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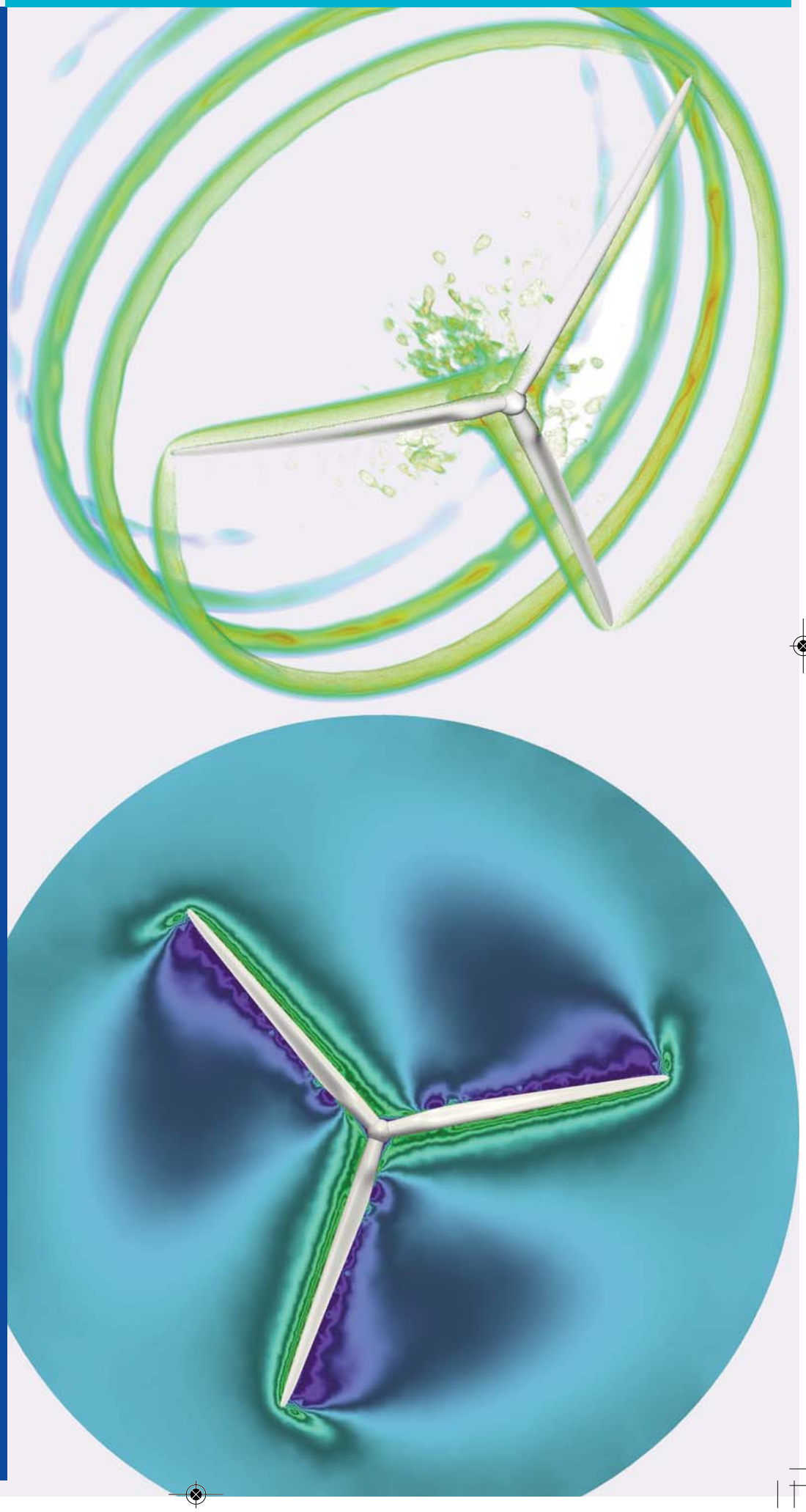

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contents

editorial

The number of natural catastrophes that impact our world increases annually at an impressive and worrying rate. Some 850 natural catastrophes were recorded in 2009, while this number was barely 120 in 1970 (Source: Munich RE, Topics Geo 2010). Recent dramatic examples are the earthquake and tsunami in Japan, the flooding in the Mississippi river, the typhoons in Louisiana, the volcanic eruptions in Iceland and the seismic event in Spain, just to name a few. Indeed earthquakes, floods, hurricanes, tsunamis, volcanic eruptions, landslides, forest fires, etc., are frequent hazards that have catastrophic consequences in the lives of many thousands of people around the world, not to mention their devastating and economic impact on existing constructions and infrastructures.

To the list of natural hazards we could add the so called anthropic, for "man-made", hazards and "industrial" hazards. The list here includes explosions, sea spills, chemical spills, transport accidents, provoked fires, terrorist events, etc.

Computational methods have been occasionally used to study the effect of hazards on constructions and/or people. The name forensic computational engineering has been given to studies aiming to explaining the effects of an hazard "a posteriori" using computational methods.

The undesirable exponential growth in all types of hazards in the world has motivated the need for research in new ways of evaluating "ex ante" the risk induced by a specific hazard, its effects on constructions and on human lives and the alternative procedures for mitigating them. A number of Governmental Agencies in the world have included in their programmes the development of new mathematical models and numerical methods helping risk assessment and management for a variety of hazards in order to mitigate their consequences on people and infrastructures.

The study of the effect of an hazard on existing constructions requires state-of-the-art computational methods. Indeed, for many cases, such as the study of the vulnerability of structures to floodings, tsunamis or landslides, there is a need for new computational techniques allowing the treatment of complex fluid-soil-structure interactions. Similar difficulties invariably appear in other hazards, such as the study of the action of fires, explosions and earthquakes on constructions, to name just a few.

Computational methods for assessment of the risk induced by natural, industrial and anthropic hazards appears as a new field that encompasses a number of multidisciplinar areas in Computational Mechanics. Clearly, there is a need for a next generation of computational procedures that will help engineers to design new constructions and infrastructures capable of resisting better the impact of specific hazards, thereby helping to protect human lives. The scientific and technical challenges in this field are enormous, but so are the issues at stake.

Hopefully, through cooperative and multidisciplinary research the IACM community will be able to contribute new computational methods and tools helping the future generations to investigate and control the risks in our lives.

Eugenio Oñate
Editor of IACM Expressions

Towards the Integrative Modeling of the Self-Regulated Closed-Loop Cardiovascular System

by
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" .... this kind of integration will contribute in ...making modeling-based diagnoses, therapy and surgical planning more accurate ... "

Introduction and Motivation

Over recent decades we have seen the enormous growth of scientific publications seeking to model the behavior of the human cardiovascular system (CVS). Most of these publications focus their attention on certain aspects of the response of the system. In particular, and using for example, the insight gained in the mechanics of fluids, solids, fluid-structure interaction and multi-scale constitutive behavior, countless of these publications have addressed the modeling and simulation of blood circulation through arteries and veins. Several of these publications represent the behavior of the CVS using lumped models (0D Models). Keeping this approach, but now incorporating the effect of arterial pulse propagation, we encounter publications focused in the use of distributed models (1D Models) in order to simulate the behavior of blood flow circulation in large deformable arteries. More recently, contributions have addressed the problem of coupling 1D Models for arterial circulation with 0D Models for modeling venous circulation, including pulmonary and cardiac circuits. With the increasing accuracy of medical imaging, reconstruction of specific arterial geometry emerged allowing the modeling of local bloodstream behavior (3D Models) in patient-specific arterial districts. Many of these works seek to assist the planning of several medical procedures and the understanding of the genesis and evolution of various diseases of the CVS (for example the evolution of aneurysms up to rupture, cardiac disorders, plaque deposition, among others). In general in those publications the results are obtained with the use of a stronger or weaker degree of coupling with global (systemic) hemodynamics. In fact, several of these publications use boundary conditions obtained by invasive procedures in order to set up the cardiovascular scenarios of interest, and hence only valid for those situations. In this regard, these 3D models are rarely coupled with a 1D - 0D model of the cardiovascular system seen as a closed circuit and, therefore, can not provide the sensitivity of the local response to changes occurring at other sites of the CVS such as insufficiency and/or stenosis of heart valves and or situations of rest or moderate exercise.

It is interesting to mention that, more recently, several publications have raised the need for new models capable of (i) incorporating the behavior of other parts of the human body at different time and geometric scales so as to describe the genesis and development of several diseases and (ii) integrating the CVS with the behavior of others systems such as respiratory and central nervous system, among others. In this context, it is appropriate to point out the great number of publications related to the modeling of several control mechanisms which mediate the pressure in order to maintain adequate blood flow to any part of the human body. However, we notice that most of these publications are working on models of the CVS seen as a closed loop but characterized by a reduced number of lumped components.

Based on this quick overview of the sequence of events in the modeling of the CVS, it is evident that over the years such models have become more sophisticated allowing for a better understanding of the complex interactions taking place in the CVS. However, as said before, it is clear also the necessity of a new class of models capable to integrate not only all these advances [8, 13] but also allowing the interaction between the CVS and systems such as autonomous nervous, respiratory, digestive, endocrine and lymphatic [9], which influence in a significant manner the behavior of the CVS under normal or altered conditions due to diseases or human intervention. In this context, we are convinced that models with this level of integration will

contribute in the near future making modeling-based diagnoses, therapy and surgical planning more accurate and appropriate.

The above motivation led the LNCC/MCT (Petrópolis, Brazil) to start in 1998 its activities of R&D in this field, creating in 2005, in conjunction with the Brazilian government, support for the HeMoLab Laboratory. In turn, this institution has coordinated and headquartered the National Institute of Science and Technology in Medicine Assisted by Scientific Computing (INCT-MACC) since the end of 2008. Over these years the HeMoLab Laboratory developed a system [7], (see http://hemolab.lncc.br), that currently consists of a set of tools to set up, simulate and analyze a closed loop dimensionally-heterogeneous (0D-1D-3D) model accounting for arterial pressure pulse propagation, arterial-venous-cardiac-pulmonary levels of circulation and local blood flow in 3D domains obtained from patient-specific medical image data. Particularly, and as shown below, the (i) venous circulation together with the pulmonary circulation, the functioning of the heart chambers (modeled using elastance models) and valves (which are modeled taking into account the inertia of the fluid, vortex formation and the ability to represent insufficiency or stenosis diseases) are incorporated with 0D Models; (ii) the larger arteries are approximated through 1D models and (iii) specific arterial districts are approximated with 3D models whose geometries are obtained from medical images of a given patient using computational tools already incorporated in the HeMoLab System *(Figure 1)*. Furthermore, this computational model is integrated with another system that allows us to model and simulate several mechanisms which are relevant in the self-regulation processes of the CVS (*Figure 1* shows a schematic representation of the integration between the cardiovascular model and the baroreflex mechanism). Using this current configuration of the HeMoLab System it is possible to conduct detailed hemodynamic analyses at any part of the arterial tree taking into account all effects provided by the integration of the closed loop and the dimensional heterogeneity of the computational cardiovascular model with the several control mechanisms incorporated in the system. Evidently, this provides adequate descriptive capabilities to reproduce a wide range of physiological and pathophysiological conditions.

A Dimensionally-heterogeneous Closed-loop for the Cardiovascular System

In the context of modeling the hemodynamic aspects of the cardiovascular system, we identify the following levels of detail (also called levels of integration): (i) the hemodynamics of large arteries, (ii) the local circulation in specific vessels, (iii) the peripheral circulation, (iv) the venous circulation and (v) the cardiac/pulmonary circulation. Such levels of circulation sometimes refer to a certain geometrical scale (for instance the blood flow in large arteries, or in specific districts), and sometimes refer to a given vascular entity (the heart, or a given peripheral bed). In addition, we identify two different time scales, referred to as (i) the heart beat-scale and (ii) the baroreflex-scale.

In the context introduced in the previous paragraphs, our work goes in the direction of developing a computational model of the entire cardiovascular system borrowing the most important features of the different models available in the literature. Thus, the model available in the HeMoLab System is endowed with very large descriptive and predictive capabilities. Indeed, it allows to account for specific vessels, systemic arteries, peripheral circulation, systemic veins, pulmonary and heart circulation and complex valve functioning (see *Figure 1*).

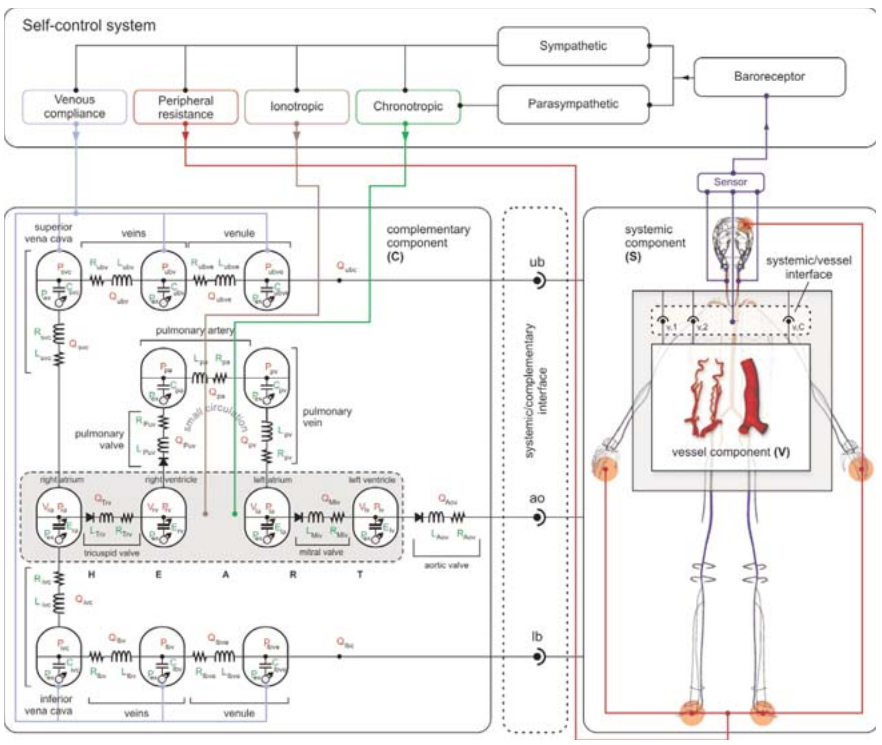

Figure 1: *A dimensionally-heterogeneous closed-loop of the cardiovascular system (HeMoLab System) integrated with the baroreflex control mechanism*

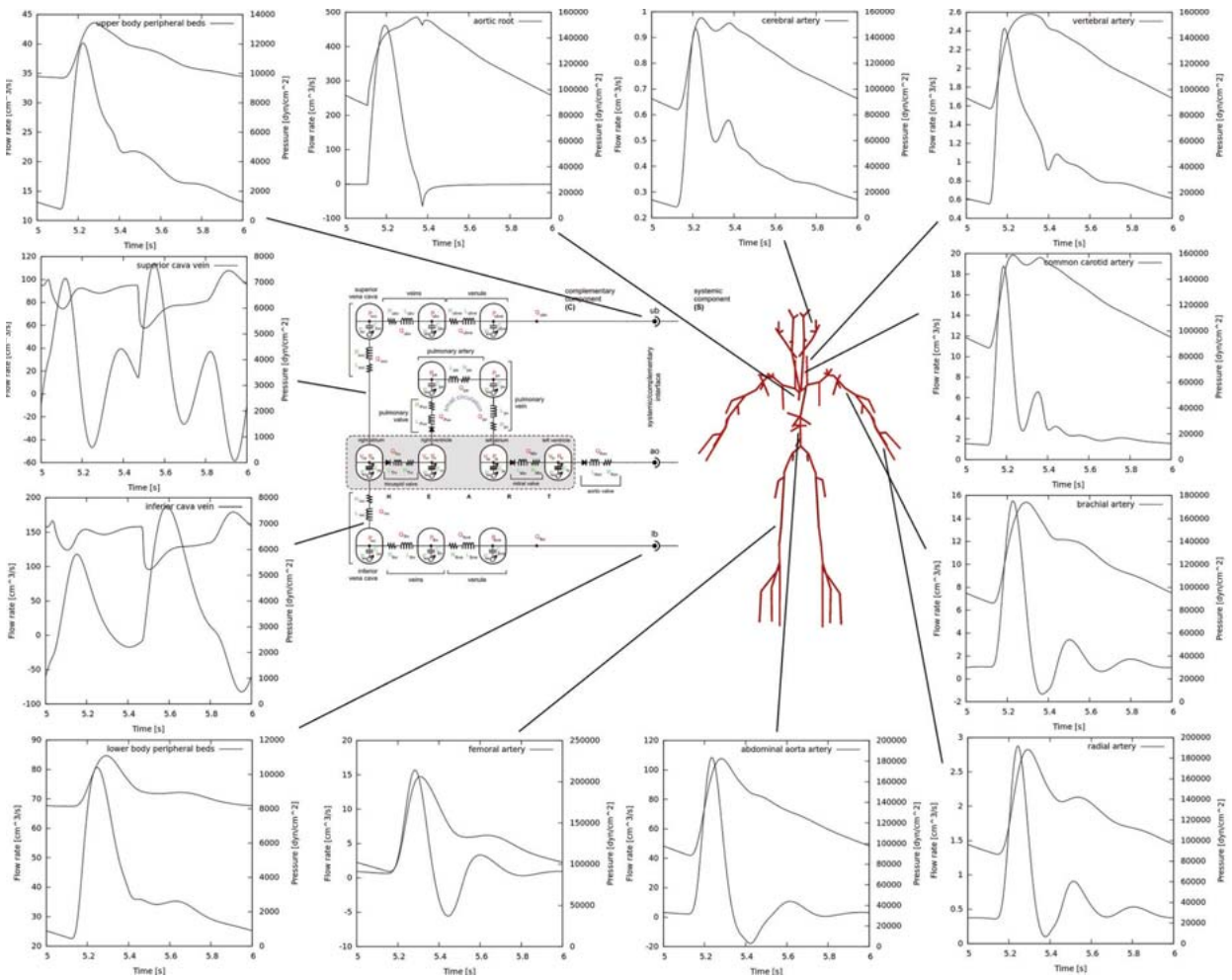

Figure 2: *Flow rate and pressure records at several locations of the cardiovascular system*

Rather than multiscale modeling of the cardiovascular system in this case we refer to it as integrative modeling of the cardiovascular system. In the present approach and following [1], the arterial tree is described by a 1D model with 128 arterial segments (we are in the calibration process of a more detailed arterial tree containing about 600 arterial districts), in order to simulate the propagation phenomena in the larger arterial vessels. The inflow and outflow locations of this 1D Model are coupled with proper lumped parameter descriptions (0D Model) of the remainder part of the circulatory system, closing the network. Following Stergiopulos and collaborators [15], at each outflow point we incorporate the peripheral circulation in arterioles and capillaries by using 0D three-component Windkessel models. In addition, and following the ideas proposed in [11], the whole peripheral circulation converges to the venous system through the upper and lower parts of the body. These two main compartments are represented using lumped models for the venules, veins and cavas (inferior and superior). The right and left heart circulations, as well as the pulmonary circulation, are also modeled by means of 0D models. Particularly, inspired in a model proposed by Korakianitis and Shi [10], we point out the modeling of the four heart valves which is carried out by using a non-linear model that allows to consider different degrees of valve stenosis and or regurgitation (insufficiency). Finally, the 0D model of the left ventricle is coupled with the inflow boundary in the 1D model, closing the cardiovascular loop. The entire 0D model which performs the coupling between the outflow and inflow points in the arterial tree consists of 14 compartments. Finally, following [2-4], the HeMoLab System allows the incorporation of 3D models automatically fed with appropriate (natural) coupling conditions at the coupling interfaces with the corresponding 1D model.

Using this kind of system it is possible to retrieve the pressure and flow rate in any location of the system *(Figure 2)*. Moreover, it allows to analyze the sensitivity of the solution in a local part of the system (for example a 3D patient-specific arterial district) due to changes in the behavior in another part of the system (for example at a global scale). In this direction, for a patient-specific cerebral

aneurysm and for different degrees of aortic valve insufficiency, *Figure 3* gives the pressure and flow rates at the proximal and distal section of the aneurysm. *Figures 4* and *5* show the comparisons between hemodynamic factors such as WSS (wall shear stress index) and OSI (oscillatory shear index), respectively. Recall that these results were obtained without considering the presence of the short-term regulation mechanisms.

Working with this kind of platform and tools it is easy to increase the level of detail of the arterial network. In fact and as mentioned before, we are in the calibration process of a detailed arterial tree containing about 600 arterial districts. *Figure 6* shows a detailed arterial network for the arm incorporated to the HeMoLab System. The same figure features the flow rates at several locations of the vascular network.

Self-regulated Closed-loop Cardiovascular System

As mentioned before, following several authors [5, 6, 12-14, 16], we adapt and implement in the HeMoLab System the following auto-regulation mechanisms of the cardiovascular system: baroreflex (blood pressure control by sensing pressure in the systemic network), cardiopulmonary (blood pressure control by sensing pressure in the pulmonary circulation), chemoreflex (control of O2 and CO2 concentration) and blood flow local control mechanisms. *Figure 1* gives a

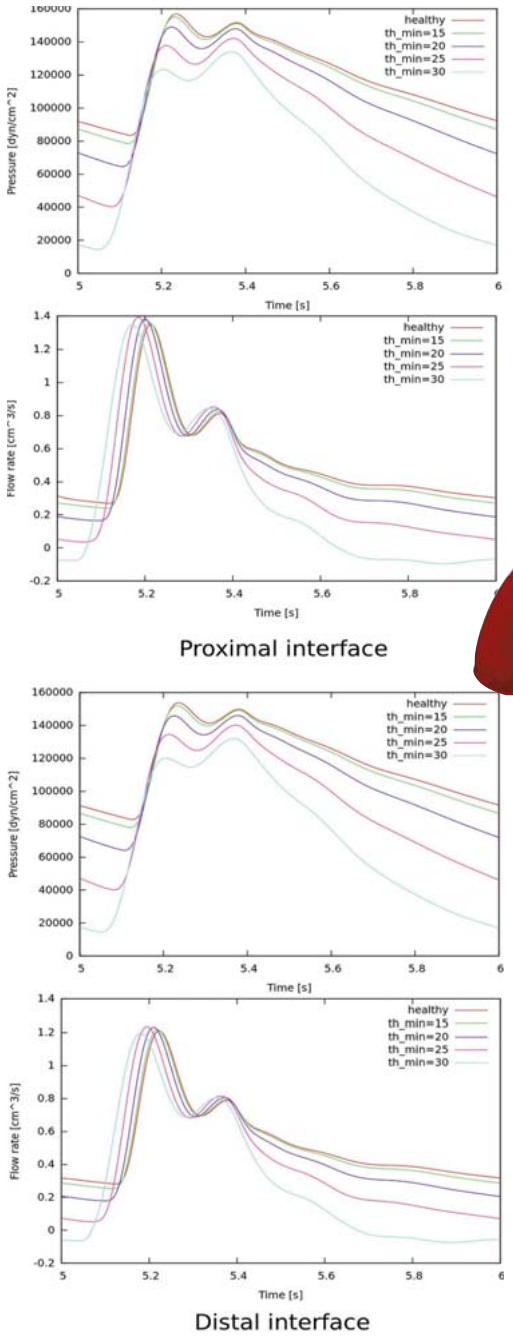

Figure 3:
Sensitivity of flow rate and pressure at proximal and distal section of a patient-specific cerebral aneurysm due to several degrees of aortic valve insufficiency

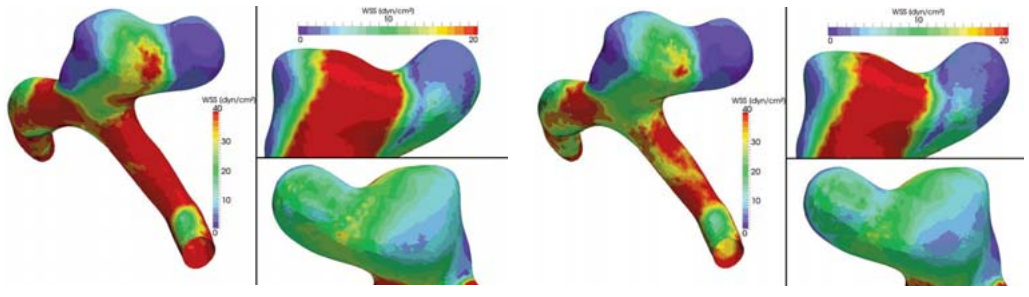

Figure 4:
WSS (wall shear stress index) at specific-patient cerebral aneurysm for healthy and insufficiency aortic valve characterized by a minimum open angle θ*=25*

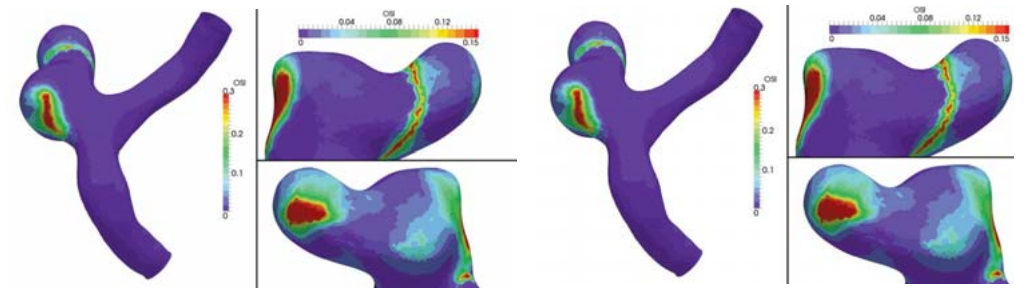

Figure 5:
OSI (oscillatory shear stress index) at specific-patient cerebral aneurysm for healthy and insufficiency aortic valve characterized by a minimum open angle θ*=25*

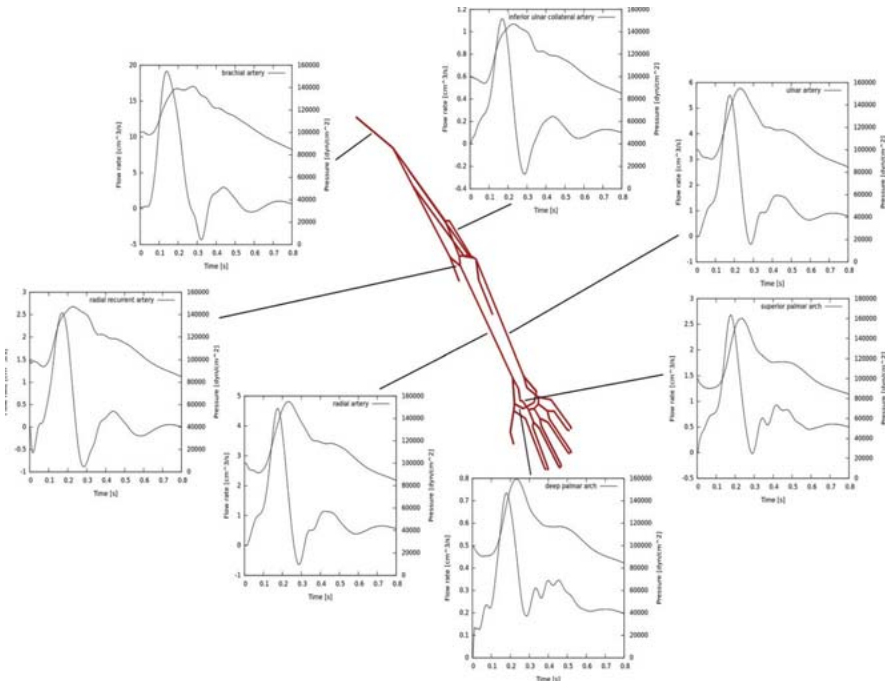

Figure 6:
Pressure and flow rate curves at several points in a detailed arterial network of the arm already incorporated in the HeMoLab System

representation of the baroreflex mechanism integrated in the HeMoLab System. In particular, the afferent part of the baroreflex depends upon the blood pressure measured at the aortic arch and at both carotid sinus independent of the fact that these arterial districts could be modeled using 1D or 3D models. The efferent pathways for these stimuli provoke changes on heart rate, cardiac contractility in the four chambers, venous compliances and peripheral arterial resistances (in the actual configuration of the HeMoLab System this implies changes in the arterioles and capillaries resistances of 55 Windkessel terminals). Figure 7 allows the comparison on the heart frequency, maximum elastance of the left ventricle, blood flow rate and pressure at different locations of the CVS when none, moderate and acute hemorrhage during 10 sec. is considered at the abdominal aorta artery and just the baroreflex control is activated.

Hence, this tool makes it possible to analyze the differences in the behavior of the CVS when the baroreflex mechanism is considered or disregarded. For example, *Figure 8* shows the blood pressure and blood flow rate at the common carotid artery in the case of the above acute hemorrhage. Notice the shorter cardiac period and the larger amplitude in the oscillations of the flow rate, which yield a different local blood flow behavior.

In the same manner, consider the case of an insufficiency aortic valve characterized by a minimum opening angle θ=30 and a patient-specific cerebral aneurism as shown in *Figures 3 – 5*. For this case

Figure 7:
Cardiovascular behavior for none, moderate and acute hemorrhage during 10 sec. at the abdominal aorta artery

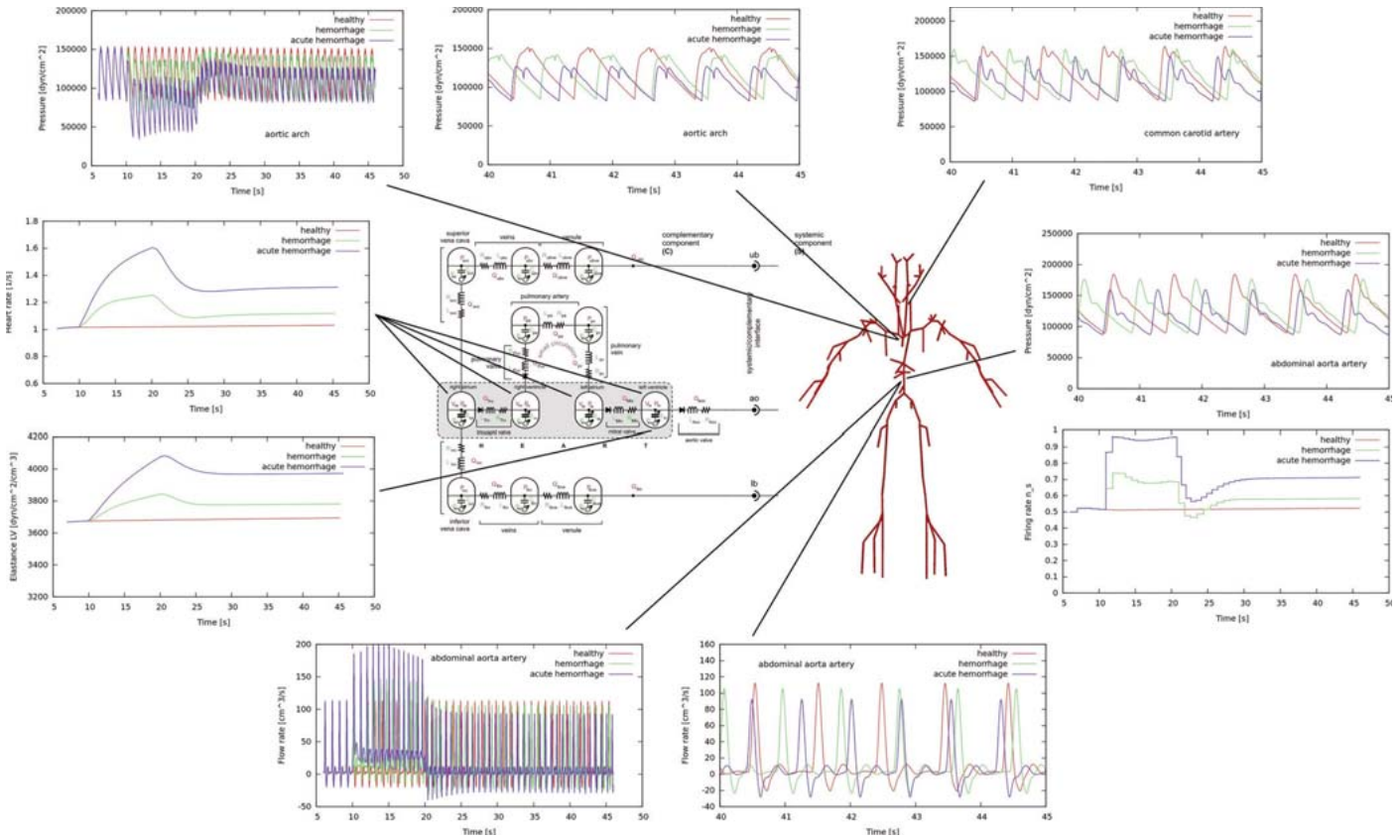

Figure 9 displays the pressure and the flow rate at the proximal section of the aneurism when the baroreflex control mechanism is activated and deactivated. Moreover, it is interesting to observe the difference in the behavior of the WSS index at the cerebral aneurism which is shown in *Figure 10*. The WSS index tends to increase when the baroreflex control mechanism is considered.

The question that shows up here is whether control mechanisms are capable of modifying the local hemodynamics environment or not, in such a way that stable hemodynamics conditions for a given aneurism turn into unstable conditions, after their action. Indeed, from *Figures 8 - 10* it can be noted that the local hemodynamics changes substantially as a result of changes in the underlying global hemodynamic quantities. We believe that this question should motivate further research in this field.

Final Considerations

The use of platforms like the HeMoLab System, in which dimensionally-hetero-geneous closed loop representations for the cardiovascular system are employed, offers a justified approach for performing numerical simulations involving the inter-play of different global and local phe-nomena. In fact, it is worthwhile to highlight the following advantages in the use of this kind of platforms

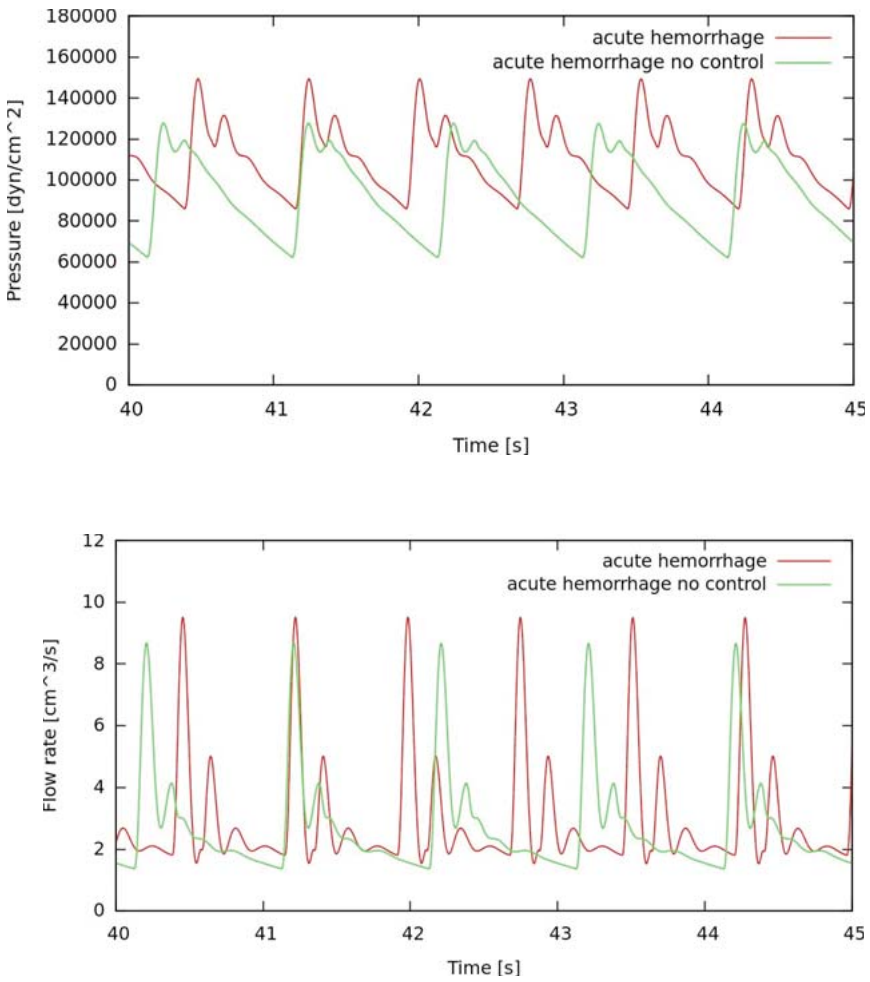

Figure 8:
Regulated and non-regulated blood pressure (top) and blood flow rate (bottom) at common carotid artery in the case of acute hemorrhage during 10 sec. at the abdominal aorta artery

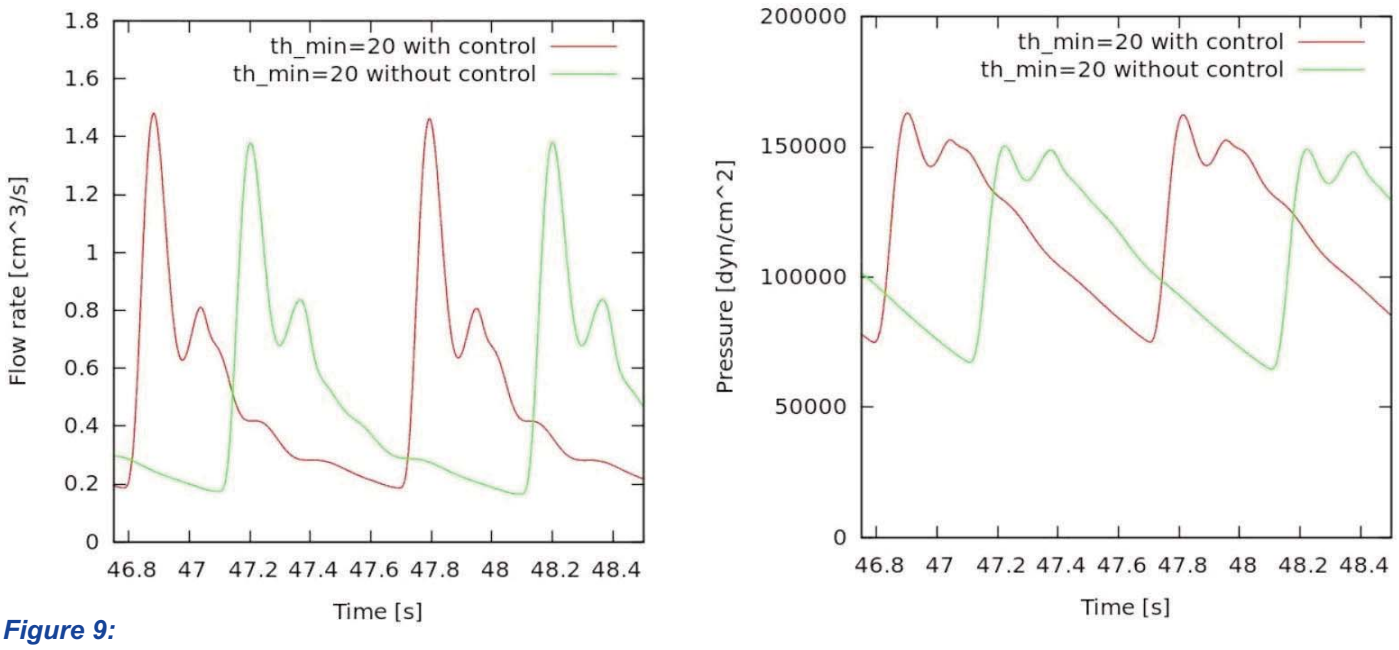

Figure 9:
Controlled and non-controlled blood pressure (right) and blood flow rate (left) at the proximal section of the patient-specific cerebral aneurism when an insufficiency aortic valve characterized by a minimum opening angle θ*=30 is considered.*

- more and more arterial districts can be easily incorporated using 0D-1D Models;
- such topological refinement allows the possibility to substitute any specific district with a detailed 3D Model obtained from patient-specific medical images. What is more, the boundary conditions to be applied to the 3D Model are natural boundary conditions given automatically during the dimensionally-heterogeneous coupling process;
- finally, there is no difficulty to incorporate (integrate) others systems intimately related with diverse factors controlling the behavior of the normal (or abnormal) functionality of the cardiovascular system.

All these potentialities allow the possibility to perform computational simulations of the CVS with acceptable accuracy ranging a wider set of physiological and pathological conditions, and furnishing a further contribution to the improvement of diagnoses, therapy and surgical planning. ●

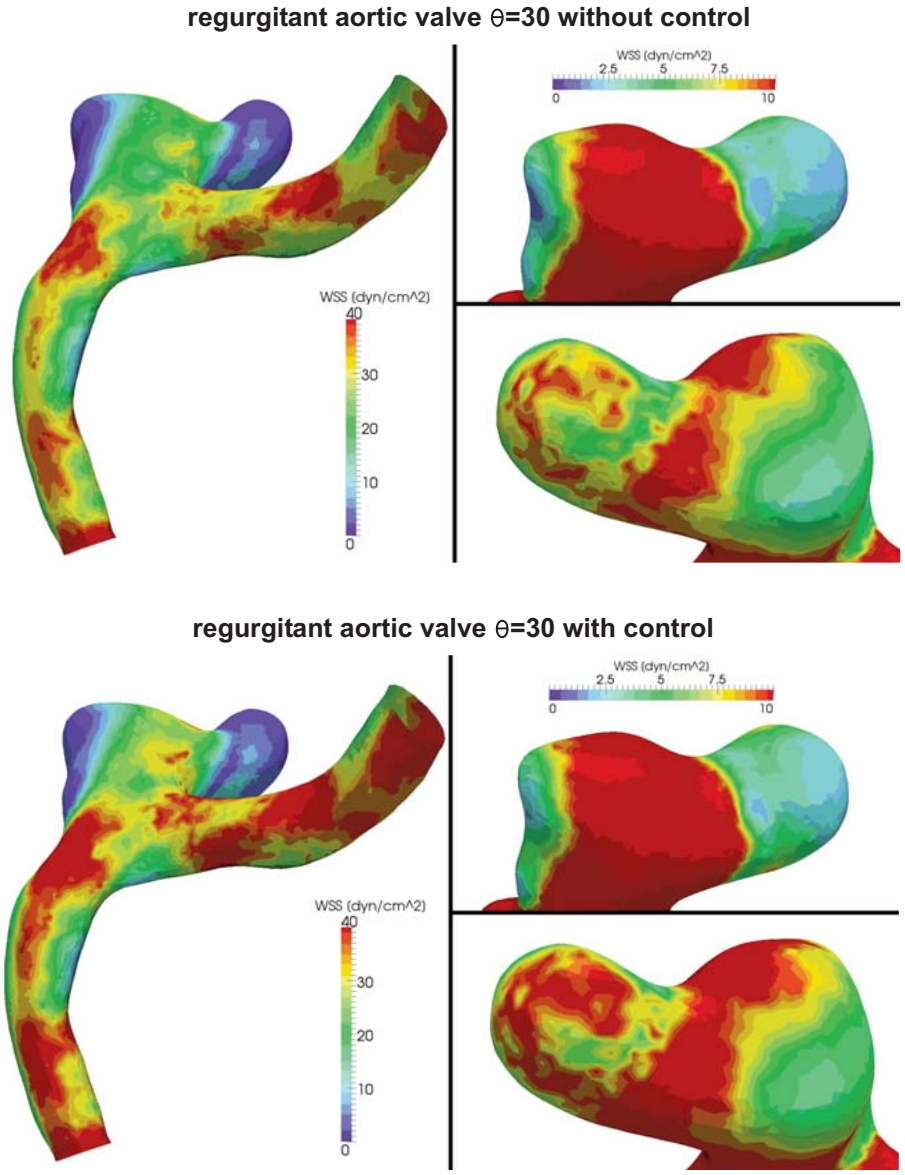

Figure 10:
Controlled and non-controlled WSS index at the patient-specific cerebral aneurism when an insufficiency aortic valve characterized by a minimum opening angle θ=30 is considered

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High Quality Mesh Deformation Method for Large Scale Unstructured Hybrid Grid

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In solving unsteady flow problems involving moving boundaries caused by geometric deformation or relative motion of multiple bodies, dynamic grid or moving mesh is one of the key techniques, especially for simulations in some aeronautical applications. Both surface and volume mesh in the flow field need to be updated at each time step of the solution process. For large scale fluid-structure system, millions or even more mesh elements are usually involved; therefore it is very important to develop an efficient and high quality moving or dynamic grid technique, which can maintain the primary grid qualities as far as possible at each time step or each design change.

Due to the efficiency, mesh deformation approach is one of the most desirable categories of the dynamic grid method. The widely used mesh deformation methods include spring analogy [1-5] and elastic solid based methods [6-9]. Both of them require solution of the static equilibrium equations to determine the new locations of the grid points at each time step, and suffer the limitation of large deformation. For its efficiency, the algebraic grid deformation technique attracts much attention. Liu and Qin et al. [10-12] proposed a simple and efficient method for dynamic grid deformation based on Delaunay graph mapping of the original mesh. This algebraic approach is simple, efficient and no iteration is needed. It works for arbitrary mesh type and is able to handle multiple bodies in relative motion. However, intersection or illegal elements occur occasionally in the background Delaunay graph for complex geometries with large relative movements. Allen [13] also developed an algebraic approach to mesh motion. However, the construction of motion connection between grid point and its connection points is local in sense of interpolation. This is likely to cause non-smoothing transition of deformation and may decrease the quality of deformed mesh.

In this paper we focus on the methodology and algorithm for efficient and quality mesh deformation for large scale unstructured grid, which is widely used in discretized numerical models. To preserve the quality of mesh, this paper presents a high quality mesh deformation approach with the aid of barycentric coordinates, which are commonly used in computer graphics and geometric modeling. This non-iterative algebraic approach is efficient, easy to implement, and works for any type of mesh. Since the interpolation of barycentric coordinates is global, the transition of deformation for the grid is relatively smooth. Thus maintaining the primary qualities of the grid is expected. Testing results show that the proposed approach can preserve grid quality in original grid even for relatively large deformation cases.

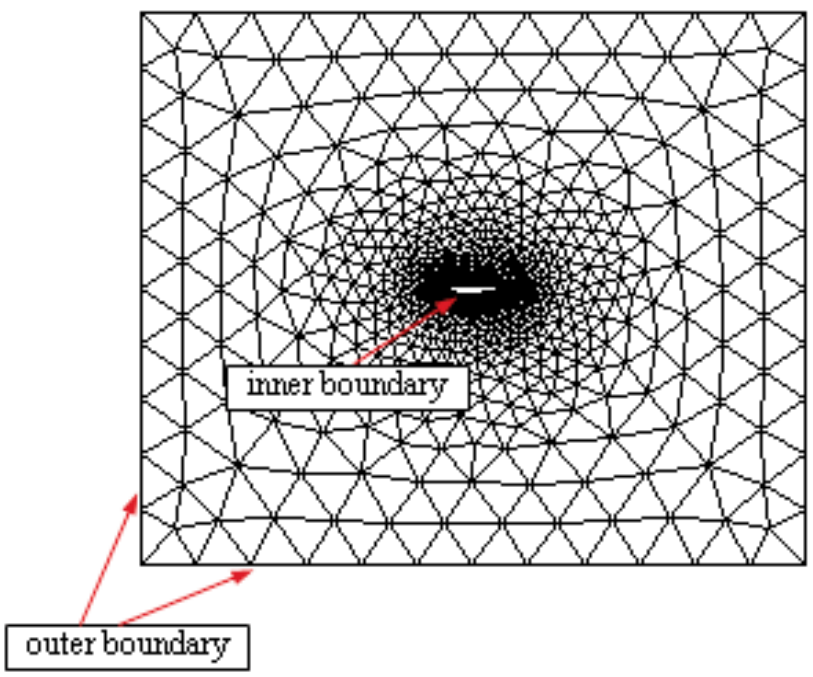


Figure 1:
Outer and inner boundaries for hybrid grid around an aerofoil

Barycentric coordinates

Barycentric coordinates are extremely useful in computer graphics applications. Since they allow inferring continuous data over a domain from discrete or continuous values on the boundary of the domain, barycentric coordinates are commonly used in a wide range of applications of shading, interpolation, parameterization, and space deformations.

"It is easy to implement and applicable to any grid type ... since the interpolation of barycentric coordinates is global, the transition of deformation in computational domain is relatively smooth."

Barycentric coordinates for triangles are area coordinates, which are well-known in finite element method. They provide a convenient way to linearly interpolate data that is given at the corners of a triangle. The concept of barycentric coordinates can be extended in several ways to convex polygons with more than three vertices. One is the mean value coordinates [14, 15], which is well-defined and applicable for arbitrary planar polygons. Due to the Lagrange property of mean value coordinates, the interpolation of data that is given at the vertices of a set of polygons can be done directly and efficiently, without solving a linear system.

Mean value coordinates have a number of important properties, such as well-defined everywhere, smoothness, linear independence, and refinability. Also they enable a very efficient and robust implementation.

Basic mesh deformation approach
In numerical simulation of fluid-structure interaction problems, for example, aeroelastic analysis of aerofoil, the computational domain is usually defined by fixed outer boundaries and inner boundaries which can deform or move (see 2D illustration in *Fig. 1*).

The deforming geometries necessitate dynamically updating the computational grid to cover the changed domain. The grid deformation needs to calculate the displacement of each grid point according to the motion of boundary points. For a two-dimensional computational grid, the geometrical boundaries can be described by a set of nested polygons, and for three-dimensional, a set of nested polyhedrons. With the aid of barycentric coordinates, a novel approach for grid deformation [16, 17] is presented as follows.

The deformation procedure is divided into the following steps:

1) Search for points on each boundary and re-order them anticlockwise;
2) For each grid point in computational domain, evaluate its barycentric coordinates for each boundary;
3) Interpolate displacement of each grid point according to the motion of boundary points;
4) Calculate new location for each grid point;
5) Check illegality of the deformed grid. (If found, reduce the motion of boundary points and return to step 3).

The presented approach is algebraic, non-iterative, easy to implement, and applicable to any grid type. More important, since the interpolation of barycentric coordinates is global, the transition of deformation in computational domain is relatively smooth. Thus maintaining the primary qualities of the grid is expected.

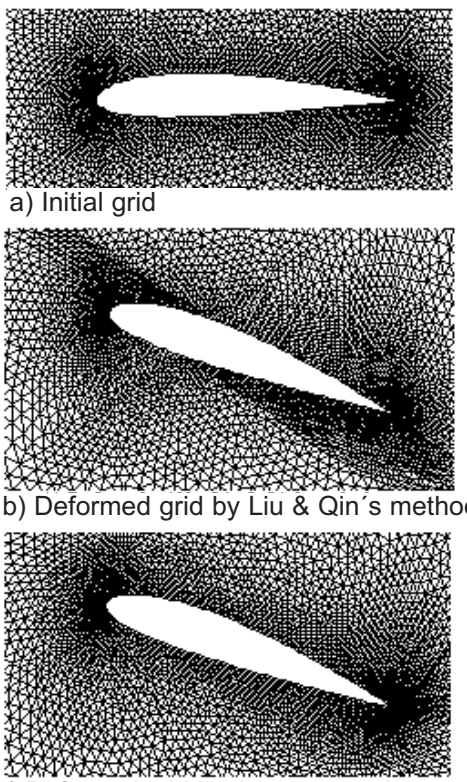
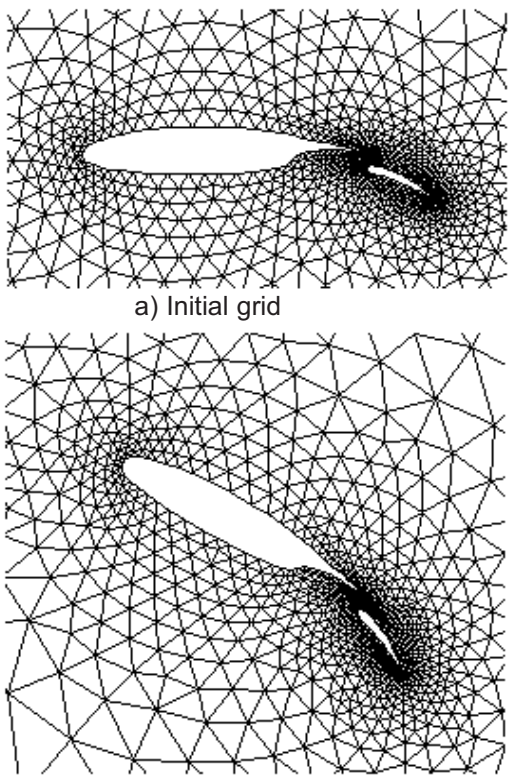


Figure 2:
Grid around a single wing

Figure 3:
Moving grid around two-body under rotation



The proposed grid deformation approach is tested by a number of examples to illustrate its effectiveness, including rotation/deformation of a single wing and multi-body relative motion. The first example in is rotation of a single wing. The deformed grids given by Liu and Qin's method [10-12] and the presented approach are shown in *Fig. 2b*) and *Fig. 2c*). Obviously, the presented approach achieves much higher quality for deformed mesh. *Fig. 3* and *Fig. 4* demonstrate deformed grid around two-body by the presented approach under rotation and relative motion, respectively. Deformation of hybrid grid around a single wing under rotation is illustrated in *Fig. 5*. All results show that the proposed approach can preserve grid quality in original grid even for large motions.

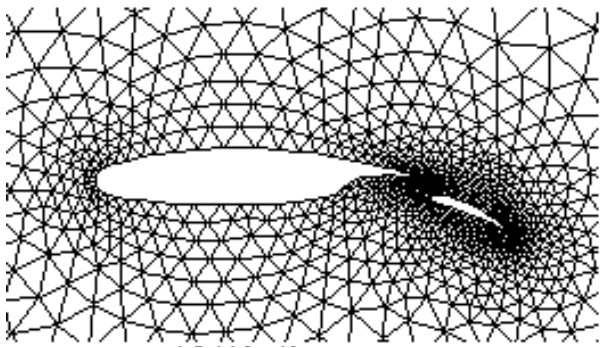
A practical scheme for mesh deformation
A practical moving grid or mesh deformation approach which combines the algebraic moving grid approach based on the barycentric coordinate interpolation and background graph mapping [18, 19] is presented.

The main steps of the proposed approach are summarized as following:

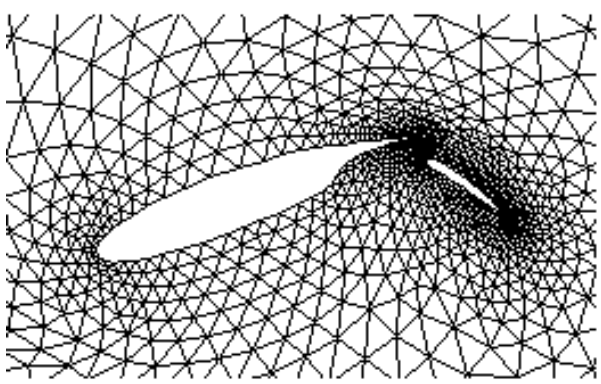
1) Insert the points inside of the deformation area based on the feature of the mesh and deformation;
2) Generate the background mesh using boundary points and the inserted points;
3) Locate the mesh points and calculate the related location parameters;
4) Compute the deformation of the inserted points by using the algebraic method based on the interpolation of barycentric coordinates;
5) Move the background mesh based on the displacements of boundary points and the inserted points;
6) Relocate the mesh points: calculate the new location of the mesh points based on the relative location of the mesh points in old background mesh and deformed background mesh.

The effectiveness of the approach has been illustrated through a number of two - dimensional and three-dimensional examples, including rotation/deformation of a single wing and multi-body relative motion. The test cases show that these desirable grid qualities in the original grid are carried over in the moving meshes. Introducing points inside of the deformation area is helpful for constructing good quality background mesh, which can enhance the deformation capability of the approach and gain good quality for moving mesh. The algebraic method based on the interpolation of barycentric coordinates is able to obtain a more smooth result for movement of inserted points, and thus also improve the quality of moving mesh.

Figure 4:
Grid around 2-body under relative motion

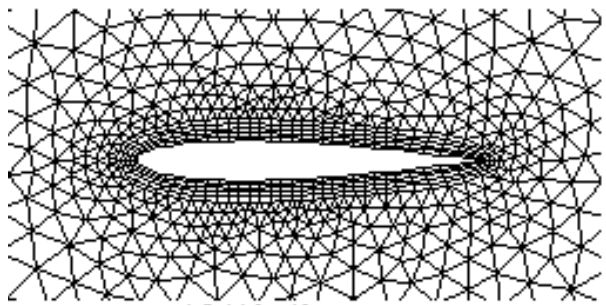


a) Initial grid

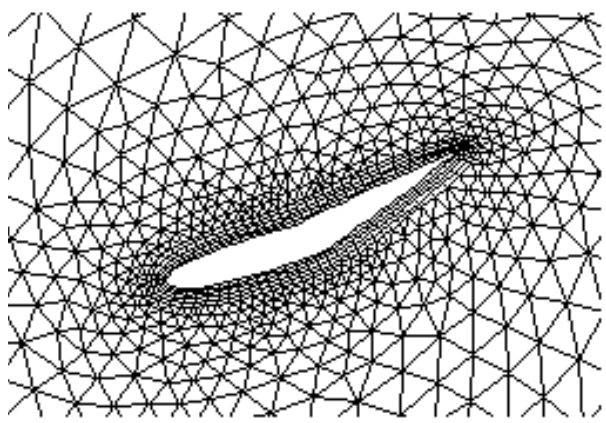


b) Deformed grid by the presented approach

Figure 5:
Hybrid grid



a) Initial grid



b) Deformed grid by the presented approach

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To raise the efficiency and improve the quality of deformed mesh further, two strategies are employed in the presented approach. One is decomposition of the boundary motion, so that small deformation and relatively large rotation components of the motion can be separately treated. The other is setting encapsulation boxes for some local regions of interest (ROI), which undergoes small deformation but large rotation.

Mesh untangling and quality improvement

Although the barycentric coordinate interpolation and introducing points inside of the deformation area are helpful for keeping good quality for moving mesh, the quality of mesh in particular local region is still unsatisfactory when the movement of the boundary is large. Sometimes illegal elements even occur. For such circumstances, we may reduce the motion of boundaries; however, perform extra mesh untangling and quality improvement is a good choice. For our present purposes, simultaneous procedures of smoothing and untangling are preferable, such as the approaches in [20-23]. After the mesh untangling and quality improvement procedure, the invalid elements can be eliminated and the quality of mesh can be further improved.

Conclusions

The suggested method is highly efficient and requires only non-iterative algebraic calculations. It is easy to implement and applicable to any grid type. More important, since the interpolation of barycentric coordinates is global, the transition of deformation in computational domain is relatively smooth. By the extra mesh untangling and improvement, maintaining the primary qualities of the grid is expected. Testing results demonstrate the efficiency and effectiveness of the proposed approach. It is suited for grid deformation in numerical simulation of large fluid-structure interaction problems with moving boundaries. ●

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Addressing Wind Energy Challenges Through Advanced Simulation

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The rising cost and fluctuating prices of oil and natural gas, as well as their constantly diminishing supplies, create the need for cheaper, sustainable alternative energy sources, such as wind. As a result, countries around the world are putting substantial effort into the development of wind energy technologies. Currently in the EU, 50 GW of electricity comes from the on-land and 1 GW from offshore wind turbines. The EU target is to raise the on-land production to 130 GW and offshore to 50 GW by 2020. The latter figure represents a *fifty-fold increase*. In the US, currently 25 GW of electricity comes from wind. The US Department of Energy has recently established the objective that wind power supply 20% of the US energy needs by 2030 [1].

These very ambitious goals put pressure on the wind energy industry research and development to significantly enhance current wind generation capabilities in a relatively short period of time, and simultaneously decrease costs associated with wind energy conversion to electricity. This calls for transformative concepts and designs (e.g., a new generation of floating offshore wind turbines) that must be created and analyzed with high-precision scientific and engineering methods and tools. These include complex-geometry, 3D, time-dependent, multi-physics predictive simulation methods and software that will play an increasingly important role as demands for wind energy grow.

Out in the ocean, the winds are typically stronger and are more sustainable than inland, providing a more reliable source of energy. This in part explains the attraction of offshore designs. However, offshore wind turbines are exposed to harsh environments and must be designed to reliably sustain increased wind loads. Increased wind speeds also imply that the blades of significantly larger diameter must be designed and built for optimal performance. Larger diameter blades also imply that the towers must be longer and larger in diameter, and the foundation must now be able to sustain wave and ocean current loading on the towers, in addition to wind loads. These are significant engineering challenges that must be addressed through advanced research and development that involves large-scale simulation.

Figure 1: *Typical wind turbine designs.* ***Left:*** *Horizontal Axis Wind Turbine (HAWT).* ***Right:*** *Vertical Axis Wind Turbine (VAWT)*

"... to simulate the coupled problem, equations governing the air flow and blade deformation need to be solved simultaneously, with proper kinematic and dynamic conditions coupling the two physical systems."

Wind turbine designs

There are two distinct wind turbine designs: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT) (*see Figure 1*). The difference between the designs is that HAWTs rotate around an axis that is horizontal, and VAWTs rotate around a vertical axis. Currently, HAWTs are a more popular concept, both for small- and large-scale wind turbine designs. They are considered to be more efficient, because the wind impacts the blades at a consistent angle for the entire rotation cycle. They are self- starting and are more easily controlled. However, HAWT designs require tall towers, leading to expensive manufacturing, installation and maintenance. VAWTs do not require high towers and expensive installation, and fit very nicely in close spaces and urban areas. However, because the wind direction relative to the rotating blade is constantly changing, the efficiency of the existing designs suffers and the blades are more prone to fatigue failure. Nevertheless, there is currently an increased interest in VAWTs, mainly due to the advantages listed earlier.

In steady wind HAWTs are subjected to statistically stationary wind loads. The variation in the wind loads comes from wind turbulence generated at the trailing edge of the blades and the blade structural response. However, in the mean, during steady wind operation, the aerodynamic loads on the turbine blades are not changing. This situation enables the application of simple approaches to wind turbine aerodynamics prediction, such as those used in FAST [2]. Given the experienced user, wind torque and thrust data may be obtained with good accuracy for steady, laminar wind conditions. In the case of VAWTs, even in steady wind, the distribution of wind loads on the blades changes rapidly with rotation. As a result, the analysis of VAWTs is likely to require the use of advanced computational technology proposed in this work. The lack of adequate analysis tools may also explain the relatively low popularity of VAWTs and the modest nature of their current designs.

Modeling challenges and current numerical approaches for wind turbines

Simulation of full-scale wind turbines in 3D is challenging for the following reasons. The flow is fully turbulent, requiring highly accurate methods and increased grid resolution. The presence of thin turbulent boundary layers complicates the situation further. Wind turbine blades are long and slender structures, with complex distribution of material properties, for which the numerical approach must have good approximation properties and avoid locking. Wind turbine simulations involve moving and stationary components, and fluid-structure interaction (FSI) coupling must be efficient and robust to preclude divergence of the computations. Data generated by the simulations must be efficiently handled, stored, and post-processed for quantities of engineering interest and visualization.

The Blade Element Momentum (BEM) is the most widely used method in the wind turbine aeroelastic modeling. BEM is implemented in FAST [2], an open source code that is considered to be the "gold standard" in wind turbine blade aeroelastic simulation. FAST is based on look-up tables and provides blade cross-section steady-state lift and drag forces given the airfoil type, relative wind speed, and angle of attack. The lift and drag data comes from experimental databases for different airfoil types. The effects of the hub, trailing edge turbulence, and blade tip are modeled using empirical relationships. Modeling assumptions in FAST preclude simulation of physical phenomena that emanate from the time-dependent and geometrically complex nature of the problem. For this, 3D modeling is essential.

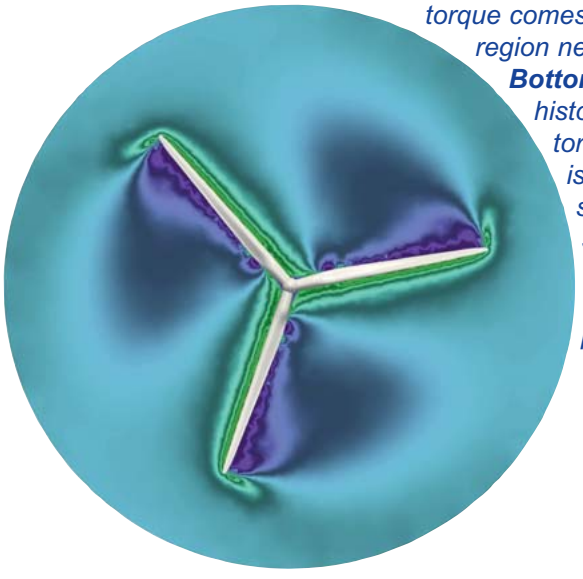
In recent years, standalone 3D fluid mechanics simulations with simplified wind turbine configurations were reported in [3,4], some at reduced scale and some with limitations in terms of the representation of the exact geometry and prediction of the FSI involved. Structural analyses of the individual turbine blades under assumed load conditions or loads obtained from separate computational fluid dynamics simulations were also reported (see, e.g., [5,6]). In this work, we advocate the development and use of advanced simulation procedures for wind turbine configurations. In particular, coupled FSI simulations at full scale are essential for accurate modeling of wind turbines. The motion and deformation of the wind turbine blades depend on the air flow, and the air flow patterns depend on the motion and deformation of the blades. In order to simulate the coupled

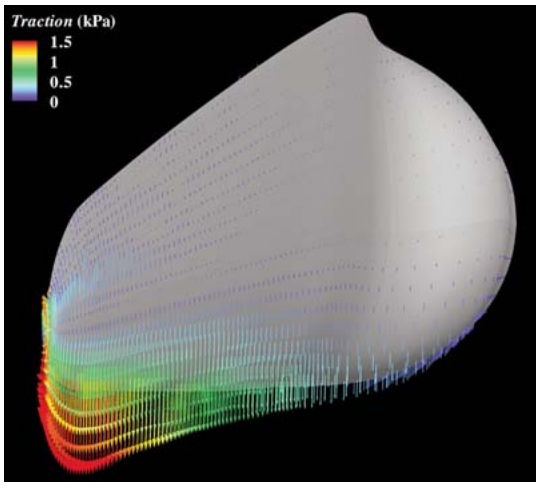
problem, equations governing the air flow and blade deformation need to be solved simultaneously, with proper kinematic and dynamic conditions coupling the two physical systems. Without that the modeling cannot be realistic.

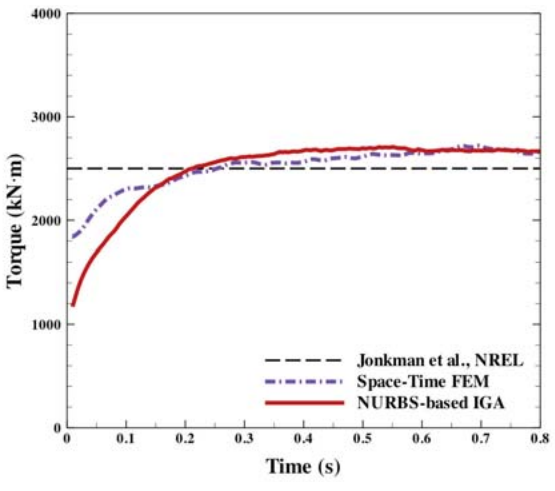
Advancing the state-of-the-art in wind turbine simulation

The first 3D, time-dependent CFD and FSI simulations of wind turbine rotors at full scale and realistic wind conditions were presented in [7-12]. Using a template-based approach, a full-scale Non-Uniform Rational B-Splines (NURBS) model of the NREL 5MW offshore baseline wind turbine rotor was created. The wind turbine blade geometry is defined in [13] with the rotor radius of 63 m. We performed both pure CFD and FSI simulations for realistic wind conditions and rotor speeds. The pure aerodynamics simulations were performed with both NURBS-based Isogeometric Analysis [14-15] and space-time linear FEM. The results of these simulations are summarized in *Figure 2*. The air flow is modeled using the residual- based variational multiscale (RBVMS) formulation of the Navier-Stokes equations [16]. The finite element simulations were performed using a newly-developed multi-scale space-time formulation [17], which is the space-time version of the RBVMS. Very good agreement with NREL results [13] were achieved for the prediction of the aerodynamic torque using both methods. The aerodynamic torque is a key quantity in evaluating how much power a given wind turbine is able to extract from the wind stream. This result is encouraging in that 3D time-dependent simulation with a manageable number of degrees of freedom and without any empiricism is able to predict important quantities of interest for wind turbine rotors simulated at full scale.

Figure 2:
NREL 5MW offshore baseline wind turbine rotor aerodynamics.
Top left: *Isogeometric analysis simulation from [7]. Isosurfaces of air speed, which illustrate the complexity of the turbulence involved. The tip vortex is convected by the ambient airflow with very little decay*
Top right: *Space-Time tetrahedral FEM simulation from [9]. Isocontours of air speed at an axial cut*
Bottom left: *Wind traction vectors on the blade surface (from [7]), projected onto the plane of rotation, point in the direction of rotation and propel the spinning blade forward. Note that the most significant contribution to the aerodynamic torque comes from the blade region near the tip*
Bottom right: *Early time history of aerodynamic torque. Both isogeometric and space-time FEM simulations produce accurate results that match the predictions in [13]*







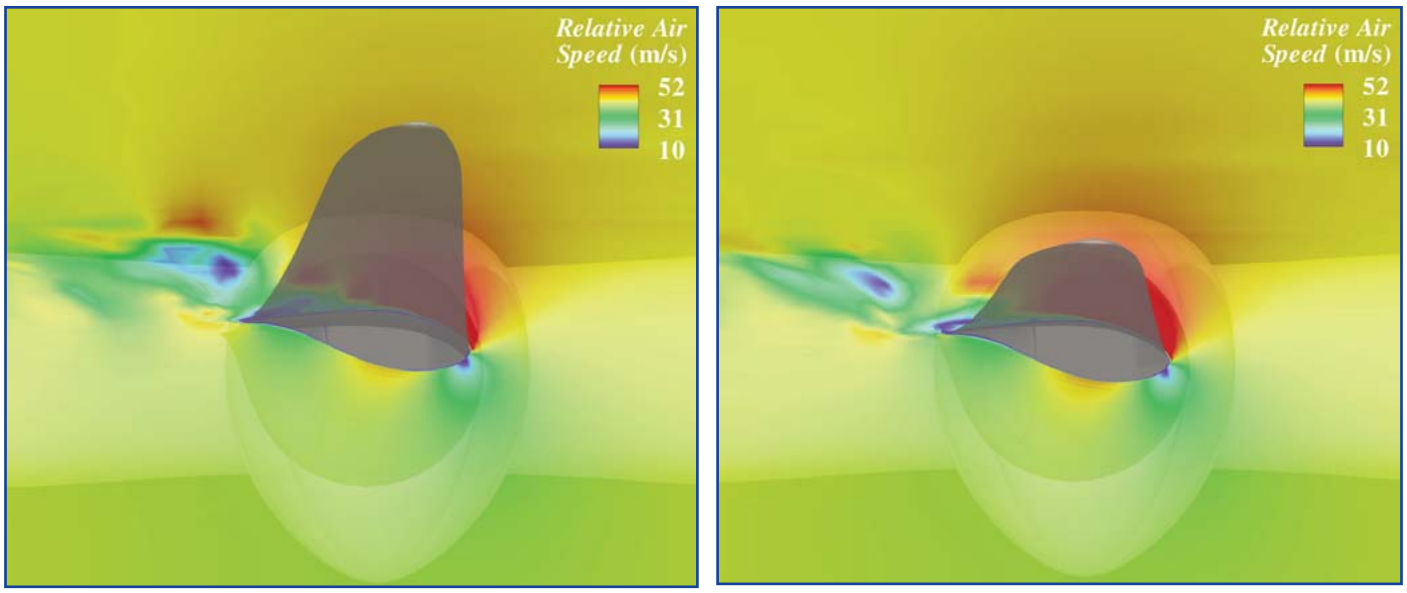


Figure 3:
View of the rotor from the tip of the blade at two time instances during the simulation. Isocontours of the relative fluid speed plotted on the moving fluid mesh. The flow is attached on the pressure side and separates on the suction side of the blade

The FSI cases in [8,12] were computed using the NURBS-based isogeometric discretization only. The structure is governed by the large-deformation rotation-free Kirchhoff-Love shell formulation [18], with the aid of the bending strip method [19]. The blades are modeled as multi-layer composite shells. The fluid and structure are strongly coupled at their interface. The strong coupling is in part facilitated by the fact that the structure has only displacement degrees of freedom. The FSI equations are solved in a strongly coupled fashion, where the increments of the fluid, structure and mesh motion solution are computed every Newton iteration.

Figure 3 shows the rotor from the tip of the blade at two time instances during the simulation. Isocontours of the relative wind speed plotted on the moving fluid mesh at a 30 m radial cut are displayed. Note that the FSI effect is clearly pronounced in this view. The flow is attached on the pressure side and separates on the suction side, creating trailing-edge turbulence. The trailing edge turbulence excites high-frequency torsional modes of the blade, as illustrated in *Figure 4*. Time history of the aerodynamic torque is also shown in *Figure 4* together with the reference steady-state aerodynamic torque result from [9]. Given the significant differences in the computational modeling approaches, the two values are remarkably close.

Remark.
Isogeometric analysis is particularly well suited for wind turbine simulation for the following reasons:

1. *In isogeometric analysis the geometry and solution fields are represented using the same functional description. As a result, integration of wind turbine geometry design and computational analysis is greatly simplified. This unified representation of the geometry and solution fields allows for a simple integration of different software components needed for different stages of modeling and simulation;*
2. *Isogeometric analysis is an inherently higher-order accurate technique. In addition, isogeometric functions are of higher continuity than standard finite elements. Due to these favorable properties, isogeometric analysis was shown to have superior per-degree-of freedom accuracy for wall-bounded turbulent flows and thin structures. As also pointed out in [17], this superior per-degree-of-freedom accuracy has great benefits from the standpoint of efficient utilization of high-performance computing resources;*
3. *Rotating mechanical components, such as wind turbine rotors, are naturally handled in an isogeometric framework due to the ability of the method to exactly and parametrically represent all conic sections and, in particular, circular and cylindrical shapes [20].*

Remark.
The wind turbine aerodynamics is dominated by high rotation rates of the fluid near the curved surfaces of the wind turbine blades. High fluid rotation rates in the presence of curved walls are problematic for turbulence models that are based on eddy viscosities. The RBVMS turbulence modeling methodology builds on the weak form of the Navier-Stokes equations, and the turbulence modeling does not make explicit use of eddy viscosities. This in part explains the good numerical performance of the RBVMS methodology for wind turbine simulation (see [21] for a discussion).

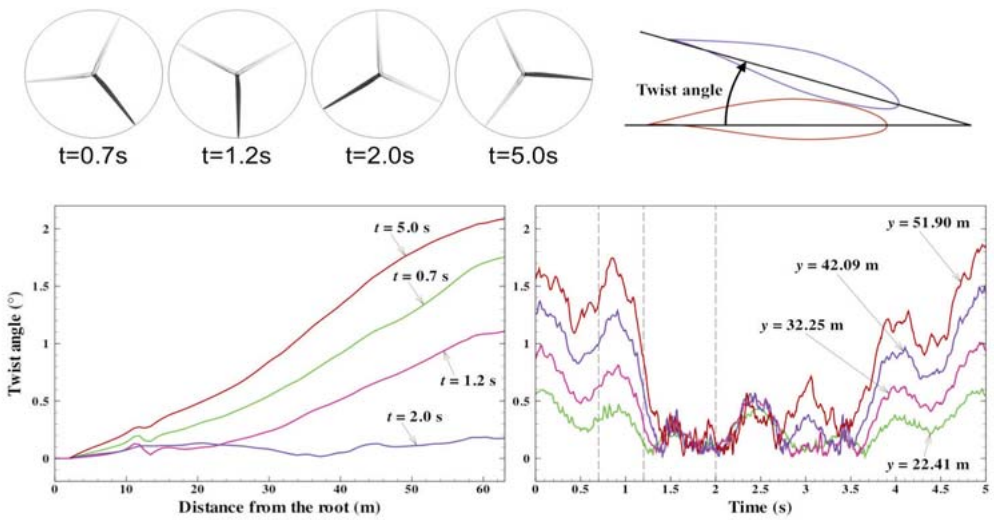


Figure 4:
Top: *Wind turbine blade position at different times in the simulation*
Bottom left: *Time history of the aerodynamic torque. Comparison of the rigid and deformable blade simulations to the results reported in [13]. Note that the deformable blade exhibits high-frequency oscillation in the aerodynamic torque*
Bottom right: *Time history on the twist angle (defined in the top right-hand corner) for airfoil cross-sections at different axial locations. Note the high frequency of the cross-section twisting in response to the forcing due to the trailing-edge turbulence*

Opportunities for wind turbine simulation

Development and application of advanced computational methods to wind turbine simulation is still in its infancy. As a result, many possibilities and directions exist for advanced simulation for wind turbines: 1) Simulation of VAWTs is a fruitful direction due to the renewed interest in this technology (*see Figure 5*); 2) Wind turbines are subjected to turbulent inflow of air, which must me modeled, possibly using stochastic methods. Wind turbulence, which is always present in real situations, is viewed as one of the key factor that determines the aerodynamic efficiency of wind turbines, and thus should be accounted for in the modeling; 3) Influence of the tower on the aerodynamic performance of a wind turbine is likely to be important and needs to be considered; 4) The effect of wind turbine placement relative to other wind turbines on its aerodynamic efficiency is not well understood, and may be studied using advanced numerical methods that are appropriately formulated for this complex setup; 5) The trend toward building wind turbines with larger and larger rotor radii creates a demand for more cost-effective design of tower structures using composite materials [5]. Computational analysis and optimization of such tower structures will likely play an important role in the future; 6) Wind turbines generate audible noise that is unpleasant to animals and humans alike. As a result, wind turbine blade shape optimization to reduce the noise produced by the wind turbine presents an important computational problem.

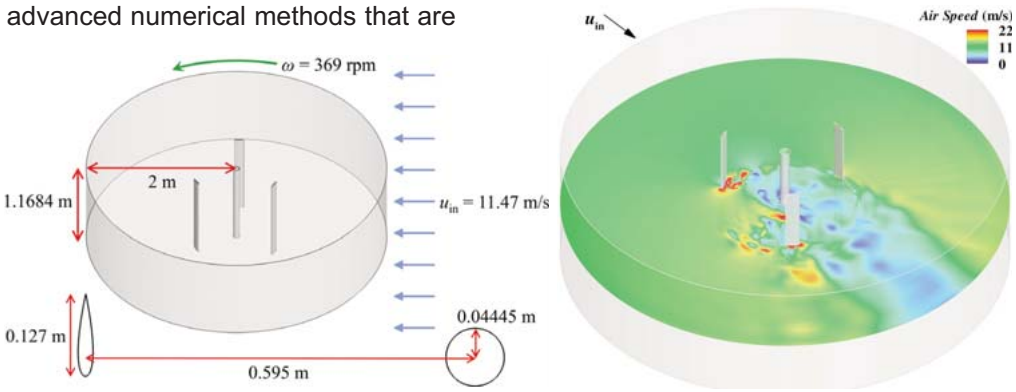


Figure 5:
VAWT model based the Windspire design [22]
Left: *The problem domain and boundary conditions*
Right*: Preliminary simulation using NURBS-based isogeometric analysis from [23]. Isocontours of air speed at an axial cut. Further studies of WAVTs are planned in the future work*

"The trend toward building wind turbines with larger and larger rotor radii creates a demand for more cost-effective design of tower structures using composite materials."

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Isogeometric Analysis: A Path to Higher-Order Explicit Methods

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The automobile crashworthiness simulations used to design today's cars are performed using explicit finite element methods. Typical design calculations use over a million structural elements, and higher resolution calculations frequently exceed ten million elements. Explicit time integration methods are required to efficiently advance the solution in time because small time steps are necessary to accurately simulate the complicated buckling phenomena of the automobile structure and the inflation of the airbags from their initially folded configurations. In addition, the number of elements in the simulations is too large for an implicit solution on the clusters of 32 to 128 cores commonly used in the automobile industry today.

The elements used in these simulations are highly optimized for speed. Uniformly reduced integration, hourglass (zero energy mode) control, and linear basis functions are the norm.

Higher order elements have not been attractive for explicit calculations primarily for three reasons: 1) the stable time step side decreases rapidly with the increase in the polynomial degree, 2) full integration must be used since effective hourglass control is not available for higher order elements, and 3) they are not as robust as linear elements for problems with large deformations.

The stable time step size issue has perhaps been the most pernicious: The stable time step is governed by the largest eigenvalue of the system, and for a fixed number of degrees of freedom, the largest eigenvalue increases rapidly with the degree of the Lagrangian basis functions. This is not true, however, for the basis functions used in isogeometric analysis.

Isogeometric analysis [1,2] generalizes and improves on the finite element analysis in the area of geometric modeling and representation by using the same basis functions for analysis that are used in CAD. The initial development was performed with NURBS (nonuniform rational B-splines), and has expanded to encompass T-Splines [3], LR-Splines, and other basis functions.

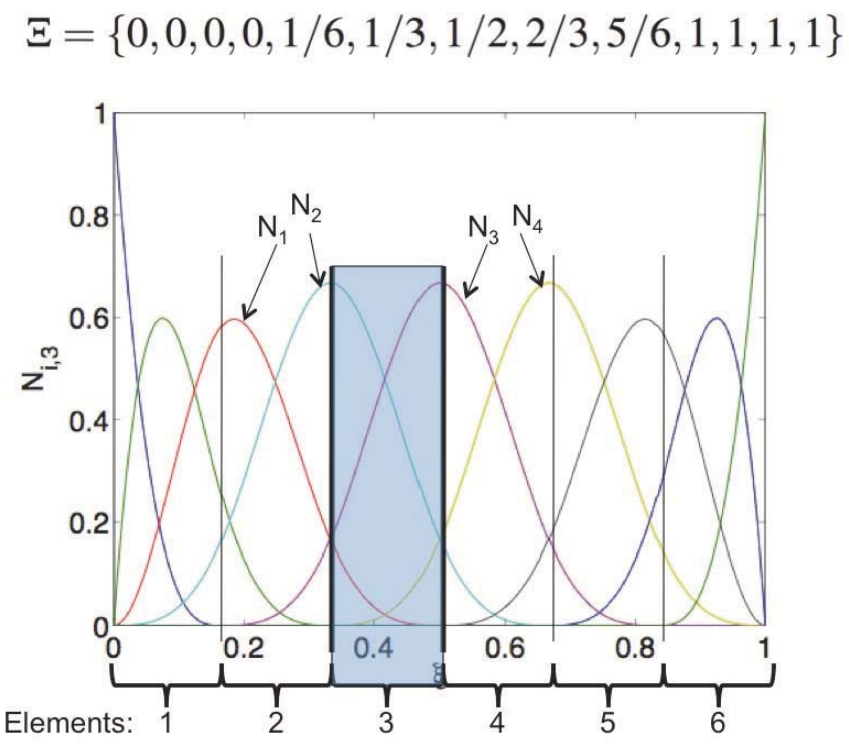


Figure 1: *Cubic NURBS. The four basis functions for the third element are labeled*

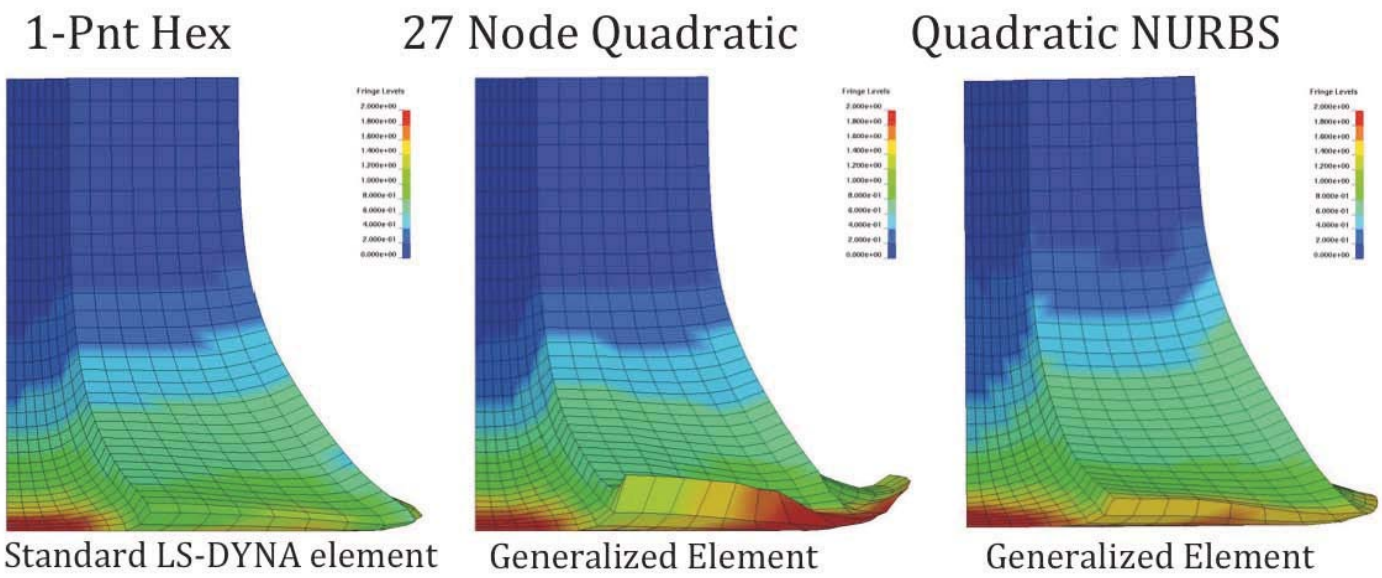


Figure 2: *Comparison of the bar impact problem using a standard 1-point hex, a 27-node solid with quadratic Lagrangian basis functions, and a quadratic NURBS element*

Formulation	# Nodes/ CP	Peak Plastic Strain	# Time Steps
1-Pnt Hex	2677	2.164	2136
Quad. Lagr.	2677	2.346	3370
Quad. NURBS	648	2.479	954

NURBS and B-splines are defined in terms of knot vectors, and provided that the knots are not repeated, have C^{p-1} continuity for degree p splines. An example of cubic basis functions is shown in *Figure 1* on the interval from 0 to 1. They are non-negative everywhere, they are clearly not interpolatory, and the interior basis functions span p + 1 knot intervals. Each successive pair of knots defines an element in one dimension. The number of basis functions in the interval is equal to the number of elements plus the degree. For the example, the number of elements in *Figure 1* is six, the degree is three, and there are nine basis functions. This is in marked contrast to Lagrangian basis functions, where the number of basis functions in one dimension is one plus the number of elements times the degree of the polynomial. Using cubic Lagrangian basis functions on six elements would therefore require nineteen basis functions. The higher continuity of the NURBS effectively adds constraints to the solution, reducing the total number of degrees of freedom.

Based on the early successes of isogeometric analysis, Professor T. J. R. Hughes and the author obtained NSF research funding to investigate the application of isogeometric analysis to metal stamping. A central challenge of metal stamping simulation is to predict the spring back of a stamping once it has been removed from the die and to adjust the geometry of the die to compensate for it. Since the design shape for the stamping is defined by NURBS surfaces, using NURBS for the analysis is a natural approach to eliminating the discretization error due to approximating geometry with linear finite elements. While pursuing the enhanced accuracy, we unexpectedly found increased computational speed and efficiency with NURBS in explicit calculations [4,5,6].

A simple bar impact calculation, illustrated in *Figure 2*, demonstrates the efficiency of explicit isogeometric methods [4]. The first calculation was performed using the standard hex solid element in LS-DYNA with 1-point integration and hourglass control, one of the fastest solid elements available. It required 2,136 time steps to complete the analysis. Using the generalized element formulation [4] in LS-DYNA, the standard 27-node quadratic solid was tested. As expected with higher order Lagrangian elements, it took significantly more time

steps than the linear element, 3370. However, the quadratic isogeometric NURBS element, also tested using the generalized element formulation, obtained essentially the same peak plastic strain in only 954 steps, less than half of the number for the linear hex. The time step size was determined for the linear hex elements with the standard characteristic length calculation in LS-DYNA, which has been shown to be robust and accurate. For the quadratic elements, the maximum eigenvalue of the system was calculated using the optional power iteration strategy available in LS-DYNA to obtain an accurate maximum time step size estimate [7].

Of greater interest than the number of time steps is the computational cost for a given level of accuracy. The standard linear element required 4.6 seconds on a laptop, the quadratic, 10.9, and the NURBS, with full integration, took 9.3 seconds. However, the quadratic NURBS runs stably without any hourglass modes using uniformly reduced integration. If the quadratic NURBS is integrated using just 8 integration points instead of 27, the cost of the calculation drops to 3.9 seconds, significantly less than the cost of the solution using linear basis functions with 1-point integration.

Robustness is difficult to characterize, however all indications are that isogeometric elements are far more robust than their Lagrangian counterparts of the same degree. In a recent investigation using solid elements, Lipton *et al*. found that higher order NURBS were more robust than lower order ones [8]. The square-tube buckling problem, shown in *Figure 3*, has long been a benchmark problem for the robustness of both contact algorithms and shell elements [9]. The result shown here is for quartic (p=4) NURBS [4].

Dr. Stefan Hartmann of Dynamore has compared the cost and accuracy of the isogeometric shells for metal stamping to the standard element formulations with the NUMISHEET benchmark problem [10], shown in Figure 5. The reference solution, obtained by using adaptivity with the type-16 elements in LS-DYNA, took 43.7 hours on a single 2.2 GHz AMD Operton. Using a fixed mesh of 2 mm with the same element formulation took 21 hours. The quadratic isogeometric element, however, with 4 mm elements, took only 14.5 hours for the same level of accuracy. Coarser meshes run faster. However, the elements needed to be 4 mm or smaller to conform to the detailed discretization of the drawbead. All three simulations gave comparable accuracy. Cubic and quartic elements with 4 mm meshes also gave excellent accuracy, but the CPU costs increased to 42 and 111 hours, respectively.

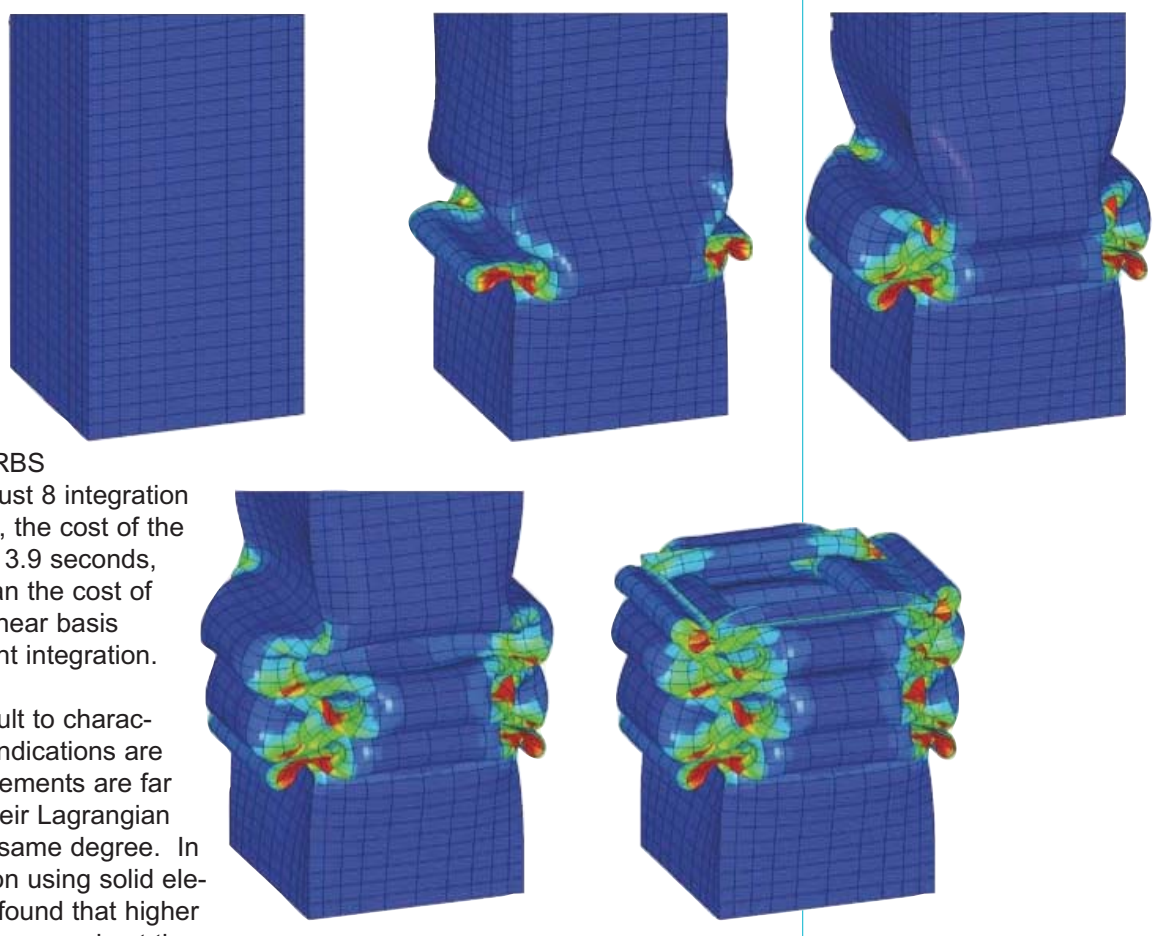
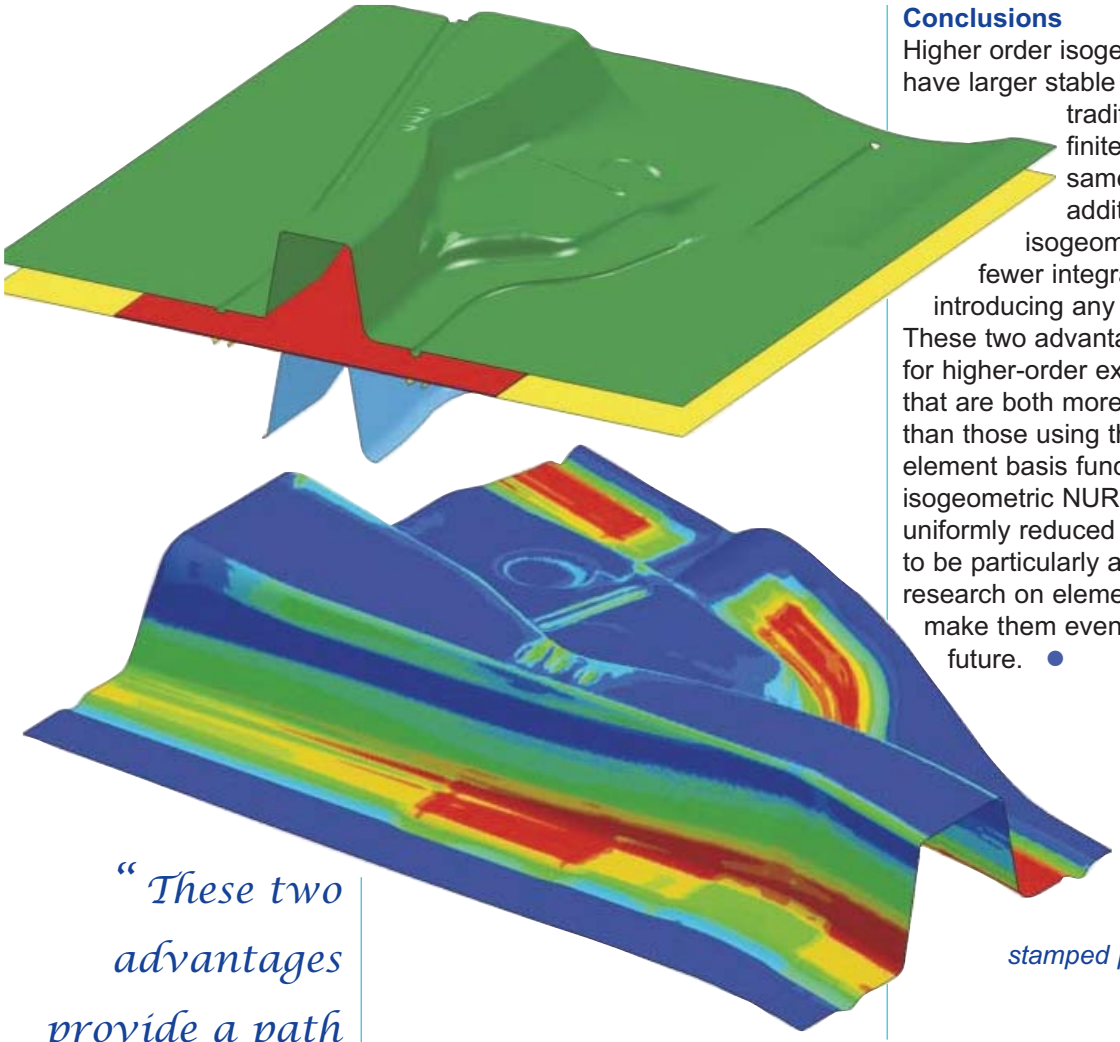


Figure 3:
Sequence of a square tube buckling using quartic (p=4) NURBS elements

All of these results were obtained using sub-optimal integration rules and an implementation that is not highly optimized. Recent research [11] demonstrates that substantial reductions in the number of integration points are feasible, even in comparison to the uniformly reduced integration methods shown here. And, of course, with experience, the isogeometric element implementation will improve in speed.



Conclusions

Higher order isogeometric elements have larger stable time step sizes than traditional higher-order finite elements of the same element size. In addition, the higher-order isogeometric elements permit fewer integration points without introducing any zero energy modes. These two advantages provide a path for higher-order explicit formulations that are both more accurate and efficient than those using the traditional finite element basis functions. The quadratic isogeometric NURBS elements with uniformly reduced integration appear to be particularly attractive. Additional research on element integration may make them even more attractive in the future. ●

Figure 4: *The NUMISHEET benchmark problem. The top figure shows the initial configuration, and the bottom shows the final stamped part. Courtesy of Stefan Hartmann, Dynamore*

" These two advantages provide a path for higher-order explicit formulations that are both more accurate and efficient than those using the traditional finite element basis functions. "

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The Cycle of Ideas in Research, Development and Technology Transfer

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"... policy should put the emphasis on reaching a successful end ..."

When people talk about research, development and technology transfer (RTD in short) and commercial industrial activities, it is quite usual to mix up the objectives, resources and responsibilities. There is a growing opinion, spread by some public administrators and the media, that research groups at universities and RTD centers must be "profitable". In other words, many people would wish that research were funded with competitive funds or even loans (either public or private) and that the outcome of the research got into the market rapidly, so that the profits from marketing the corresponding products would allow research groups to be financially self-sustaining.

It is also usually argued that companies should increase their research activity and invest more resources in finding new discoveries. The humoristic limit of this situation is anticipating that companies would produce Nobel laureates and that a research group would be among the 10 first positions in the ranking of economic organizations in a country. Certainly, both these situations are not impossible, although they are highly improbable. The opposite case is, unfortunately, more frequent, ie. that researchers compelled by their needs to guarantee the financial survival of their groups, abandon or considerably reduce their fundamental research activities, and that companies, confusing a Technical Department with an Innovation Department, consider themselves self-sufficient and underestimate or ignore the contact with the real RTD world.

How the Cycle works

The above concepts can be clarified if we examine what we call the **Cycle of Ideas**. *Figure 1* shows a scheme of the transit of an idea, from the instant it originates until it is transformed in an industrial and commercial success. Similarly, as it happens in other biological environmental cycles (the water cycle or the cycle of plants, for instance), the cadencies and tempos are very important and their perturbation can lead to negative results.

Ideas (and I basically refer here to scientific advances) usually originate in an university environment, where many professionals have the mission of thinking, studying, investigating and eventually discovering new areas of knowledge. The idea (the new discovery) would be equivalent to a seed, in the sense that even being very important (essential) it is far from becoming a fruit.

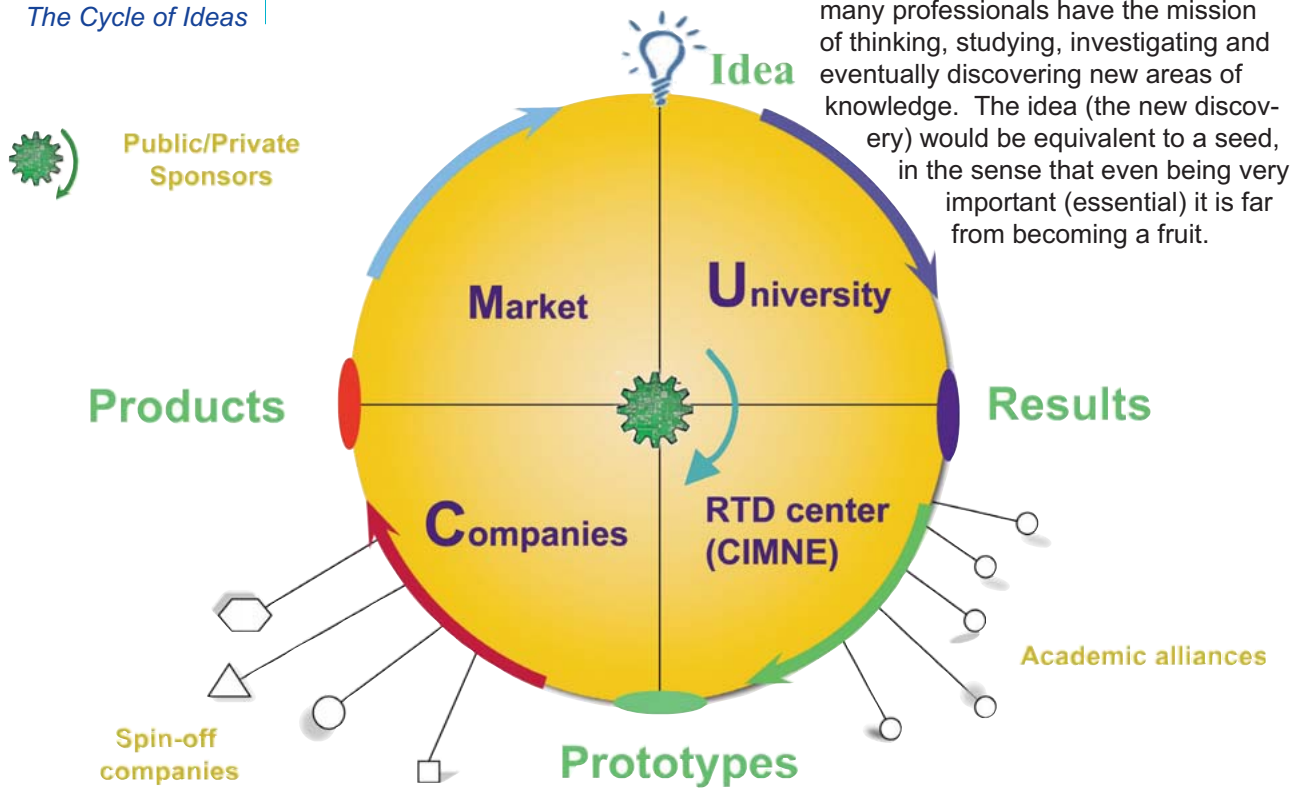

Figure 1: *The Cycle of Ideas*

The idea matures in its "*tour*" by the first quadrant of the Cycle (the University) until it produces tangible results (thesis, papers, computer programs, physical devices, etc.). These "results", if they are not filed and protected, can be easily lost. This could lead to undesirable repetitions or duplications.

What then do you do with the results of an idea?. The best is that they evolve until they reach the level of a prototype; ie. until they became something (a software code, a system, a device, etc.) that works in a contrastable manner in the hands of a person different from the author. The transit of a *result* to a *prototype* is not a trivial one and it demands an organization, efficient and capable staff and resources that are usually far from the ordinary means of a university group. The best alternative is, therefore, that the idea follows its route to specialized institutions, adjacent to the university, with the specific mission of transform knowledge into tangible things (prototypes).

Many organizations of this type have been created around the world in the last few years. An example is the International Center for Numerical Methods in Engineering (CIMNE, www.cimne.com) in Barcelona, Spain. Some of these organizations are called Research Centers and others Innovation Centers. This terminology is sometimes deceiving, as it apparently indicates that some centers must focus on research and not on technology transfer, and vice-versa. The truth is that research and technological development are essential activities in both type of, so called, RTD centers. What is important is that they should have the capability of teaming up with research and industry environments with a practical vision.

University and enterprise

Can a prototype be released into the market with a guarantee of success?. The answer is (probably) no. The distance between a prototype and a product is typically a long one. Getting a product is an objective in itself and mixing it up with RTD tasks is not advisable and leads to frustrations. Products should be developed in companies where specialists devote their time and talent exclusively to obtaining, validating and documenting a product, as well as defining the marketing plan.

Once a product has finally reached the market, it would enter into the last quadrant of the Cycle of Ideas. There the objective is a commercial success. In order to reach that, the company should establish the necessary alliances around the world. The Cycle ends up with the return of part of the profits, from the marketing of the product, to the place where the idea originated (the University).

Clearly, the "rotation speed" of the idea around the Cycle can be increased with the help of funding from external public and private sponsors, as is metaphorically shown in the figure.

These concepts are in fact very simple. However it is typically very difficult to put them into practice. What are these difficulties?.

Some difficulties

Among the difficulties that prevent good ideas from becoming a full industrial (and commercial) success story, I would focus on just three that are based on my own experience. The first one is the lack of perception of the limits of an organization. Humans are limited and so are organizations. In reality, things are only done to its best within the limits of a person or an institution. For instance, universities and research centers don´t have the competence of an enterprise, and vice-versa. To act beyond the *limits of competence* is a temptation to which many groups in universities, research organizations and enterprises frequently fall. There are indeed very few examples of successful "unlimited" organizations.

The second difficulty is the usual lack of adequate *interfaces* between the different agents that are involved in the transformation process of an idea. These interfaces require, among other things, people with the capacity of understanding the problems and requirements at both sides of the "quadrants".

Finally, I mention the importance of *good alliances* in all directions. University and research groups should weave a network of industrial and academic organizations around themselves, with complementary skills at national and international levels, which will help them to develop and exploit knowledge with a guarantee of success. Again, from my own experience, I refer to the network of CIMNE Classrooms in Spain and Latin America and the spin-off companies created by CIMNE.

Policies

If the above concepts are accepted, then we can better guess the difficulty and/or convenience of implementing one or other policy for stimulating RTD work at universities, research centers and companies. It is non credible that a university or a research center can make a profit from the exploitation of the outcome of an idea in the short/mid term. Consequently, the policy of some Government agencies of providing reimbursable loans instead of grants for funding research in universities and research centers, has a high probability of failure, in the sense that they will not be able to return the loans on time. A more interesting (and feasible) approach would be that parts of the grants are linked to the success in the research, validated in the form of contrastable results. On the other hand, the policy for funding innovation work in companies should include the modality of non-returnable loans for happy-ending histories in the achievement of an innovative product.

The right policy should put the emphasis on reaching a successful end in the RTD activity, and not in the RTD work in itself, as is the usual case. The target would be always the same, helping an idea to become something useful and profitable. ●

Computational Analysis Framework for Fatigue Crack Nucleation in Metallic Polycrystalline Microstructures

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" The novel framework introduced paves the way for a paradigm change in fatigue modeling of metals and alloys ..."

1. Introduction

Material design plays an intrinsic role in comprehensive structural design for enhanced performance and life. It puts high demands on effective modeling and simulation methodologies to establish quantitative relations between the material microstructure and physical properties at different length scales. Rapid advances in computer technology and computational sciences enable sophisticated simulations that can unravel the underpinnings of complex microstructure on material behavior. In concert with significant advances in experimental methods, computational tools at multiple scales are able to introduce paradigm changes that can enhance the fundamental understanding of microstructure-property relations to enable materials and process design. Emergent thrusts in integrated computational materials engineering or ICME and virtual materials systems are fostering unprecedented advances in multiscale materials modeling, integrating microstructure representations, constitutive descriptions, computational algorithms and experimental methods. These approaches are forcing a fundamental restructuring of materials data for structural engineering based on a hierarchy of model parameterizations and validations, rather than the current application-specific design limits.

Fatigue or time delayed fracture is an important material behavior that occurs under cyclic loading conditions due to start up and shut down processes or load reversals. Fatigue failure in the microstructure evolves in multiple stages, viz. crack nucleation due to inhomogeneous plastic flow or grain boundary failure, subsequent crack growth by cyclic stresses, and coalescence to cause fast crack propagation. For many metals and alloys, it has been experimentally observed that fatigue crack nucleation dominates 80-90% of total life. A large body of literature exists on fatigue of metals. The phenomena of high cycle and low cycle fatigue have been traditionally characterized using macroscopic parameters like applied stresses, cyclic frequency, loading waveform, hold time etc., as well as statistical distributions of fatigue life and fatigue strength. Predictions of these models can suffer from significant scatter due to the absence of robust underlying physical mechanisms and microstructural representations. Morphological and crystallographic characteristics, e.g. crystal orientations, misorientations, micro-texture and grain size distribution, play significant roles particularly in the nucleation and propagation of fatigue cracks. Accurate modeling of fatigue failure inherently involves coupling of multiple spatial scales ranging from those of individual grains to that of polycrystalline aggregates as well as structural components. The recent years have witnessed a paradigm shift towards the use of microstructure-based detailed mechanistic models for predicting fatigue crack nucleation and propagation, [1,2] as a promising alternative to more empirical models. A number of these approaches seek accurate description of material behavior through crystal plasticity based finite element models. While, computational models of polycrystalline materials implementing crystal plasticity models are making great strides in predicting local stress-strain behavior with reasonable accuracy, fatigue failure predictions with high fidelity are still far from mature. Morphological and crystallographic heterogeneities in polycrystalline microstructures pose severe challenges to these computational models. Ghosh et. al. have developed image-based crystal plasticity finite element (CPFE)

models for deformation and creep in titanium alloys and ratcheting fatigue of HSLA steels in [1, 10-12]. These calculations provide a platform for the implementation of physics-based crack nucleation and propagation, accounting for microstructural inhomogeneity [13,14]. A major bottleneck with 3D CPFE simulations for fatigue life prediction is the accommodation of large number of cycles to failure, observed in experiments. In single time-scale CPFE solutions using conventional time integration algorithms, each cycle is resolved into a large number of time steps. A high time step resolution is required for each cycle throughout the loading process, often leading to prohibitively large computational requirements. Accelerated time integration schemes are indispensable for simulating large number of cycles to failure with high spatial and temporal resolution. Some of the current trends in multi-scale modeling of real material have been discussed in two recent books by the author [1,2].

This article discusses a comprehensive computational micromechanical deformation and failure analysis framework developed by the author's group to address the challenging issue of fatigue crack nucleation in polycrystalline microstructures of metals and alloys [1-16]. The framework has been developed for titanium alloys and nickel-based superalloys, materials that find widespread utilization in the automotive and aerospace sectors. It incorporates four essential ingredients in its development. They include:

(i) computer simulation of polycrystalline microstructures from experimental data,
(ii) image-based crystal plasticity finite element models for metals and alloys,
(iii) fatigue crack nucleation models, and
(iv) multi-time scale model for crystal plasticity without scale-separation requirements. The following sections summarize these developments.

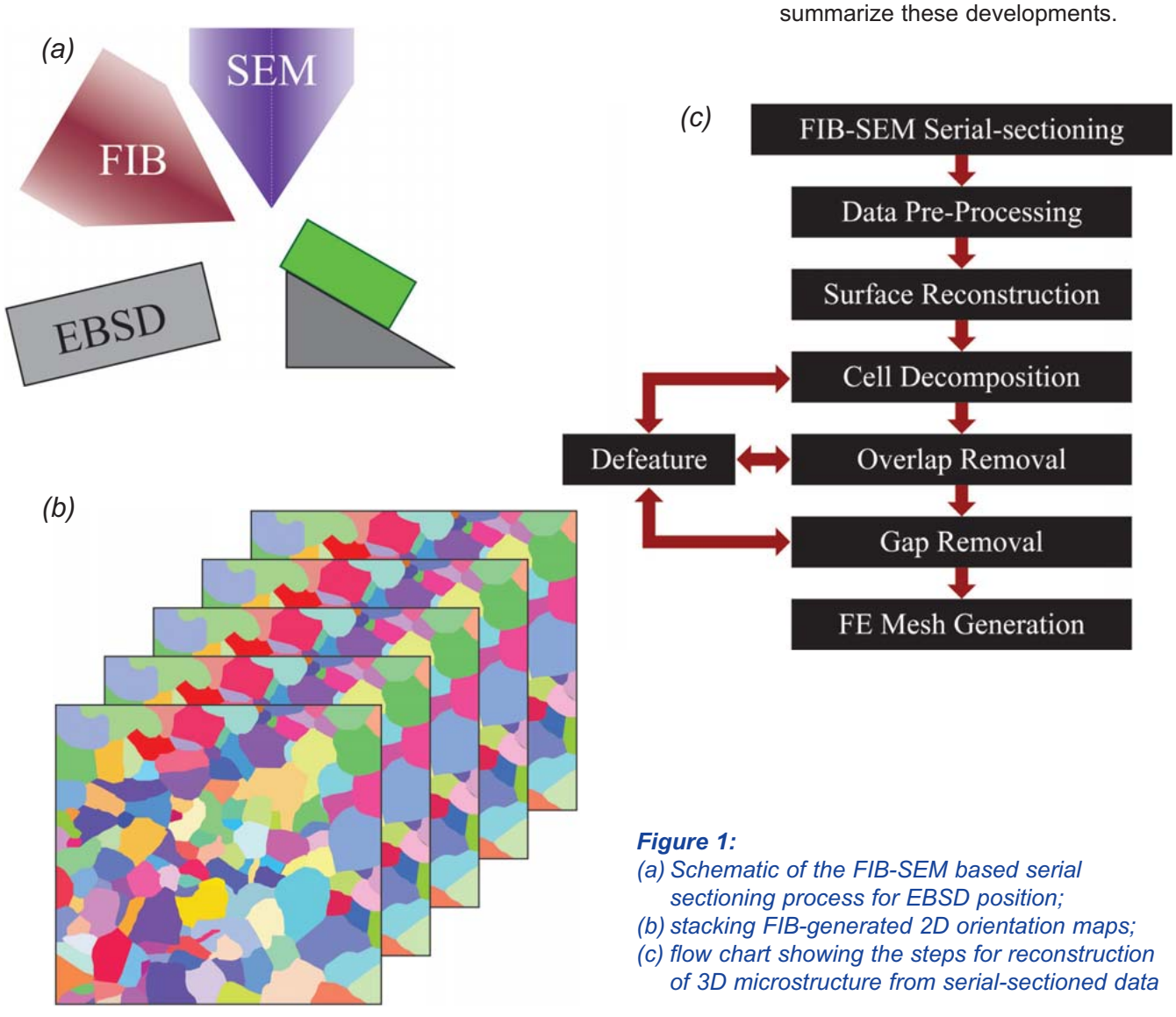


Figure 1:
(a) Schematic of the FIB-SEM based serial sectioning process for EBSD position;
(b) stacking FIB-generated 2D orientation maps;
(c) flow chart showing the steps for reconstruction of 3D microstructure from serial-sectioned data

2. 3D Polycrystalline Microstructure Reconstruction for FE Analysis

Three dimensional microstructural data acquisition and characterization have been effectively accomplished in the recent times using an automated approach using a dual beam focused ion beam-scanning electron microscope (DB-FIB-SEM) system, described in [3]. The procedure acquires crystallographic orientation information from electron backscatter diffraction (EBSD) maps of a series of sequentially stacked cross sections. This advanced data acquisition process has been used to develop two independent methods of generating high-fidelity reconstruction of 3D polycrystalline microstructures by Ghosh et. al. in [4-7]. The computer simulated microstructures can subsequently be discretized and analyzed by computational methods like the finite element method for material microstructure-response maps. The first of these seamless reconstruction methods is a CAD-based methodology using advanced primitives for geometric modeling and manipulation. The second method creates statistically equivalent virtual microstructures based on rigorous statistical characterization of grain-level microstructures from serial-sectioning data and application of these statistical descriptions to generate equivalent grain structures. A brief description of these methods is provided next.

2.1 CAD Based Reconstruction of 3D Polycrystalline Microstructures from DB-FIB-SEM Data

The CAD-based method of creating 3D grain structures through post-processing of the DB-FIB-SEM generated orientation imaging microscopy (OIM) data has been developed in [4,5]. A seamless reconstruction process requires the following steps, also summarized in *figure 1(c)*.

I. *Dual Beam Focused Ion Beam-Scanning Electron Microscope (FIB-SEM) Data Acquisition and Pre-Processing:* This step includes collection of data from experiments shown in *figure 1(a,b)*, segmentation of individual grains, data-cleanup and alignment. The 3D orientation data set can be used to perform segmentation of the individual grains in the microstructure.

II. *Domain Construction for Individual Grains:* At the start of the reconstruction process, each grain is represented as a set of contiguous voxels in 3D raster, from which surface-points belonging to grain-pairs are identified. The grain-pair interfaces are represented by non-uniform rational B-spline orNURBS surfaces (defined by the Cox-deBoor recursion formulae), fit through these surface-points. The constraint on these surface patches is that they be smooth, accurate and extendable. Following surface reconstruction, the volumetric domain of each grain is constructed by a cell-decomposition process to reconstruct individual grains from the grain surfaces. In this method, an arbitrary shaped solid is defined as the universe cell and arbitrary shaped surfaces are considered as the partitioning surface.

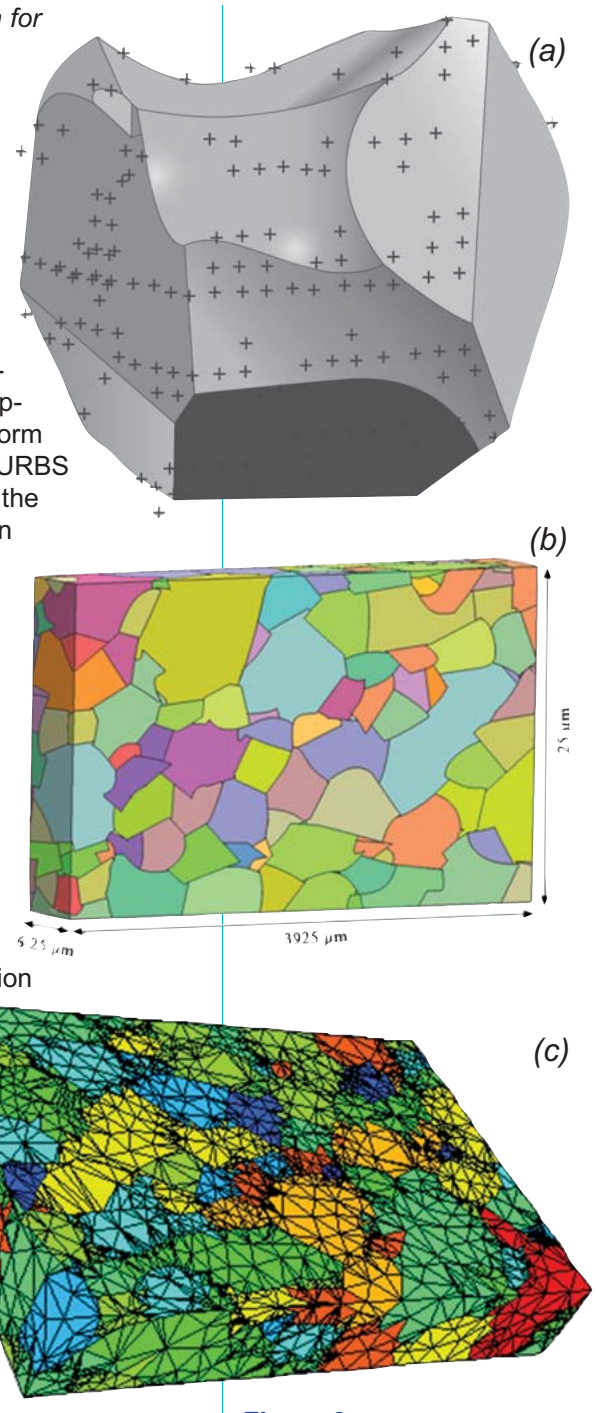


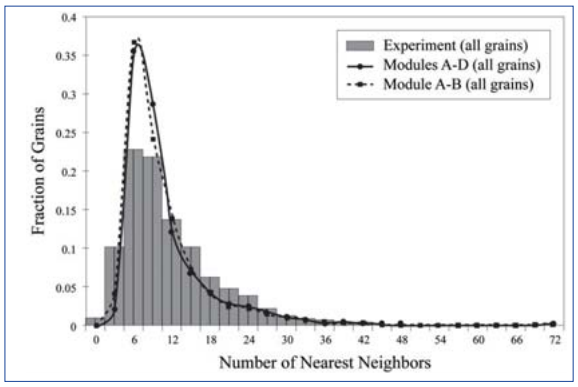
Figure 2:
(a) A reconstructed grain showing discrete surface data point,
(b) CAD based polycrystalline microstructure reconstruction,
(c) meshed microstructure using an adaptive meshing process

III. *Retaining Grain Boundary Compatibility in the Polycrystalline Aggregate:* Individually constructed grains by the hierarchical solid reconstruction process, when assembled in a polycrystalline aggregate, may incur gaps and overlaps between them due to isolation from the other grains in the ensemble. Regions occupied by more than one grain (overlaps) and regions where there are no grains present (gaps) are non-physical and should be removed by a partitioning and adaptive surface reconstruction.

IV. *Defeaturing Spurious Artifacts in Reconstructed Grains:* The process of grain reconstruction and compatibility enforcement can lead to non-physical artifacts such as slivers or cracks in the microstructure. Defeaturing removes these artifacts during their creation process prior to their implementation in a finite element mesh and model. It is introduced before overlap removal, gap removal or mesh generation. *Figure 2(a)* shows a defeatured grain after reconstruction, overlap removal and gap removal respectively.

V. *Generating the Finite Element Mesh:* Due to the geometric complexity of grain shapes, it is sometimes impossible to generate a conformal mesh using standard commercial software. A conforming algorithm for high quality mesh consists of identifying nodes on the grain boundaries, which serve as seed points for 3D Delaunay triangulation to yield a conforming mesh of tetrahedral elements. Local changes are made to nodes and elements to improve the quality of the mesh or "collapsibility index" without affecting the overall geometric representation of the microstructure. Mesh improvement operations include (a) node deletion, (b) node relocation and (c) edge collapse. An algorithm for collapsing smaller elements at regions of low solution gradients is introduced. In addition to geometric considerations, the resulting mesh also takes the distribution of evolving variables into account. The resulting graded mesh shown in *figure 2(c)* consists of highly-refined elements in regions of critical geometry and larger elements elsewhere.

(a)



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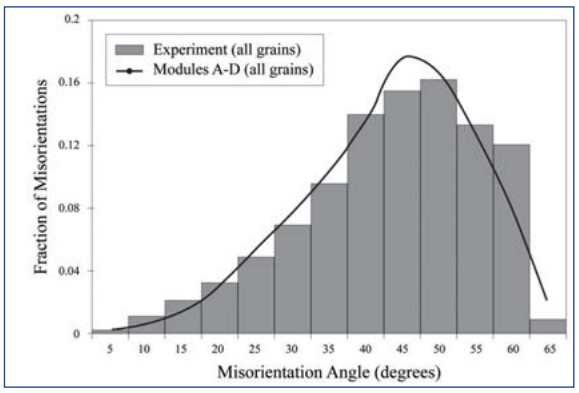
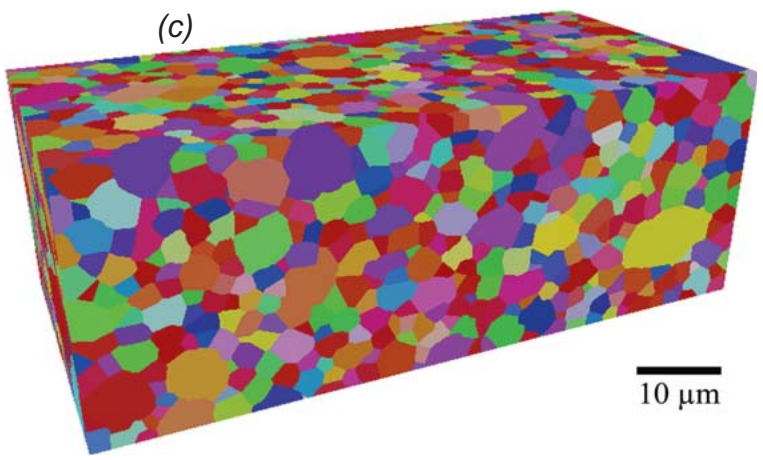


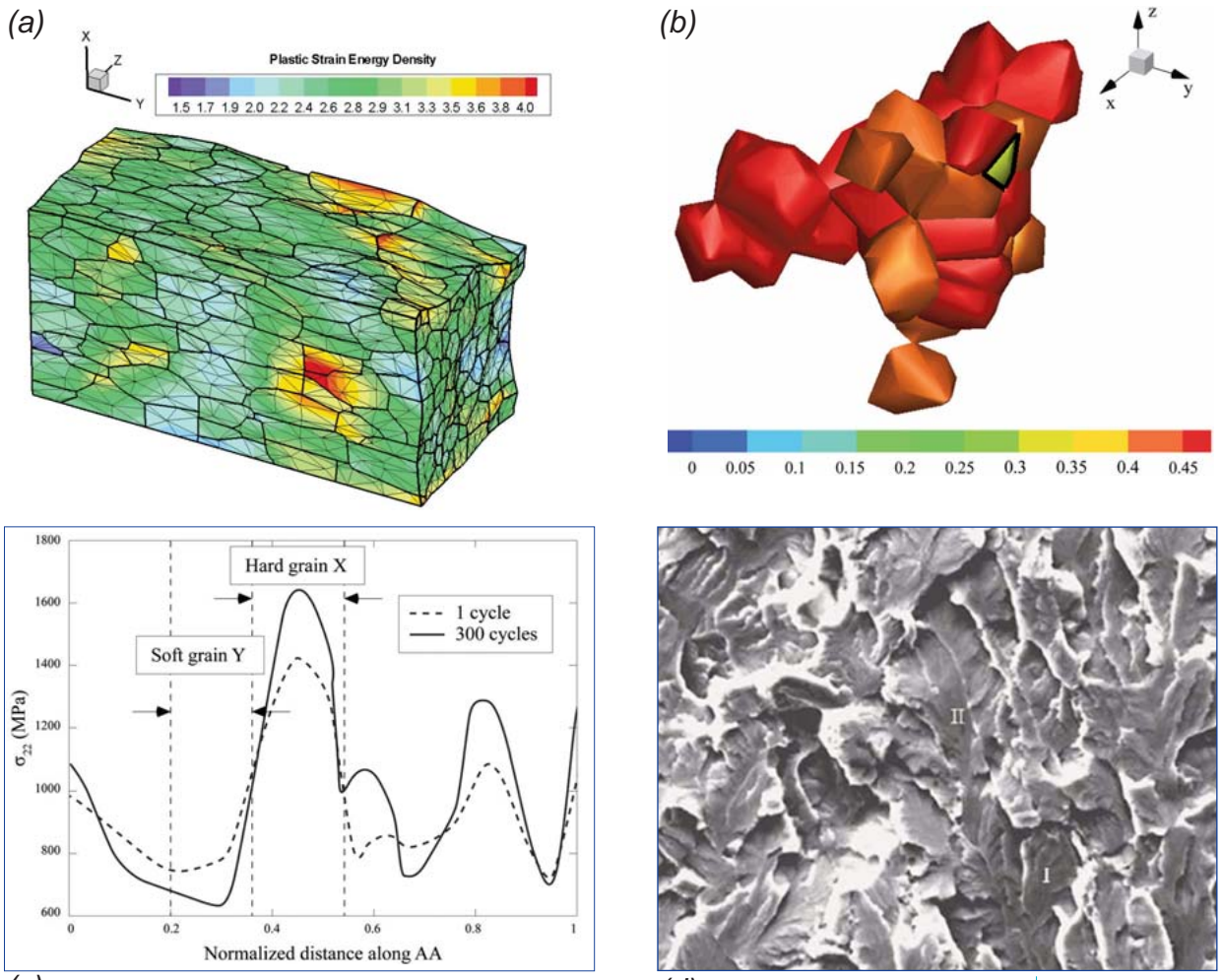
(c)



2.2 Statistically Equivalent Synthetic Polycrystalline Microstructures from DB-FIB-SEM Data

The ability to characterize microstructural features using effective statistical methods is an important advancement in computational materials science as it allows correlating material response functions with microstructural features. Recent progress in generating virtual 3D microstructures in [8,9] use collection of statistical distributions of grain size and shape to infer the 3D structure, that bound the microstructure generation process. Ghosh et. al. in [6,7] have created a comprehensive microstructure simulator from statistical distributions of 3D experimental data that can feed into a computational model. This work includes statistical characterization of grain-level 3D microstructural data obtained from the DB-FIB-SEM system

Figure 3:
Experimental and statistically simulated microstructural distribution functions of
(a) normalized grain volume and
(b) crystallographic misorientation distribution function; and
(c) a synthetic microstructural volume generated by the synthetic microstructure generator



to develop distribution and correlation functions for the morphology and crystallography. Direct 3D measurement of microstructural parameters allows one to describe features without the need for stereological interpolation, thus enabling a higher fidelity characterization. Statistical characterization quantifies various parameters and their correlation functions, which define the morphology and crystallography of polycrystalline alloys as shown in *figure 3 (a,b)*. Morphological parameters include grain volume, number of contiguous neighbor grains and grain shapes, while the orientation distribution function, misorientation distribution function and micro-texture function describe the crystallography. Measuring individual grains in the polycrystalline microstructure make way for parameter distribution functions including higher order moments. The statistical descriptions are subsequently used to generate grain structures. The statistically equivalent grain generation methodology is made up of four principal modules, viz. (i) equivalent ellipsoidal grain generator, (ii) constrained grain packer, (iii) seed point generator-constrained Voronoi tessellation tool and (iv) crystallographic orientation assignment. *Figure 3(c)* depicts a typical statistically equivalent microstructure generated by this simulator.

3. Image-Based Crystal-Plasticity FE Models for Deformation and Fatigue Crack Nucleation in Polycrystalline Aggregates

Image-based micromechanical computational models of polycrystalline metals and alloys account for actual grain morphology and crystallographic orientations, as well as mechanisms that govern deformation and failure. Various slip and micro-twinning modes govern the deformation of crystalline, e.g. face centered cubic *(fcc)*, body centered cubic *(bcc)* or hexagonal close-packed *(fcp)* materials. Deformation twins nucleate to accommodate the overall inelastic strain, when dislocations causing slip are limited due to low critical resolved shear stress on favorable slip systems, especially in hcp crystals. These mechanisms can be modeled by grain level

Figure 4:
(a) CPFE model of a polycrystalline microstructure undergoing creep deformation;
(b) local stress distribution in grains with a hot-spot (green);
(c) evolution of stress distribution with cycles along a line showing load-shedding behavior,
(d) basal slip fractograph showing nucleation site

crystal plasticity constitutive models for slip and twinning. Image-based rate and size dependent crystal plasticity models for deformation and creep have been developed for in titanium alloys *(hcp)*, nickel-based superalloys *(fcc)* and HSLA steels *(bcc)* in [1,10-12]. For example, α/β forged Ti-6242 consisting of colonies of transformed β-phase in a matrix of primary α-phase has been modeled in [1,10,11]. Evolution of slip system deformation resistance is controlled by both statistically stored dislocations corresponding to homogenous plastic deformation and geometrically necessary dislocations that accommodate the incompatibility of the plastic strain field. Material parameters for individual slip systems are calibrated from micro-strain experiments. *Figure 4(a)* shows the stress contour plots in a deformed polycrystalline Ti6242 microstructure under creep loading. The corresponding grain to grain average stresses are depicted in *figure 4(b)*. Under creep or dwell loading, favorably oriented microstructural regions undergo significant plastic straining due to slip on favorably oriented slip systems. Compatibility requirements result in a time-dependent rise in the local stress near the grain boundary in adjacent unfavorably oriented grains. This phenomenon is known as load shedding, in which time dependent local stress concentration near grain boundaries is caused by dislocation pileup in neighboring grains, as shown in *figure 4(c)*. This local stress rise has been found to cause premature crack initiation in crystalline materials [1,13,14].

Premature fatigue failure in polycrystalline alloys, e.g. Ti alloys, under dwell loading conditions has been associated with low temperature creep induced early crack nucleation. Nucleation can dominate the fatigue process, occurring at 80 - 90% of the total life in these alloys. Thus, accurate assessment of the nucleation time is critical to predicting fatigue life. Experimental studies on crack evolution in Ti-6242 samples using quantitative tilt fractography and electron back scattered diffraction (EBSD) techniques in SEM show that crack initiates in a hard-orientation grain surrounded by soft-orientation grains undergoing creep deformation (figure 4(d)). Ghosh et. al. have developed a novel grain-level crack nucleation criterion utilizing evolving variables in crystal plasticity finite element simulations in [1,13]. The experimentally validated nucleation model is able to effectively

(a)

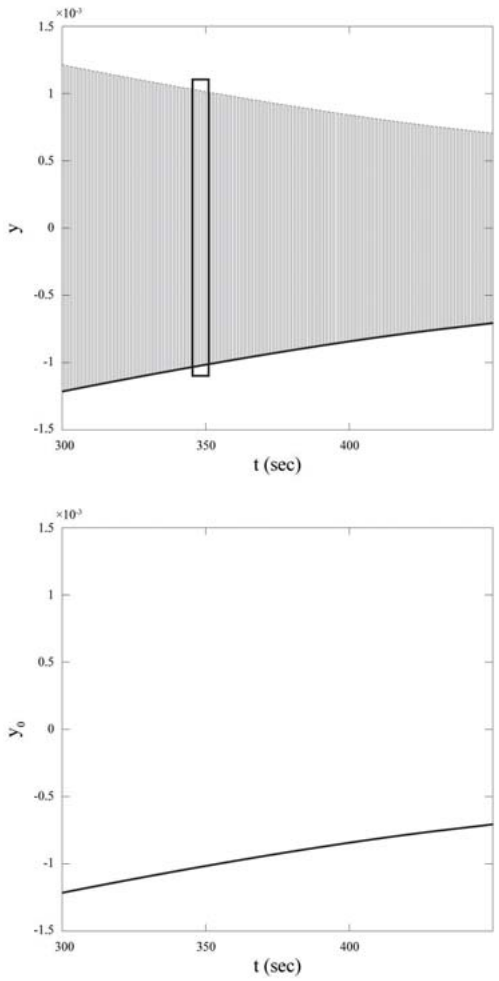
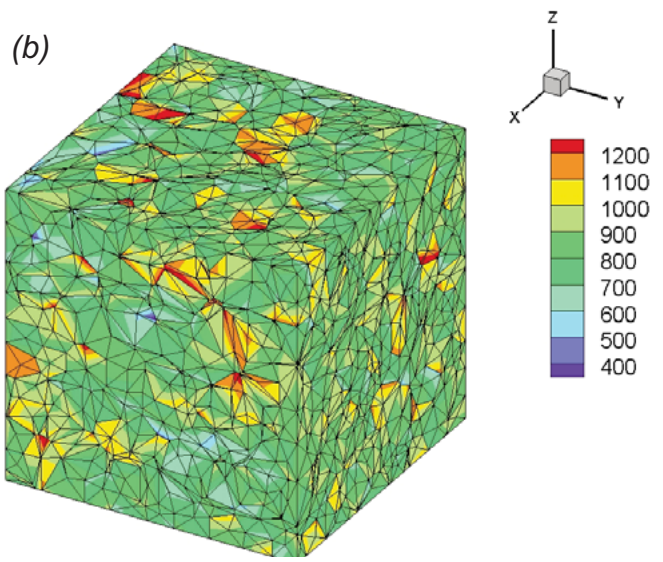


Figure 5: (a - d)
Decoupling fine and coarse time scale responses for cyclic loading:
(a) fine scale solution,
(b) stress contour at 10000 cycles created by the WATMUS based CPFEM simulation,

(b)



predict the number of cycles as well as the crystallographic characteristics of the location. The non-local crack nucleation model includes: (i) interaction of all active slip systems through plastic deformation gradients in the calculation of micro-crack opening, (ii) dislocation pile-up through the magnitude of plastic deformation gradient and the distance from grain boundary and (iii) mixed-mode cracking is considered.

4. Multi-Time Scaling Crystal Plasticity FEM for Cyclic Deformation in Polycrystalline Materials: WATMUS Algorithm

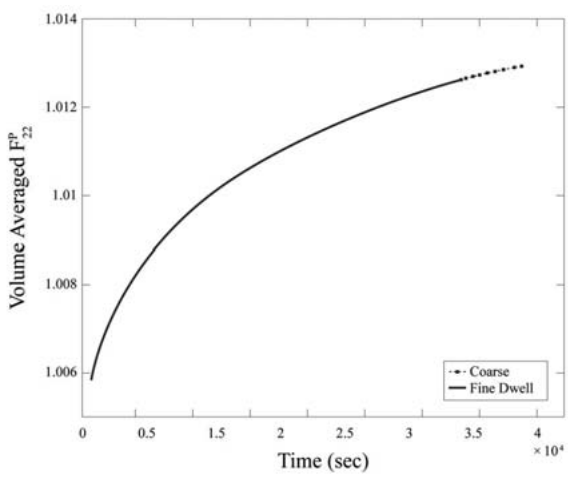
Fatigue life in metallic materials is typically of the order of thousands of cycles, depending on the material and loading conditions. A major shortcoming of CPFE simulations for fatigue life prediction is modeling the large number of cycles to complete failure or its nucleation. In single time-scale FE solutions using conventional time integration algorithms, each cycle is resolved into a number of time steps. In crystal plasticity calculations, this leads to exorbitant computational requirements. Consequently, 3D CPFE simulations for cyclic deformation have resorted to simulating a small number of cycles and subsequently extrapolating the results to thousands of cycles for making fatigue life predictions. Extrapolation or block integration methods can however lead to considerable error, particularly when it comes to the evolution of microstructural variables. The requirement of simulating a large number of cycles to reach the local states of crack nucleation and growth presents significant challenges due to the existence of different time scales, ranging from the scale of each load cycle to that of the component life. Methods of multi-scaling in the temporal domain can avert some of these challenges. The method of direct separation of motions, based on locally periodic or nearly periodic assumptions in the temporal domain, cannot be extended to crystal plasticity solutions due to strong non-periodic response of evolving plastic variables and also due to localization in the spatial domain. In addition, they often invoke two-way coupling between time scales that requires solution of initial value problems at both time scales and does not provide any advantage over single time scale calculations. Asymptotic expansion based homogenization methods are also not suitable for CPFE simulations at or near fully reversed loading.

Ghosh et. al. have developed a multi-resolution wavelet transformation based multi-time scaling (WATMUS) algorithm in [1,15,16] for accelerated CPFE simulations to overcome the above deficiencies. The WATMUS methodology introduces wavelet decomposition of nodal displacements and all associated variables in the finite element formulation to decouple the response into a monotonic coarse cycle-scale behavior and oscillatory fine time scale behavior within each cycle. The wavelet

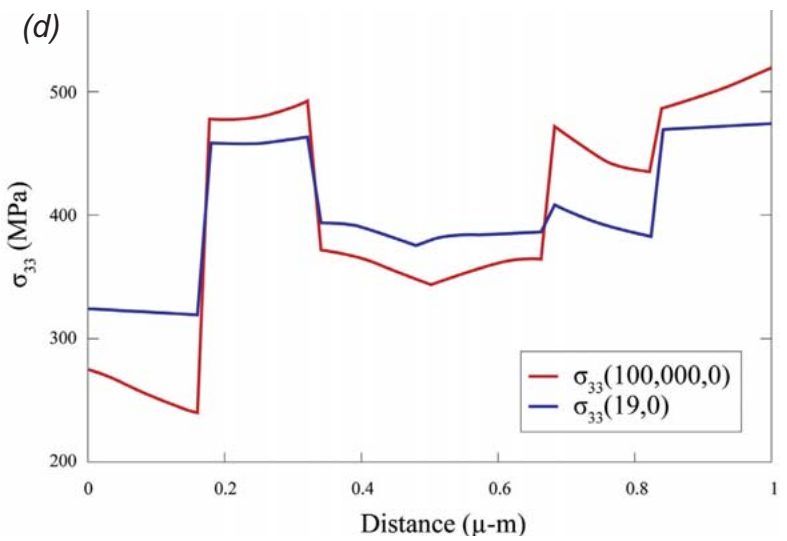
" ... an example of piecing together a sequence of computational algorithms and modules to address a grand challenge problem that is difficult to tackle using simplified models and codes."

(c) comparison of the evolution of volume averaged plastic strain by the WATMUS-based and fine time scale simulations,
(d) evolution of local stresses with cycles for rate dependent crystal plasticity

(c)



(d)



"Multi-resolution wavelet bases functions are effectively able to capture the rapidly varying fine scale response ..."

decomposition naturally retains the high frequency response through the wavelet basis functions and transforms the low frequency material response into a "cycle scale" problem of coefficients undergoing monotonic evolution. No assumption of scale separation is needed with this method. Multi-resolution wavelet bases functions are effectively able to capture the rapidly varying fine scale response, which necessitates very small time steps in conventional single time scale FEM simulations. The number of wavelet coefficients can be optimally controlled through an adaptive control technique. The coarse cycle scale variables exhibit monotonic behavior that especially stabilizes with saturating hardness at higher levels of deformation. Relatively large increments, traversing several cycles at a time, can therefore be utilized in the numerical integration scheme with significantly enhanced efficiency. The WATMUS simulations exhibit approximately over 100 times speed-up, even with relatively low number of cycles. Subsequently, fine scale variations in temporal response at any point in a microstructural point can be recovered from values of wavelet coefficients and coarse scale state variables. As shown in *figure 5 (c)*, the WATMUS-based plastic strain evolution matches very well with the averaged fine scale CPFE simulations. Fine scale variations in temporal response at any point in a microstructural point can be recovered from values of the coarse scale state variables as shown in *figure 5(d)*.

In summary, this article demonstrates an example of piecing together a sequence of computational algorithms and modules to address a grand challenge problem that is difficult to tackle using simplified models and codes. Multi-scale modeling at different length and time scales is at the core of this development. The novel framework introduced paves the way for a paradigm change in fatigue modeling of metals and alloys, consistent with the current thrust in integrated computational materials engineering or ICME. ●

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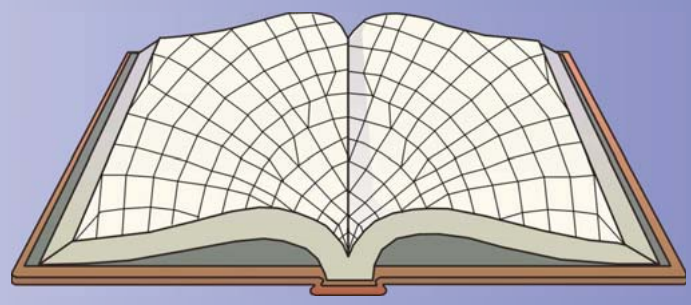
STRUCTURAL ANALYSIS WITH THE FINITE ELEMENT METHOD

LINEAR STATICS

VOLUME 1: BASIS AND SOLIDS



Eugenio Oñate

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Contents: Foreword, Preface,

1. *Introduction to the Finite Element Method for Structural Analysis,*
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Appendices: A. Matrix Algebra, B. Solution of Simultaneous Linear Algebraic Equations, C. Computation of the Element Refinement Parameter, D. GID, References, Author index, Subject index.

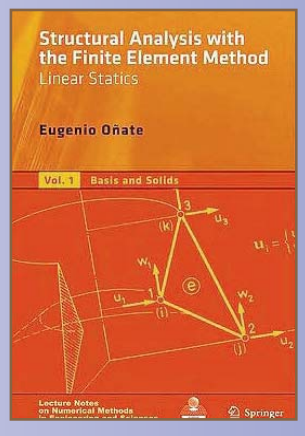
BOOK REVIEW

This is the first volume out of two with the same title. The present volume deals with the basis of the Finite Element Method (FEM) for linear static problems and its application to rods (longitudinal deformation) and 2D and 3D solids. Volume 2 covers the FEM analysis of beam, plate and shell structures, with emphasis on structures made of composite materials. This is an advanced undergraduate textbook for engineering students, and has emerged (in its Spanish version) from the notes of a course taught by the author at the Technical University of Catalonia (UPC). The background required from the reader is the standard knowledge acquired in basic mathematics and engineering courses studied in the first years of engineering schools.

This is an excellent textbook for engineering students. It is well written, pleasant to read, and provides the student who encounters FEM for the first time with a painless entry into the world of finite elements in the context of structural analysis. In the following sections I will outline those aspects in the book that especially appealed to me.

On pp. 5-7, the author explains very clearly the concepts that lead from the real physical structure to the computational model. Many books and courses on FEM do not dwell on this and start immediately from the mathematical model. I find this

Eugenio Oñate



by
DAN GIVOLI
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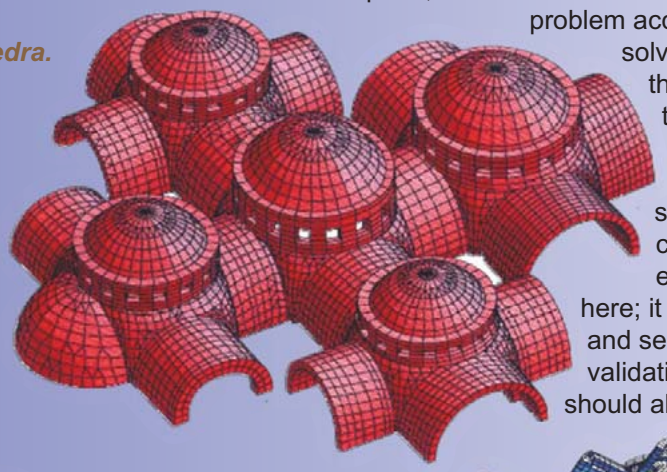


Fig. 8.32 from the book, p. 305, showing analysis of Saint Mark's Basilica in Venice using 20-noded exahedra. Shown are the mesh (top), contours of displacement modulus (bottom left) and damaged zones (bottom right).

introduction quite essential to undergraduate students. Moreover, on pp. 8-14 the author discusses verification and validation of FEM results. (To use the words of the author on p. 13, "verification serves to check that we are solving the structural problem accurately, while validation tells us that we are solving the right problem.") Among other things, the important subject of "manufactured solutions" is discussed in this context. I am not aware of any other FEM book which treats these concepts so early; in other books this subject is either not mentioned at all or is covered as an advanced topic toward the end of the book. I value the approach taken here; it emphasizes the importance of this issue, and sends an educational message to the reader: validation and verification are not a "luxury," but should always be in the mind of every FEM practitioner.

In chapter 1 the author takes the classical approach, that in fact presents FEM in the way it was developed historically. In later chapters the more general and modern approach to FEM is presented, along with many recent advances. This order of presentation is beneficial to the intended audience, since it shows the student how FEM has historically immerged from structural analysis. In section 1.8 the principle of minimum total potential energy is presented for sequential bar systems; however in the remainder of the book the more general approach of virtual work is adopted.

The exposition throughout the book is detailed and "patient". For example, in chapter 2 the author shows how the FEM global equations can be obtained in two ways: (1) by approximating the displacement field on the element level and performing the assembly (section 2.3.1), and (2) by using the global displacement interpolation field (section 2.4). This is important in giving the student confidence in grasping the relation between the global and element levels. The well-organized way in which the book is written manifests itself especially in chapter 8 that deals with 3D solid elements; the text, illustrations and tables cause this technically involved material to look quite simple. This chapter also includes some beautiful color figures showing applications. Two of them are shown here.

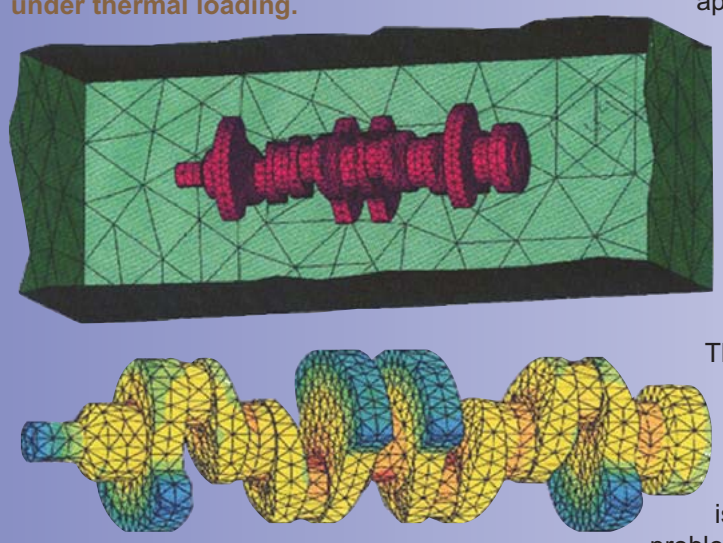


Fig. 8.35 from the book, p. 307, showing thermal-stress analysis of a crankshaft during the casting process using 4-noded tetrahedra. Colors indicate the von Mises stress field under thermal loading.

In section 2.7 the author discusses Richardson's extrapolation, which produces from a number of FE solutions obtained with meshes of different density an additional solution which is much more accurate. Although this is a classical method, it is rarely covered in general or solid-mechanics FEM books; for some reason it usually enjoys much more exposure in CFD.

Chapters 4-7 deal with 2D solid elements for elasticity. The author chooses to jump right into the cold water of plane elasticity rather than treat scalar problems first, like the deflection of a membrane or St. Venant Torsion. Although some may find the transition from 1D rod directly to 2D elasticity a bit drastic, this way the student is immediately exposed to the practical and interesting problem of elasticity without having to spend time on "toy problems" first. Also, one should keep in mind that this is a book/course intended for engineering students who are probably already familiar with the theory of elasticity.

Here is a list of some of the more advanced subjects that the book covers so nicely:

- **Requirements for convergence** (pp. 101-111 for rod elements, pp. 214-219 for 2D solid elements), including the patch test, completeness and stability. This is another example of a very early coverage of an important topic that in other books is usually discussed much later. Again, the educational message is that these convergence-related concepts should be in the mind of the analyzer from the outset.

- **Error types** (pp. 111-116), including discretization error, error in the geometry representation, integration error, constitutive equation error and round-off error. The same comment as in the previous item on the educational benefit applies here.

- **Enhancing the performance of 2D elasticity elements** (pp. 149-154 and p. 185), including reduced integration, assumed strain, incompatible modes and drilling rotations.

- **Computation of nodal stresses and recovery techniques** (pp. 329-338), including superconvergent patch recovery techniques and iterative enhancement.

- **Error estimation and mesh adaptivity** (pp. 338-354), including various adaptivity strategies.

- **Pre-processing and post-processing** (chapter 10, pp. 355-382), including CAD concepts, mesh generation techniques and visualization.

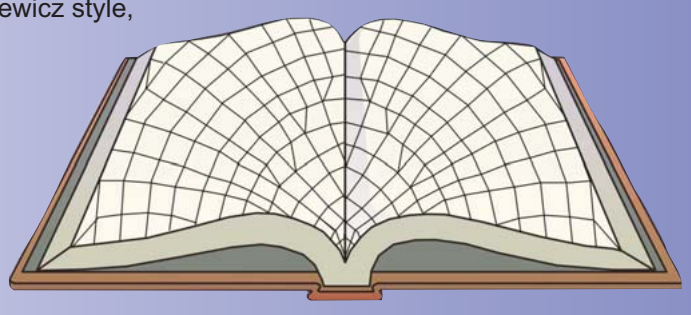
- **Constraints** (pp. 314-320), including penalty and Lagrange multiplier methods, and a brief discussion on locking.

"Vol. 1 ... fits perfectly to a basic one-semester course."

Section 9.4 on displacement constraints starts with a discussion on a direct procedure to solve constrained problems via elimination. Here I will make my only reserved remark. The constraint Ca=g is written here side by side with the global FE equations Ka=f, but these two systems contradict each other. Thus the problem consisting of these two systems together is not well-posed since a solution does not exist. This is in contrast to the constrained minimization problem appearing in the next section, which is well-posed. One can see this difficulty clearly in Example 9.2 on p. 317: the first equation in the FE system is $(EA/l)(u_1-u_2)=P$, while the constraint is $u_1-u_2=0$. Surely these two equations cannot hold at the same time…

So how come the direct procedure is successful after all? This procedure eliminates some equations and thus produces a new system that has a unique solution; in fact the elimination process is so designed as to produce the correct solution, which is also obtained by the Lagrange multiplier method. In other words, the procedure is legitimate; but without explanation, the fact that no solution exists to the problem consisting of Ca=g and Ka=f may confuse the student. I remember that I was very confused by this contradiction when I saw it in another book, back when I was a student. However, this is a minor point that does not affect the very high quality of this book.

The book contains many detailed examples that are extremely helpful to the student. The exposition is nice and clear throughout. The external appearance of the book is very pleasant to the eye, inviting to read, and full of illustrations and tables. The sharp black-and-white illustrations, in the familiar Zienkiewicz style, are very clear. The few colorful figures add to the excellent appearance of the book.



In summary, this in an ideal textbook on FEM in structural analysis for undergraduate engineering students. Vol. 1 reviewed above fits perfectly to a basic one-semester course. Vol. 2, published in 2011, would make an excellent second course, on FEM for composite beam, plate and shell structures. ●

Joint WCCM/APCOM 2010 Congress
A Down-Under Event of Significance

by
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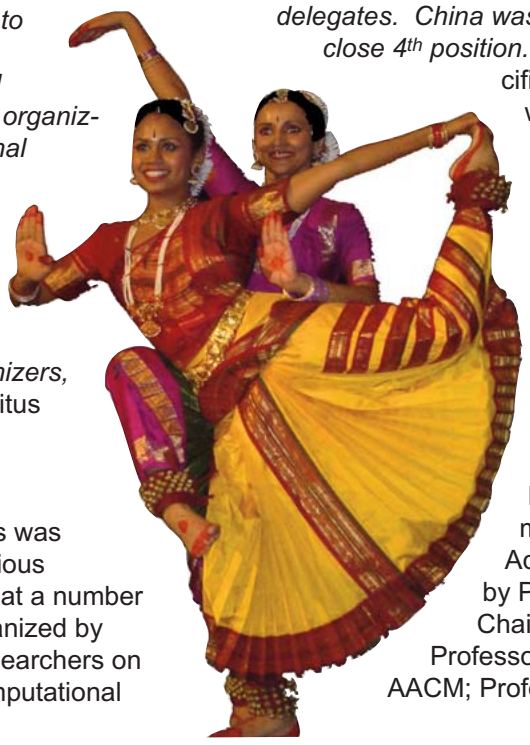
WCCM/APCOM 2010 Conference organisers

The Joint 9th World Congress on Computational Mechanics and 3rd Asian Pacific Congress on Computational Mechanics was held in the beautiful harbour city of Sydney, Australia during July 19-23, 2010 under the auspices of Australian Association for Computational Mechanics (AACM), Asian Pacific Association for Computational Mechanics (APACM) and International Association for Computational Mechanics (IACM).

Three years ago, when given the privilege of organizing this magnificent event, it was never anticipated that the Global Financial Crisis and the European Financial Crisis in addition to unprecedented strength in the Australian Dollar will all happen to the detriment of organizing a successful international congress. Despite these, a record number of international delegates compared to any other previous technical gathering in Australia were received by the organizers, Professor Khalili and Emeritus Professor Valliappan of WCCM/APCOM 2010.



The format of this congress was similar to those of the previous congresses in the sense that a number of Mini-Symposia was organized by leading academics and researchers on latest developments in computational mechanics applied to various fields of engineering, science and applied mathematics. Plenary and Semi-Plenary lectures on important, recent developments in computational mechanics were delivered by eminent authorities in their fields.

The Congress was enriched by about 1100 contributions, including 8 plenary lectures, 15 semi plenary lectures, 100 keynote presentations and 926 standard presentations. There were 147 Mini-symposia and more than 40 General Sessions. It was represented by 49 countries - Japan topped the list with 200 delegates followed closely by US wit*h 199 delegates. China was third and Australia in a close 4th position. Regiona*lly, Asian pacific region topped the list with 500 delegates followed by Europe and Africa and then Americas. A significant aspect of this congress compared to the previous congresses in this series was that more than 30% of all delegates were in the student category.

In the opening ceremony, the Welcome Addresses were delivered by Professor Khalili, Chairman. WCCM/APCOM; Professor Valliappan, President, AACM; Professor Yagawa,

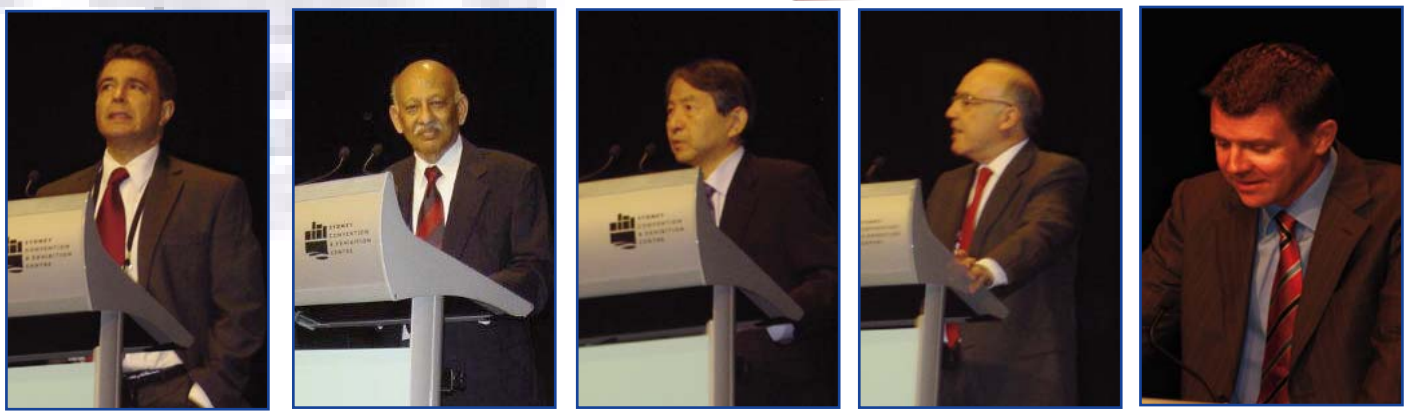


Figure 1 - 5:
Opening Ceremony Welcome addresses delivered by: Profs N. Khalili, S. Valliappan, G.Yagawa, E. Oñate and Hon.Treasurer of NSW M. Baird

Secretary General, APACM and Professor Onate, President, IACM. The Opening Address to the Congress was given by Mr Mike Baird,The Hon.Treasurer for the New South Wales (NSW) Government. A group of delegates who helped to make the Congress a successful event was entertained to an Appreciation Dinner at the NSW Parliament House. Ms Jodi McKay, The Hon. Minister for Science and Tourism welcomed them and expressed her thanks also.

The congress was sponsored by The University of New South Wales (UNSW), The University of Newcastle, Centre for infrastructure and Safety at UNSW, Simulia, World Scientific, International Association for Computational Mechanics (IACM) and US Association for Computational Mechanics (USACM) through the provision of 50 travel grants largely for the students and the young scientists for which the organizers are thankful.

Overall the Congress was a tremendous success with technically rich and culturally engaging programs such as the Welcome Dance by the Aboriginal people, original owners of the wonderful land of Australia, the Classical Bharathanatyam Dances by Indian dancers and the performance by the Sydney String Quartet for both delegates and accompanying persons. ●

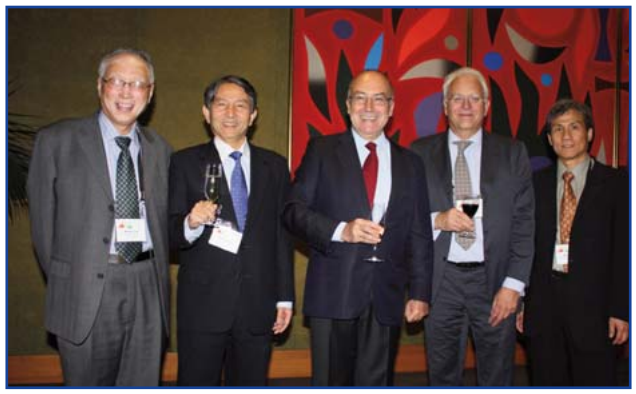


Figure 6:
From left to right: Professors Yuan, Yagawa, Oñate, Wriggers & Liu

Figure 7:
From left to right: Mrs Khalili, Prof Khalili, Prof Reddy, Prof Valliappan & Mrs Valliappan at the Banquet

Figure 8:
The auditorium during the welcome ceremony

Figure 9:
Aboriginal musician, one of the many cultural programs at the conference.

Figure 10:
Ms Jodi McKay,Hon.Minister for Science and Tourism delivering Welcome and Appreciation Address

iacm AWARDS 2010

Last year 2010, all the membership of IACM and all other members of the computational mechanics community were invited to submit nominations for the IACM 2010 Awards.

The proposed Awards were:

- The **IACM Fellows Award** recognizing individuals with a distinguished record of research, accomplishment and publication in areas of computational mechanics and demonstrated support of the IACM through membership and participation in the Association, its meetings and activities.
- The **IACM Award for Young Investigators in Computational Mechanics** recognizing outstanding accomplishments, particularly outstanding published papers, by researchers 40 or younger.
- **The IACM Award for Computational Mechanics** for contributions to traditional areas, such as computational structural mechanics and computational fluid dynamics, but may also be given to recognize contributions outside these specific areas. For example, the Award may be given in recognition of accomplishments in software development, scientific computing, research contributions in computational electromagnetics, semiconductor device simulation, biomechanics or other areas not traditionally embraced by computational structural mechanics and fluid dynamics but which have general applicability to computational mechanics
- **The IACM Award** in recognition of outstanding and sustained contributions to the broad field of computational mechanics. These contributions shall generally be in the form of important research results which significantly advance the understanding of theories and methods impacting computational mechanics, but special individual contributions in leadership and administration, industrial applications, and engineering analysis that advance computational mechanics shall also represent accomplishments worthy of recognition

***Gauss-Newton Medal* - Eugenio Oñate**

Prof. EUGENIO OÑATE, Civil Engineer by the Technical University of Valencia (1975) and Ph.D. by the University of Swansea, Wales, UK (1979), Director of the School of Civil Engineering of Barcelona (1983-89), Director of the International Center for Numerical Methods in Engineering (CIMNE) of the Technical University of Catalonia (since 1987), Honorary President of the Spanish Society of Numerical Methods in Engineering (SEMNI) (since 2004), Past- President of the European Community on Computational Methods in Applied Sciences (ECCOMAS) (2000-2004) and Past-President of the International for Association Computational Mechanics (IACM) (2002-2010). He has received a number of awards from universities and scientific and technological organizations worldwide. He is author of numerous scientific papers on developments and applications of numerical methods for structural problems, fluid dynamics and industrial forming processes.

***IACM Award* - Peter Wriggers**

Peter Wriggers studied Civil Engineering. He obtained his Dr.-Ing degree at the University of Hannover in 1980. From 1983-84 he was Visiting Scholar at UC Berkeley. He finished his Habilitation in 1986. In 1990 he was appointed as Full Professor at the Institute of Mechanics at TH Darmstadt. From1998 to 2008 he held the Chair for Mechanics in Civil Engineering in Hannover. Since 2008 he is director of the Institute of Continuum Mechanics in the Faculty of Mechanical Engineering at Leibniz Universität Hannover. From 2003 to 2004 he held the position of “Linkage Professor” at the University of Newcastle in NSW, Australia. Peter Wriggers is a member of the “Braunschweigische Wissenschaftliche Gesellschaft,” the Academy of Science and Literature in Mainz, and the German National Academy of Engineering “acatech.” He is momentarily president of GAMM and GACM. He acts as Editor-in-Chief for “Computational Mechanics.” He was awarded the Fellowship of IACM and received the “Computational Mechanics Award” of IACM and the “Euler Medal” of ECCOMAS.

***IACM Award* - Mingwu Yuan**

Professor Mingwu Yuan, was born in 1939. He graduated from Department of Mathematics and Mechanics of Peking University in 1960 and post-graduated from the same department in 1964. He visited and worked with Edward L. Wilson at UC Berkeley from 1980 to 1982. He worked on a variety of finite elements, different algorithms for static and eigenvalue problems and mesh generation, moving grid algorithms. He published more than 200 papers in domestic and international journals. He also organized and developed a large commercial general purpose structural analysis software package for more than 25 years and has more than 1000 users nationwide. As the Chairman he successfully organized the Sixth World Congress on Computational Mechanics in Beijing, September 2004.

• **The IACM Congress Medal** (Gauss-Newton Medal) the highest award given by IACM. It honors individuals who have made outstanding, sustained contributions in the field of computational mechanics generally over periods representing substantial portions of their professional careers. The medal is bronze and carries the images of Newton and Gauss in recognition of the synergy between mathematics, numerical analysis, and mathematical modeling of physical events that underpin much of the broad field of computational mechanics.

A total of 88 nominations were received for the different Awards. A Jury was formed by:
- The IACM Executive Committee
- The IACM Honorary Members
- For each award, the most recent winner of that award (with the exception of the Fellows Award), performed the selection of the awardees.

Note: the members of the Jury nominated for an award were ineligible to vote for that award and was thus removed entirely from the selection of that award.

Prof. Tinsley Oden presents Prof. Carlos Felippa the Computational Mechanics award, during the IACM World Congress last July 2010 in Sydney.

The following are the IACM 2010 Awardees:

Gauss-Newton Medal:
Eugenio Oñate

IACM Awards:
Mingwu Yuan & Peter Wriggers

IACM Computational Mechanics Awards:
Carlos Felippa, Jacob Fish & Takashi Yabe

IACM Young Investigator:
Yuri Bazilevs

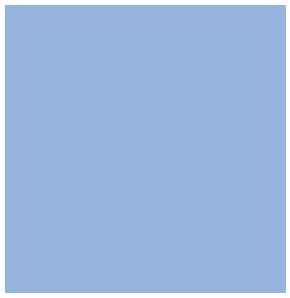
IACM Fellows:
David Benson, Tadeusz Burczynski, Pedro Diez, Raul Antonino Feijoo, Somnath Ghosh, Woody Ju, Trond Kvamsdal, Tod Laursen, G.R. Liu, Panayiotis Papadopoulos, Stefanie Reese, Scott Sloan, Takashi Yabe, Y.B. Yang. ●

***IACM Computational Mechanics* - Carlos Felippa**
Carlos Felippa is Professor of Aerospace Engineering Sciences since 1986, at the University of Colorado, Boulder, where he participated in the creation and development of the Center for Aerospace Structures. Prior to that, he was with the Structural Analysis Research Group at Boeing, and the Applied Mechanics Group of the Lockheed Palo Alto Research Laboratories. His main research interests are Nonlinear and Dynamic Structural Analysis, Finite Element Methods, Computational Multiphysics, and Advanced Software Architectures. He is the author or co-author of over 150 journal papers, 8 book chapters, and 4 course-based online books. He has received several honors and awards, including the USACM Computational Sciences Prize, a SEMNI Award, the Alexander von Humboldt Research Award, and a NASA Software Development Award.

***IACM Computational Mechanics* - Jacob Fish**
Dr. Fish is the Redfern Chaired Professor in Engineering and Director of the Multiscale Science and Engineering Center at Rensselaer. He is a recipient of the USACM Computational Structural Mechanics award, the Rensselaer SOE Research Award and several best paper awards. He has written over 170 journal articles, book chapters and two books including the popular finite element textbook co-authored with Ted Belytschko. Dr. Fish is a Fellow of American Academy of Mechanics, USACM and IACM. He is a past President of USACM, Editor-in-Chief of the Journal of Multiscale Computational Engineering and Associate Editor of the International Journal for Numerical Methods in Engineering and serves on the editorial board of several journals.

***IACM Computational Mechanics* - Takashi Yabe**
Takashi Yabe is a professor at Tokyo Institute of Technology. His main research areas include the computational fluid dynamics and laser application. He was engaged in laser fusion at Institute of Laser Engineering, Osaka University and achieved highest neutron production (awarded in 1987). He also proposed a new numerical scheme called CIP method. The citations to this work exceed 1200. Because of this work, he was invited to give a bicentenary memorial lecture at the Royal Institution of Great Britain in 1999. He is also appointed as an Honorary Fellow in International Society for Computational Fluid Dynamics. Recently he proposed a new energy cycle that combines desalination, solar–pumped laser and its application to smelting of magnesium used for fuel. He was appointed as “Heroes of the Environment” by TIME in 2009. He is a CEO of Electra Co. Ltd and a Chairman of Pegasos-Electra Co. Ltd. founded for this project. ●



10th World Congress on Computational Mechanics

8-13 July 2012 • São Paulo • Brazil



www.wccm2012.com

Mini-Symposium Proposal is now Open!

Important Dates

Mini-symposium proposal period	March 1 - July 31, 2011
Notification of mini-symposium acceptance	until August 31, 2011
Deadline for abstract submission	November 30, 2011
Notification of abstract acceptance	until January 31, 2012
Deadline for full-paper submission (optional)	March 31, 2012
Deadline for early registration	March 31, 2012


The Escola Politécnica da Universidade de São Paulo is pleased to announce and invite you to the tenth edition of the **WORLD CONGRESS ON COMPUTATIONAL MECHANICS (WCCM 2012)**, to be held in São Paulo, Brazil, July 8-13, 2012. Please take a look at your agenda and plan to join us for a truly exciting congress.

Since its first edition in 1986, the WCCM has become one of the most important conferences in the fields of Computational Engineering and Sciences. It aims at providing a top forum for discussion and presentation of state-of-the-art research results as well as industrial and non-industrial applications. In this tenth edition, São Paulo is thrilled to host all professionals, scholars and researchers involved in these fields and promote a very high level meeting in 2012. We look forward to welcoming you in Brazil for the WCCM 2012!

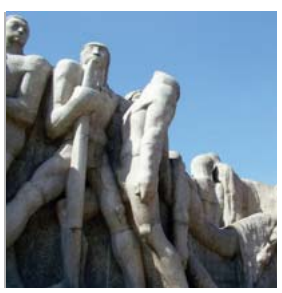
Paulo M. Pimenta
CHAIRMAN

About Brazil

Brazil is a very attractive country with distinguished features and many places that deserve your visit. Of continental dimensions, it is the fifth largest and fifth most populated country in the world. From the Amazonas rainforest to the low lands of Pantanal, from the Iguaçu Falls to the 8000 km of beautiful beaches along the coast, including those belonging to the former capitals of Salvador and Rio de Janeiro, you have the opportunity to feel Brazilians´ reputation as a warm and friendly people.

About São Paulo

The modern city of São Paulo is the fourth largest city in the world. Visitors to São Paulo can be sure to enjoy all the benefits of a sophisticated and cosmopolitan city, with comfort and facilities meeting international standards and an immense variety of cultural and leisure activities. Brazil´s major financial, commercial, medical and technological center will plunge you into the city´s flowing experience of crossing economic expansion together with never-ending entertainment.



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Association of Computational Mechanics Taiwan

ISCM III - CSE II

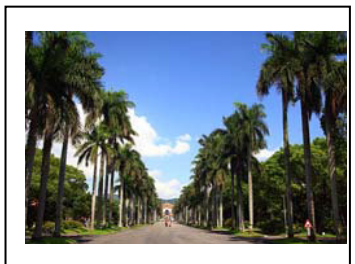
Third International Symposium on Computational Mechanics (ISCM III)
In conjunction with
Second Symposium on Computational Structural Engineering (CSE II)
5 -7 December, 2011, Taipei, Taiwan
http://iscm3.caece.net/

The objectives of ISCM III-CSE II are to discuss the latest development and application of computational methods in all aspects of engineering and science with a special emphasis on mechanics. Plenary lectures, minisymposia, and special sessions that highlight the latest trends are planned.

The conference is organized jointly by ACMT(Association of Computational Mechanics Taiwan), NTU (National Taiwan University), YunTech (National Yunlin University of Science and Technology, and STAM (Society of Theoretical and Applied Mechanics).

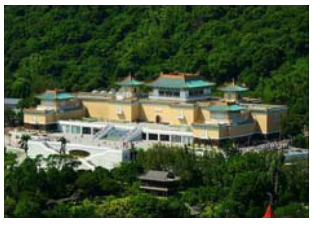
Honorary Chairmen: Herbert Mang, Jun-Zhi Cui
Coference Chairmen: Yeong-Bin Yang, Ming-Wu Yuan
Scientific Advisory Committee Chairmen: Jiun-Shyan (JS) Chen, Yong Yuan
Local Organizing Committee: Chuin-Shan David Chen, Liang-Jenq Leu

Taipei is the most important cultural, political and economic center of Taiwan with a population of more than 3 million. While the city has been modernized in the past half a century, it nevertheless preserves the rich cultural traditions of Chinese history. The National Palace Museum located in the suburb of Taipei is word famous for its priceless collection of artistic treasure, which represent over 3,000 years of Chinese history. Even a brief stay in Taipei is enough to take in most of its attractions.


NTU


Sun Moon Lake


Taipei 101


National Palace Museum

Important Dates

Mini-symposium submission due:	March 15, 201
Abstracts submission due:	July 15, 201
Early registration due:	September 15, 201
Registration due (for abstracts to be presented in the symposium):	October 15, 201
Hotel reservation due:	October 15, 201
Conference date:	December 5-7,201

http://iscm3.caece.net/
Contact: Secretariat General
Prof. C-S. David Chen (dchen@ntu.edu.tw)

CSMA 2011

10th Edition of CSMA Meeting

For all inclusions under CSMA please contact

Alain Combescure
INSA de LYON
France
alain.combescure@insa-lyon.fr

The 10th installment of the (French) National Conference on Structural Computational Mechanics (CSMA2011, **http://csma2011.lmgc.univ-montp2.fr/**), organized by the CSMA association and the Laboratoire de Mécanique et de Génie Civil of the University of Montpellier 2, was held on May 9-13, 2011 near Toulon, France. Its attendance reached 400 participants, most of them from all French research departments involved in computational mechanics, and including 150 doctoral students. About 20 participants came from outside of France (notably Belgium, Canada, Germany, Italy, Switzerland, UK and USA). Senior and junior scientists have presented 290 high-quality communications distributed into 64 thematic sessions. The residential format (a hallmark of all events of the CSMA series), where all participants are fully accommodated on-site in a pleasant setting, permitted a relaxed yet studious ambiance conducive to lively discussions until late into the evenings and cementing a close-knit community. All sessions were very well attended. All full-length conference papers are posted on a dedicated Internet repository (http://hal.archives-ouvertes.fr/CSMA2011/fr/) within the HAL open-access archive maintained by CNRS.

Each day featured a plenary lecture in the main programme. The invited plenary speakers were Sir J.M. Ball (Oxford Univ., UK), D. Clouteau (LMSSMat, Centrale Paris), H. Devaux (HDS-Design company), M. Fivel (SIMaP, Univ. of Grenoble) and C. Rey (LMT, ENS Cachan). Two additional plenary lectures were given by M. Papadrakakis (ECCOMAS and Univ. of Athens, Greece) and J.L. Archimbaud (PLUME, the French label office of open source research software).

Moreover, the following topics have been highlighted as pre-nominated minisymposia with invited organizers: Dynamic behaviour of material and structures; Coupling of discrete and continuous models; Fluid-structure interaction; Structural morphogenesis; 3D Image processing and identification; Numerical simulation and optimization of processes. Altogether the minisymposia gathered over 100 communications.

The CSMA PhD awards for the years 2009 and 2010 were conferred during a dedicated session where the laureates gave short plenary presentations of their work. ●

Figure 1:
Sir J.M. Ball (Oxford Univ., UK), P. Alart (LMGC, Univ. of Montpellier 2)

Figure 2:
The General Assembly Animation. In front of the white screen from left to right: S. Pagano, M . Bonnet, A. Combescure and C. Cornuault

Figure 5:
Groups of participants enjoying a moment during the conference

Figure 3 and 4:
plenary lectures given by M. Papadrakakis (Head of ECCOMAS and Univ. of Athens, Greece) and H. Devaux (HDS-Design company)

CSMA 2011
Organizating Committee Chairman
Stéphane Pagano
(LMGC, Montpellier)

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Association Chairman
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(LAMCOS, INSA Lyon)

USACM

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Isogeometric Analysis 2011: Integrating Design and Analysis
Austin, Texas
January 13 – 15, 2011

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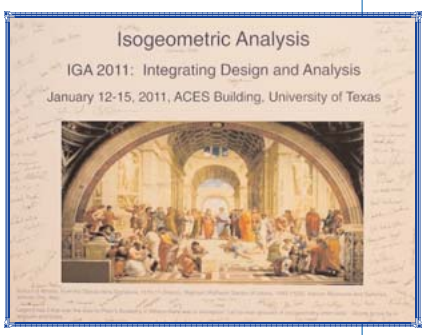

Figure 1: *Conference poster signed by participants*

The first conference on Isogeometric Analysis was held in the Institute for Computational Engineering and Sciences (ICES) at the University of Texas at Austin, January 13-15, 2011. The conference was jointly sponsored by ICES and the United States Association for Computational Mechanics (USACM).

This was the first focused Thematic Conference held under the auspices of USACM. The conference chairmen were Professors Yuri Bazilevs and Dave Benson of the University of California, San Diego, and Professor Tom Hughes of ICES. The purpose of the conference was to provide a forum for members of the Computer Aided Geometric Design (CAGD) and Computational Mechanics (CM) communities to come together and exchange ideas on the new field of Isogeometric Analysis, which attempts to unify design and analysis in order to simplify the arduous and time-consuming task of analysis model development. Originally conceived to be a small workshop, the number of registrants quickly exceeded 100, with over 60 from abroad. To accommodate as many of the submitted abstracts as possible, 72 half-hour presentations were scheduled in two simultaneous sessions over three days.

The conference was preceded by a hands-on T-spline training session taught by Matt Sederberg, CEO of T-Splines, Inc., Michael Scott, a Ph.D. student in ICES, and Robert L. Taylor of the University of California, Berkeley, who is also a Corporate Fellow at Simulia. A highlight of the training session was the conversion of a trimmed NURBS (non-uniform rational B-spline) design model of an automobile roof to an untrimmed T-spline model using the CAD program Rhino with the T-Splines, Inc., plug-in, and the transferring of the T-spline model to Professor Taylor's well-known finite element analysis program FEAP, within which a three-dimensional vibration analysis was performed. All this was done in real time, with no geometry clean-up or feature removal, and no mesh generation. The T-spline, represented in terms of its Bezier element file, was directly utilized as the finite element analysis model in FEAP. This was a graphic illustration of the vision of Isogeometric Analysis and its future potential.

Many luminaries from the CAGD and CM communities were in attendance, as well as a large contingent of young and eager research engineers, scientists, and mathematicians.

Among the senior members of the CAGD community represented were Tom Sederberg (Brigham Young University), Rich Reisenfeld and Elaine Cohen (University of Utah), Tom Lyche (University of Oslo), Michel Bercovier (Hebrew University), who also is a member of the

Figure 2: *Opening session of the conference*

Figure 3: *Organizers, from the left, Dave Benson, Tom Hughes and Yuri Bazilevs*

CM community in good standing, Chandra Bajaj (ICES), Tor Dokken (SINTEF), etc. Senior members of the CM community in attendance were Robert L. Taylor and Sanjay Govindjee (University of California, Berkeley), Rene de Borst (Eindhoven), Kaspar Willam (University of Houston), Pål Bergan and Trond Kvamsdal (Norwegian University of Science and Technology), Ivo Babuška and Leszek Demkowicz (ICES), Arif Masud (University of Illinois), etc.

An egalitarian philosophy was adapted in that all speakers had exactly the same time for their presentations. Ample time for breaks and catered lunches was scheduled so that delegates would have the opportunity to meet and discuss technical issues. Receptions and/or dinners were organized every day, including a conference banquet and farewell dinner. Lively discussions were very much apparent during these social events.

Session topics included Implementation and Software, Optimization, Analysis-suitable Geometry, Mathematical Methods, T-splines, Biomedical Applications, Locally Refinable Splines, Structures, Fluid-structure Interaction, Phase Fields, and Fluids. The papers delivered indicated much progress has already been made instantiating the vision of Isogeometric Analysis, but many outstanding issues remain, suggesting future research directions. The conference was characterized by an air of enthusiasm and excitement at the intellectual vitality and future prospects of Isogeometric Analysis. It was informally decided to hold a second thematic conference on Isogeometric Analysis within two years, possibly in Europe. Stay tuned! ●

Figure 4:
Banquet. Standing left to right, Rene de Borst, Trond Kvamsdal, John Evans, Austin Cottrell, Yuri Bazilevs, Pål Bergan. Seated left to right, Tor Dokken, Ruth Hengst, Tom Hughes, Chandra Bajaj

Figure 5:
Rich Reisenfeld and Elaine Cohen

Figure 6:
Bob Taylor and Sanjay Govindjee

USACM Thematic Conference on
Multiscale Methods and Validation in Medicine and Biology

The first USACM Thematic Conference on Multiscale Methods and Validation in Medicine and Biology will be held at the Embassy Suites Hotel San Francisco Airport Burlingame on February 13-14, 2012.
The title of the conference is Biomechanics and Mechanobiology. The organizers are Suvranu De, William Klug, and Wing Kam Liu.

The theme of the conference is the linking of disparate spatial and temporal scales using experimentation, image analysis and visualization, and computing for the purpose of investigating some of the most intriguing problems in biological and medicine science and technology. Discussions will relate to state-of-the-art research in computational sciences that investigate phenomena in Biomechanics and Mechanobiology through a multiscale perspective or providing efficient, coarse-grained description at the same scale. Emphasis will be placed on novel techniques in computing, experimentation and visualization, multidisciplinary research approaches that demonstrate successful synergies; computational reconstruction of experimental findings; and experimental and visualization techniques that support validation of computational models.

Further information about the conference may be found at **http://mmvmb.usacm.org/.**

JSCES

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Message from the JSCES's President

On behalf of the Japan Society of Computational Engineering and Sciences (JSCES), its members and on my own behalf, I sincerely express condolences to the victims of the earthquake and tsunami of the Higashi Nihon Daishinsai (Great East Japan Disaster). I also express sincere compassion to those who are taking refuge for the Daishinsai and Fukusima Daiichi nuclear reactors disasters.

Many concerns, get-well emails and encouraging words have been offered to the JSCES and its members since the disaster. I truly appreciate the friendship shown by the community of computational mechanics, especially by IACM, and sincerely express my appreciation to individuals who gave us supportive and encouraging messages.

Figure 1:
Floor slab with bridge beams turned upside down by the March-11 Tsunami and bridge piers left (Utatsu Brigde in Utatsu, Miyagi, May 28, 2011)

The March-11 earthquake of magnitude 9.0 was one of the most powerful earthquakes in recorded history *(Figure 1)*. The unprecedentedly large-scale and grave combination of the earthquake itself, tsunami and nuclear disaster caused extensive and severe damage on all the economical, industrial and educational activities in Japan. Research and development activities in computational mechanics are unexceptional.

We believe that computational engineering and science will play a crucial role for the reconstruction of Japan, and that the JSCES in some small way will be of service. Taking this opportunity, I would like to hope that the members of IACM will continue to favor us with their generous support. ●

May, 2011
Koichi Ohtomi
President
The Japan Society of Computational Engineering and Sciences

Annual Conference

The JSCES hosted the Sixteenth Conference on Computational Engineering and Science, which was held on May 25-27, 2011, at the Kashiwa Campus of the University of Tokyo (Chiba, Japan). The conference lasted three days and was attended by about 430 participants. About 280 papers with full lectures were presented by researchers as well as graduate students and practitioners in the conference composed of 6 tracks and 33 minisymposia. As an unprecedented experiment, five sponsoring software venders and distributers provided separate "Lunch-on Seminars" during lunch time, which presented their activities to the audience being lunch boxes served *(Figure 2)*.

Figure 2:
Lunch-on Seminar given by software venders and distributers (16th JSCES Annual Conference)

Because of the Great East Japan Disaster, we were forced to postpone the plenary lecture by Prof. P. Wriggers, and the selections of "Best Paper Award" and "Visualization Award" were aborted. Instead, we had a special symposium entitled "The JSCES's Activities on Quality Management of Engineering Simulations" and a special visualization contest "Graphics Face-off for Tohoku District's Products" sponsored by software venders. All these events in this conference were quite successful.

The significance of JSCES's annual conference has been determined as an established setting for the exchange of ideas in the field of computational engineering and science, and for the enlightenment of state of the art in this field. The effort will continue to have the next year's conference in Kyoto, May 2012. ●

~ General Assembly Meeting ~

The JSCES was incorporated in June 2010 under a new regulation about government-affiliated public corporations and hold the second general assembly meeting of the JSCES in May 19, 2011. Prior to the deliberation in the assembly, a special symposium was held and then Dr. Noboru Kikuchi (Roger L. McCarthy Professor, The University of Michigan and Executive Vice President, Toyota Central R&D Labs., Inc.) presented a plenary talk entitled "Toward Computational Engineering for Manufacturing" *(Figure 3)*.

On the same day, inviting Prof. T. Kawai (the first president) and Dr. M. Shoji (the second president) as special guests, we had the award ceremony where the JSCES awarded various kinds of JSCES prizes to senior and young researchers, and practitioners. This year's recipients are Prof. Y. Ohnishi and Dr. F. Sakai (The JSCES Award), Dr. K. Sato (The JSCES Merit Award), Prof. K. Suzuki (Kawai Medal), Dr. K. Yamamura (Shoji Medal), Dr. S. Ogawa and Prof. T. Aoki (Outstanding Paper Award), Dr. T. Nishiura (Outstanding Paper Award), Prof. T. Uehara (Young Researcher Award), Dr. G. Nakamura (Young Researcher Award) *(Figure 4)*. Also, this year's "The JSCES Grand Prize" was awarded to Prof. Peter Wriggers for his outstanding contributions in the field of computational engineering and sciences. ●

Figure 3:
Special lecture by Professor Noboru Kikuchi in the JSCES symposium

Figure 4:
Group shot of recipients of The JSCES Award, Shoji Medal, Outstanding Paper Award and Young Researcher Award

Other activities:

This year, the Fourth Korea-Japan (KJ) Joint Workshop on Computational Engineering with the Computational Structural Engineering Institute of Korea (COSEIK) was held from April 14 to 15 at Grand Hotel in Pusan, Korea. Ten talks were interchangeably given by Korean and Japanese young scientists *(Figure 5)*. Although the JSCES's president could not attend and the size of the workshop was smaller than the previous ones as a result of the Great East Japan Disaster, the participants from the JSCES received a warm welcome by Prof. Jong Seh Lee (President of COSEIK) and the members of COSEIK. The efforts made by Profs. Sang Joon Shin, Maenghyo Cho (Seoul National University) and M. Asai (Kyushu University) are greatly appreciated.

At present, the JSCES (the current president, Dr. Koichi Ohtomi) has about 850 members, all of who are registered as international members of the IACM. The JSCES periodically publishes both quarterly magazines (http://www.jsces.org/Issue/Journal/index.php) and internet journals (http://www.jstage.jst.go.jp/browse/jsces).

Finally, as an IACM affiliated society in Japan, the JSCES will continuously support the IACM as well as Prof. G. Yagawa, the first Japanese President of IACM. ●

Figure 5:
Group shot of participants of the Fourth Korea-Japan Workshop (15th of May, 2011)

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WCCM 2012

in São Paulo

Join us, you are most welcome!

The **10th World Congress on Computational Mechanics** (WCCM 2012) will take place in the vibrant city of São Paulo, Brazil, **8 -13 July 2012**. Please take a look at your agenda and plan to join us for a truly exciting congress. This tenth edition is a historic landmark to our community and you will have the opportunity to meet distinguished colleagues, have a fruitful exchange of ideas and also feel the Brazilians' reputation as a warm and friendly people. We are strongly committed to making this an outstanding, enjoyable and memorable.

Further and updated information at **http://www.wccm2012.com/**

10th World Congress on Computational Mechanics

CILAMCE 2011

32nd CILAMCE 2011 will take place in a UNESCO World Heritage Site

The first edition of the Iberian Latin American Congress on Computational Methods in Engineering (CILAMCE) was held in Rio de Janeiro in 1977, and the last one in Buenos Aires (Argentina) in conjunction with the MECOM del Bicentenario, November 2010.

The conference aims to create a forum in which engineers, researchers and students can exchange ideas and information about the computational methods, currently available systems and improvements in computer technology to solve various complex practical and theoretical engineering problems. The CILAMCE conference has played a major role in the dissemination of the most recent computational applications and computational developments in engineering among professionals, researchers and students of the Iberian Latin American community.

CILAMCE 2011, the 32nd CILAMCE Conference, is being organized by the Graduate Programs in Civil (PROPEC) and Mineral Engineering (PPGEM), of the Federal University of Ouro Preto - Brazil (UFOP) and will take place in the historic city of Ouro Preto, a World Heritage Site as designated by UNESCO.

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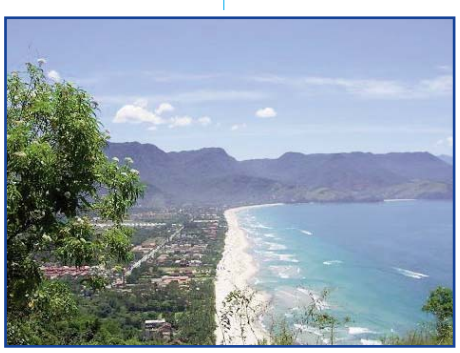
Further details, dates and updated conference information can be found in the CILAMCE 2011 webpage **http://www.acquacon.com.br/cilamce2011/en/.**

UNCERTAINTIES 2012



The **1st International Symposium on Uncertainty Quantification and Stochastic Modeling** - UNCERTAINTEIS 2012 - (**http://www.set.eesc.usp.br/uncertainties2012/**) will be held at Maresias Beach, São Paulo, Brazil, from February 26 to March 2, 2012. Call for Abstracts is already open and deadline for abstract submission is **August 15th, 2011**.

UNCERTAINTIES 2012 arises from the scientific community's interest in having a proper forum for discussion of academic, scientific and technical aspects of uncertainty quantification in mechanical systems.

conference diary planner

25 - 29 July 2011	**USNCCM Congress 11 - US National Congress on Computational Mechanics**		
	Venue: Minneapolis, Minnesota	*Contact*:	http://usnccm.org/
5 - 7 Sept 2011	**2nd International Conference on Computational Methods for Thermal Problems**		
	Venue: Dalian, China	*Contact*:	http://www.thermacomp.com
5 - 8 Sept 2011	**IABEM Symposium 2011 - International Association for Boundary Element Methods**		
	Venue: Brescia, Italy	*Contact*:	http://cesia.ing.unibs.it/iabem2011/index.html
6 - 9 Sept 2011	**ICCESMM11 - Meshless & Other Novel Computational Methods**		
	Venue: Zonguldak, Turkey	*Contact*:	http://www.iccesmeshless.org
7 - 9 Sept. 2011	**COMPLAS XI - XI Int. Confrerence on Computational Plasticity Fundamentals & Applications**		
	Venue: Barcelona, Spain	*Contact*:	http://congress.cimne.com/complas2011
12 - 14 Sept 2011	**TCCM 2011 - Trends and Challenges in Computational Mechanics**		
	Venue: Barcelona, Spain	*Contact*:	http://tccm2011.unisalento.it/
18 - 23 Sept 2011	**ASEM11+ - Advances in Structural Engineering and Mechanics**		
	Venue: Barcelona, Spain	*Contact*:	http://asem11.cti3.com/
21 - 23 Sept 2011	**SIMBIO 2011 - Simulation and Modeling of Biological Flows**		
	Venue: Barcelona, Spain	*Contact*:	http://www.eccomas.org
21 - 23 Sept 2011	**III International Conference on Mechanical Response of Composites**		
	Venue: Hannover, Germany	*Contact*:	http://www.composite2011.info
28 - 30 Sept 2011	**MARINE 2011 - 4th Int. Conference on Computational Methods in Marine Engineering**		
	Venue: Lisbon, Portugal	*Contact*:	http://congress.cimne.upc.es/marine2011/
5 - 7 Oct 2011	**Membranes 2011 - 5th Int.Conference on Textile Composites and Inflatable Structures**		
	Venue: Barcelona, Spain	*Contact*:	http://congress.cimne.com/membranes2011/
24 - 28 Oct 2011	**COBEM 2011 - Int. Congress of Mechanical Engineering**		
	Venue: Natal, Brasil	*Contact*:	http://www.ufrn.br/cobem2011natal
26 - 28 Oct 2011	**PARTICLES 2011 - II Conference on Particle Based Methods, Fundamentals & Applications**		
	Venue: Barcelona, Spain	*Contact*:	http://congress.cimne.com/particles2011
1 - 4 Nov 2011	**ENIEF 2011 - XIX Congreso sobre Métodos Numéricos y sus Aplicaciones**		
	Venue: Rosario, Argentina	*Contact*:	http://www.enief2011.fceia.unr.edu.ar/
9 - 11 Nov 2011	**ICCB2011 - V International Congress on Computational Bioengineering**		
	Venue: Mazatlán, México	*Contact*:	http://www.iccb2011.org
13 - 16 Nov 2011	**CLIAMCE 2011 - 32nd Iberian-Latin-American Cong. on Computational Methods in Eng.**		
	Venue: Ouro Preto, Brazil	*Contact*:	http://www.acquacon.com.br/cilamce2011/en/
14 - 17 Nov 2011	**ACOMEN 2011 - Advanced Computational Methods in Engineering**		
	Venue: Liege, Bellgium	*Contact*:	http://www.ltas.ulg.ac.be/acomen2011/
24 - 25 Nov 2011	**CoRAM 2011 - Recent Advances in Nonlinear Models - Structural Concrete Applications**		
	Venue: Coimbra, Portugal	*Contact*:	http://www.dec.uc.pt/coran2011/
24 - 28 June 2012	**ECCM15 - 15th European Conference on Composite Materials**		
	Venue: Venice, Italy	*Contact*:	http://www.eccm15.org
25 - 28 June 2012	**BEM/MRM 2012 - Int. Conf. on Boundary Elements & other Mesh Reduction Methods**		
	Venue: Split, Croatia	*Contact*:	http://www.wessex.ac.uk/bem2012cfpa.html
8 - 13 July 2012	**WCCM 2012 - 10th World Congress on Computational Mechanics**		
	Venue: Sao Paulo, Brazil	*Contact*:	http://www.wccm2012.com
10 - 14 Sept 2012	**ECCOMAS 2012 - 6th European Cong. on Computational Methods in Applied Science & Eng**		
	Venue: Vienna, Austrai	*Contact*:	http://eccomas2012.conf.tuwien.ac.at

10th World Congress on Computational Mechanics

8-13 July 2012 • São Paulo • Brazil