections.

with different cross sections. It is assumed that the particles are allowed to adhere to each other and as well at the tube wall. The suspended particles are randomly inserted at the inflow boundary with an initial velocity which is conform to the inflow velocity of the fluid. To compute the flow in the tube, a mesh consisting of 2.304.000  $Q_1/Q_0$  elements is used. This yields a discretized system with 2.304.000 pressure and 6.953.280 velocity nodes. The presence of adhesive van der Waals forces leads to a deposition of suspended particles onto the tube wall. The deposition grows with an increasing simulation time, in particular at the end of the smaller cross section part. With more particles adhering to the wall, the velocity increases locally, and the particles experience higher drag forces. In Fig. 6 (left), one can observe the influence of the developed agglomerates on the velocity and pressure field of the fluid phase when they stick to the tube wall or slide along the wall. For the case when the traction forces exceed the adhesive forces, single particles and agglomerates break off and are subsequently transported away by the flow field. The strong local impact of the dispersed phase on the fluid phase is here obvious.

The complexity of the evolution of the multiphase flow situation at the outflow of the smaller cross section part is reflected in Fig. 6 (right). Due to the four-way coupled description of the particulate flow, the strong mutual phase interactions in this region can be reproduced by the developed DNS fluid-particle solver.

The two benchmark examples shown above demonstrate that the proposed four-way coupled approach is suitable for the simulation of particulate flow problems within the DNS framework.

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COMMUNICATED BY WOLFGANG WALL, CHAIRMAN OF THE ECCOMAS TECHNICAL COMMITTEE "COMPUTATIONAL FLUID DYNAMICS"

# MULTIFRACTAL, MULTIGRID, MULTISCALE: LARGE-EDDY SIMULATION BY "MULTI-" TO THE POWER OF THREE

## INTRODUCTION

Turbulence is ubiquitous in everyday life. The shape of wings for airplanes, the design of efficient combustion engines, accurate weather forecasting and even successful athletes in ski jumping, to name but a few examples, strongly rely on the knowledge of turbulent flows; see Figure 1 for turbulence in a box. The nonlinear nature of turbulence gives rise to an enormous range of length and times scales. As a result, Direct Numerical Simulation (DNS), which aims at resolving all features down to the smallest scales, is hardly feasible for all but the simplest turbulent flows. In contrast to DNS, approaches based on the Reynolds-Averaged Navier-Stokes (RANS) equations merely compute the mean flow, leaving all turbulent features to a model. Large-Eddy Simulation (LES) can be categorized in between the aforementioned approaches. While the larger scales, which depend on the specific flow problem and are therefore of particular significance, are directly represented, the smaller scales, which exhibit universal properties, remain unresolved. The impact of the unresolved scales, which are also referred to as subgrid scales, is crucial for the correct evolution of the resolved scales, though. Therefore, proper modeling is

required to incorporate the interaction between resolved and unresolved scales.

Piomelli [1] summarized four requirements which a successful subgrid-scale model should fulfill: (i) predict the overall dissipation correctly, (ii) vanish in laminar flow, (iii) depend strongly on the smallest resolved scales rather than the entire turbulent spectrum and (iv) predict the local energy transfer between resolved and subgrid scales. Moreover, the actual applicability of the overall approach to LES of practically relevant flows is also of particular importance. In this respect, there are two further aspects that deserve closer attention and were also raised to some extent in Piomelli [1]: A promising approach to LES should

not only include a subgrid-scale model satisfying the aforementioned prerequisites but also (v) allow for convenient application to complex geometries and (vi) remain computationally efficient.

Owing to its favorable trade-off between computational cost and modeling effort compared to DNS and RANS, LES receives continuously increasing attention as an approach for computationally investigating turbulent flows of scientific and technological relevance. A promising and comprehensive approach to LES is presented in the following. It is built up from approaches - the "multi-"s from the headline - that allow to meet the just mentioned demands.

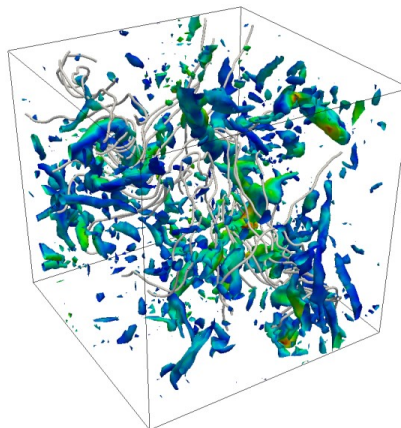


Figure 1: LES of turbulence in a box.

## A BRIEF INSIGHT INTO MULTIFRACTALS

Multifractal structures originate from the repeated application of a scale-invariant multiplicative process on an initial field. In consecutive cascade steps, the considered field is mapped from one cell to smaller subcells. The distribution of the considered field contained in one cell among the subcells is governed by a set of multipliers  $\mathcal{M}$ , with  $0 < \mathcal{M} < 1$ . Depending on whether a deterministic or stochastic cascade

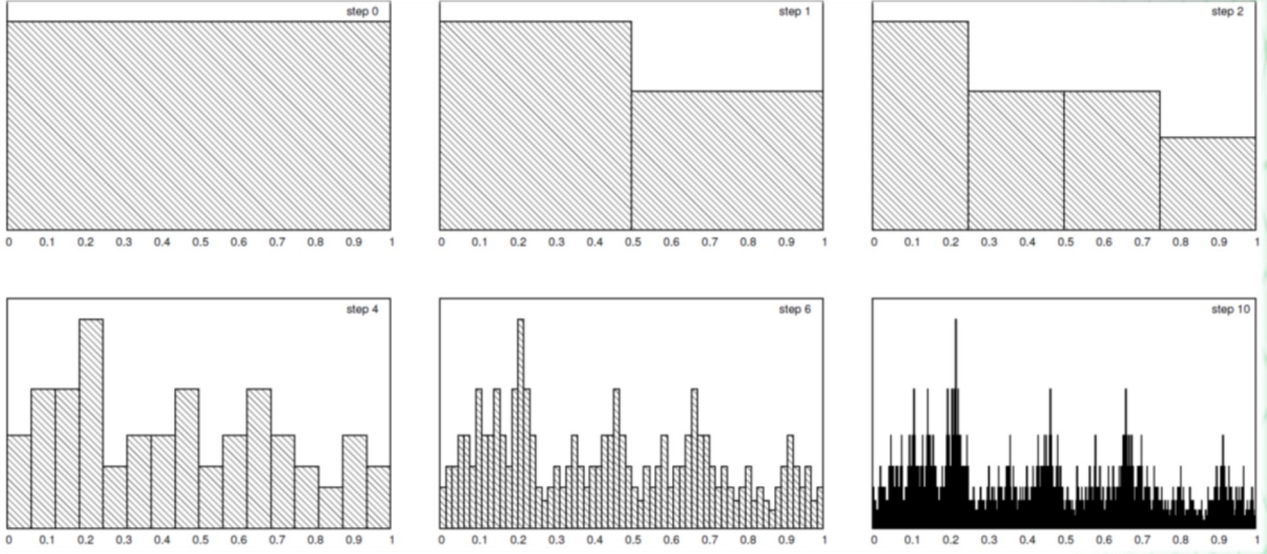


Figure 2: One-dimensional stochastic cascade: initial field as well as resulting fields after  $\mathcal{N} = 1, 2, 4, 6$  and  $10$  cascade steps.

is applied, the multipliers are either prescribed or obtained randomly from a scale-invariant distribution. After a sufficient number of cascade steps, this procedure leads to a highly intermittent field, which exhibits multifractal scaling properties.

Assuming a measure  $\vartheta$ , for instance, mass, the multiplicative cascade is mathematically expressed as

$$\vartheta(\mathbf{x}) = \vartheta_0 \prod_{n=1}^{\mathcal{N}} \mathcal{M}_n(\mathbf{x}),$$

where  $\mathcal{N}$  denotes the number of cascade steps and  $\vartheta_0$  the total amount of the measure to be distributed within a given domain.

For illustration purposes, a one-dimensional stochastic cascade, displayed in Figure 2, is considered. At each stage of the cascade, the measure contained in one cell is divided between two subcells, each half the size of the parent cell. The multiplier of the left subcell is chosen at random from two possible values, which sum up to one. The remaining value is assigned to the right subcell. Passing through the cascade, the intermittency increases, and the measure becomes concentrated onto

successively smaller parts of the domain.

In turbulent flows, gradient-magnitude fields such as the kinetic-energy dissipation rate and the enstrophy are subject to multiplicative processes caused by the repeated stretching and folding of the vorticity and strain-rate fields. As a result, scale similarity, which can be mathematically described by multifractals (see, e.g., Sreenivasan [2]), is provoked at inertial-subrange scales in these fields, which are known to exhibit significantly intermittent features.

## THE ALGEBRAIC VARIATIONAL MULTISCALE-MULTIGRID-MULTIFRACTAL METHOD FOR LES

The separation between resolved and subgrid scales constitutes the fundamental step of LES. Usually, the elimination of the smaller scales is achieved by filtering the Navier-Stokes equations. The variational multiscale method (see, e.g., Hughes et al. [3]) provides an alternative framework for scale separation in

LES. By this concept, scale separation based on a variational projection of the governing equations is assumed for identifying resolved and subgrid scales. This variational projection naturally emanates from the discretization of the governing equations; see, e.g., Gravemeier [4].

The **multifractal** scale similarity in the enstrophy field at inertial-subrange scales enables a novel subgrid-scale modeling approach to LES of turbulent incompressible flow, as originally introduced by Burton and Dahm [5, 6]. In the multifractal subgrid-scale modeling approach, the subgrid-scale velocity  $\hat{\mathbf{u}}$  is directly evaluated via the law of Biot-Savart:

$$\hat{\mathbf{u}}(\mathbf{x}, t) = \frac{1}{4\pi} \int \hat{\boldsymbol{\omega}}(\tilde{\mathbf{x}}, t) \times \frac{\mathbf{x} - \tilde{\mathbf{x}}}{\|\mathbf{x} - \tilde{\mathbf{x}}\|^3} d\tilde{\mathbf{x}},$$

using a multifractal reconstruction of its associated subgrid-scale vorticity  $\hat{\boldsymbol{\omega}}$ . The reconstruction of the subgrid-scale vorticity field consists of two steps, which separately recover its magnitude and orientation. The magnitude of the subgrid-scale vorticity is determined via a multiplicative cascade distributing the total subgrid-scale enstrophy over each element or grid cell. The orientation of the subgrid-scale

vorticity field is determined using an additive decorrelation cascade, starting from the local orientation of the smaller resolved scales. This cascade thus likewise builds on physical reasoning since various experimental and computational studies indicate that the velocity fields of adjacent scale ranges are highly correlated (see, e.g., Meneveau and Katz [7]). As a result from the overall procedure, an approximate analytical expression for the subgrid-scale velocity depending on the velocity of the smaller resolved scales is eventually obtained.

The multifractal subgrid-scale approximation relies on the smaller resolved scales. As suggested by Gravemeier et al. [8], level-transfer operators from plain aggregation algebraic **multigrid** methods are used to further decompose the resolved scales. Level-transfer operators from plain aggregation algebraic multigrid methods are obtained in a purely algebraic way and can be computed for arbitrarily designed meshes without additional effort. Using the approach proposed by Gravemeier et al. [9, 10], Comerford et al. [11] demonstrated the convenient applicability of the resulting scale-separating operator to such problem configurations in the context of LES of pulmonary airway flow.

Eventually combining all the aforementioned building blocks, that is, the derivation within the framework of the Variational Multiscale Method, the evaluation of the subgrid-scale velocity based on the Multifractal subgrid-scale modeling approach and the identification of the required smaller resolved scales by level-transfer operators from plain aggregation Algebraic Multigrid methods, a novel approach to LES, referred to as the Algebraic Variational Multiscale-Multigrid-

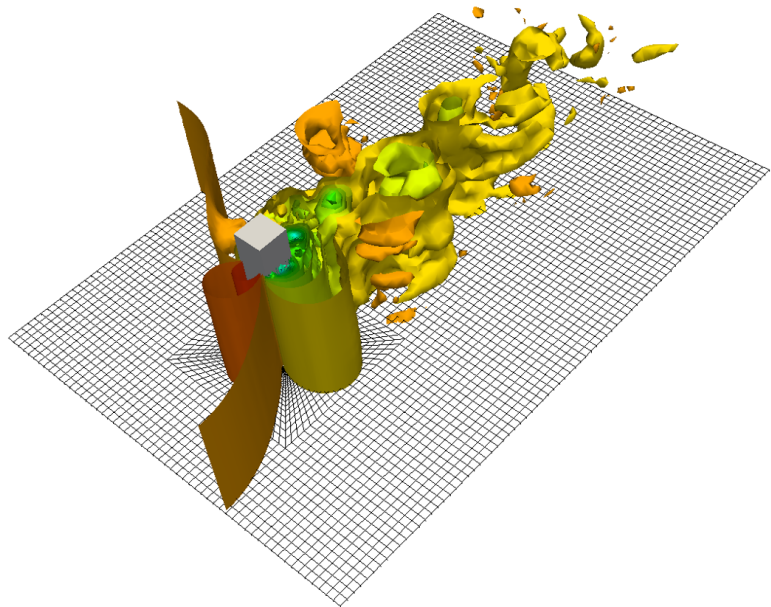


Figure 3: LES of turbulent flow past a bluff body.

Multifractal Method is obtained, abbreviated by AVM<sup>4</sup>; see Rasthofer and Gravemeier [12] for details. Figure 3 provides an exemplary result depiction from its application to LES of turbulent incompressible flow past a bluff body. LES of turbulence in a box is shown in Figure 1.

The further development of the AVM<sup>4</sup> for LES of passive-scalar mixing in turbulent incompressible flow is presented in Rasthofer et al. [13]. Multifractal scaling properties in the scalar-variance diffusion rate constitute the basis of the modeling approach for the subgrid-scale scalar quantity. Both low and high-Schmidt-number mixing is naturally incorporated into the modeling procedure. For extending it towards LES of turbulent weakly compressible flow, the low-Mach-number limit of the compressible Navier-Stokes equations is considered. In Rasthofer et al. [14], a variable-density enhancement of the AVM<sup>4</sup> is derived, where the subgrid-scale velocity and temperature field are recovered by the multifractal subgrid-scale modeling approach.

Currently, the AVM<sup>4</sup> is also extended to turbulent incompressible two-phase flows. Two bulk fluids separated by an infinitely thin interface are considered. The face-oriented Nitsche-type extended variational multiscale method for two-phase flow, developed by Schott et al. [15], uses an extended finite element approach together with the level-set method. The level-set method describes the evolution of the interface on a fixed grid. The extended finite element method allows for accurately representing the discontinuities in the solution fields across the interface inside elements cut by the interface. The proposed method particularly takes into account stability issues to cope with the entire range from viscous-dominated laminar flow to highly transient turbulent flow. Unifying the AVM<sup>4</sup> with this form of an extended finite element method leads to a novel method for LES of turbulent two-phase flow, which is referred to as the XAVM<sup>4</sup>. An exemplary result depiction from LES of turbulent two-phase bubbly channel flow is shown in Figure 4.

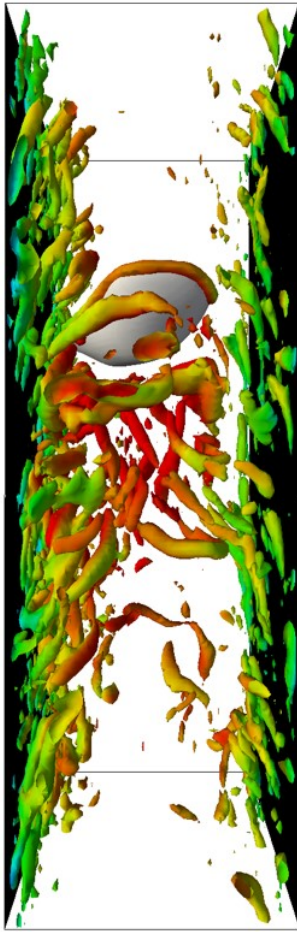


Figure 4: LES of turbulent two-phase bubbly channel flow.

## SUMMARY

The AVM<sup>4</sup> constitutes a novel and comprehensive approach to LES of turbulent incompressible and weakly compressible flow. Its building blocks, that is, the variational multiscale method, multifractal subgrid-scale modeling and scale separation based on level-transfer operators from plain aggregation algebraic multigrid methods, enable a method that promises to match the demands for computational methods for LES outlined in the introduction.

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# DISCONTINUOUS PETROV GALERKIN (DPG) METHOD WITH OPTIMAL TEST FUNCTIONS

## 1 GALERKIN METHOD

Conforming Finite Element (FE) methods form a special class of Galerkin methods. Construction of a FE method starts with a variational formulation. A boundary value problem (BVP), or an initial boundary value problem (IBVP) usually admits many possible variational formulations that differ from each other with different functional settings (choice of trial and test spaces) reflecting different regularity assumptions on the material data (coefficients of operators) and load (right-hand sides of the equations, boundary, and initial conditions). Each variational formulation gives rise to a different FE method and, most importantly, different kind of convergence. For instance, the classical linear elasticity problem can be written out as a system consisting of two sets of equations to be solved for elastic displacements and stresses: momentum equations and geometry (Cauchy) relations combined with Hooke's constitutive law. If we relax (integrate by parts) momentum equations, and use the geometry/constitutive equations to represent stresses in terms of displacements, we end up with the classical Principle of Virtual Work. If

we choose to relax the geometry/constitutive equations and keep the momentum equations in the strong form, we get the so-called mixed formulation. If we do not integrate by parts at all, we get a trivial variational formulation that is equivalent to the strong form of the equations (in the  $L^2$  sense), and provides a starting point for the classical least squares method. Finally, if we relax *both* sets of equations, we get the so-called *ultraweak variational formulation*.

Stability and well-posedness of different formulations can be studied using the Babuška-Nečas Theorem which is a relatively straightforward interpretation of Banach Closed Range Theorem. The famous inf-sup condition relating the trial and test energy spaces is equivalent to boundedness below of the operator corresponding to the bilinear or sesquilinear (for complex-value problems) form governing the variational formulation. A more refined application of the Closed Range Theorem (for both continuous and closed operators) is used to prove that all formulations are simultaneously well- or ill-posed with *equal or order 1 - equivalent* inf-sup constants. The functional setting changes, but the inf-sup constant remains the same.

The operator corresponding to the variational formulation is defined on the trial space but it takes values in *dual* to the test space. One might argue that dealing with operators whose values are functionals rather than functions, comprises the essence of variational problems.

The Galerkin method or, more precisely, its extension by Alexander Petrov (1959), approximates the variational problem by replacing the trial and test spaces with finite-dimensional subspaces of equal dimension. In simple words, the solution is represented as a linear combination of  $N$  predefined trial basis functions, and the test functions are represented as linear combinations of  $N$  predefined test basis functions. The problem reduces to a system of  $N$  linear (for linear problems) algebraic equations to be solved for the  $N$  unknown coefficients (degrees-of-freedom) in the representation for the solution.

The famous Babuška's Theorem (1971) establishes a sufficient condition for well-posedness (stability) of the discrete problem *and convergence* of the discrete solution to the exact one: we need to satisfy the discrete version of the inf-sup condition, and the discrete inf-sup constant should remain

bounded away from zero as we increase  $N$  (refine the mesh). Hence the famous phrase:

*(uniform) discrete stability and approximability imply convergence.*

## 2 THREE HATS OF THE DPG METHOD

**Hat 1: optimal test functions.** Babuška's Theorem is not constructive. It tells you that the discrete stability is a must, but it does not tell you how to get there. The main trouble is with the fact that the continuous inf-sup condition *does not* imply its discrete version. Indeed, in the infinite-dimensional inf-sup condition, supremum is taken over the whole, infinite-dimensional test space, whereas in the discrete inf-sup condition, the supremum is taken only over the finite-dimensional discrete test space.

Usually both finite dimensional trial and test spaces are assumed to be given. This is especially natural if the functional setting is symmetric, i.e. the test and trial spaces are the same. From the conceptual point of view, the choice of the trial space controls approximability, whereas the choice of  $V_h$  affects stability. The original idea behind DPG [9] was to assume that the trial shape functions are given, but then *compute* the corresponding discrete test space in such a way that the maximum in the sup-inf condition is realized (hence the term *optimal test functions* in the title). By construction therefore, the discrete problem *automatically inherits* the stability of the continuous one.

**Hat 2: Minimum residual method.** Surprisingly perhaps, the idea of optimal testing is *equivalent* to the minimization of the residual measured in *the dual norm* corresponding to the test norm. The

philosophical message is clear: *the minimum residual method is the most stable version of the Petrov-Galerkin scheme*. In the particular case when the test space coincides with standard  $L^2$  functions, we recover the classical version of Least Squares. Similarly, for self-adjoint positive-definite problems, i.e. when the bilinear form is symmetric (or hermitian) and positive-definite, so it can be used to define the energy norm, if we use the *energy norm* for the test norm, we recover the standard Galerkin - Ritz method.

The residual can be interpreted as a special "energy norm" of the FE error - the difference between the exact and approximate solution. Once we realize that DPG delivers the minimum residual or, equivalently speaking, orthogonal projection in the energy product, many properties of the DPG method are less surprising. For instance, stiffness matrix is always hermitian and positive-definite. Most importantly, being a Ritz method (in the energy product), DPG *does not suffer* from any preasymptotic behavior.

**Hat 3: Mixed method.** DPG method can also be interpreted as a mixed method in which one solves simultaneously for the approximate solution and the Riesz representation of the residual, the so-called *error representation function* [7]. The mixed problem interpretation not only reinforces the message that DPG comes with an error evaluation built-in, but also provides a point of departure to analyze the effects of approximating the optimal test functions and residual.

## 3 REALITY MEETS THE DREAMS: PRACTICAL DPG

In practice, the computation of optimal test functions or error

representation function involves inversion of Riesz operator corresponding to the test norm, i.e. a solution of an additional infinite-dimensional variational problem. This is not feasible, and we have to resort to an approximate inverse only. This is done by replacing in all three interpretations above, the infinite-dimensional test space with an *enriched test space* whose dimension is essentially larger than that of the trial space. In other words, the residual is evaluated by testing it over the large but finite-dimensional enriched space only, and the optimal test functions and error representation function are determined only approximately. Can we still claim all nice properties of DPG ? In short, the answer is a conditional yes ! Critical in assessing the damage is the construction of appropriate Fortin operators [13], a natural concept for a mixed method.

## 4 PARADIGM OF BREAKING TEST FUNCTIONS (SPACES)

What makes the DPG method practical, is the use of broken test spaces. We can take any well posed variational formulation and "break test functions" i.e. replace the globally conforming test functions with discontinuous test functions living in the so-called *broken* energy spaces. Breaking test functions comes with a cost of introducing extra variables, the so-called fluxes and/or traces that live on the mesh skeleton. Going back to our linear elasticity example, we can take any of the four possible variational formulations and "break" the test spaces. For the trivial variational formulation (equivalent to the strong formulation in  $L^2$ ), there is nothing to break as we are testing with  $L^2$  functions that present no global conformity requirements. In the classical formulation, breaking test functions results in the

introduction of extra fluxes, for the mixed formulation, we need extra traces, and for the ultraweak formulation, both traces and fluxes are added to the unknowns. The resulting number of *interface unknowns* is exactly the same for all four formulations.

There are a few important points we can make. If the original formulation is well posed, so is the one with broken test spaces, and the corresponding inf-sup constants are of the same order [8]. In particular, the inf-sup constant for the broken test spaces is *mesh-independent*. This is a consequence of a special, mesh-dependent norm in which we measure the additional unknowns: traces and/or fluxes.

The most important consequence is the *localization* of the computation of optimal test functions and the residual. If the test norm is *localizable*, i.e. it can be represented as the sum of the corresponding norms over individual elements, the Riesz operator becomes block-diagonal, and its inversion can be done elementwise. Breaking test functions essentially doubles the number of interface unknowns which constitutes the main cost of the DPG method. The rest of the computations is purely local and, therefore, embarrassingly parallelizable.

## 5 ROBUST TEST NORMS

DPG method is *not* a single method but methodology. For different test norms, we measure the residual in corresponding different dual norms, and obtain different results. It becomes quickly clear that the choice of a right test norm is crucial. For “baby” problems, one can use standard norms. For singular perturbation problems, we strive for the construction of a *robust* DPG

method for which the stability properties (ideally) should be uniform in the perturbation parameter. For many problems, the adjoint graph norm is the right choice. This is the case for linear acoustics (robustness in wave number) [10], nearly compressible elasticity (robustness in Poisson ratio) [1, 4], beams, plates and shells (robustness in thickness) [14, 3].

For convection dominated problems, the use of adjoint graph norm leads to optimal test functions that develop boundary layers and are difficult to resolve [15]. An alternate strategy for constructing *robust test norms* based on a stability analysis for the adjoint equation in context of the ultraweak formulation was proposed in [12, 5], and recently generalized to the standard variational formulation for reaction dominated diffusion in [11].

## 6 GENERALIZATION TO NONLINEAR PROBLEMS

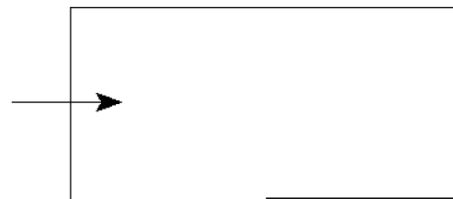
Concept of a minimum residual method can be extended to nonlinear problems. In short, we solve the nonlinear problem by linearizing it, and applying the DPG methodology to the linearized problem. If the test norm is fixed, the resulting scheme can be interpreted as a Gauss-Newton method for the original nonlinear (residual) minimization problem. Contrary to linear problems, we

have not developed yet any theory for nonlinear problems and the generalizations to non-linear problems are purely formal. This has not stopped us from computing. The DPG technology has been successfully applied to both compressible and incompressible Navier-Stokes equations, see Ph.D. dissertations of Jesse Chan [6] and Nate Roberts [16]. Jamie Bramwell applied the DPG technology to inverse problems [2]. In particular, based on Trilinos, Nate Roberts developed a general C++ infrastructure for 2D DPG problems. He is in process of developing an extended version of the code supporting solution of 3D steady-state problems and space-time problems in two space dimensions. The code should be released to public domain in early 2015.

## 7 EXAMPLES

We finish the bed time reading with a few pictures of representative examples illustrating perhaps the most striking feature of the DPG method - its lack of preasymptotic stability problems. Being a minimum residual method, DPG is a Ritz method and Ritz methods do not exhibit any preasymptotic stability problems. One can start the adaptive solution process from a very coarse mesh that matches geometry only.

The first example deals with a well



$$M_{\infty} = 3, \text{Re}_L = 10000, \text{Pr} = 0.72, \gamma = 1.4, \theta_{\infty} = 390^{\circ}[\text{R}]$$

Figure 1: Flat plate problem data

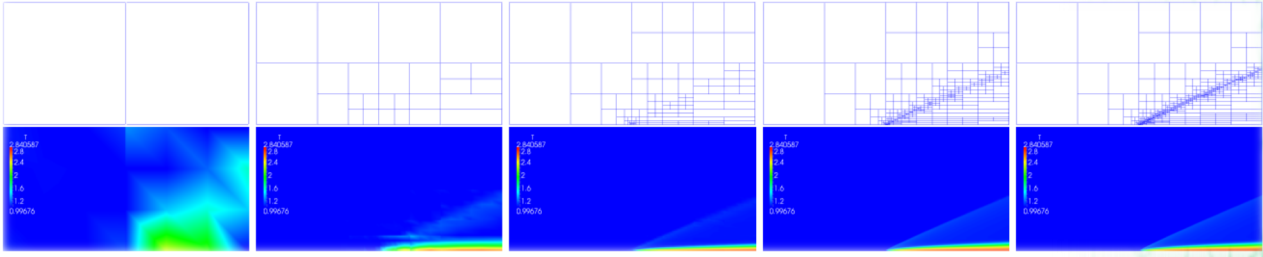


Figure 2: Flat plate problem: meshes 0,3,7,11,14 with the corresponding temperature resolution

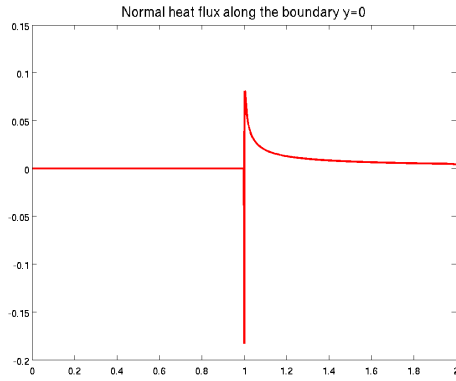


Figure 3: The fully resolve heat flux along the plate

known test for compressible NS equations - the flat plate problem, see Fig. 1. A supersonic flow impinges on an infinite plate developing a shock and a boundary layer, both originated at the stagnation point. Fig. 2 presents a series of automatically generated meshes (quadratic elements), and the corresponding temperature distribution. The DPG method delivers a perfect resolution of the heat flux along the plate shown in Fig. 3.

The second example deals with 3D Maxwell equations and it is a mathematical joke - a Fichera corner microwave problem. We feed the microwave with the lowest propagating mode in an attached waveguide shown in Fig. 4.

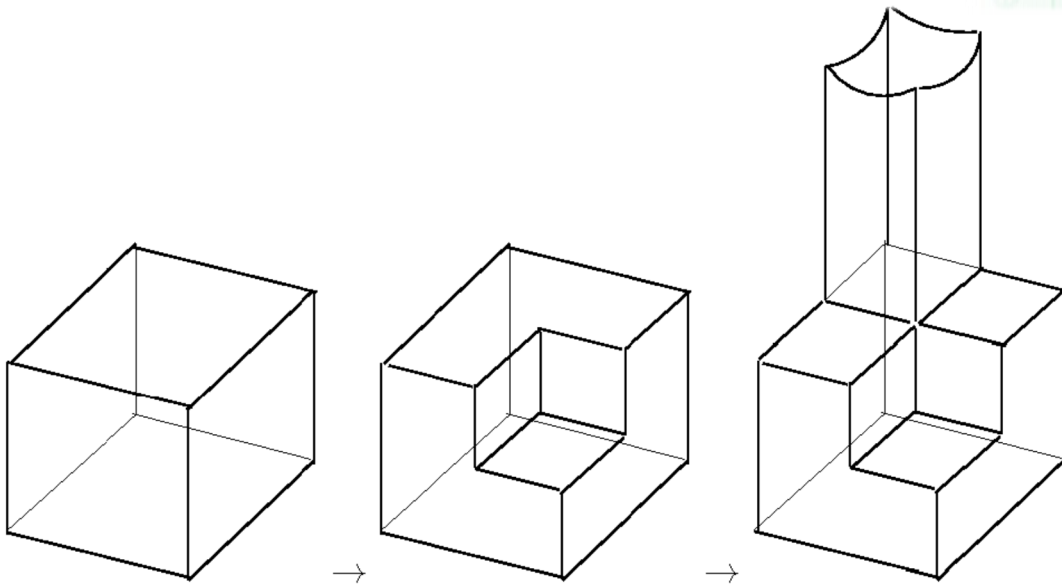


Figure 4: How to make a Fichera microwave:  $\epsilon = \mu = 1$ ;  $\sigma = 0$ ;  $\omega = 5$  (1.6 wavelengths in the cube)

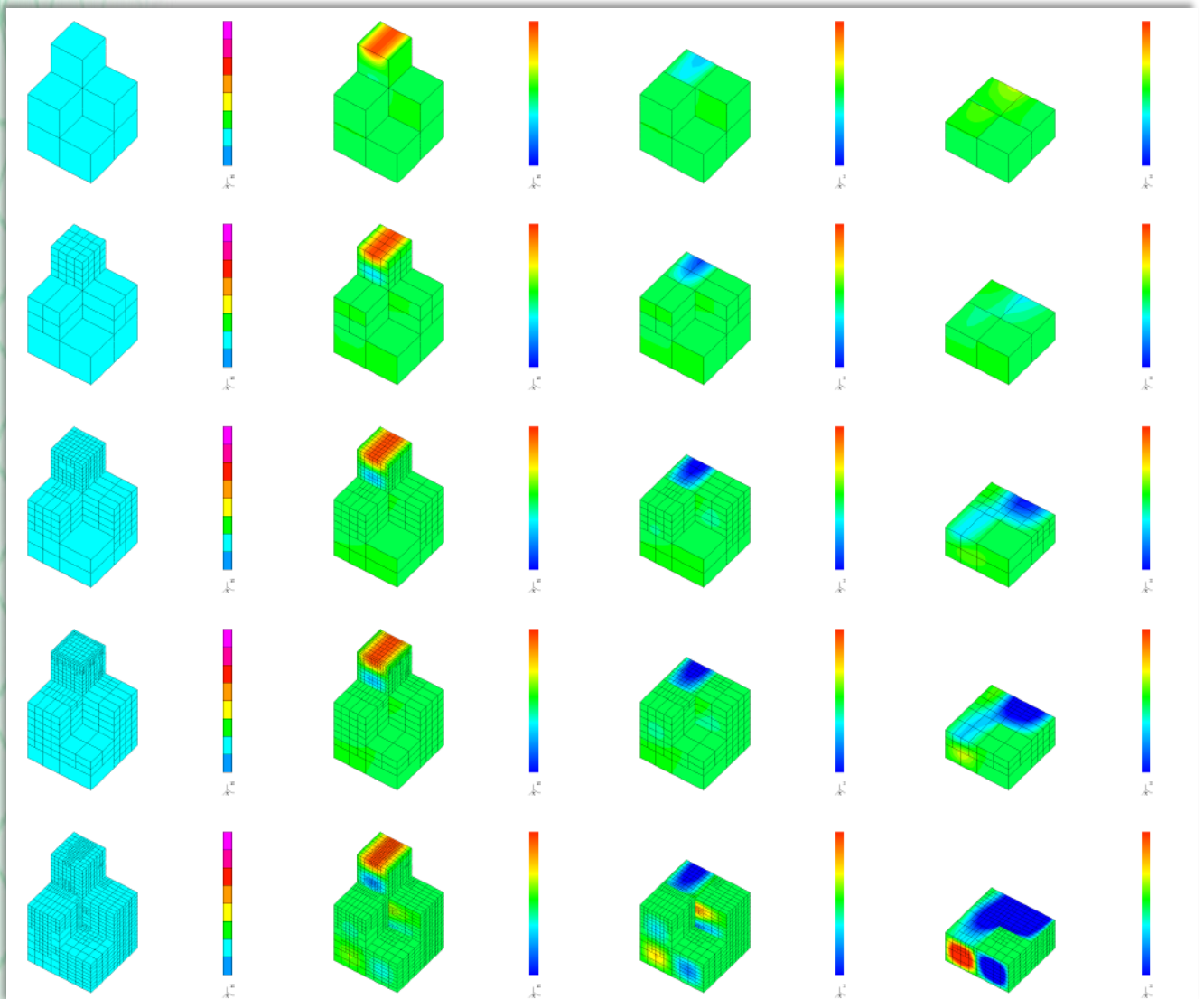


Figure 5: Sequence of adaptive meshes and the corresponding real part of  $E_x$  component of the electric field displayed with the same scale.

The point, we are trying to make, is that we can start the adaptive process with a mesh that does not even resolve the wave (meets the Nyquist criterion). Try to do the same with the standard Galerkin method !

## 8 CONCLUSIONS

We hope to get you interested in the DPG methodology. The method can be implemented within any standard code that supports exact sequence elements or hybrid methods. It comes with an a posteriori error evaluation (not estimation) built in. It automatically guarantees stability for any well posed problem. It can be

implemented within your favorite variational setting by breaking test spaces. Most importantly, it allows to control the norm of convergence.

The DPG research has barely started. We have a fairly complete theory for linear problems but very little for nonlinear ones. Very little work has been done on solvers and we are in process of producing our first 3D solutions. We invite you to join the DPG team!

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COMMUNICATED BY HARALD VAN BRUMMELEN, CHAIRMAN OF THE ECCOMAS TECHNICAL COMMITTEE  
"COMPUTATIONAL APPLIED MATHEMATICS"

# ZIENKIEWICZ CENTRE FOR COMPUTATIONAL ENGINEERING (ZCCE)

## SWANSEA UNIVERSITY, UK

<http://www.swansea.ac.uk/engineering/research/centres-and-projects/zienkiewicz-centre-for-computational-engineering/>

### 1. HISTORY AND INTRODUCTION

The history of the Zienkiewicz Centre may be traced back to the early 1960s, when the late Professor Olek C. Zienkiewicz became Head of the Civil Engineering Department in Swansea. Civil Engineering in Swansea is well known for its innovation in the area of computational mechanics, in general, and finite element methods, in particular. Prof Zienkiewicz's enthusiasm and hard work led to a new generation of computational mechanics researchers in Swansea and elsewhere. Professors Lewis FEng, Morgan FEng and Owen FRS, FEng were among the senior members of this Department. The academic structure in Swansea changed about ten years back. The computational mechanics researchers from different engineering disciplines have now been assembled together to form a single group. This research grouping was initially referred to as the Civil and Computational Engineering Centre, headed previously by Professors Bonet, Morgan and Hassan in turn. In honour of

Professor Zienkiewicz, this Research Centre is now known as the Zienkiewicz Centre for Computational Engineering.

The Zienkiewicz centre currently has more than forty full-time, part-time and emeritus academic staff members, nearly one hundred graduate students and a large number of postdocs and researchers. The Centre is currently home to six research groups, focused on important current topics of computational research. The groups contain internationally renowned researchers with strong links with IACM, ECCOMAS and related associations. To support the further development of computational mechanics activities



Figure 1. Professor Olek Zienkiewicz (1921–2009), Founding Editor, *International Journal for Numerical Methods in Engineering*, First President of IACM.

in the UK, the Zienkiewicz Centre is hosting the next Association of Computational Mechanics–UK conference in 2015 (<http://www.swansea.ac.uk/engineering/research/acme2015/>).

### 2. RESEARCH ACTIVITIES IN THE CENTRE

Major research projects have been pursued within each of the six groups within the Centre. To provide a flavor of activities within the Centre, some of the current research topics are considered below. Some of the largest translational research projects within the centre include ASTUTE (<http://www.astutewales.com/en/>).

A wide variety of different research areas are pursued within the centre ranging from traditional mechanics to biomechanics and nanotechnology.

#### **Aerospace Engineering and Structures Group**

Compliant aircraft, with a range of deformations comparable to birds, has been a dream for many years. Earlier aviation pioneers tried to replicate aspects of bird flight, but

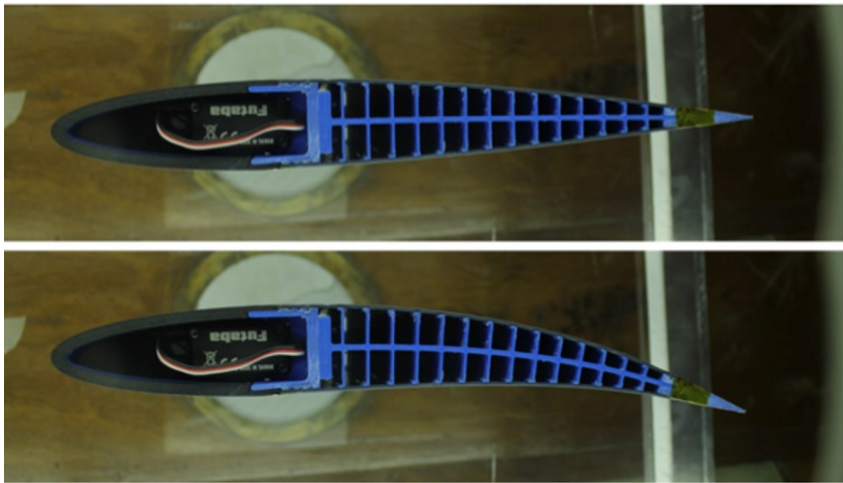


Figure 2. The FishBAC morphing camber concept .

higher air speeds and larger payloads have required aircraft design to deviate from their biological inspiration. The design of conventional fixed wing aircraft can only be optimized for a limited region of the flight envelope; mechanisms such as deployable flaps and wing sweep are used extensively to enlarge this envelope. The development of more accurate analysis tools, advanced smart materials, and the increasingly demands for improved aircraft performance, are driving research into compliant morphing aircraft. These aircraft have the potential to adapt and optimize their shape to improve flight performance or achieve multi-objective mission roles. The challenge is to optimize

morphing concepts across the length scales: system level optimization is required to determine performance benefits; aero-structural models are required for local effects, such as camber change; and detailed models are required for components, such as compliant skins. One promising concept developed at Swansea, through a European Research Council Advanced Grant led by Professor Michael Friswell, is the FISHBAC morphing camber, illustrated in Figure 2.

#### Biomedical Engineering and Rheology Group

Clinical research is increasingly focused towards the control and prevention of cardiovascular diseases, cancer and diabetes. Thus,

researchers are intensively engaged in understanding the basic mechanisms of such diseases. Due to the complexity and multitude of parameters involved in such studies, subject-specific computational modelling offers a pathway to faster understanding. Subject-specific disease modelling in the Centre is currently funded through a Welsh Government grant between Swansea and Cardiff Universities. This is an excellent example of the Centre's multidisciplinary activities. This collaborative multiscale project of clinical relevance has started investigating the association between blood flow in arteries, electrical activities in smooth muscle cells and endothelial function. The project involves computer scientists, clinicians, biologists and engineers. The final outcome of the project is expected to be a software platform for cardiovascular drug testing and understanding. Due to the interlink with diabetes and the model's similarity with cancer, the software will have wider potential in drug testing and disease control. This project is currently led by Proessor P. Nithiarasu in the Centre in collaboration with the College of Medicine in Swansea and Cardiff Universities.

#### Computational Methods in Engineering Group

The FLITE unstructured mesh computational aerodynamics design system, originally developed by Swansea researchers, was considered by BAE Systems to provide a step change in their design cycle. Following its use in the successful THRUST SSC project, FLITE has been employed, since 2007 in the aerodynamic design process for the BLOODHOUND supersonic car. In 2015, BLOODHOUND will attempt to set a new World Land Speed Record vehicle.

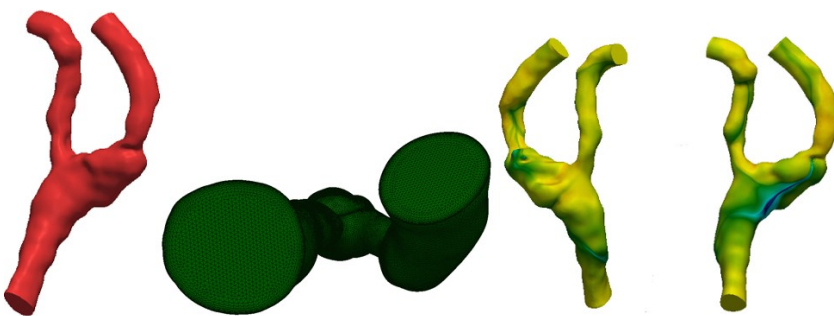


Figure 3 . Subject-specific modelling and fundamental investigation of vasomotion and endothelial dysfunction .

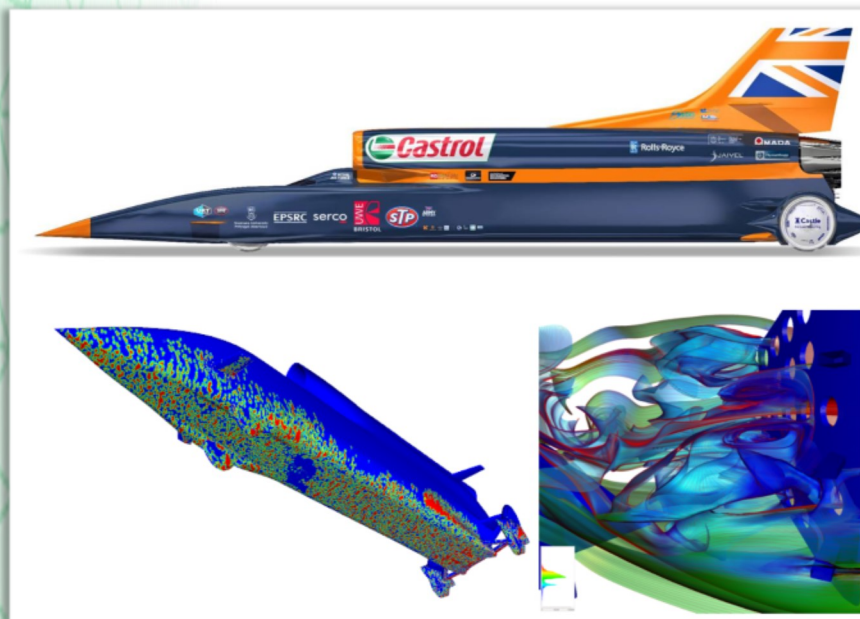


Figure 4 . Schematic view of Bloodhound and computational modelling results .

Initially, the FLITE system was used to demonstrate the practical feasibility of designing an aerodynamic shape that was capable of safely achieving 1000 mph. This work enabled the public launch of the BLOODHOUND project in 2008. Simultaneously, the creation of the BLOODHOUND education programme was announced. The objective of the education programme is to inspire a new generation of British engineers to tackle the challenges of the 21st century, using science, technology, engineering and mathematics (STEM). This programme includes school visits, FE roadshows and events, the BLOODHOUND website and resources, the BLOODHOUND Education Centres and the BLOODHOUND Ambassadors programme (see Figure 4). As a result of these activities, public engagement with the project has been a phenomenal success with over 5,059 schools signed up as education partners, ensuring the project reached over 1.5 million primary and secondary school students. In addition, 229 UK and

overseas colleges and 40 universities have signed up. Over 5,000 people have joined the 1K supporters' club and 11,000 people have contributed to have their names put on the vehicle's tail fin. An army of BLOODHOUND ambassadors travels across the UK delivering STEM public engagement activities. The BLOODHOUND project website currently receives an average of 50,000 hits per month following the public launch. FLITE has been extensively used to guide the shaping of the external geometry of the vehicle to its fully matured final design, completed in late 2012. Professors Hassan, and Morgan and Dr Evans lead the BLOODHOUND project.

#### Solid Mechanics and Coupled Systems Group

**PROTOTOUCH** is a large multidisciplinary EU funded research project aimed at the virtual prototyping of flat screen haptic displays. The main research goal is to exploit multiscale multiphysics simulation software, supported by neurophysiological measurements,

for the virtual prototyping and optimisation of tactile displays, which with the associated research activities, will lead to a radical understanding of the underlying design principles and hence to the development of future generation devices. This will be achieved by the deployment of an interdisciplinary network involving experts in tactile displays, computer simulation, cognitive and neural science, psychophysics, information processing, materials science, tribology and medical rehabilitation. The research is biomimetic in nature, being based on an understanding of the cellular, neurological and psychophysical response to tactile experiences such as those associated with tactile displays. The research group in Swansea, which is led by Prof Peric and Dr Dettmer, is focusing on multiphysics based computational modelling of touch in tactile displays spanning several length scales (see Figure 5). At the smallest scale the computational models of touch receptors responsible for mechanotransduction have been developed, while at the macroscale the focus is on complex physics at the interface between the finger pad and tactile devices (see Figure 5).

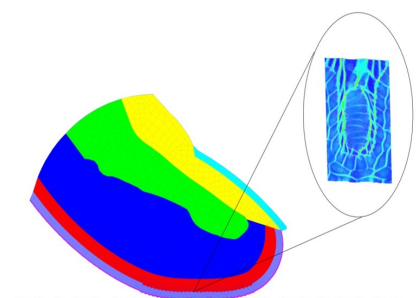


Figure 5. A multiscale computer model of a finger incorporating various anatomical layers of skin, tissue and bone, together with a detailed finite element model of the Meissner corpuscle at the microscale .

### 3. CENTRE'S INTERNATIONAL COLLABORATIONS

Many researchers within the centre have individual collaborative arrangement with various institutions all over the world. Although the centre has strong links with Brazil, India, Russia, South Africa, US and many other countries, two of the well-established research links are explained below.

#### China:

Zienkiewicz centre has strong research links with Tsinghua University, the premier university in China. Promoted by Dr Chenfeng Li at Zienkiewicz Centre and Prof Song Cen at Tsinghua's School of Aerospace, a strategic research partnership for the general field of computational engineering has been established between the two organisations. The Zienkiewicz centre's research collaboration with China has started in 2002 and since then it has involved over 20 academics from each side. The Swansea-Tsinghua partnership organizes a biannual workshop in computational mechanics and computational engineering, with the first joint workshop held in Beijing in July 2011 and the second workshop held in Swansea in July 2013.

The Swansea-Tsinghua partnership in computational engineering is multidimensional, facilitated by a range of collaborative activities, from regular bilateral academic visits and PhD student exchange to joint research grants funded by the Royal Academy of Engineering, British Council, European Union FP7, National Natural Science Foundation China and Chinese Scholarship Council. Since 2007, this strategic research collaboration has led to over 20 joint publications in leading international journals. Nominated by Prof Chuhan Zhang at Tsinghua University, Prof Roger J Owen (FRS, FREng) of Zienkiewicz centre was elected to the Chinese Academy of Science in 2011, which is the highest academic recognition in China.

Zienkiewicz centre also has close collaborations with a number of other leading research groups in China, and among these include groups from Peking University, Zhejiang University, Beihang University and Shanghai Jiaotong University.

#### Spain:

International collaborative Postgraduate training programmes between the "Zienkiewicz Centre in Computational Engineering" (ZCCE) at Swansea University (SU) and the Universitat Politècnica de Catalunya

(UPC) coordinated by Dr. Antonio J. Gil, Dr. R. Sevilla and Prof. J. Bonet

International collaborative Postgraduate training programmes between our Centre and UPC stretch back to 2007, when European funding was awarded for the establishment of the Erasmus Mundus Masters Course (EMMC) in Computational Mechanics (<http://www.cimne.com/cm>). Building upon this, SU and UPC successfully formed a partnership with other highly prestigious European institutions and in 2009 this group was granted the European Training Network "Advanced Techniques in Computational Mechanics" for training early stage researchers in this field of science. Thereafter, in 2012, SU and UPC secured further competitive funding for the renewal of the EMMC and the implementation of a new Erasmus Mundus Joint Doctorate entitled "Simulation in Engineering and Entrepreneurship Development", considered to be among the flagship PhD training programmes in Europe (<http://www.cimne.com/emjd-seed/>). All these programmes, with an approximate value of 10M euros, have facilitated and strengthened the research collaboration between academics of these two institutions through the supervision of some high calibre students. Throughout these years, more than 130 Postgraduate students have successfully completed schemes of study and have since either secured R&D positions in European industry or are now working in Academia.



Figure 6. The first Tsinghua-Swansea workshop for computational engineering held in Beijing, July 2011.

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# E-CAERO AND E-CAERO 2

## TWO EUROPEAN PROJECTS (IN FP7 AND H2020)

### CONNECTING ECCOMAS ACTIVITIES WITH OTHER EUROPEAN SOCIETIES WITH INTERESTS IN AEROSPACE RESEARCH AND TECHNOLOGY

E-CAero (European Collaborative Dissemination of Aeronautical research and applications) was a FP7 European Coordination and Support Action (FP7-AAT-2008-RTD-1, under the call AAT.2008.7.0.7. *Supporting the harmonised dissemination of European scientific knowledge from ad-hoc organisations in the field of aeronautics and air transport*) aiming at starting a new collaborative work culture between European associations with interests in the field of Aeronautical research.

In particular, the objectives were to

- Reinforce the network of the participating organizations by promoting inter-organizational cooperation. Identify and promote best practices.
- Propose upgrading measures, tailored to the specific needs of the participating organizations.
- Improve significantly the industrial end-users participation in the actions programmed by the member organizations.

It was also mentioned that, eventually, this might lead to the creation of an umbrella legal entity merging the Aeronautic interests of the partners.

The six partner associations were: ECCOMAS (represented by CIMNE, acting as coordinator), ERCOFTAC, CEAS (represented by DGLR), EUCASS, EUROMECH, EUROTURBO (represented by VKI). The institutes hosting their permanent secretariats represented three of the six partners. This was also the case of ECCOMAS who, as a non-profit



Figure 1. Logos of E-CAero and the six partners .

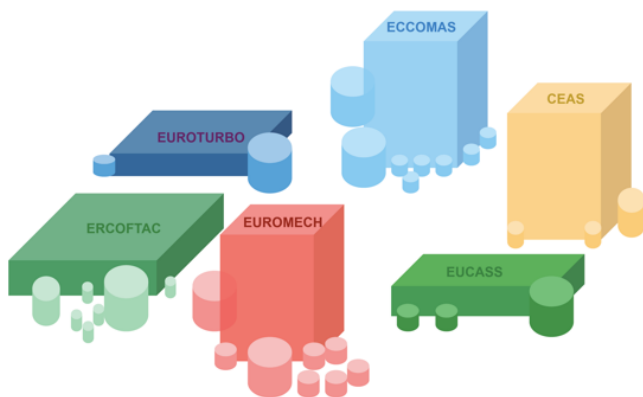


Figure 2. Six societies with independent activities configuring a fragmented European landscape.

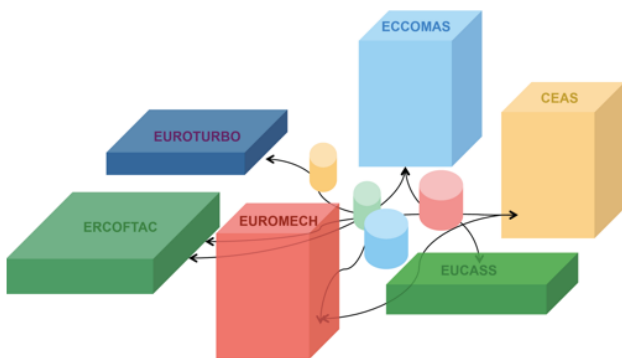


Figure 3. Some activities and services were shared during E-Caero.

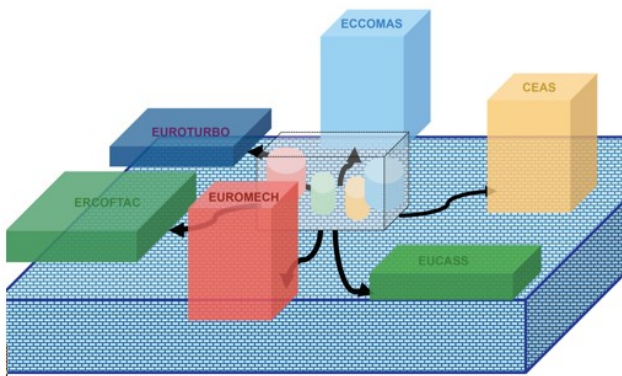


Figure 4. E-CAero 2 aims at creating a common platform to harmonize activities and share resources.

association legally registered in France, has no associated personnel and therefore no means to carry out the administrative tasks required. The coordinators for ECCOMAS were P. Díez and J. Périaux.

The project started September 2009 and (after obtaining a 14 months time extension) was closed end October 2013. The main benefits for ECCOMAS of the E-CAero project were the interaction with the partner associations and the exchanges in promoting common activities with them aiming at harmonizing the policies for conferences, communication (paper and journal) and having an active role in shaping the European Landscape for Aeronautical Research. Moreover, E-CAero supported many ECCOMAS activities (congresses, conferences, workshops, schools) to allow interaction and joint organization with the partner associations.

E-Caero 2. After the closing E-CAero, the EC opened a new call in the H2020 (MG1.6-2014, *Topic: Improving skills and knowledge base in European Aviation*, *Specific challenge: The European aviation sector should have access to a highly skilled workforce which can rely on a strong scientific knowledge base to be able to properly address the environmental and competitiveness challenges facing both the aeronautics and the air transport sectors. Two specific domains have to be addressed: 1) To analyse and define the evolving skill needs of the sector and propose changes to the education of aviation engineers accordingly, and to attract more young people to aviation careers. 2) To reduce the fragmentation in the dissemination of scientific and technical knowledge in Europe and enhance its global impact.*). The second specific challenge was considered as an invitation to apply for an E-CAero 2 project with the objective to deepen the existing collaboration and harmonization. The proposal was submitted on March 27, 2014. The novelty of E-CAero 2 is the commitment to create a platform to coordinate the collaboration activities between the six associations.

The E-CAero 2 project is aimed to go collaboratively further in the operability of a European Community in Aeronautics and Astronautics (ECAA), involving the six associations participating in E-CAero. ECAA aims to define jointly a wide coordination mechanism of the associations which devote its activities, totally or partially, to aeronautics and air transport. The action will contribute to enhance the impact and accessibility of publications relevant to European aviation and aerospace, in particular those issued from European Commission (EC) funded projects. The deployment of conferences must be strongly rationalized to reduce the duplicity, and overlapping of events, while their visibility is improved and the audience increased. The actions taken in this project are aimed at being self-supportable after the end of the project.

As for the ECCOMAS participation, in this second application we tried to get ECCOMAS as a legal partner and include CIMNE as a third partner providing all the administrative support. The process of creating a legal identity for ECCOMAS to be recognized by the EC was long and time consuming (in particular for our treasurer, R. Abgrall, who obtained the documents from the French administration tracing the legal existence of ECCOMAS). Nevertheless, this could not be completed on time because it required also a particular financial

identity (that for a society registered in France as ECCOMAS means obtaining the so-called SIREN number). This is also a tedious procedure that has been now started but was not completed in time to start the project. Thus, we had to repeat the scheme of using the permanent secretariat in CIMNE as the legal entity representing ECCOMAS. However, this experience is going to be valuable for ECCOMAS because the complete legal identification for EC is soon to be completed and therefore in the future it could be taken as a standard partner.

The E-CAero project and its sequel are aligned with the aim and goals of the ECCOMAS Industrial Interest Group (IIG) recently launched by the Executive Committee after the initiative of Prof. Jacques Périaux. Another initiative of this group is the CM3 (Computational Multi Physics, Multi Scales and Multi Big Data in **Transport Modeling, Simulation and Optimization**: Green Challenges in Automotive, Railways, Aeronautics and Maritime Engineering) conference to be held in Jyväskylä (Finland) on May 25–27, 2015, see <http://www.mit.jyu.fi/scoma/cm3/>.

This thematic conference addresses the challenges in Multidisciplinary Scientific Computing, now one of the powerful design technologies used in industry. This trend has been enhanced by the ever-increasing capabilities of computational technology, storing of information and the decreasing cost of computer

hardware. Consequently, analysis of Multidisciplinary Big Data is also becoming extremely important in process control, intelligent systems for surveillance and safety procedures. All these aspects are treated in the CM3 conference in connection with the industrial needs. Accordingly, an important industrial participation is expected, combined with the EC involvement.

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# ECCOMAS YOUNG INVESTIGATORS CORNER

## NOTES ON THE EYIC MEETING IN JULY 2014

The ECCOMAS Young Investigators Committee (EYIC) has been created in order to promote the main goals of ECCOMAS among young researchers, with special emphasis in encouraging activities of young ECCOMAS members. In this spirit, the first EYIC meeting in the new composition of members was held in the frame of the WCCM-ECCM-ECFD 2014 in Barcelona. The members agreed on the main tasks of the committee: As a means of communications, a section of the ECCOMAS webpage has been set aside for EYIC. It can be found under <http://www.eccomas.org/vpage/1/0/Committees/YIC-General>. Over the course of the next months, this page will be enriched with information interesting to young researchers, such as open positions, opportunities, thematic conferences, summer schools, etc. (everyone – both junior or senior – is strongly encouraged to contribute posting news, information, and announcements!). Furthermore, the members of EYIC will try to create awareness for specific needs of young ECCOMAS participants, reaching from more transparency of the structure and the opportunities to contribute to the ECCOMAS organization all the way to child care possibilities at conferences. As a counterpart to EYIC, the young researchers will try to promote the idea of Young Sections within the national organizations. This concept is already practiced in some organizations and the feedback from both younger and older members is entirely positive.

### EYIC next Events

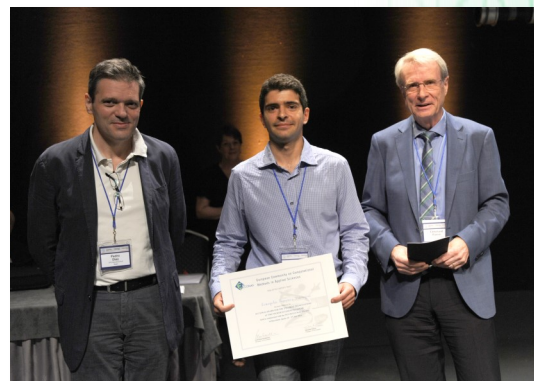
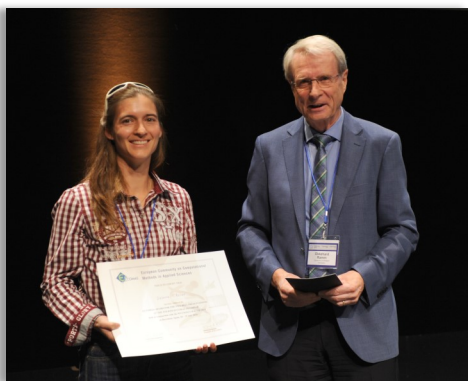
Call for the best two PhD theses 2014 (deadline):  
Call for the YIC 2017 proposals (deadline):

### Important Dates

February 16, 2015  
April 20, 2015

## AWARDS FOR THE BEST PRESENTATIONS AT THE ECCOMAS PhD OLYMPIAD 2014

The 4<sup>th</sup> ECCOMAS PhD Olympiad was held in conjunction with the WCCM-ECCM-ECFD 2014 in Barcelona, Spain, in July 2014. There were 13 participants from 9 countries, who presented their works within 2 sessions. The ECCOMAS awards for the two best presentations at the OLYMPIAD were given to Debora Clever from Germany for the presentation “Optimal control - Discretization, application and augmentation” and Evangelos Papoutsis-Kiachagias from Greece for the presentation “Adjoint methods for turbulent flows, applied to shape or topology optimization and robust design”. Congratulations!



# 3<sup>rd</sup> ECCOMAS YOUNG INVESTIGATORS CONFERENCE 2015

## ECCOMAS PhD OLYMPIAD 2015

We would like to invite you to join us for the **YIC GACM 2015: July 20-23, 2015 in Aachen, Germany**.

This Young Investigators Conference (YIC) will be the third meeting of its kind organized as ECCOMAS Conference. On this particular occasion, we have the opportunity to hold the conference in conjunction with the GACM (German Association of Computational Mechanics) Colloquium for Young Scientists. As a new series of scientific events, the YIC focuses on bringing together young researchers to discuss, learn, and collaborate. As a conference designed by young researchers for young researchers, we will offer a variety of highlights such as a Science Slam, Journal Club, and numerous social events, thus nurturing the networking idea behind the conference. In addition, we will host the **ECCOMAS PhD Olympiad of 2015**. The event will be held in direct sequence with the AC.CES conference ([www.ac-ces.rwth-aachen.de](http://www.ac-ces.rwth-aachen.de)), organized by the graduate school AICES of RWTH Aachen. In contrast to the YIC and the GACM colloquium, the concept of the AC.CES is based on invited speakers with high international recognition in their particular fields. We will offer an optional combined package, giving participants the opportunity to profit from both conferences.

Please visit our website for further details: [www.yic.rwth-aachen.de](http://www.yic.rwth-aachen.de)

### Important Dates

|                                      |                  |
|--------------------------------------|------------------|
| Abstract submission deadline:        | January 16, 2015 |
| Notification of abstract acceptance: | March 6, 2015    |
| Submission of (optional) full paper: | May 15, 2015     |
| Early registration deadline:         | May 15, 2015     |



# RECENT ADVANCES IN REDUCED ORDER MODELING FOR VISCOUS AND THERMAL FLOWS IN PARAMETRIZED SETTINGS

*(ECCOMAS J.L.LIONS AWARD 2014 FOR GIANLUIGI ROZZA)*

Recent research of Prof. Gianluigi Rozza and his team within **SISSA, International School for Advanced Studies, mathLab** (<http://mathlab.sissa.it>) aims at developing and consolidating the capabilities of computational reduction strategies for problems governed by parametrized partial differential equations (PDEs). Parameters might be both physical (material properties, nondimensional coefficients such as Reynolds or Prandtl numbers, boundary conditions, forcing terms) and geometrical (i.e. quantities which characterize the shape of the domain and of the system itself). See Fig.1.

This research fits into the fields of numerical analysis and scientific computing, with a special interest in computational mechanics, and to applications in the contexts of simulation, optimization and control. In the latter cases iterative minimization procedures entailing

several numerical resolutions of PDEs (each time with different values of control or design variables or different physical and geometrical scenarios) are involved, thus requiring high computational efficiency. For this reason, suitable model order reduction techniques, such as reduced basis methods [1], are mandatory to achieve this goal.

With the increasing need of real time tools for parametrized computing, Reduced Basis (RB) methods have known a remarkable development in the last decade because they make possible a strong reduction of computational times required when solving parametrized PDE problems, owing to a crucial decomposition of the computational procedures. In an offline pre-processing stage, a suitable basis is stored by solving the original problem for a set of parameter values, properly selected in an automatic and optimal way. During an online stage, for each new

parameter value the PDE is found as a combination of the previously computed basis functions, by means of a Galerkin projection [3]. This problem has a very small size (related with the number of the selected bases, which are typically very few). The resulting procedure is not only rapid and efficient but also accurate and reliable, thanks to suitable, residual-based, a posteriori error estimators.

Research activities in this field have led to a significant development of the reduced order methods for many different problems, and to applications of interest in several real-life scenarios [2]. Moreover, in order to perform efficient numerical simulations in complex and variable geometric configurations, as required for instance in engineering or medical applications, RB methods need to be coupled with efficient parametrization techniques for curves and surfaces.

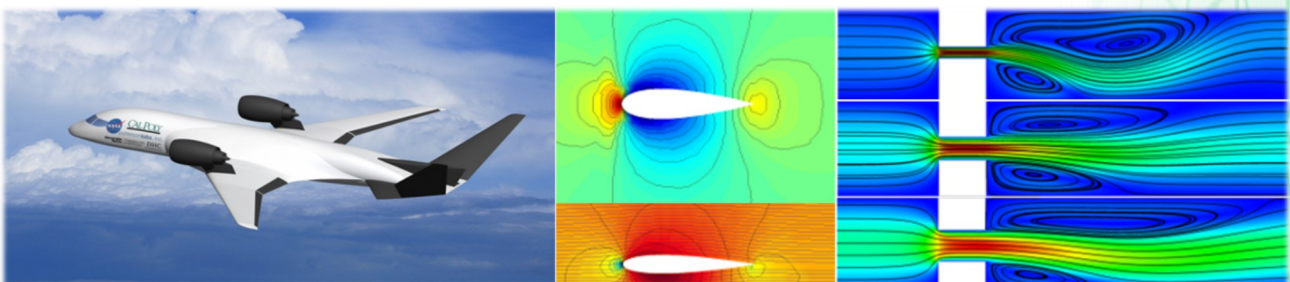


Figure 1 Examples of problems: geometrical parametrization of airfoils in aeronautics or turbomachinery, Coanda effect, flow instabilities and bifurcations in fluid mechanics (SISSA mathLab).

Ongoing research aims at deepening the theory and the methodology of the RB methods for problems in fluid dynamics, characterized by very different physical and temporal scales, but also complex nonlinear problems like bifurcations and instabilities. Another task is devoted in delivering ready tools for applications in naval, nautical, aerospace and mechanical engineering, as well as in medicine (fluid-structure interactions between blood flows and arterial vessels in the human cardiovascular system), biology (motility of cells and micro-organisms), porous media (groundwater flows), and also

geophysics (simulation of the Earth's mantle dynamics). The developed methodologies could be properly combined and coupled with novel techniques in data assimilation, uncertainty quantification for the solution of complex inverse problems arising in the multidisciplinary fields previously mentioned.

[1] Rozza G, Huynh DBP, Patera AT (2008). Reduced basis approximation and a posteriori error estimation for affinely parametrized elliptic coercive partial differential equations. Archives of Computational

Methods in Engineering, vol. 15, p. 229-275.

[2] Quarteroni A, Rozza G (2013) Reduced Order Methods for Modeling and Computational Reduction. MS&A series, Vol.9, Springer, Milano, Italia.

[3] Rozza G (2011). Reduced Basis Approximation and Error Bounds for Potential Flows in Parametrized Geometries. Communications in Computational Physics, vol. 9, p. 1-48.

Links:

<http://www.math.sissa.it>  
<http://people.sissa.it/~grozza>

## COMPUTATIONAL HOMOGENIZATION OF MICRO AND NANO-STRUCTURED MATERIALS: CONTRIBUTIONS TO RECENT CHALLENGES

*(ECCOMAS O. C. ZIENKIEWICZ AWARD 2014 FOR JULIEN YVONNET)*

Recent research of Julien Yvonnet's group focuses on several topics in computational multiscale methods for solid materials.

The first one deals with the **development of advanced computational homogenization methods**, including: filter-based homogenization techniques to treat non-separated scales [1], non-concurrent methods for solving heterogeneous viscoelastic [2], nonlinear [3] structure problems and multiscale instabilities [4].

Another subject is the **multiscale modeling of imperfect interfaces** at the microstructural level and

their effects on the macroscopic properties of the materials by using XFEM/Level-set methods [5]. We have also recently contributed to the development of **advanced numerical methods for microstructure problems** and related multiscale techniques, based on Model Reduction (POD) [6], XFEM/Level-set methods, Lippmann-Schwinger iterative algorithms or series expansion methods.

Finally, we have introduced computational methodologies to construct **size-dependent FEM models of nanostructures** [7] based on surface energy models

identified by ab initio calculations. The whole publication list can be found at <http://msme.u-pem.fr/equipe-mecanique/meca/yvonnet-julien/>.

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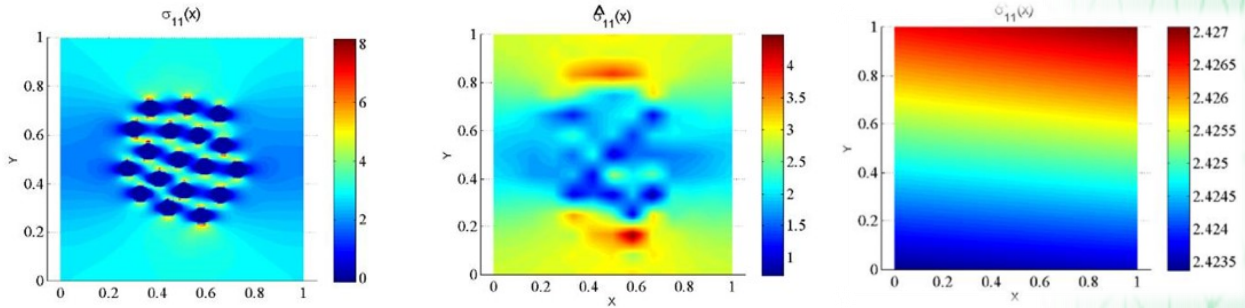


Figure 1. Construction of homogenized models with different characteristic wavelength using filter-based homogenization [1].

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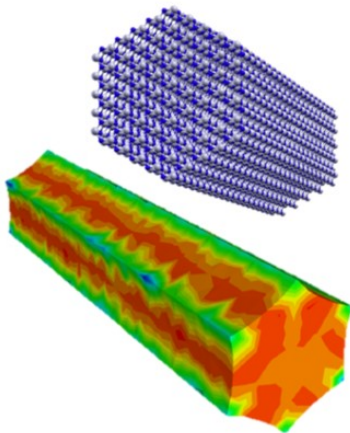


Figure 2. Ab initio model of a AlN nanowire and size-dependent FEM model: polarization and relaxation due to surface residual stress [7].

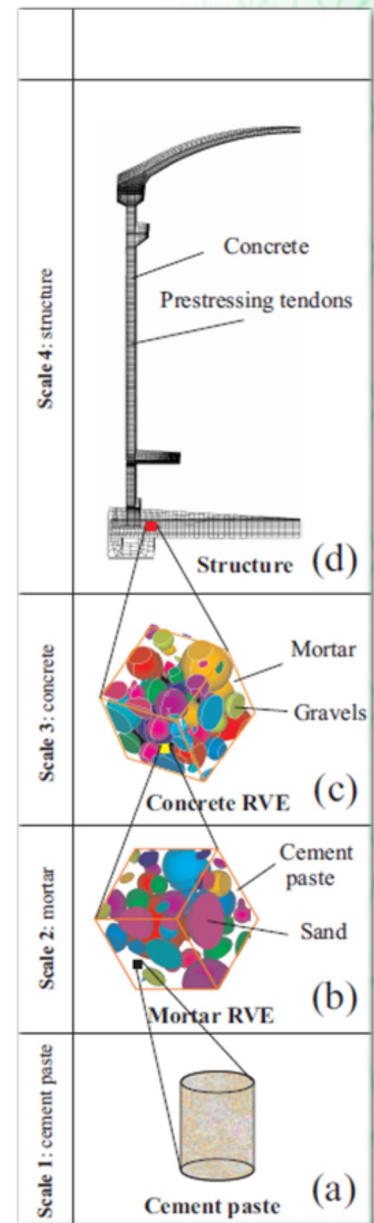


Figure 3. A four-scale creep analysis of a nuclear containment structure by means of the decoupled viscoelastic homogenization method [2].

## Welcome to ECCOMAS Congress 2016 in Crete, Greece!

The European Community on Computational Methods in Applied Sciences (ECCOMAS) is pleased to announce the **ECCOMAS Congress 2016** to be held in Crete, Greece in **June 5-10, 2016**.



### Previous Editions of ECCOMAS Congresses:

Paris (1996), Barcelona (2000), Jyvaskyla (2004), Venezia (2008), Vienna (2012).

### Organizers



**Greek Association for  
Computational Mechanics  
(GRACM)**

*with the support of*  
**Institute of Research  
and development for  
Computational Methods  
in Engineering Sciences  
(ICMES)**



### Minisymposia

Relevant scientists in the fields of the congress are invited to organize Minisymposia in the different fields of the conference. Participation of research teams from all parts of the world is welcomed and encouraged, as well as proposals of Minisymposia in new developing areas. Guidelines for the proposal and organization of Minisymposia and detailed information concerning the congress may be found on the website (<http://www.eccomas2016.org>).

### Congress Venue

The Congress will take place at the **Creta Maris Convention Center**, one of the largest convention centers in the Mediterranean (website: <http://www.conference-greece.com>). The complex is part of the Creta Maris Beach Resort overlooking Hersonissos Bay one of the most developed touristic resorts of Crete. The Convention Center is located 24 km away from Heraklion International Airport with many daily flights to and from Athens and regular and charter flights from 50 major cities of Europe and overseas.



### Important Dates

Deadline for submission of Minisymposia proposals: **June 30, 2015**

Deadline for abstract submission: **November 29, 2015**

Deadline for submitting the final contribution and early payment: **February 29, 2016**

For further information please visit <http://www.eccomas2016.org> or contact the Congress Secretariat: [info@eccomas2016.org](mailto:info@eccomas2016.org).

# ECCOMAS

## LEONHARD EULER MEDAL 2014

### AWARDED TO PROFESSOR FRANCO BREZZI



*"The ECCOMAS Leonhard Euler medal is awarded for outstanding and sustained contributions to the area of computational solid and structural mechanics".*

In 2014 the Euler medal was awarded to Professor Franco Brezzi, University of Pavia, Italy.

Franco Brezzi graduated with a degree in mathematics at the University of Pavia in 1967. He became a full professor of mathematical analysis at Turin University of Technology in 1975; after two years he returned to the University of Pavia and stayed at his alma mater until 2006. He continued to work as director for the Institute for Applied Mathematics and Information Technology of the Italian Research Council and became a professor of the Institute for Advanced Studies. Professor Brezzi got several awards, among them the IACM Gauss-Newton Medal, the SIAM von Neumann Award and

recently the Blaise-Pascal Medal for Mathematics by the European Academy of Sciences.

Franco Brezzi is surely one of the most prominent applied mathematician being able to equally influence researchers in both Computational Mathematics and Engineering. His pioneering work on the stability of mixed finite elements, once and forever referred to as inf-sup or Babuska-Brezzi condition, was a landmark for reliable FE Analyses. The spectrum of his research is not limited to fundamental theoretical results but reaches into areas like bifurcation problems, plates and shells, finite element stabilization techniques, residual-free bubbles and subgrid-scale simulations, and virtual

elements; the list is by far not complete. As a personal remark I would like to say that I am always excited when I listen to his enthusiastic and lively talks.

On behalf of ECCOMAS I would like to congratulate Professor Franco Brezzi for this outstanding distinction.

EKKEHARD RAMM  
PRESIDENT OF ECCOMAS



*ECCOMAS Euler Medal award to Franco Brezzi*

# THE CLUSTERED ECCM V AND ECFD VI JOINTLY ORGANIZED WITH WCCM XI BARCELONA, JULY 2014

The clustered 5th European Conference on Computational Mechanics (ECCM V) and 6th European Conference on Computational Fluid Dynamics (ECFD VI) of ECCOMAS were jointly organized with the 11th World Congress on Computational Mechanics of the IACM (WCCM XI) in Barcelona, on July 20 – 25, 2014.

The event was organized by the Spanish Association of Numerical Methods (SEMNI), in the year of its 25th Anniversary, with the support of the International Center for Numerical Methods in Engineering (CIMNE).

The joint organization of the WCCM XI - ECCMV – ECFD VI aroused a big interest in the computational methods community. It was hosted at the Congress Complex constituted by the Hotel Rey Juan Carlos and the Palau de Congressos de Catalunya. Sixty three countries were represented by over 3600 participants. **This has been, so far, the largest congress in the computational methods history.**

The congress was a forum to communicate and share new ideas and methods that will foster the development in computational methods and their applications in mechanics, engineering and applied sciences.

The congress also gave participants the opportunity to visit Barcelona, one of the most appealing and interesting cities in the south of Europe, always open to multicultural events and innovation.

## SCIENTIFIC PROGRAM

The cooperation of the **Scientific Committees** members and **Minisymposia Organizers**, and the enthusiasm of researchers from all over the world, resulted in a high level scientific program.

The quality of the scientific program was highlighted by the **Invited Lectures** given by scientists of international prestige in the fields of the congress.

**Opening Session:** J. Tinsley Oden (USA)

**Plenary Lecturers:** Rémi Abgrall (France), Patrick Le Tallec (France), Shigeru Obayashi (Japan), Michael Ortiz (USA), Jaume Peraire (USA) and Kenjiro Terada (Japan) .



*The organization team of the Congress: From left to right: Prof. Xavier Oliver (chairman of ECCM V, UPC), Prof. Eugenio Oñate (chairman of WCCM XI, CIMNE/UPC), Mrs. Cristina Forace (general manager of the conference, CIMNE) and Prof. Antonio Huerta (chairman of ECFD V, UPC)*



*Participants during a coffee-break*



*Opening Session at the main Auditorium Hall*

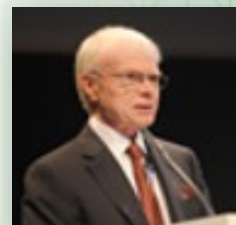
**Semi-plenary Lecturers:** Marino Arroyo (Spain), Santiago Badia (Spain), Manfred Bischoff (Germany), Javier Bonet (UK), Tadeusz Burczynski (Poland), J. S. Chen (USA), Francisco Chinesta (France), Bernardo Cockburn (USA), Elías Cueto (Spain), Leszek Demkowicz (USA), Pedro Díez (Spain), Alberto Figueroa (UK), Jacob Fish (USA), José Manuel García Aznar (Spain), Hector Gomez (Spain), Sergio R. Idelsohn (Argentina), Umberto Perego (Italy), Alessandro Reali (Italy), Bernhard Schrefler (Italy), Katsuyuki Suzuki (Japan), Harald van Brummelen (Netherlands), Peter Wriggers (Germany), Shinobu Yoshimura (Japan) and Yong Yuan (China).

**Industrial Lecture:** Klaus Becker (Airbus, Germany)

**Closing Session:** Thomas J.R. Hughes (USA)



*Opening session head table, from left to right: X. Oliver, A. Huerta, G. Yagawa, A. Mas Colel (Minister of Economy and Knowledge of Catalanian Government and President of CIMNE), E. Ramm, S. Olivella and E. Oñate*



*From left to right: Professors J. Tinsley Oden, Michael Ortiz, R mi Abgrall, Kenjiro Terada, Jaume Peraire, Patric Le Tallec, Shigeru Obayashi and Thomas J.R. Hughes addressing the opening, plenary and closing lectures.*

**Young Investigators awardees** were invited to present their scientific work in special semi-plenary sessions.

The **ECCOMAS PhD Olympiads** were also organized as a part of the congress. Young researches coming from different European associations presented the best PhD theses defended during 2013.

## EXHIBITION

The technical program was complemented by an exhibition, strategically located at the center of the daily activities of the congress to facilitate the interaction of participants interested in viewing and discussing publications, software, hardware, and other materials related to computational mechanics.

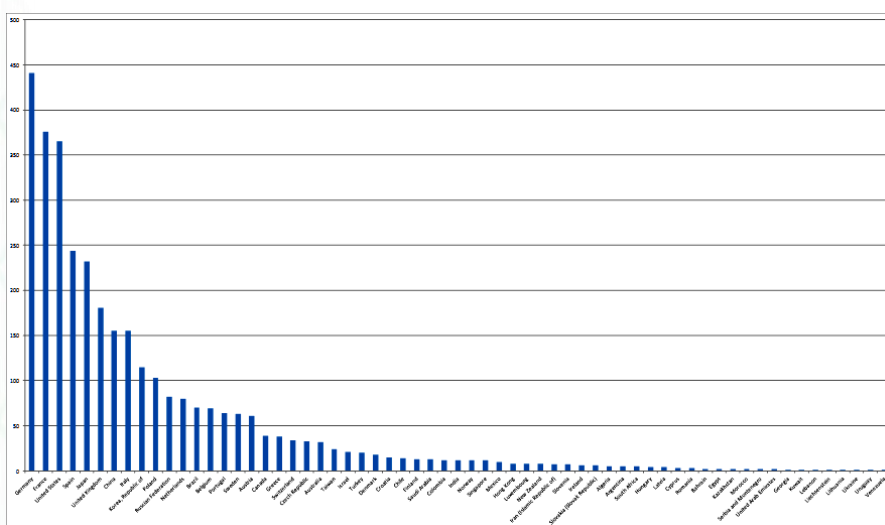


*Exhibition at the WCCM-ECCM-ECFD 2014*

## THE CONGRESS IN FIGURES

As a response to the call for abstracts, 4142 contributions were received and went through the review process. In the end, the scientific program scheduled 3152 papers presented in 543 sessions (48 parallel rooms).

- Registered participants: 3636 from 63 countries
- Papers: Oral presentations: 3037  
Poster presentations: 115
- Minisymposia: 218
- Contributed sessions: 26
- Maximum number of parallel sessions: 48



|                    |     |                |    |                            |    |                       |   |
|--------------------|-----|----------------|----|----------------------------|----|-----------------------|---|
| Germany            | 441 | Austria        | 61 | Norway                     | 12 | Romania               | 3 |
| France             | 376 | Canada         | 39 | Singapore                  | 12 | Bahrain               | 2 |
| United States      | 365 | Greece         | 38 | Mexico                     | 10 | Egypt                 | 2 |
| Spain              | 244 | Switzerland    | 34 | Hong Kong                  | 8  | Kazakhstan            | 2 |
| Japan              | 232 | Czech Republic | 33 | Luxembourg                 | 8  | Morocco               | 2 |
| United Kingdom     | 181 | Australia      | 32 | New Zealand                | 8  | Serbia and Montenegro | 2 |
| China              | 155 | Taiwan         | 24 | Iran (Islamic Republic of) | 7  | United Arab Emirates  | 2 |
| Italy              | 155 | Israel         | 21 | Slovenia                   | 7  | Georgia               | 1 |
| Korea, Republic of | 115 | Turkey         | 20 | Ireland                    | 6  | Kuwait                | 1 |
| Poland             | 103 | Denmark        | 18 | Slovakia (Slovak Republic) | 6  | Lebanon               | 1 |
| Russian Federation | 82  | Croatia        | 15 | Algeria                    | 5  | Liechtenstein         | 1 |
| Netherlands        | 80  | Chile          | 14 | Argentina                  | 5  | Lithuania             | 1 |
| Brazil             | 70  | Finland        | 13 | South Africa               | 5  | Ukraine               | 1 |
| Belgium            | 69  | Saudi Arabia   | 13 | Hungary                    | 4  | Uruguay               | 1 |
| Portugal           | 64  | Colombia       | 12 | Latvia                     | 4  | Venezuela             | 1 |
| Sweden             | 63  | India          | 12 | Cyprus                     | 3  |                       |   |

## FEMALE RESEARCHERS MEETING

All female researchers (from junior to senior) of the WCCM-ECCM- ECFD 2014 were invited to a network meeting in the evening of Wednesday July 23. The meeting was promoted by Miriam Mehl and Dörte C. Sternel.

The meeting started with three short presentations on general and personal career paths given by Dörte C. Sternel (TU Darmstadt), Lois Curfmann McInnes (Argonne National Lab) and Sabine Roller (Universität Siegen) followed by a reception with some snacks financed by the SPPEX Priority Program of the German Research Foundation. Among the participants there were a few established senior researchers but also a lot of very promising young researchers still figuring out whether to select an academic career.

## CONGRESS BANQUET

The congress banquet, on Thursday July 24, gathered 2200 people at the International Convention Center of Barcelona (CCIB). The CCIB is unique in Europe for the impact and originality of its architecture, for the versatility of its column-free meeting halls and spaces and for the superb use it makes of the warm, natural Mediterranean light.



*Spot shoots of the banquet in the CCIB*

## AWARDS

ECCOMAS delivered the awards for 2014, most of them during the opening ceremony of the congress. The president of ECCOMAS, Prof. Ekkehard Ramm, delivered the following Awards:

- Euler Medal: **Franco Brezzi**
- O. C. Zienkiewicz Award for Young Scientists in Computational Engineering Sciences: **Julien Yvonnet**
- J. L. Lions Award for Young Scientists in Computational Mathematics: **Gianluigi Rozza**
- ECCOMAS Award for the Best Ph.D Theses of 2013 on Computational Methods in Applied Sciences and Engineering: **Henning Sauerland** and **Francesc Verdugo**.
- During the closing ceremony ECCOMAS also delivered an award to Two Best PhD Olympiad Oral Presentations: **Debora Clever** and **Evangelos Papoutsis-Kiachagias**.



*IACM and ECCOMAS Awardees during the Opening Ceremony of the congress*



*From left to right: IACM John Argyris Award for Young Investigators: **Alessandro Realì**, J. L. Lions Award for Young Scientists in Computational Mathematics: **Gianluigi Rozza**, ECCOMAS Award for the Best Ph.D Theses of 2013 on Computational Methods in Applied Sciences and Engineering: **Henning Sauerland** and **Francesc Verdugo**, O. C. Zienkiewicz Award for Young Scientists in Computational Engineering Sciences: **Julien Yvonnet**.*

# ECCOMAS THEMATIC CONFERENCES 2015

| Acronym          | ECCOMAS Thematic Conference                                                                                 | Location                    | Date         |
|------------------|-------------------------------------------------------------------------------------------------------------|-----------------------------|--------------|
| KomPlasTech      | Conference on Computer Methods in Materials Technology                                                      | Krynica-Zdrój, Poland       | Jan 11-14    |
| HONOM            | European Workshop on High Order Nonlinear Numerical Methods for Evolutionary PDEs: Theory and Applications  | Trento, Italy               | Mar 16-20    |
| SYMCOMP          | International Conference on Numerical and Symbolic Computation: Developments and Applications               | Faro, Portugal              | Mar 26-27    |
| COUPLED PROBLEMS | VI International Conference on Coupled Problems in Science and Engineering                                  | Venice, Italy               | May 18-20    |
| COMPDYN          | 5th International Conference on Computational Methods in Structural Dynamics and Earthquake Engineering     | Crete, Greece               | May 23-25    |
| UNCECOMP         | International Conference on Uncertainty Quantification in Computational Sciences and Engineering            | Crete, Greece               | May 25-27    |
| CM3              | Computational Multi Physics, Multi Scales and Multi Data in Transport Modeling, Simulation and Optimization | Jyväskylä, Finland          | May 25-27    |
| ICCCM            | International Conference on Computational Contact Mechanics                                                 | Hannover, Germany           | May 27-29    |
| Rehab Structures | International Conference on Recent Advances in Rehabilitation and Sustainability of Structures              | S. Miguel, Azores, Portugal | Jun 1-2      |
| CFRAC            | Computational Modeling of Fracture and Failure of Materials and Structures                                  | Cachan, France              | Jun 3-5      |
| SMART            | Conference on Smart Structures and Materials                                                                | Azores, Portugal            | Jun 3-6      |
| ADMOS            | VII International Conference on Adaptive Modeling and Simulation                                            | Nantes, France              | Jun 8-10     |
|                  | 2nd International Conference on Multi-scale Computational Methods for Solids and Fluids                     | Sarajevo, BiH               | Jun 10-12    |
| MARINE           | VI International Conference on Computational Methods in Marine Engineering                                  | Rome, Italy                 | Jun 15-17    |
| ICTE             | 4th International Conference on Tissue Engineering                                                          | Lisbon, Portugal            | Jun 25-27    |
| MULTIBODY        | Multibody Dynamics                                                                                          | Barcelona, Spain            | Jun 29-Jul 2 |

| Acronym    | ECCOMAS Thematic Conference                                                                                                                                        | Location                      | Date      |
|------------|--------------------------------------------------------------------------------------------------------------------------------------------------------------------|-------------------------------|-----------|
| COMPLAS    | XIII International Conference on Computational Plasticity                                                                                                          | Barcelona, Spain              | Sep 1-3   |
| COMPOSITES | V Conference on Mechanical Response of Composites                                                                                                                  | Bristol, UK                   | Sep 7-9   |
| X-DMS      | eXtended Discretization MethoS                                                                                                                                     | Ferrara, Italy                | Sep 9-11  |
| EUROGEN    | 11th International Conference on Evolutionary and Deterministic Methods for Design, Optimization and Control with Applications to Industrial and Societal Problems | Glasgow, UK                   | Sep 14-16 |
| PARTICLES  | IV International Conference on Particle-based Methods                                                                                                              | Barcelona, Spain              | Sep 28-30 |
| MEMBRANES  | VII Internacional Conference on Textile Composites and Inflatable Structures                                                                                       | Barcelona, Spain              | Oct 19-21 |
| VipIMAGE   | V Conference on Computational Vision and Medical Image Processing                                                                                                  | Santa Cruz de Tenerife, Spain | Oct 19-21 |
| ICBT       | International Conference on Biomedical Technology                                                                                                                  | Hannover, Germany             | Oct 28-30 |
|            | 3rd Workshop «Reduced Basis, POD or PGD-Based Model Reduction Techniques: a Breakthrough in Computational Engineering?»                                            | Cachan, France                | Nov 4-6   |

## ECCOMAS SPECIAL INTEREST CONFERENCES 2015

| Acronym  | ECCOMAS Special Interest Conference                              | Location           | Date    |
|----------|------------------------------------------------------------------|--------------------|---------|
| AfriComp | International African Conference on Computational Mechanics      | Marrakech, Morocco | Jan 5-7 |
| CMwM2015 | International Conference on Continuous Media with Microstructure | Lagów, Poland      | Mar 2-5 |
| IGA      | Isogeometric Analysis                                            | Trondheim, Norway  | Jun 1-3 |

## OTHER ECCOMAS CONFERENCES 2015

|     |                                                                                   |                 |              |
|-----|-----------------------------------------------------------------------------------|-----------------|--------------|
| YIC | ECCOMAS Young Investigators Conference 2015                                       | Aachen, Germany | Jul 20-23    |
|     | Modelling, Simulation and Characterization of Multi-Scale Heterogeneous Materials | Udine, Italy    | Sep 28-Oct 2 |



ECCOMAS

European Community on  
Computational Methods in  
Applied Sciences

**European Congress on  
Computational Methods in  
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**JUNE 5-10, 2016 CRETE, GREECE**



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