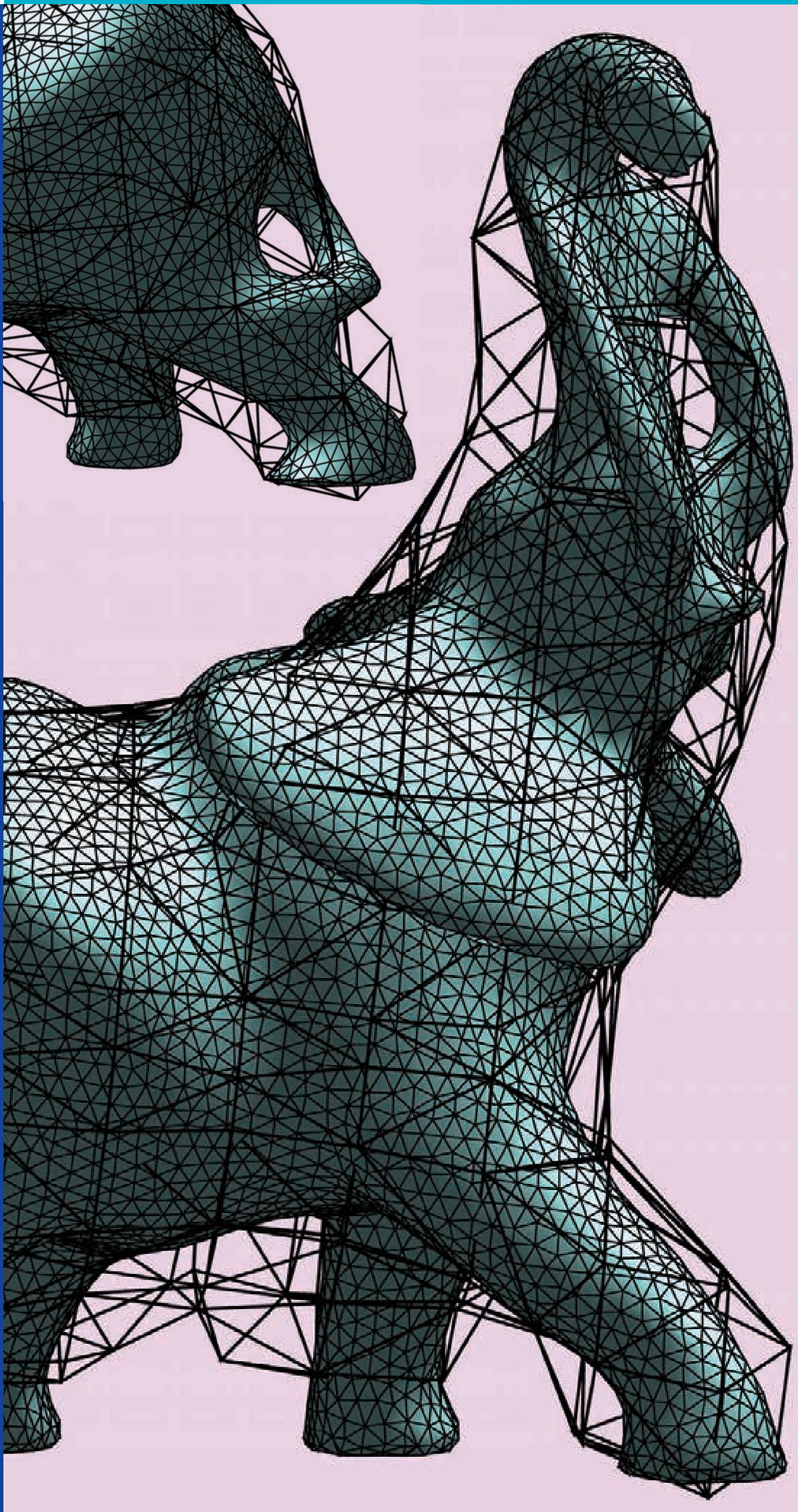
# expressions



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## IACM Expressions

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# contents



# editorial

The breadth of computational mechanics (CM) extends from the discovery of the roots of mathematical models to the development and application of numerical methods for understanding the behavior of complex systems. The scope of these systems is unlimited. It ranges from standard engineering constructions, machines and devices to living matter such as body organs, skin tissue, cells and even the human genome.

Understanding how a complex system behaves is only the first step towards taking a positive action to improve its performance, or to correct any deficiency in case it occurs. It is also most interesting the use of CM technology for thinking and creating new systems with desired properties in a "virtual" laboratory. Reality will come as a second step with the manufacture of the designed system and its validation in order to asses that it behaves as planned.

The opportunities that this creative process involving CM opens in all braches affecting human life are enormous. An example of the above ideas is the Materials Genome Initiative (MGI), launched in the US in 2011 (www.whitehouse.gov/mgi). This is a "national effort to discover, manufacture, and deploy advanced materials twice as fast, at a fraction of the cost". CM surely will play a major role in the different research programs that will result from the MGI. A good example is the use of computational methods for making an efficient and effective progress on additive manufacturing processes as a key technology for designing new materials. This topic is treated in the first article of this magazine.

This issue of Expressions also includes two articles on fundamental topics for CM, such as the unconditionally stability of the algorithms and some modelling aspects of the finite element method, as well as an article on shell elements, an eternal topic for the computational structural community. The book review section by Prof . D Givoli comments this time on a new edition of the classic book of B.A. Finlayson on Weighted Residuals and Variational Methods. These topics are the pillars of the CM technology and should be looked upon as compulsory knowledge for all the researchers in the field.

It is also most welcome the interest of the women community in CM in raising their profile. A good initiative in this direction took place in Barcelona in July 2014 during WCMM XI, when a meeting of some 150 women researchers in CM took place. The IACM is strongly supporting this movement and a second meeting of this kind was held last July in San Diego (US) during the US National Congress on CM, as reported in this magazine.

The WCCMXII in Seoul on 24-29 July 2016 will be a good occasion for new meetings of the women researchers in CM. The WCCM XII will be held in conjunction with the APCOM VI, the Asia-Pacific Congress on CM. This altogether promises to be an interesting event where the different communities on CM over the world will have an occasion to meet and interchange the outcomes of their research.

See you in Seoul.

***Eugenio Oñate***
Editor of IACM Expressions

# Computational Challenges in Additive Manufacturing for the Materials Genome Initiative

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Additive manufacturing (AM) is an umbrella term for a set of advanced manufacturing processes that allows layer-by-layer creation of three dimensional (3D) components - the present discussion will be confined to metal powder based AM processes. Some of the more common AM processes include Selective Laser Melting (SLM), Electron Beam Melting (EBM), Direct Metal Deposition (DMD), and Laser Engineered Net Shaping (LENS). Aside from the geometric complexity, local process-structure-property optimization, and rapid prototyping capabilities provided by AM processes, there are many advantageous qualities of these processes that advocate them as the frontrunners in materials and systems design. While the possibilities for design are nearly limitless in AM, the price for such freedoms come in the form of complex multiscale, multiphysics phenomena that introduce a great deal of uncertainty in the final product. Moreover, the sensitivity of the local material evolution and properties to the local process parameters is detrimental to process control. The lack of accurate in situ metrology for the thermal history, molten pool flow behavior, and the microstructure evolution is a major hurdle that reduces our ability to develop, calibrate, and validate computational models.

Interdisciplinary collaboration is the true key to the success of future AM research, requiring expertise in mechanical engineering, materials engineering, physics, and computer science. As the computational mechanics community tends to incorporate a well-distributed mixture of these expertise in research, we have a unique opportunity to play a crucial role in accelerating the ubiquitous adoption of existing AM technologies while promoting the development of novel AM processes. There are a number of questions that necessitate an answer for efficient and effective progress in AM research:

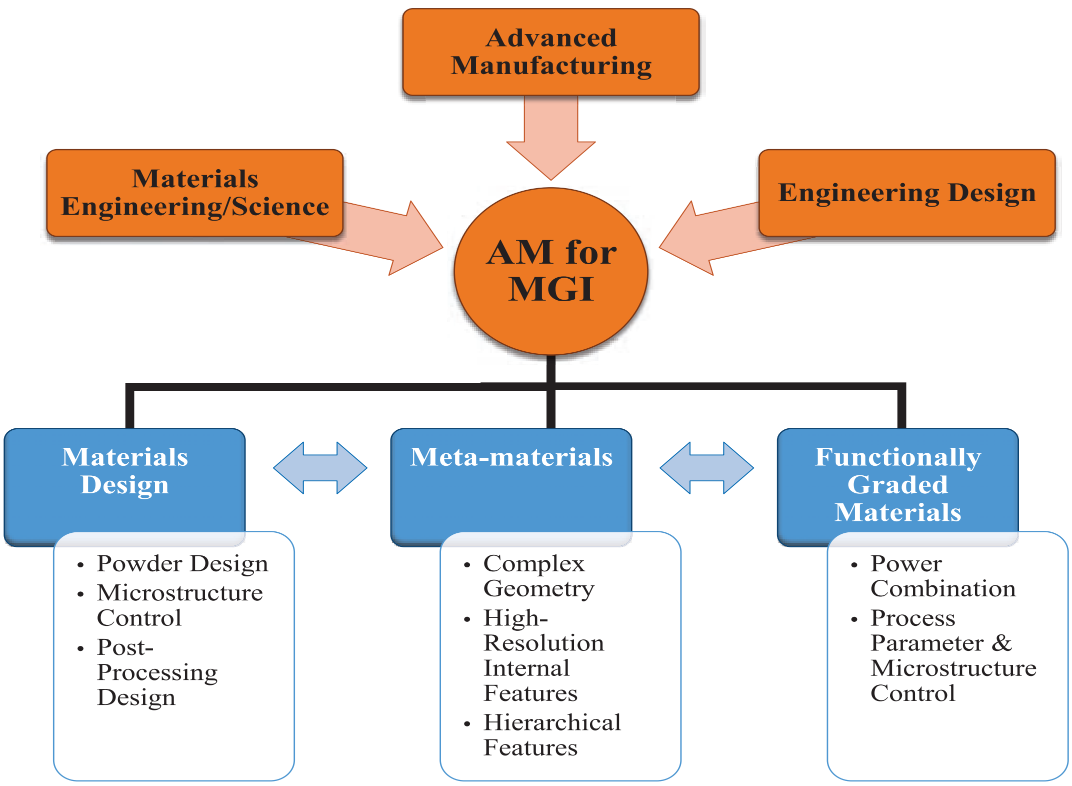


***Figure 1:*** *Impact of AM on the MGI through materials design, meta-materials, and functionally graded materials*

1. How does information from different disciplines flow in the AM setting?
2. What mathematical and numerical models are needed in order to characterize AM processes?
3. How can we use what we know from experiments to enhance our understanding of AM processes?

## Materials and Systems Design:

Perhaps one of the highest impact areas for AM research is in design of new materials. As directed by the White House in 2011, the multi-agency Materials Genome Initiative (MGI) [1] was designed in order to accelerate the discovery and rapid deployment of novel materials. From powder metallurgy, which can be used to alter the alloy composition, to meta-material design, AM processes can have a tremendous impact on the MGI (*see Figure 1*). While powder metallurgy can be viewed as a more traditional materials design concept, particular attention should be given to meta-material design using AM processes. Machining and casting processes are typically limited by topological design constraints that reduce creative freedom; these constraints are virtually non-existent for AM processes. The narrow interaction zone provided by the laser/electron beam heat source provides unique local controllability of complex structures, e.g., closed-volume internal features and local microstructure conformation control.

The primary computational challenges associated with design of materials and meta-materials revolve around developing process-structure-property (PSP) relationships. Identifying PSP relationships for casting-type processes (in the contextof the MGI) have previously been investigated by many materials engineering experts using data-driven methods, e.g., the CALPHAD method [2]. However, AM processes have the added complexity that the solidification behavior can vary greatly over the manufactured domain and the total process time and solidification time are wildly disparate. The PSP relationships for AM processes will likely require integration of existing data-driven methods with rapid 3D computational analysis methods – reduced-order modeling and stochastic methods are of particular interest.

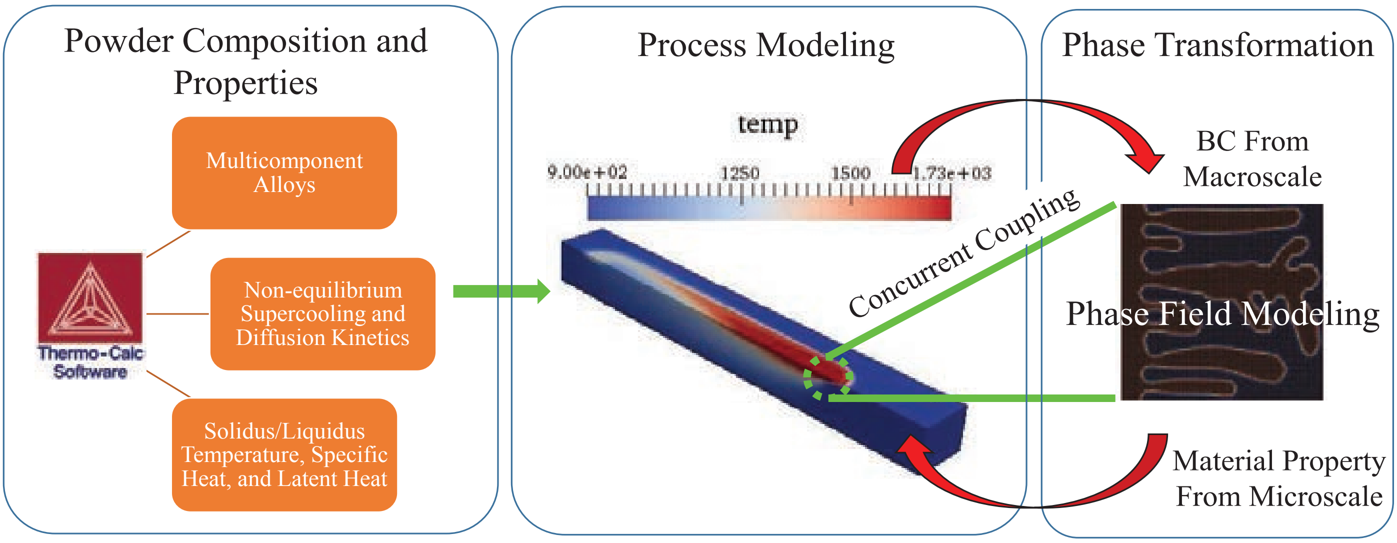


***Figure 2**: Concurrent multiscale, multiphysics modeling approach incorporating non-equilibrium supercooling and diffusion kinetics for multicomponent alloys*

Determining the effect of PSP relations on systems level design further complicates the study of AM. However, the possibility of having start-to-finish printing of functional devices in a single AM process chain, such as a printed circuit on a printed metal alloy structure, forces the research community to address challenges inherent to systems design. Unfortunately, the challenges associated with systems design using AM can only be addressed after the PSP relations have been established for the individual components of the system. What will undoubtedly come into play in the future will be computational methods for understanding the PSP relations for advanced manufacturing processes that allow difficult-to-weld material joining, e.g., friction stir welding.

## Multiscale, Multiphysics Modeling:

AM processes are governed by complex fluid-structure-gas interactions, superheating/supercooling behavior, particle flow, and a heat source that drives extremely localized cyclic phase transformation. Needless to say, AM processes are multiscale in both time and space and require consideration of multiple physical phenomena. Moreover, the current state of the experimental methods used in AM are not adequate to give accurate, high-resolution information related to the in-process physics involved. On the other hand, establishing the length and time scales of interest for analysis is not a trivial task. For example, both the geometric accuracy of centimeter-size features and the micron-size surface defects of a component can play a tremendous role in fatigue life. The porosity is developed on the surface over the course of the solidification time, which can be extremely fast but is currently up for debate (typical reported ranges are $10^3$-$10^6$ K/s but in some cases even $10^8$ K/s), while the centimeter-size feature is developed on the order of the total process time, which is typically hours to days. So, what are the critical length and time scales? This selection has an impact on both the computational time and the complexity of the necessary physics. This is a definitive "work smarter not harder" situation - we want to obtain sufficient accuracy with minimal computational cost.

*"The future of AM will be dictated by the ability of interdisciplinary collaborators ... to work together ...."*

The computational challenges associated with multiscale, multiphysics modeling of AM processes are many. The highest impact areas should be in development of multiscale methods that allow disparate length scales to be resolved with minimal added computational cost. Concurrent multiscale modeling methods [3] that incorporate non-equilibrium supercooling behavior and phase transformation analysis can have a strong impact here. Moreover, a thorough understanding of the impact of the complex physics on the thermodynamic properties of powder alloys used in AM processes requires further investigation.

Development of statistically-informed reduced-order, i.e., data-driven, modeling methods for use at the subscales of the process are of particular interest. However, data-driven methods are reliant on databases of PSP information, which in many cases for AM would require collaboration between organization/institutions who have valuable proprietary information, i.e., trade secrets. As this may not be feasible any time soon, a short-term alternative is development of better mathematical modeling and physics/mechanics-based analysis tools. In the ideal situation, the collective computational tools available to mechanical engineers and materials engineers could be integrated to yield high fidelity analysis frameworks that are readily accessible to the AM research community.

## Calibration, Validation, and Uncertainty Quantification:

As with any computational analysis, calibration, validation, and uncertainty quantification (*see Figure 3*) plays a major role in predicting the outcome of AM processes. Oddly enough, the primary computational challenge is actually obtaining experimental data in order to calibrate and validate the models. In situ metrology for AM is a quickly expanding research area but still has a long way to go. The most useful experimental measurement needed in the short term is the real-time temperature profile at the meltpool so that numerical models can be properly calibrated. Additional useful measurements would be non-destructive in situ microstructure metrics using ultrasonics. This could not only give insight to process modeling but also could potentially lead to microstructure-based process control strategies for AM processes.

At the present time, the AM research community can rely on post-process metrology as an alternative, at least from the perspective of mechanical behavior modeling. In particular, through development of correlations between process parameters and structural components (such as defects) using the latest in advanced imagery, e.g., Focus Ion Beam (FIB), Scanning Electron Microscopy (SEM), and Transmission Electron Microscopy (TEM) [4]. These correlations can further be extended to mechanical performance using standard testing procedures for calibration and validation of mechanics-based constitutive laws that incorporate microstructural information (and therefore process information). Additionally, the microstructure can in some ways be used to calibrate the thermal process model through previously developed phenomenological laws [5]. Lastly, uncertainty in the PSP relations can be quantified using these correlations.

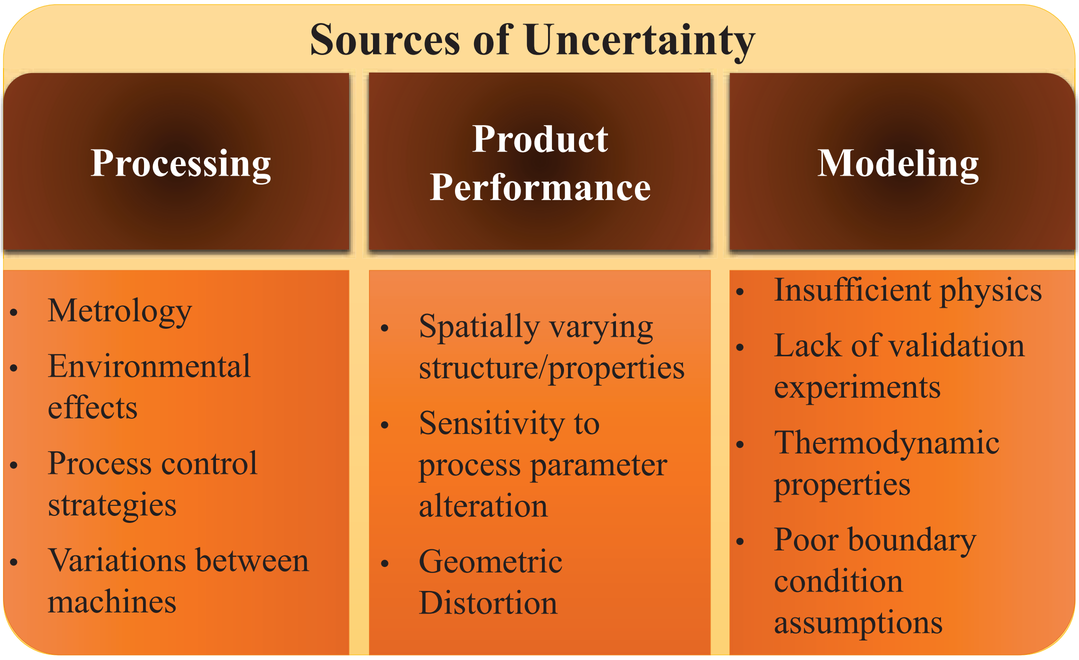


***Figure 3:*** *Sources of uncertainty in AM processes*

## Summary:

To bring it all together, AM processes provide a great foundation for design of advanced materials, individual components, and systems. While the computational community can clearly impact the progress of AM, better experimental metrology and enhanced mathematical/numerical models are required. The future of AM will be dictated by the ability of interdisciplinary collaborators (between multiple scientific fields) to work together to develop integrated modeling procedures for improved accuracy and efficiency in determining PSP relationships.

## Acknowledgements:

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# k-version of FEM and Unconditionally Stable Computational Processes

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"When seeking numerical solutions of the boundary value problems (BVPs) and the initial value problems (IVPs), if the aim is to obtain finite element solutions that approach the theoretical solutions point-wise ..., then we must design a computational framework in which this is possible."

## Current Finite Element Technology

In the numerical simulation of a wide range of physical phenomena, mathematically described in terms of boundary value problems (BVP) or initial boundary-value problems (IVP), the finite element method has emerged as one of the most powerful tools for obtaining accurate, efficient, and stable approximate solutions. Outside the realm of the solid and structural mechanics, however, the method has yet to receive such a level of acceptance and prominence. This is especially noteworthy in computational fluid dynamics (CFD), a field that is presently dominated by low-order finite difference and finite volume technologies. Many of the current finite element formulations, independent of whether one uses nurbs or spectral interpolation functions, are based on weak-form Galerkin formulation of the governing equations. It is now well-known that the success of finite element procedures based on the weak-form Galerkin formulation in obtaining favorable numerical solutions of boundary-value problems is closely tied to the degree to which the weak formulation conforms to the elements of calculus of variations, often referred to as unconstrained minimization problem. More generally, whenever any integral formulation (based on the Galerkin, Petrov-Galerkin, weighted residual, or least-squares methods, among others) conforms to the elements of calculus of variations, that is, the problem of minimizing an unconstrained convex quadratic functional, the resulting finite element formulation inherits the following highly desirable mathematical properties:

1. In the case of self-adjoint differential operator, the numerical solution becomes an orthogonal projection of the exact solution onto the trial space of a given conforming finite element approximation. As a result, the numerical solution represents the "best approximation" of the exact solution in the trial space (as measured by a well defined *energy* norm).

2. No highly restrictive compatibility requirements (such as the discrete inf-sup condition) ever arise that must be additionally satisfied by the discrete conforming function spaces of the various dependent variables because conformity of the integral forms to the elements of calculus of variations ensures that inf-sup condition is automatically satisfied.

3. The resulting linear algebraic system of global finite element equations are always symmetric and positive-definite (a property that may be exploited by both direct as well as iterative solvers).

This *ideal* setting for finite element approximation, stemming from the conformity of the integral form to the calculus of variations, is sometimes termed a *variational setting*. The method initially arose as a direct extension of the classical Ritz method [1] for self-adjoint differential operators, wherein the numerical solution is sought via a direct and discrete minimization of the total potential energy functional. The combination of the method's successful application to problems in linear elasticity along with its versatility in handling irregular domains and complex boundary conditions led researchers to extend the finite element method, in the context of the weak-form Galerkin procedure, to boundary-value problems whose weak formulations cannot be construed as global minimizers. For many such problems it was soon discovered that many of the most attractive features of the finite element method exhibited in the solution of solid mechanics problems described by self-adjoint differential operators were no longer present.

In recent years, there has been a large body of work attempting to recover *some* of the attractive features of the ideal *variational setting* for problems whose Galerkin based weak formulations are either estranged or completely divorced from any notion of unconstrained functional minimization. Many of the advocated procedures may be viewed as stabilized Galerkin formulations and include methods such as the SUPG [2, 3], penalty [4], and Galerkin least-squares [5], among others. Unfortunately, the success of these methods is often intertwined with *ad hoc* parameters that require mesh and/or solution dependent fine-tuning.

Furthermore, it is worth noting that although the various stabilized Galerkin formulations can often sidestep the discrete infsup condition, they cannot generally inherit the best approximation property nor produce symmetric positive-definite coefficient matrices for the case when the governing equations contain non-self-adjoint and non-linear operators.

In addition to the stabilized Galerkin formulations, there has also been renewed interest over the past two decades in developing finite element formulations for problems outside the realm of solid mechanics that recover most, *if not all,* of the attractive features of the ideal *variational setting*. One such formulation is based on the least-squares method and allows for a finite element model to be developed for any boundary-value problem in a setting of *residual functional* (see, for example, [6–9]). The least-squares method is based on the residual functional minimization, wherein a least-squares functional is constructed from the sum of the squares of the norms of the partial differential equation residuals (where the norms of standard Sobolev spaces are typically employed). Such functionals are purely mathematical in nature and do not have the meaning of energy of a system. The integral form is obtained via a direct minimization of the least-squares functional. The finite element model is then obtained in the usual way, and it inherits the desirable properties discussed previously for the ideal *variational setting*.

When seeking numerical solutions of the boundary value problems (BVPs) and the initial value problems (IVPs), if the aim is to obtain finite element solutions that approach the theoretical solutions point-wise with as many features of the theoretical solutions as desired and the computational processes are unconditionally stable, then we must design a computational framework in which this is possible. In this article, the authors describe one such frame work using the Galerkin method with weak form and least-squares method depending upon the type of differential operator. The mathematical classification of differential operators and the integral forms, variational consistency (VC) or variational inconsistency (VIC) of the integral forms, the $C^k$-finite element approximations, inherent error computations, and adaptivity are the most important features of such a computational framework. These aspects for the BVPs and the IVPs are discussed and computed solutions for some model problems are presented here.

For the purpose of the discussion, we consider the operator equation

$$A_x\phi + A_t\phi - f = 0 \ in \ \Omega$$

where the differential operator $A_x$ contains spatial derivatives of $\phi$ up to order $2m$, and $A_t$ is the time differential operator. Let $\bar{\Omega}^T = \cup\bar{\Omega}^e$ be a discretization of $\bar{\Omega}$ in which $\bar{\Omega}^e = \Omega^e \cup \Gamma^e$ is the domain of the $e$th element with closed boundary $\Gamma^e$. Let $\phi_h^e$ be the local approximation of the theoretical solution $\phi$ over $\bar{\Omega}^e$ and $\phi_h = \cup_e \phi_h^e$ be the global approximation of $\phi$ over $\bar{\Omega}^T$. In the following we discuss various aspects of BVPs ($A_t = 0$) and IVPs that constitute an ideal computational framework with the features of theoretical solutions.

## Boundary Value Problems (BVPs)

### The $k$-version FEM

The theoretical solutions of $A_x\phi - f = 0$ can be of class $C^J(\bar{\Omega})$, $J \geq 2m$ but are never of class $J < 2m$. Thus, if $\phi_h$ is to approach $\phi$, then $\phi_h \in V \subset H^{k,p}(\bar{\Omega}^e)$, $H^{k,p}$ being the inner product space of order $k$ in which $k \geq 2m+1$ ensures global differentiability of $\phi_h$ of order greater than or equal to $2m$. Surana et al. [10–12] introduced this concept and have shown that $k$ is independent of $h$ (the characteristic length) and $p$ (the polynomial degree of local approximation). Hence $k$ is a parameter, in addition to $h$ and $p$, that plays a crucial role in choosing desired spaces in which the actual solutions lies. Obviously, for $A_x\phi - f = 0, k = 2m + 1$ is minimally conforming space that ensures global differentiability of approximation $\phi_h$ of order $2m$, as needed for the solutions of the boundary value problem. Thus, $h$, $p$, and $k$ are three independent parameters in the design of a suitable computational framework in which global approximation $\phi_h$ of $\phi$ over $\bar{\Omega}^T$ has desired global differentiability characteristics dictated by the theoretical solution $\phi$ of the BVP.

### *Mathematical classification of differential operators and integral forms*

In order to address the numerical solutions of the totality of all BVPs, the differential operators appearing in all BVPs must be mathematically classified as self-adjoint, non-self-adjoint, and non-linear. The integral forms over $\bar{\Omega}^T$ can be constructed either by using the fundamental lemma of the calculus of variations yielding: Galerkin method (GM), Petrov-Galerkin method (PGM), and Galerkin method with weak form (GM/WF) as methods of approximation or by constructing a residual functional and setting its first variation to zero which yields the least squares process (LSP) as a method of approximation. When $k \geq 2m+1$,

*"... demonstrates the power of higher order spaces, VC space-time integral forms, and the resulting unconditional stability of the evolution."*

the integrands in the integral forms are continuous, that is, the integrals over $\bar{\Omega}^T$ are Riemann. This is essential to ensure that no damage is done by the discretization $\bar{\Omega}^T$ of $\bar{\Omega}$ and by the approximation $\phi_h = \cup_e \phi_h^e$ of $\phi$. Clearly, this is only possible due to $k$. When the local approximation is substituted in the integral form over $\bar{\Omega}^e$ (with appropriate choice of the test function in GM, PGM, and GM/WF), we obtain the associated finite element model for the $e$th element which, when summed over $\bar{\Omega}^T$, yields the assembled set of algebraic equations for the discretization $\bar{\Omega}^T$. We must examine various integral forms for the three classes of differential operators to determine which combination of integral forms and differential operators yield positive-definite coefficient matrices in the algebraic systems so that a unique solution of the algebraic system is ensured.

### VC and VIC integral forms

Establishing the variational consistency of the integral forms from various methods of approximation is critical in ensuring that the algebraic systems for $\bar{\Omega}^T$ are solvable and that the solutions are unique. Calculus of variations considers extremums of the functionals (definite integrals in our case). If $I(\phi)$ is a functional (assumed to exist) that is differentiable in its arguments, then the first variation of $I(\phi)$ set to zero (i.e., $\delta I(\phi)= 0$) is a necessary condition for obtaining $\phi$ that yields extremum of $I(\phi)$ and the second variation of $I(\phi)$ (i.e., $\delta^2 I(\phi)$) is the sufficient condition or the unique extremum principle. A unique $\delta^2 I(\phi)$ ($> 0, = 0$, or $< 0$ implying minimum of $I(\phi)$, saddle point, or maximum of $I(\phi)$ respectively) is a unique extremum principle that ensures that $\phi$ obtained from $\delta I(\phi)= 0$ is unique, hence yields a unique extremum of $I(\phi)$. Additionally a $\phi$ obtained from $\delta I(\phi) = 0$ also satisfies Euler's equation resulting from $\delta I(\phi) = 0$ which is a differential equation. Thus, here in lies the correspondence between calculus of variations and the solutions of differential equations (BVPs in this case).

Thus, if $A_x\phi - f = 0$ is the BVP, then there must exist a functional $I(\phi)$ (generally assumed to exist) such that $\delta I(\phi)= 0$ gives the integral form constructed from a chosen method of approximation, then $\delta^2 I(\phi)$, that is, the first variation of the integral form must yield a unique extremum principle so that a unique solution of the algebraic system from $\delta I(\phi)= 0$ (i.e., the integral form) is ensured. The integral forms with unique extremum principle are called variationally consistent integral forms and those that do not have a unique extremum principle are termed VIC integral forms [10–13]. VC integral forms yield symmetric positive-definite algebraic systems, hence ensure unique solution of the algebraic system. VIC integral forms on the other hand yield non-symmetric coefficient matrices, the eigenvalues of which may be partially or completely non-positive or even complex and the eigenvectors may be complex too. These algebraic systems are not ensured to be solvable, and if they are solvable the solutions may not be unique. Surana and Reddy [13] have shown that GM, PGM, and WRM always yield VIC integral forms for all three classes of differential operators; GM/WF yields VC integral form for self adjoint operators only when the bilinear functional in the weak form is symmetric. On the other hand, the integral forms resulting from the residual functional (LSM, LSP) are always variationally consistent for self adjoint and non-self adjoint operators. For non-linear operators the integral forms resulting from the residual functional can be made VC with small adjustments [13–16]. Thus, out of all of the methods of approximation based on fundamental lemma, only the GM/WF is worth considering for only self-adjoint operators whereas the integral forms resulting from the residual functional is VC for all three classes of differential operators, hence are ensured to yield positive-definite coefficient matrices in the algebraic systems for $\bar{\Omega}^T$, thus are worthy of consideration. Surana and colleagues [17,18] have shown that for self-adjoint operators the integral forms resulting from the residual functional yield superior (more accurate) computational processes than those from GM/WF, integral forms in both being VC.

### Error computation and adaptivity

Generally, computation of error requires the theoretical solution which for most problems of practical interest is not possible to obtain. In the absence of this the general philosophy has been estimations of solution errors. The $k$-version of finite element method provides an alternative to both of these approaches. We recall that if we choose $k \geq 2m+1$ for the approximation space $H^{k,p}$, then the integrals over $\bar{\Omega}^T$ in the entire computational process remain Riemann. This aspect is crucial for accurate error computation in the computed solution $\phi_h$. Let $E^e = A_x\phi_h^e - f \;\forall x \in \bar{\Omega}^e$ be the residual function for an element $e$ and $E = A_x\phi_h - f \;\forall x \in \bar{\Omega}^T$ be the residual function for the whole discretized domain, then we can construct a residual functional $I(\phi_h)$

using $I(\phi_h) = (E, E)_{\bar{\Omega}^T} = \sum_e (E^e, E^e)_{\Omega^e} = \sum_e I^e(\phi_h^e)$ in which $I^e$ is the residual functional for an element $e$. We note that the integral in $(E, E)_{\bar{\Omega}^T}$ is Riemann due to $k \geq 2m+1$, hence $I(\phi_h)$ as a sum of $I^e(\phi_h^e)$ is precise, that is, without any error or approximation. For theoretical solution $\phi$ the residual functional $I(\phi)$ is obviously zero as $E = A_x\phi - f = 0$ and as $I(\phi)$ is positive for any $\phi$ other than the theoretical solution, the minimum value of $I(\phi)$ is zero as well. Thus, proximity of computed $I(\phi_h)$ for the approximation $\phi_h$ to zero is a measure of the proximity of $\phi_h$ to $\phi$. When $I(\phi_h) \rightarrow 0$, $I^e(\phi_h^e) \rightarrow 0$ for each element, hence $E^e \rightarrow 0$ for each element in the pointwise sense. This claim can only be made if $k \geq 2m+1$ as the integrals over $\bar{\Omega}^T$ are Riemann only when $k \geq 2m+1$. Thus, in the $k$-version of finite element method with $k \geq 2m+1$, $I(\phi_h)$ is a measure of error (without the knowledge of theoretical solution) in the solution $\phi_h$ over $\bar{\Omega}^T$ whereas $I^e(\phi_h^e)$ are a measure of error in each element (locally) and can be used to guide the adaptive process, that is, the elements with the largest value of $I^e$ are candidates for refinement and/or increase in $p$- level. Thus, we note that with $k$- version in conjunction with $h$- and $p$- versions, the finite element computational process is self-contained, self-deterministic in the error measures, and self-directive (i.e., adaptive) if improvement is needed in the computed solution $\phi_h$.

## Some remarks

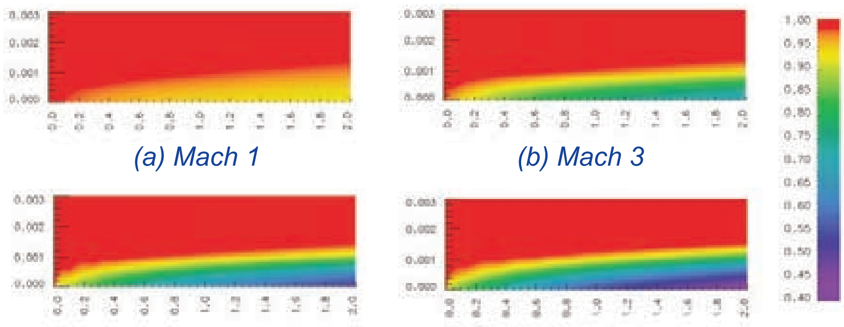
- The integrals in the finite element process must remain Riemann over $\bar{\Omega}^T$;otherwise, the underlying physics is disturbed in the computational process.
- Minimally conforming order of space $k$ is controlled by the highest order of derivative of $\phi$ in $A_x\phi - f = 0$, if the integrals resulting from the fundamental lemma of calculus of variations or residual functional are to be Riemann.
- VC integral forms yield unconditionally stable computational processes. VIC integral forms cannot ensure this.
- For the three classes of differential operators (self adjoint, non-self adjoint, and non-linear), of all of the methods of approximation based on the fundamental lemma of calculus of variations, only GM/WF yields VC integral forms for self adjoint operators (linear elasticity and linear structural mechanics). For non-self adjoint and non-linear operators, GM, PGM, WRM, and GM/WF all yield VIC integral forms. Only the integral forms based on residual functional (LSP, LSM) are VC for all three classes of differential operators. If our goal is to satisfy $A_x\phi - f = 0$ in the piecewise sense, then LSP is superior over GM/WF even for self-adjoint operators.
- $k$- version eliminates a posteriori error estimation as $I(\phi^h) = (E, E)_{\bar{\Omega}^T} = \sum_e I^e(\phi_h^e) = \sum_e (E^e, E^e)_{\Omega^e}$ is in fact a measure of the error in the computed solution $\phi_h$ when $k \geq 2m+1$.
- Processes based on $k$- version have built-in measure of element error $I^e$, hence a guide for adaptivity. When $k \geq 2m+1$, $I^e$ can also be computed in any method of approximation (for example in GM/WF) to design adaptive processes.
- A computational framework based on the $k$- version, operator classification, and VC integral forms is a highly meritorious computational framework in which unconditional stability of computations is always ensured for all BVPs. Additionally this mathematical framework provides quantitative measure of error in the computed solution and a mechanism for adaptivity.
- With $k$- version of finite element method, the mathematical models with the highest order derivatives of the dependent variable can be used in the computations. This results in reduction of dependent variables in the computational processes, hence improved computational efficiency.

## Initial value problems (IVPs)

For initial-value problems (i.e., when $A_t \neq 0$), the finite element approaches consist of (a) space-time decoupled methods and (b) space-time coupled methods. In space-time decoupled methods, space and time are treated nonconcurrently. In this approach stability of the computations is dependent on discretization characteristic length in space and the size of the time step. Also, decoupling space and time is contrary to the physics of most evolution problems. Nonconcurrent refinements in space and time and their impact on accuracy is generally difficult to quantify. In this approach time accurate evolution can neither be claimed nor achieved.

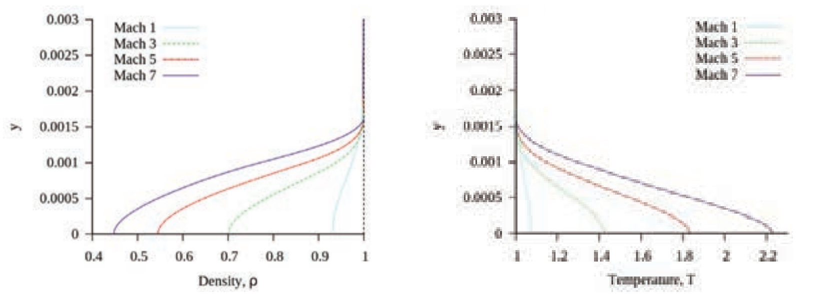
On the other hand, in space-time coupled methods concurrent dependence of all quantities of interest on space and time is preserved as dictated by the mathematical description and the physics.

The space-time differential operators can be mathematically classified over the space-time domain as non-self adjoint and nonlinear, but never self-adjoint due to open boundary at the final value of time. Considerations of space-time GM, PGM, WRM, GM/WF, and LSP or LSM methods of approximation follow similar approach as described for boundary value problems. Correspondence of the space-time integral form to elements of the calculus of variations and the space-time Euler equation establishes space-time variational consistency (STVC) or spacetime variational inconsistency (STVIC) of the integral forms. Only STVC integral forms yield unconditionally stable computational processes. Surana and Reddy [19] have shown that only space-time LSP or LSM based on space-time residual functional yields STVC integral forms for both classes of differential operator. All other space-time methods of approximation result in space-time integral forms that are space-time VIC. It can be shown that for IVPs the space-time domain and the space-time strip or slab for an increment of time are mathematically equivalent. Thus, the computations can be performed using space-time integral form for an increment of time and then time-marched to calculate the entire evolution. This is computationally efficient and provides control over accuracy, that is, we only march in time when the integrated sum of squares of the spacetime residual functional is within the acceptable value (see [20–28] for details on $k$- version for initial value problems and space-time coupled methods and their applications). The choice of the minimally conforming order of inner product approximation space in space and time is dictated by the highest order derivatives of the dependent variables in space and time ($k$- version in space and time). In this approach unconditional stability is ensured and time accurate evolutions are possible. All other benefits described for BVPs can also be realized for IVPs as well.



*(a) Mach 1* *(b) Mach 3* *(c) Mach 5* *(d) Mach 7*

***Figure 1:***
*Density contours for Mach 1, 3, 5, and 7*




*(a) Density ρ versus $y$ at $x$ = 2.0* *(b) Temperature $T$ versus $y$ at $x$ = 2.0*

***Figure 2:***
*Outfow conditions for Carter's plate at Mach 1, 3, 5, and 7*

## Model problems

### *High speed compressible flow over flat plate (Carter's plate)*

Here we consider flow of air over a flat plate at Mach numbers 1, 3, 5, and 7 (see [29]). The dimensionless length of the plate is two units. The mathematical model consists of compressible Navier-Stokes equations with standard constitutive theories for deviatoric stress and heat vector (Newton's law of viscosity and Fourier heat conduction law). Ideal gas law is assumed for the equation of state. The domain $\bar{\Omega}$ =(2×0.005) is discretized using a 21 × 10 graded mesh of nine-node $p$- version hierarchical elements. Constitutive relations for stresses and heat vector are substituted in the momentum and energy equations, giving rise to second-order spatial derivatives of velocities and temperature. Solutions of class $C^{22}$ in $x$ and $y$ are computed at $p$ = 7 both in space and time for each Mach number using Stokes flow as initial or starting solution in Newton's linear method. For all Mach numbers, $I(\phi_h)$ of the order $O(10^{-6})$ or lower is achieved, confirming good accuracy of the computed solutions. All integrals are Riemann over the discretization $\bar{\Omega}^T$. *Figure 1* shows color contours of density $p$ for Mach numbers 1, 3, 5, and 7. With progressively increasing Mach number, significant density variations over progressively increasing range is observed as expected. *Figure 2* shows density and temperature (due to viscous heating only) as functions of distance $y$ at the exit ($x = 2$). At Mach 7, the density at the plate drops from free stream value of 1 to 0.4, while the temperature $T$ rises from free stream value of 1 to 2.2. Solutions are smooth, $I(\phi_h)$ values $O(10^{-6})$ or lower, and Riemann integrals over $\bar{\Omega}^T$ ensure accurate computed solutions.

### *Evolution of a double shock at $Re$ = 1,000*

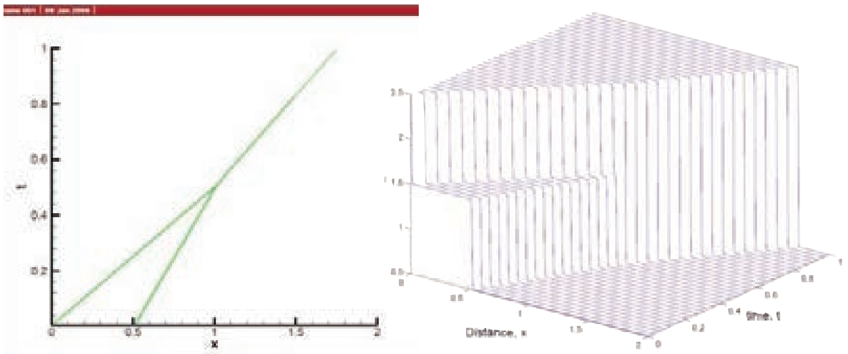
Two shocks initiate due to BC ($\phi$= 1.5 at $t$ = 0, $\phi$ = 2.5 at $t \leq 0$) and IC ($\phi$ = 1.5 for $0 \leq x \leq 0.5$, $\phi$ = 0.5 for $x > 0.5$) in continuous and differentiable manner over small time increment and spatial length that propagate at different speeds (BC shock being faster than IC shock). These shocks interact and form a single shock that propagates [see *Figures 3 (a) and (b)*] [26]. Computed solutions are of class $C^{11}$ in space and time for a first order system; $I(\phi_h)$ values for $\bar{\Omega}^T_{xt}$ less than or equal to $O(10^{-8})$ are achieved for each space-time strip in the space-time LSP. A Reynolds number of 1,000 is considered. A hundred-element uniform discretization ($\Delta x$ = 0.01) is used for a space-time strip with $\Delta x$ = 0.005 (all quantities are dimensionless). Smooth and accurate evolution (due to low $I$ values) is observed. STLSP is used for a space-time strip with time-marching. Upwinding or any other adjustments are not used.

### *Transonic shock at $Re$ = 1,000*

Here we use BC: $\phi(0,t)$ = -0.5;
IC: $\phi(x,0)$ = -0.5 for $-1 \leq x \leq 0$, $\phi(x,0)$= 2.5 for $x > 0$. All data are continuous and differentiable over small element lengths in time and space. Computations are performed using STVC space-time integral forms (STLSP) with time-marching. Contours of solution $\phi_h$ and profiles of $\phi_h$ in $x$-$t$ domain are shown in *Figures 4 (a) and (b)*. The space-time integrals are Riemann and the $I(\phi_h)$ values for each space-time strip are $O(10^{-8})$ or lower confirming accurate evolution [26]. Upwinding or any other adjustments are not used.

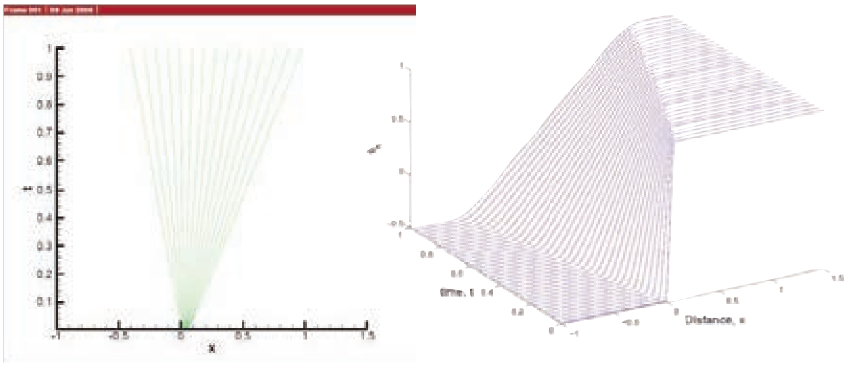
### *Riemann shock tube: 1D normal shocks in air*

We consider pressure the ratio $P_h/P_l$ =(7.58/0.88); $P_l$ = 0.88 for $-1.0 \leq x \leq 0$, $P_h$ = 7.58 for $0 \leq x \leq 1.0$, and ideal gas law. Initial temperature $T$ = 1 with reference $T_0$ = 410.52 K. Diaphragm is located at $x$ = 0 and is assumed to rupture at $t$ = 0. This initiates compression waves from right to left which pile up to create a shock. Computations are performed using STVC space-time integral forms (STLSP) for an increment of time (space-time strip) with time-marching. Upwinding methods are notused. Sustained rate of entropy production shown in *Figure 5(a)* proves the existence of shock during evolution.



*(a) Contours of $\phi_h$ in $x$-$t$ domain* *(b) Profiles of $\phi_h$ in $x$-$t$ domain*

***Figure 3:***
*Contours and profiles of $\phi_h$ in $x$-$t$ domain for a double shock at $Re$ = 1000*

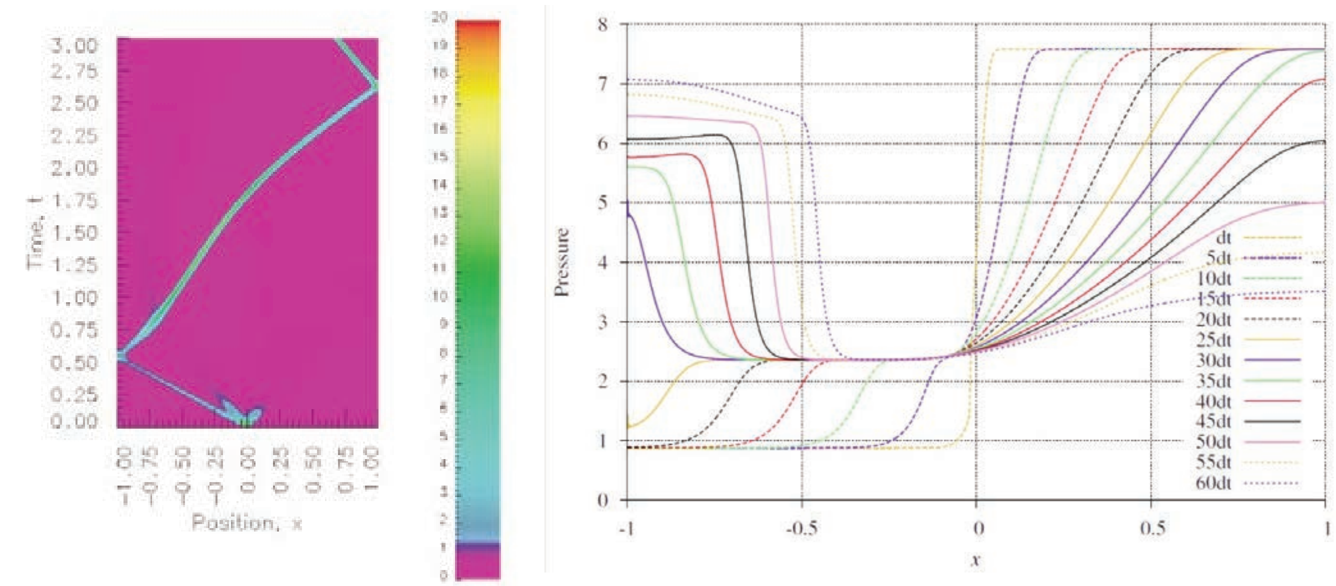


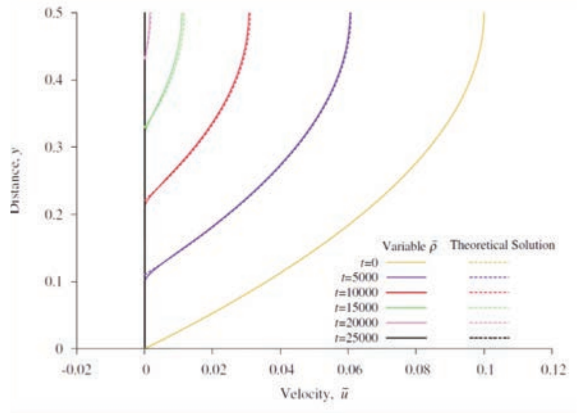
*(a) Contours of $\phi_h$ in $x$-$t$ domain* *(b) Profiles of $\phi_h$ in $x$-$t$ domain*

***Figure 4:***
*Contours and profiles of $\phi_h$ in $x$-$t$ domain for a transonic shock at $Re$ = 1000*

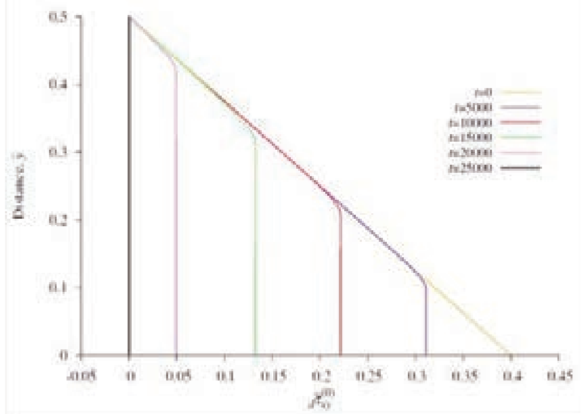
***Figure 5:***
*Riemann shock tube*

*(a) Contour of rate of entropy production* *(b) Evolution of pressure (60 time steps)*

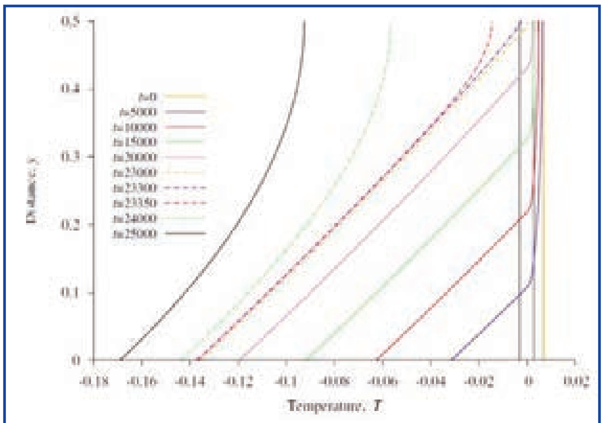





*(a) Evolution of velocity $\bar{u}$ versus $\bar{y}$*




*(b) Evolution of ${}_d\bar{\tau}_{xy}$ versus $\bar{y}$*




*(c) Evolution of $\bar{T}$ versus $\bar{y}$*

***Figure 6**:*
*Phase transition:*
*fully developed flow between parallel plates*

The shock propagates from $x$ = 0 to the left following a straight line path (compression of virgin medium). Reflection occurs at the impermeable boundary at $x$ = -1.0 and the reflected shock propagates toward the right in non-straight line path as it is propagating through already compressed medium. Another reflection occurs when the shock reaches the right impermeable boundary at $x$ = 1.0. Evolution of pressure for sixty time steps is shown in *Figure 5(b)*. Sustained pressure wave propagating to left from $x$ = 0 and clean reflection of the pressure wave from the boundary at $x$ = -1.0 is clearly observed. The rarefaction continues to occur in $0 \leq x \leq 1$. The solutions are of class $C^{11}$ in space and time for a first-order system of PDEs in space and time, hence Riemann integrals over discretization of each space-time strip; $I(\phi_h)$ values of $O(10^{-6})$ or lower for each space-time strip confirm accurate evolution (see [20–22, 27, 28] for more details).

### *Evolution of phase change: Fully-developed flow between parallel plates*

We consider evolution of phase change for fully developed flow of water between parallel plates [30]. Plates are cooled, hence solidification initiates at the plates and propagates inward towards the center of the flow. The mathematical model zero or constant shear stress in the solid region. Due to symmetry, lower half of the domain ($0 \leq y \leq 0.5$) between the plates is considered. The flow is pressure driven, that is, $\frac{dp}{dx}$ is fixed. *Figures 6 (a), (b), and (c)* show evolutions of velocity $\bar{u}$ deviatoric shear stress ${}_d\bar{\tau}^{(0)}_{xy}$ and temperature $\bar{T}$ for $0 \leq t \leq 25{,}000$. All quantities are dimensionless. At $t$ = 0, commencement of the evolution, parabolic velocity profile, linear shear stress, and uniform temperature (slightly higher than 0) are observed. At $t$ = 5,000 about one fourth of the modelled domain is frozen, which alters the velocity field, reduces flow rate, produces constant shear stress in the frozen region and, of course, the temperature drops. At $t$ = 10,000 almost half of the domain is frozen.

Upon continued freezing the velocity reduces, flow rate diminishes, shear stress in the solid portion remains constant but progressively reduces. At $t$ = 25,000 the entire domain is frozen with zero velocity, zero shear stress, and smooth temperature distribution, with lowest value at the wall and the maximum at the center of the flow. This problem demonstrates the power of higher order spaces, VC space-time integral forms, and the resulting unconditional stability of the evolution. Computations are performed using STVC STLSM for an increment of time (space-time strip) with time-marching without the use of any upwinding methods. ●

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# Notes on Finite Element Modeling

by
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*September 2015*

*"Since finite element models do not support error estimation, they are not suited for supporting design and certification decisions either."*

It is important to make a clear distinction between numerical simulation and finite element modeling:

1. In numerical simulation an *idea* of a physical reality is precisely stated in the form of mathematical equations. Model form errors, uncertainties in input data, and the errors of numerical approximation are estimated and controlled separately. This is possible only if the underlying mathematical problem (such as a problem of continuum mechanics) is well posed and the numerical problem satisfies the requirements of consistency and stability.

2. In finite element modeling, on the other hand, a numerical problem is constructed by piecing together elements from the element library of a finite element analysis (FEA) software product *without providing evidence* that the underlying mathematcal problem is well posed and the numerical problem satisfies the requirements of consistency and stability. Therefore, we cannot assume that the quantities of interest converge and their numerical errors can be estimated.

In the following we consider the practice of finite element modeling in structural engineering, with reference to finite element models of airframes constructed with the purpose to estimate loads carried by the principal structural elements [1].

A finite element model of an airframe can be viewed as a model of a three-dimensional linearly elastic frame structure. The geometric configuration of the structure approximates the geometric configuration of the airframe. The stiffness and mass of the components are approximated by assemblies of the stiffness and mass matrices of one- and two-dimensional finite elements and rigid or flexible links The components are chosen so as to approximate the structural stiffness and mass of the components of the airframe such as spars, spar caps, ribs, skin, etc.

The frame is loaded by forces applied at the nodes. The applied forces satisfy the equations of static equilibrium for the entire structure. The frame is statically indeterminate internally and therefore the distribution of internal forces depends on the structural stiffness and connection details of its components. The quantities of interest (QoI) are the nodal forces and moments. Using the QoI the principal structural elements are isolated as free bodies for detailed strength and durability analyses on the basis of which design and certification decisions are made.

The construction of the finite element model for an airframe is a large undertaking [2]. A number of ad hoc decisions are incorporated in the finite element model. Also, there are known errors, such as; many structural and geometric details are neglected, shell elements are used in regions where the assumptions incorporated in shell theories do not hold, reconciliation of degrees of freedom among different element types may violate the requirement of continuity or impose unnecessary constraints, etc.

Since finite element models are not approximations to the solutions of well-defined mathematical problems, the question of why it is possible to obtain credible results from finite element models deserves consideration. The apparent credibility of results stems from the following:

1. Finite element models have the property that computed nodal forces acting on the boundaries of any element or group of elements satisfy the equations of static equilibrium. Many analysts mistakenly believe that this is an indication of solution

[1] *A principal structural element is an element of structure that contributes significantly to the carrying of flight, ground and pressurization loads and whose integrity is essential in maintaining the overall structural integrity of the aircraft. Principal structural elements include all structures susceptible to fatigue cracking, which could contribute to a catastrophic failure. (FAA AC No: 25.571-1D).*

[2] *See, for example, http://web.mscsoftware.com/support/library/conf/auc97/p00497.pdf*

quality. However, equilibrium of nodal forces is satisfied independently from the finite element solution as long as the elements can represent rigid body displacement and rotation modes. Therefore, equilibrium of nodal forces is *not* an indication of solution quality at all [3].

2. The conceptual errors in finite element modeling are not clearly visible because there are similarly large errors of approximation. To see that the quantities of interest are divergent, it would be necessary to use sequences of progressively refined finite element meshes much finer than what is used in engineering practice.

3. Finite element models are "tuned" to match known outcomes of experiments. Tuning is nothing more than covering up model form errors with nearly compensating errors in numerical approximation. This is a dangerous practice because a finite element model tuned to match the observable results of an experiment cannot be assumed to be similarly tuned or remain tuned for other quantities of interest, configurations and load cases. Note that the main purpose of the finite element model of an airframe is to support strength and durability calculations for multiple load cases.

4. When the goal is to evaluate the relative merit of two or more competing designs from the perspective of structural response (structural stiffness and the lowest natural frequencies) then reasonable conclusions may be drawn from finite element models because the errors affect each finite element model in roughly the same way.

For the reasons stated under items 2 and 3, substantial uncertainties are introduced into the load models of principal structural elements through the practice of finite element modeling. The estimation of these uncertainties is not possible by analytical means because finite element models, having been formulated outside of the rules governing the formulation of mathematical models, preclude the application of error estimation procedures. These uncertainties directly affect the predicted margins of safety.

Similar considerations apply in automotive engineering where tuned finite element models are used for the prediction of crashworthiness parameters. The discrepancies between predictions based on finite element models and the outcomes of crash tests are treated as random variables called "bias" [4].

**Important corollary:** Finite element models are not suited for supporting design and certification decisions. This is because design rules are stated in the form:

$$F_{max} \le F_{all}$$

where $F_{max}$ is the maximum value of a computable quantity (QoI) and $F_{all}$ is its allowable value. The design rules may also specify the mathematical model to be used.

Application of design rules involves solution verification and data verification. Since $F_{max}$ is approximated by numerical means, only an approximation to $F_{max}$ is available which we denote by $F_{num}$.
We need to ask: Under what conditions is it justified to replace $F_{max}$ by $F_{num}$? Suppose we can say only that the accuracy of the numerical approximation can be guaranteed to be:

$$| F_{max} - F_{num} | \le \tau F_{max}$$

where $\tau$ is the relative error. Designers and certifiers of design are obligated to consider the worst case scenario, which is underestimation of $F_{max}$:

$$F_{num} = (1 - \tau) F_{max}.$$

The design rules require $F_{max} \le F_{all}$, however since we know only $F_{num}$ and its error bound we have to show that:

$$F_{num} \le (1 - \tau) F_{all}.$$

This demonstrates that:

a) Numerical errors penalize design: $F_{all}$ is set by authorities responsible for formulating and approving design rules, taking into account aleatory uncertainties and model form errors in a conservative manner. Therefore $F_{all}$ is already set at a low value. Further lowering $F_{all}$ on account of numerical errors imposes a penalty on design that can be eliminated through the application of properly formulated numerical simulation procedures.

b) It is essential to have a reliable estimate of the size of the numerical errors in terms of the quantities of interest, otherwise the design rules could be violated: It is not sufficient to report a computed number, it is necessary to estimate the value of the relative error ( $\tau$ ) as well. Since finite element models do not support error estimation, they are not suited for supporting design and certification decisions either. ●

[3] *Even if the computed nodal displacements were to be replaced by numbers from a random number generator, the equations of equilibrium would be satisfied. See Szabó B. and Babuška I., Introduction to Finite Element Analysis: Formulation, Verification and Validation. John Wiley & Sons, Chichester 2011.*

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# Raising Women's Profile in Computational Mechanics:

## Women Researchers' Forum at USNCCM

by
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During the 13th US National Congress on Computational Mechanics, in San Diego, CA. the Women Researchers' Forum met for a panel discussion on the evening of Tuesday the **28th July 2015**. This event was sponsored by Elsevier and supported by the local organizing committee chaired by Professors Yuri Bazilevs and Dave Benson of the University of California, San Diego. The invitation was open to all women attending the USNCCM13, approximately 40 women of all nationalities and all career stages gathered to meet and share experiences. The opening addresses were given by Professor Antonio Huerta, IACM Secretary General and Professor Somnath Ghosh, USACM President. Both gentlemen expressed their societies' strong support for raising women's profiles in the computational mechanics community and for increasing women researchers' participations through USACM Technical Thrust Areas (TTA).

***Figure 1:*** *Entrance Poster for the Event*


The panel consisted of three researchers each from a different career stage and background: **Professor Lorraine Olson**, the Department Head for Mechanical Engineering at Rose-Hulman Institute of Technology and an ASME fellow with a particular passion for undergraduate education. **Dr. Rekha Rao**, a chemical engineer at Sandia National Laboratories, Albuquerque, with research interests in computational fluid dynamics and coupled multiphysics including non-Newtonian rheological models. **Dr. Yongjie Jessica Zhang**, Associate Professor at Department of Mechanical Engineering, Carnegie Mellon University and the chair of Isogeometric Analysis TTA.

The panel discussion began with each panelist giving a brief introduction of themselves and their career paths. As each discussed her career path, many questions arose relating to work-life balance. The specific challenges in managing demands of family and care-giving responsibilities with research were discussed, some practical tips were given, and geographic employment law differences were discovered. The issues such as a "two-body problem" and funding opportunities for returning after a significant childcare break (e.g. Daphne Jackson Fellowship in the U.K.) were discussed, although such funding opportunities seem rare in the U.S.

The lack of confidence and imposter syndrome, often associated with women professionals, was also raised. This is a well-known social phenomenon that is experienced at all levels. Studies have shown that imposter syndrome is commonly reported in high-achieving women, graduate students and academics in science, so perhaps it is not surprising that many identified this phenomenon in themselves.

Several other issues, career progression and how to increase women's interest in STEM throughout the career stages resulted in lively discussions.

The principal take away being: Yes, there are formal provisions in place to provide equal opportunities for women however there is a prevailing undercurrent of gender bias experienced (to varying degrees) at all stages of the women researchers' career from academic studies through tenure.

One very specific concern raised was the negligible representation of women at the senior leadership level in the computational mechanics communities such as female plenary/semi-plenary speakers and committee members. In immediate response to this concern, the local organizing committee of the World Congress on Computational Mechanics (WCCMXII) has decided to invite two women plenary/semi-plenary speakers for Seoul in 2016. They have also invited us to hold another Women Researchers' Forum during WCCM which Elsevier has once again agreed to sponsor.

At the general level activities such as mentorships for junior women, financial support for women to attend conferences, and engaging women members in leadership roles are well-supported. Thanks to Professor Wing Kam Liu and the IACM Executive Council and Professor Somnath Ghosh and the USACM Executive Council for their ongoing commitment to continuing these long term endeavors.

Most encouraging was the acknowledgment that while intangible the reality is women have a lower profile in computational mechanics, likely in all fields of STEM. Resolution of which require new efforts and collaboration to affect a palpable change. We regard this summer evening in San Diego to be the first step to address the issue constructively and collectively move forward towards a more balanced community.

For further information or to contribute towards the activities or for those who wish to attend the WCCM Women Researchers' Forum in 2016, please contact Dr. H Alicia Kim, alicia@ucsd.edu. ●

***Figure 2:***
*The opening address at the Women Researchers' Forum given by Professor Antonio Huerta*


***Figure 3:***
*The Women Researchers' Forum Panel: Dr. Yongjie Jessica Zhang, Dr. Rekha Rao, Dr. Lorraine Olson and Dr. H Alicia Kim (moderator)*

***Figure 4:***
*A relaxed and attentive view of delegates attending the Women Researchers' Forum*

# A Simple, Robust and Versatile Shell Finite Element

by
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*" Two central ideas were the guidelines in all of our developments ... the shell kinematical model be as simple ... as possible, and that the related discretization be robust and versatile. "*

## Introduction

Shell structures (which, in a broad sense, include plate and membrane structures) are observed in a myriad of natural structures and engineering applications. Curved roofs, vessels, solar panels, structural fabrics, nautical sails, vehicle and aircraft fuselages, ship hulls, thin biological tissues (both natural and artificial), thin films, citing just a few. They are all examples of shell structures and their presence in man´s life. The study of these types of structures is a classical activity in mechanics and dates back from the works of Mlle. Sophie Germain, G. R. Kirchhoff and Lord Kelvin still in the nineteenth century. In the last fifty years or so, its combination with numerical techniques for the solution of differential equations – like the finite element method – has boosted a solid and sustained advancement in the field, allowing for the appearance of innumerous theories and formulations. We may say that the study of such thin structures has left the domain of pure mechanics to enter that of computational mechanics, and it is not exaggeration to say that its maturity is not far from today. The appearance of reliable, general shell formulations with robust numerical discretizations for arbitrarily large deformations, though, is relatively recent in the literature. We cite the contributions of J. C. Simo and coworkers in the early 1990s as the pioneers on this regard, in our opinion. These were followed by several important works, which still continue to appear nowadays with (major or minor) specific advancements. This short paper outlines our contributions to the development of general shell models during the course of the last twenty years. It is not meant to be dogmatic nor comprehensive; instead, our purpose is merely to provide a summary of our thoughts and experiences in the field so far. Also, it is not meant to depict the state of the art in shell computational mechanics (for which case an enormous reference list would need to be included), but merely to provide a historical overview of our developments. We apologize for the hundreds (or even thousands) of other contributions on shells that will not be cited here.

### *The T6-3i shell element*

By the time J. C. Simo was first dealing with his shells, there appeared in 1993 the first contribution of our group on shells [1]. This work introduced the central ideas underlying our shell formulations and paved the way to all of our forthcoming contributions. It was centered on two key guidelines: (1) the kinematical model is to be based on a shell director and be as simple (yet general and consistent with Solid Mechanics) as possible and (2) the corresponding numerical discretization is to be robust and versatile. With this in mind, the model proposed therein was constructed with some important features, as described in what follows. First, the kinematics (of Reissner-Mindlin type, i.e. including first-order shear deformations) was based on the deformation gradient and its conjugated first Piola-Kirchhoff stress tensor, which renders cross-sectional stresses and strains that are nominal (engineering) quantities. This was a marked difference from all other models of the time (and indeed still of the majority of today´s models), which are based on second Piola-Kirchhoff stresses and Green-Lagrange strains. This aspect allowed us to work with a consistent plane stress condition, by enforcing it directly over the (nominal) transverse normal stress, instead of imposing it on the corresponding component of the second Piola-Kirchhoff stress tensor – which has no physical meaning. Second, the model was constructed with simple (and physically meaningful) degrees of freedom, namely, displacements and rotations of the shell director, allowing for a pure-displacement based formulation. No mixed or hybrid types of variables were adopted, nor complicated structures such as Euler angles or quaternions were present in the kinematical description. And third, the model introduced a fully exact expression for the linearization of its weak form, an aspect that was somewhat controversial at the time. Yet, [1] was a purely theoretical work, in the sense that no numerical scheme for solution of the corresponding boundary value problem was presented, but [2] presented numerical results for the similar case in rods. Only 10 years after, in [3], the model was implemented and fully tested. This was done by using the finite element method, for which a new shell element – the so-called T6-3i element, which bears its name to this section – was devised. The T6-3i soon became the base for several developments of our group. It may be described as a simple element having two major features: it is triangular, an aspect that is much desired for robust FEM simulations employing general unstructured meshes, and it is purely displacement-based, in the sense that no numerical techniques such as assumed natural strain (ANS), enhanced assumed strain (EAS) or reduced integration with hourglass stabilization are invoked in its formulation. It has six nodes and combines standard quadratic shape functions for interpolation of the displacement field with linear shape functions for interpolation of the rotation field, this latter being related to the mid-side nodes of the triangle only. This explains its name: "T" stands for triangle, "6" for the number of nodes for the displacement field, "3" for the number of nodes for the rotation field, and "i" implying it is an incompatible element w.r.t. the rotations. Interestingly enough, such incompatibility suffices to render the element locking-free in the thin-shell limit, allowing one to work with a full Gaussian quadrature for integration of the element´s stiffness matrix and unbalanced force vector (i.e., allowing for the use of three integration points at mid-side nodes), with no need of stabilization techniques. *Figure 1* illustrates some of the capabilities of the element as presented in that work.

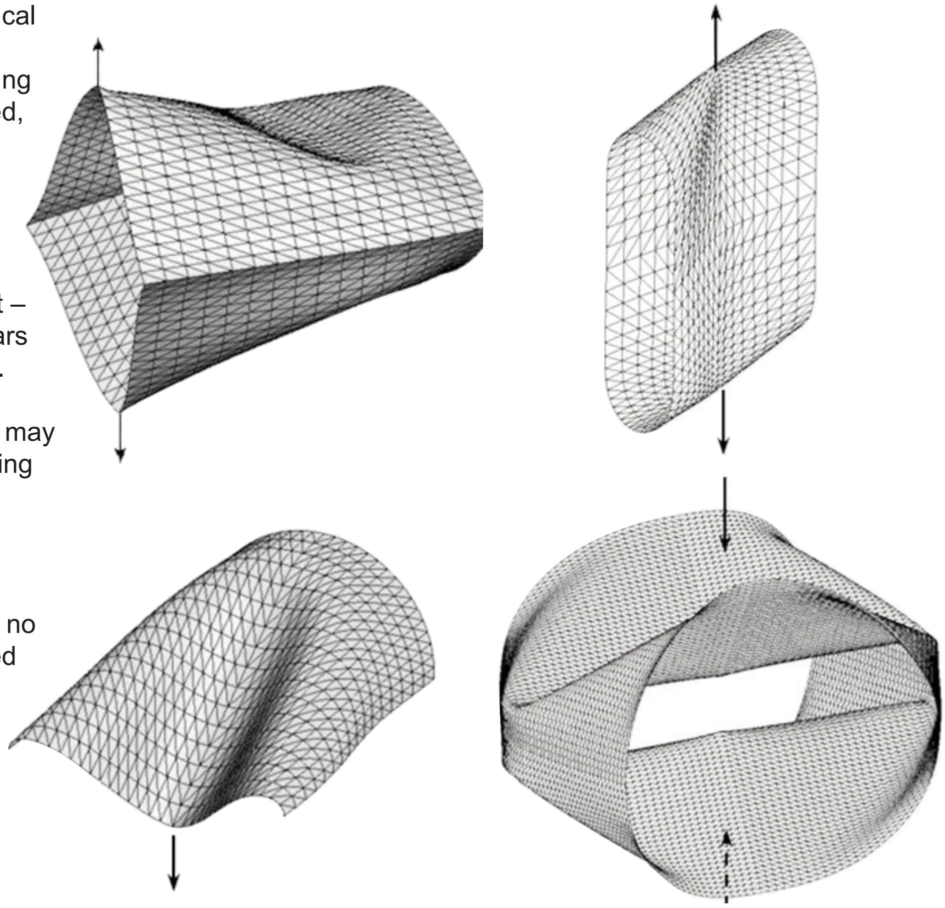
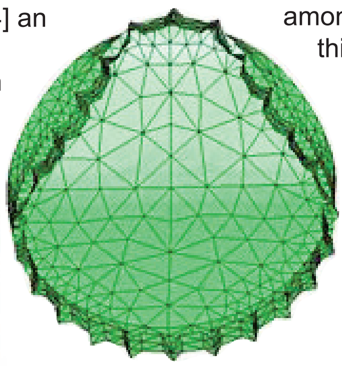


***Figure 1:***
*Some of the first results obtained with the T6-3i shell element, as published in [2]*

One year later, we presented in [4] an extension of the model of [1] to incorporate thickness deformation in the shell kinematics.

Differently from all other models that took thickness change into account at that time, we insisted in the pure-displacement concept and devised a kinematics with an enriched displacement field in the thickness direction, rendering a model with 8 degrees of freedom. By allowing for thickness change, however, the so-called thickness or Poisson locking appears, and again we did not resort to any numerical techniques to overcome it. Instead, the enrichment in the displacements proved to work well on this regard. The model was implemented in an extended version of the T6-3i, with the extra degrees-of-freedom being placed at the mid-side nodes only (the element, thus, rendered incompatible also w.r.t the thickness deformation). These developments permitted, among other things,

*Isometric View*



*Bottom View*

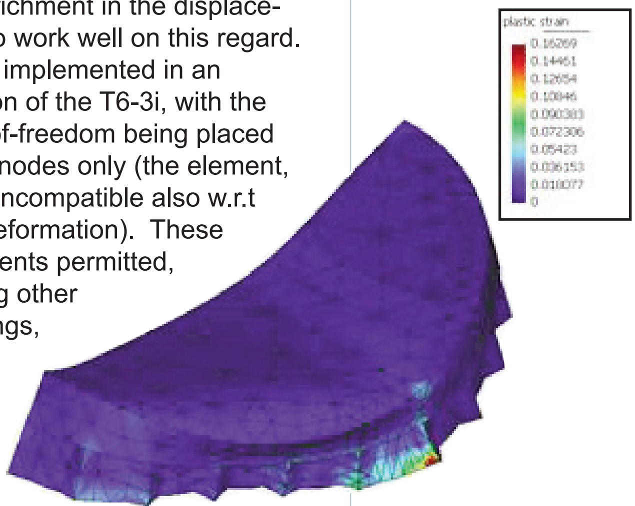



***Figure 2:***
*Elastoplastic deformation of a beer bottle cap (after opening)*

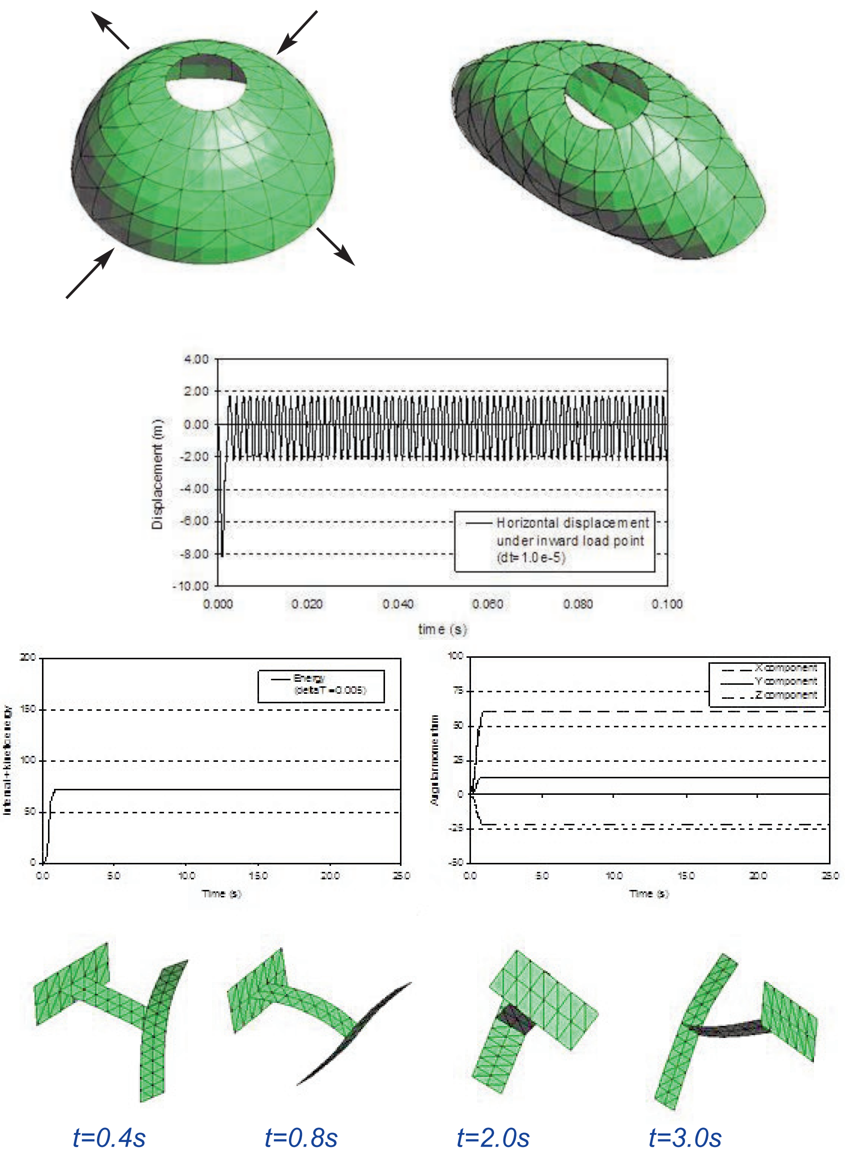



***Figure 3:*** *Vibration of a hemispherical shell (top) and dynamics of a flexible satellite structure (bottom)*

the consideration of fully three-dimensional constitutive models, i.e. constitutive models that do not need to enforce the plane stress condition, thereby facilitating the consideration of, e.g., elastoplastic materials in a more general way. By using this formulation, in [6] we proposed an elastoplastic constitutive model in the context of J2-plasticity. The model incorporates isotropic hardening and was based on the concept of a multiplicative decomposition of the deformation gradient together with a logarithmic description of the strains, allowing for finite metal plasticity in a very consistent way. A funny numerical example is displayed in *Figure 2*.

Simulation of transient dynamics problems involving arbitrarily large rotations and finite deformations was made possible with our work in [8]. Here we would like to remark that, to our knowledge, this was the first shell dynamics formulation to appear in the literature allowing for general hyperelasticity in a fully consistent manner, with exact energy and momentum conservation. The group of J. C. Simo tried to achieve that in [9], but as properly shown by T. Laursen in [11], they made a mistake in the linearization of their weak form, which in the end restricted them to work solely with materials of quadratic strain energy potentials in their examples. We, instead, have derived a fully consistent expression. This explains why, with our model, we could analyze the very same problems of [9] by using time steps as large as two orders of magnitude higher than [9], and yet attain perfect exact energy and momentum conservation. We found this to be an outstanding result of our formulation. Moreover, materials of more general potentials (i.e. other than quadratic) were permitted. *Figure 3* shows some results that we have obtained at that time. Two other aspects are still worth mentioning about this work. First is that we have adopted a very peculiar parameterization for the rotation field, by using the so-called Rodrigues rotation vector (see [10,5]). This yields an extremely simple update scheme for the rotation vector, involving only simple algebraic operations on the rotation vector instead of cumbersome manipulations on the rotation tensor, as customary. Second is that we have proposed an unusual projection scheme to construct the weak form of the shell, based on virtual velocities and virtual spins instead of virtual displacements and rotations. The resulting formulation may be seen as derived from a virtual power statement, instead of from virtual work arguments. Advantages from this are that the expression of weak form turns to be a little simpler, and an analytical proof of energy conservation for the time integration algorithm becomes straightforward. A unified approach for dealing with rods under the same framework as developed for shells was presented in [12].

More recently, we have presented a higher-order version of the shell theory in [14], aiming at describing the kinematics of composite and layered shells. Through these years, we also have worked on the development of a Kirchhoff-Love type of shell formulation. Some of our ideas can be seen in [13]. The Kirchhoff's constraint on the shell director poses an extra difficulty when dealing with finite rotations, and this has to be dealt with in a very particular way. See also [15,16].

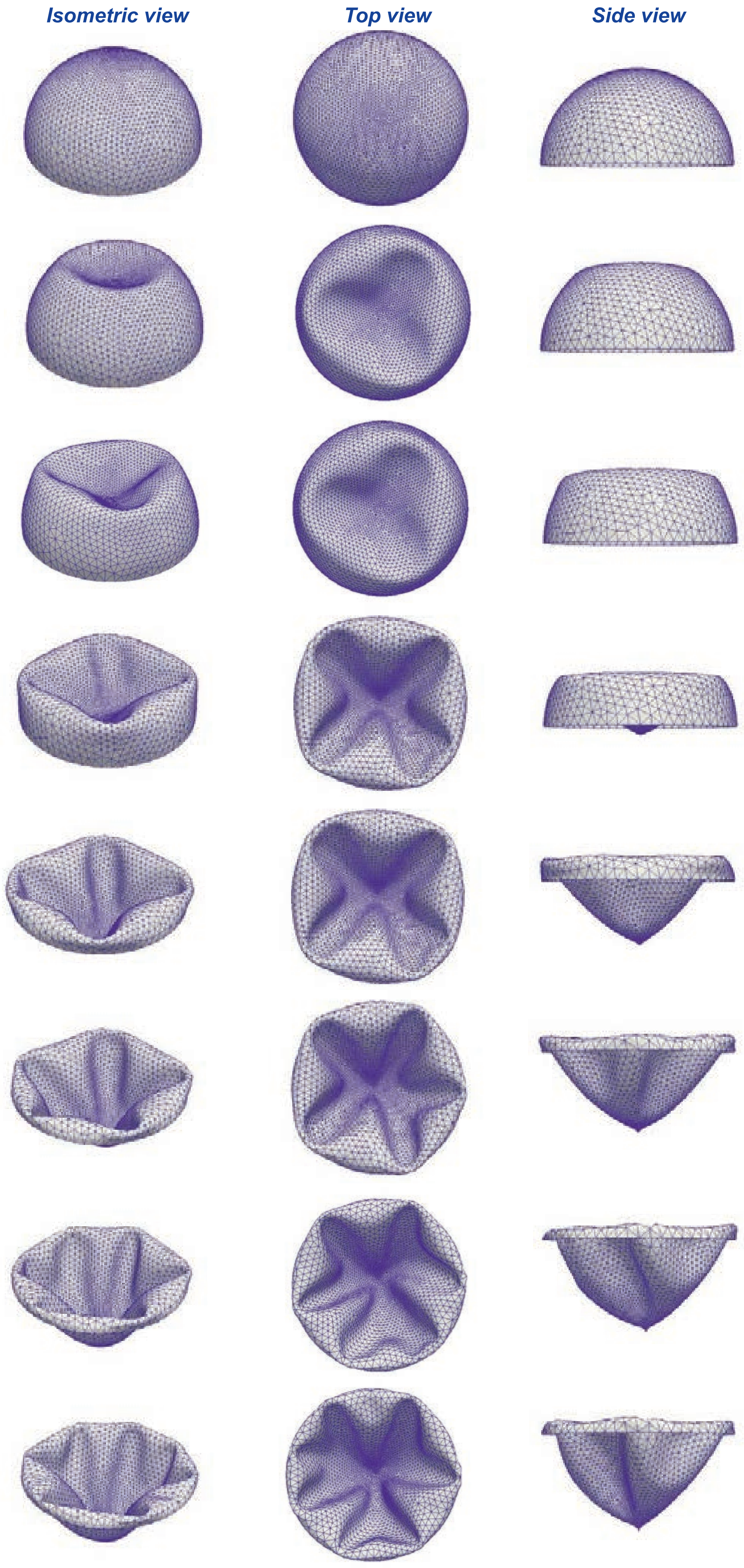



**Figure 4:**
*Snap-through of hemispherical joint*

*Time: 0.00*

*Time: 0.90*

*Time: 1.65*

*Time: 2.72*

*Time: 4.19*

*Time: 4.63*

*Time: 4.90*

*Time: 5.00*

Lately, we have been working in the development of innovative mechanisms for thin foldable structures. This has driven us to the simulation of an apparently simple problem, the (static and dynamic) snap-through of a hemispherical shell, as depicted in *Figure 4*. The material here (polyvinyl siloxane) is such that very large deformations combined with large strains are to be observed, which in turn are accompanied by the occurrence of several local snaps throughout the motion. We have analyzed the problem with different commercial FEM software, but none were able to reproduce the laboratory results (namely, the load-displacement curve). The simulations with the T6-3i, on the contrary, rendered results that are in excellent agreement with the physical tests (see also the video in **https://drive.google.com/file/d/0B3qp5xnMA_-cLXNnVjgxOW5lTGc/view?usp=sharing**

## Closing remarks

The development of finite elements for general shell applications has been a matter of research for many decades now. As said above, shell structures have lately left the domain of pure mechanics and entered that of computational mechanics, with innumerous important advancements being achieved since the time of the early pioneers of the nineteenth century. In this short paper, we have attempted to outline the contributions of our group to the field during the last twenty years. Two central ideas were the guidelines in all of our developments, namely, that the shell kinematical model be as simple (yet fully consistent) as possible, and that the related discretization be robust and versatile. We believe that, by having developed elements that are triangular and purely displacement based, which proved to work in the fully nonlinear regime in both static and dynamic applications, we have been able to give a short contribution to the already classical (but still fascinating) field of shells. ●

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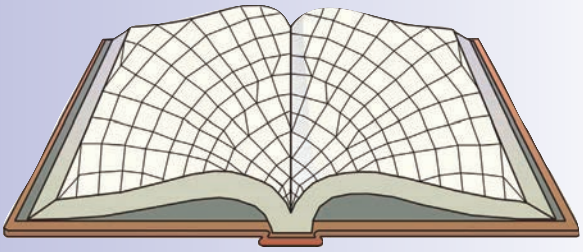
# THE METHOD OF WEIGHTED RESIDUALS AND VARIATIONAL PRINCIPLES, 2ND ED.



**_Bruce A. Finlayson_**
*SIAM, Philadelphia, PA, USA, 2014*

BOOK REVIEW

*ISBN: 978-1-611973-23-5, 412 pages, soft cover, $99 (List Price).*

*Contents: Preface to the Classics Edition; Preface; Acknowledgments; Part I: The Method of Weighted Residuals; 1: Introduction; 2: Boundary-Value Problems in Heat and Mass Transfer; 3: Eigenvalue and Initial-Value Problems in Heat and Mass Transfer; 4: Applications to Fluid Mechanics; 5: Chemical Reaction Systems; 6: Convective Instability Problems; Part II: Variational Principles; 7: Introduction to Variational Principles; 8: Variational Principles in Fluid Mechanics; 9: Variational Principles for Heat and Mass Transfer Problems; 10: On the Search for Variational Principles; 11: Convergence and Error Bounds; Author Index; Subject Index.*

This book is included in the SIAM series “Classics in Applied Mathematics.” According to SIAM, the purpose of this book series is to re-publish “monographs and textbooks declared out of print by their original publishers, though they are of continued importance and interest to the mathematical community. SIAM publishes this series to ensure that the information presented in these texts is not lost to today’s students and researchers.” A few of the books in the series have been revised with respect to their original form. The book reviewed here is not one of them; it is identical, word by word, to the original, which was published in 1972 by Academic Press.

This is the second time that I am reading this book. The first time was many years ago, when I was a PhD student. Two things in particular have left an impression on me from this first reading: the unified presentation of various weighted residual methods, and the technique that enables one to construct a variational principle for a problem involving *any* differential operator. We shall return to these issues below.

The book consists of two parts: Part I on weighted residual methods and Part II on variational principles. In both cases, the applications are taken solely from the field of fluid mechanics and heat and mass transfer. The reason is probably that these are the applications that are close to the heart of the author, who is a professor emeritus of chemical engineering at the University of Washington. From a historical perspective, this emphasis is interesting and slightly strange, since variational principles and formulations and methods of weighted residuals, and in particular the Finite Element Method (FEM), flourished in the years following the book’s original publication especially in solid and structural mechanics.

In contrast to what the reader might expect, the main themes of this book are not strongly computational in nature. In fact, it seems that the use of computers to solve complicated problems by numerical methods was still in its infancy in 1972 in the chemical engineering

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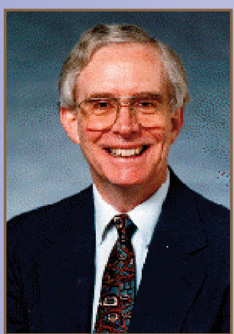
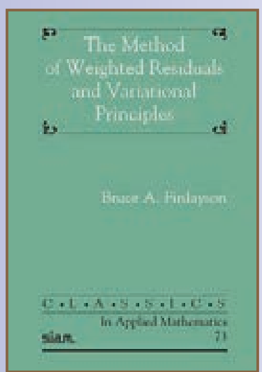


*Bruce A. Finlayson*



community, unlike, for example, the situation in civil engineering departments at Swansea, Stuttgart or Berkeley at the time. It seems that the author is not much interested in "heavy computing," and that the book is problem-driven rather than method-driven. There are not many numerical examples in this book, and those that are presented are mostly miniature. In many cases, a semi-analytical form of the solution is assumed, and when a series solution is attempted, usually only the first two or three terms (sometimes only the first!) are taken into account.

Results are given almost exclusively in small numerical tables. There are only a few figures in the book; nevertheless it is readable and pleasant to the eye. A few nice historical comments are written as footnotes. Each chapter ends with exercises, which cover the material well but which I did not find very exciting, and a list of references.

Chapter 1 devotes 4 pages to a general presentation of Weighted Residual (WR) methods. To use the book's notation, in these methods the solution $T(x)$ assumes the form

$$T = T_0 + \sum_{i=1}^{N} c_i T_i$$

and to find the unknown coefficients $c_i$ one has to solve a system of equations of the form

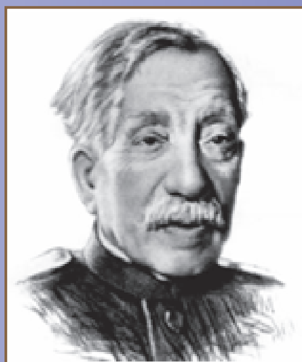
$$(w_j , R) = 0 \ , \ j=1 , .... , N.$$

Here the $w_j$ are weighting functions, and $R$ is the residual of the original equation after the series above for $T$ is substituted. Different WR methods differ in the choice of the weighting functions $w_j$. This is discussed in the text, but here I summarize the main results in *Table 1.* This sort of unification of WR methods was originally proposed by Crandall in 1956.

| WR Method | Weighting func's $w_j$ | Inventor |
|---|---|---|
| (Bubnov-) Galerkin | $T_j$ | Bubnov & Galerkin, 1913 |
| Subdomain method | $\chi_{\Omega j}$ | Biezeno & Koch, 1923 |
| Least Squares | $\partial R / \partial c_j$ | Picone, 1928 |
| Collocation | $\delta(x - x_j)$ | Slater, 1934 |
| Petrov-Galerkin | $\tilde{T}_j$ (different than $T_j$) | Petrov, 1940 |
| Method of Moments | $x^{j-1}$ | Yamada, 1947 |

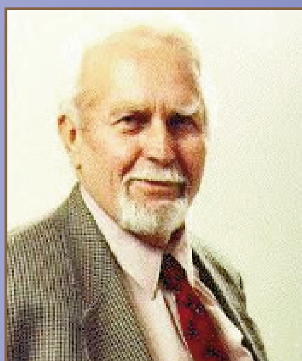
***Table 1:*** *Various WR methods, their weighting functions and their inventors. This table is not found in the book, but the text discusses all these methods, except Petrov-Galerkin methods*

Chapters 2-6 apply these various methods to a large variety of problems in fluid mechanics and heat and mass transfer. These chapters also include some general techniques, but they are always presented in the context of a specific application. For example, in Chapter 3, on eigenvalue and initial-value problems in heat and mass transfer, the author shows the use of Laplace's transform in the $z$ direction, followed by the use of the Galerkin method in the $r$ direction, then followed by the inverse transform. And in Chapter 5, on chemical reaction systems, a surprise! The Finite Element Method (FEM) appears for the first time, and is discussed on 5 pages. The early work of Zienkiewicz is cited. A numerical example is given with a mesh, called here "array," of 8 linear triangular elements, and the resulting equations are compared to those obtained by finite differences. The conclusion (p. 143) is that "with the regular array, the FEM gives results which are identical to the finite difference method. Other arrays are not necessarily equivalent." The chapter ends with a statement: "FEM … is one method of MWR which is becoming increasingly important in engineering fields, particularly in structural analysis." It is hard to dispute with this statement!



*Boris Galerkin*

Part II discusses variational principles. It starts, in Chapter 7, with a short summary of the calculus of variations. Then some simple examples of variational principles are given, for steady-state heat conduction and laminar flow in ducts. Sections 7.6-7.8 discuss the important topic of bounds (called here "enclosures") of eigenvalues via variational principles, as developed originally by Courant and Hilbert. The idea of the "reciprocal variational principle" (p. 219) is useful, since it allows one to obtain both a lower and an upper bound. In elasticity (not discussed at all in this book) we are familiar with a principle of this kind, namely the principle of complementary energy.



*Olek Zienkiewicz*

Chapters 8-10 discuss variational principles associated with various applications, but as before, some general issues are treated in passing. Chapter 8 includes the proof of Milikan that there is no variational principle associated with the Navier-Stokes equations.

Leonhard Euler

Chapter 9 includes an interesting discussion on the necessary and sufficient condition under which a problem has a variational principle (answer: it has to be self-adjoint). Also, the author shows how one can circumvent this condition in order to construct a variational principle for *any* problem, even if it is not self-adjoint. Three tricks are presented to this end. The first one is based on multiplying the equation by a certain unknown function, and determining this function such that the form of the equation becomes self-adjoint. What is not mentioned in the text is the fact that this trick is usually not applicable for problems other than in 1D. The second trick is based on replacing the original equation $Lu = f$ by the higher-order self-adjoint equation $L^*Lu = L^*f$, where $L^*$ is the adjoint operator. The third and most general trick is based on accompanying the original equation by its adjoint, and viewing both equations as one larger self-sdjoint system of equations. This can always be done, even with nonlinear non-self-adjoint equations like the Navier-Stokes equations.

Pierre Louis Maupertuis

I find it helpful to demonstrate this by a simple algebraic example (not given in the book), where self-adjointness means matrix symmetry. Consider the linear system of algebraic equations $Kd = F$, where $K$ is a non-symmetric matrix. Define the new variable $a$ which satisfies the "adjoint equation" $K^Ta = -Sd$ , where $S$ is a symmetric matrix. Then the two equations can be written together in the matrix form

$$\begin{pmatrix} S & K^T \\ K & 0 \end{pmatrix} \begin{Bmatrix} d \\ a \end{Bmatrix} = \begin{Bmatrix} 0 \\ F \end{Bmatrix}$$

This is a symmetric system, and hence a variational principle may be constructed for it.

The author points out (p. 312) that such "forced" variational principles, for problems which are originally non-self-adjoint, "are purely mathematical constructs and may have no physical meaning." However, the author does not relate to a significant *computational* disadvantage of such a principle, namely that it leads to a discrete problem which is larger by a factor of 2 than the original problem, with a matrix that has a more complicated sparse structure. In addition, questions arise on the appropriate spaces to be used for the primary and adjoint variables, which would guarantee stability. These are the main reasons why such variational principles have rarely been used in practice.

Ekkehard Ramm

This discussion has reminded me of a philosophical question that sometimes arises in the context of variational formulations: which is the more fundamental way to describe nature – via differential equations ("strong forms") or via variational (minimum or maximum) principles? As mentioned on p. 335, Euler wrote in 1744 about his belief that nature is governed solely by extremum principles. His argument was partially theological: "The universe… being the handiwork of an all-wise maker…" The fact that most problems do not possess a "natural" variational principle seems to show that Euler's belief was incorrect, although one may argue that differential equations on the macro scale describe phenomena that actually occur on a much smaller scale (atoms), and in the latter scale energy is conserved and all problems are self-adjoint.

As also mentioned on p. 335, the first two extremum principles were Fermat's principle in optics and Maupertuis' principle of least action in mechanics (later to become the principle of stationary action). Nothing more is written about the latter in the book, but I highly recommend to the reader to consult Ekkehard Ramm's delightful paper* on the history of this and another principle. In particular, Ramm's paper describes the scientific controversy on the Principle of Least Action in the early 1750s, which involved the allegation for plagiarism and forgery. Protagonists in this juicy story included (among others) Euler, Leibniz and the King of Prussia.

Chapter 10 is entitled "On the Search for Variational Principles," but is mostly devoted to the principle of minimum rate of entropy production. Chapter 11 discusses convergence and error bounds of Rayleigh-Ritz type methods. The key is the completeness of the trial space and sometimes also the coerciveness of the governing operator.

In summary, this book includes some interesting and original ideas, and a comprehensive literature review, which were very relevant and fresh when the book was first published. Today, naturally, most of it is obsolete, since the mathematical and computational literature has seen tremendous development. Had the author revised the book to make the 2nd edition updated, it would have made a great contribution, but of course this would have been a major project which would probably have lasted several years, and which not many authors would agree to embark upon. For its nostalgic and historical value, as well as for offering a few original ideas which are still of interest today, this book is recommended. ●

* E. Ramm, "Principles of Least Action and of Least Constraint," in *The History of Theoretical, Material and Computational Mechanics*, E. Stein, ed., pp. 23-43, Springer, Berlin, 2014.

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## 1st ACMT Conference

1st ACMT Conference Chair:


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The Association of Computational Mechanics Taiwan (ACMT) was founded in 2007 to strengthen the development and collaboration between researchers in the field of computational mechanics in Taiwan. In the past, ACMT has successfully held the ISCM III-CSE II in 2011, in Taipei, Taiwan. Many members of ACMT are also regular mini-symposium organizers and speakers for WCCM and APCOM events. The keenly anticipated first conference of the association was held in National Taiwan University, Taipei, Taiwan during October 22-23, 2015. The event attracted about 180 participants from universities, research institutes and industry. Among them, eleven delegates were from outside Taiwan, including China, Hong Kong, Japan, U.K. and U.S.A.

### *Participating regions*

The conference emphasized on the synthesis of computational solid mechanics and computational fluid communities in Taiwan. It featured 4 plenary speeches, 2 from computational solid mechanics and 2 from computational fluid mechanics. The plenary speeches were given by Prof. Edward C. Ting (Purdue University) on vector form computational mechanics, Prof. Jiun-Shyan Chen (UCSD) on facture to damage mechanics, Prof. Jong-Shinn Wu on unstructured direct simulation Monte Carlo method, and Prof. Kun Xu on non-equilibrium transport processes, respectively. The conference also featured 28 session keynote lectures, 50 invited lectures and 66 regular presentations. There were 16 minisymposia for topics of methods and applications related to various aspects of computational mechanics and interdisciplinary topics, including VFIFE, biomechanics, CFD, nanomaterials, fluid-structure interaction, bridge structures, etc.

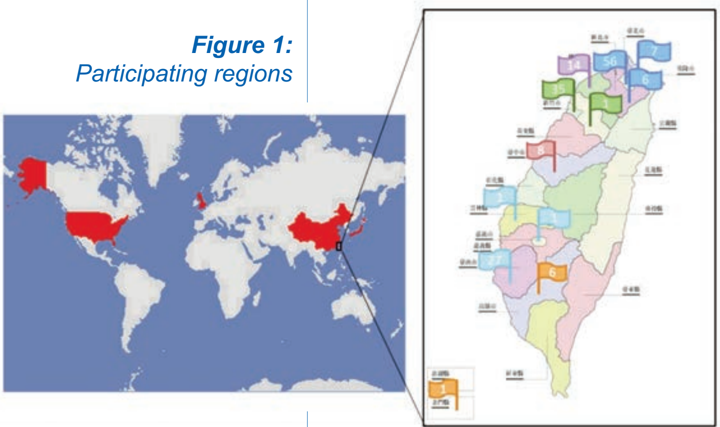


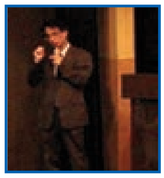
***Figure 1:*** *Participating regions*


*Welcome Speech*
*Prof. YB Yang*
*Conference Chair*


*Plenary Speech*
*Prof. Edward C. Ting*


*Plenary Speech*
*Prof. Kun Xu*


*Plenary speech*
*Prof. Jiun-Shyan Chen*


*Plenary Speech*
*Prof. Jong-Shinn Wu*

The 1st ACMT Conference was a great success, which is an excellent start for the association. Many young faculty members volunteer to organize minisymposia for the conference. We appreciate the support of plenary speakers and the minisymposia organizers and strong involvement of the participants. In the conference, the executive council committee has scheduled the date of annual conferences in next four years on October 20-21, 2016, October 19-20, 2017, October 18-19, 2018, and October 16-18, 2019 in conjunction with the 7th Asia-Pacific Congress on Computational Mechanics (APCOM). We look forward to these events and opportunities to build a strong computational mechanics community in Taiwan. ●


***Figure 2:*** *Conference Banquet in the International Convention Center of NTUH*

The Israel Association for Computational Methods in Mechanics (IACMM) has held two IACMM Symposia since our last report (see IACM Expressions No. 36). In this issue we shall report on them, as well as on other related events.

The 37th IACMM Symposium was held in October 2014 at the Tel Aviv University. The local organizers were Rami Haj-Ali and Alex Gelfgat from the Mechanical Engineering Department. Alfio Quarteroni from EPFL, Lausanne, Switzerland, gave a fascinating Opening Lecture on model order reduction for cardiovascular simulation. *Figure 1* shows Prof. Quarteroni lecturing, and *Figure 2* shows a figure from his lecture. An exciting afternoon Keynote Lecture was given by Adrian Lew from Stanford University on Universal Meshes and their use in solving problems with moving domains. *Figure 3* shows Prof. Lew lecturing, and *Figure 4* shows a figure from his talk.

The Symposium also included 9 other lectures, presented by practitioners and researchers from industry and academia. These included a talk by Brigit Mittelman, a student advised by Zohar Yosibash from the Ben Gurion University (BGU) of the Negev, on computations involving a V-notch in a 3D domain; see *Figure 5*.

The 38th IACMM Symposium was held in March 2014 at BGU. The local organizer was Erez Gal from the Dept. of Structural Engineering. The delightful Opening Lecture was given by Alvaro Coutinho form the Civil

***Figure 1:***
*(above)*
*Prof. Alfio Quarteroni lecturing at ISCM-37*

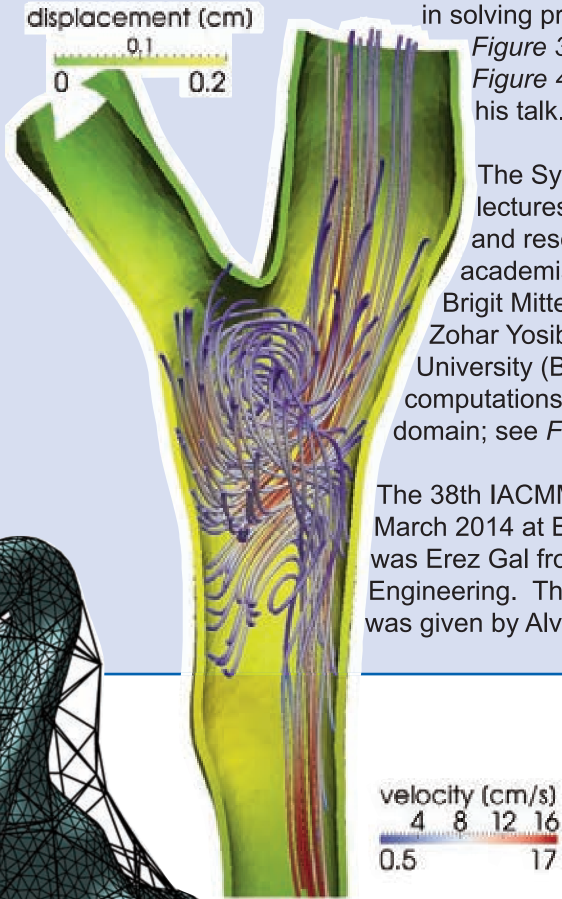



***Figure 2:***
*(right) Streamlines in carotid bifurcation: a figure from the lecture of Alfio Quarteroni at ISCM-37*

***Figure 3:***
*(above) Prof. Adrian Lew lecturing at ISCM-37*

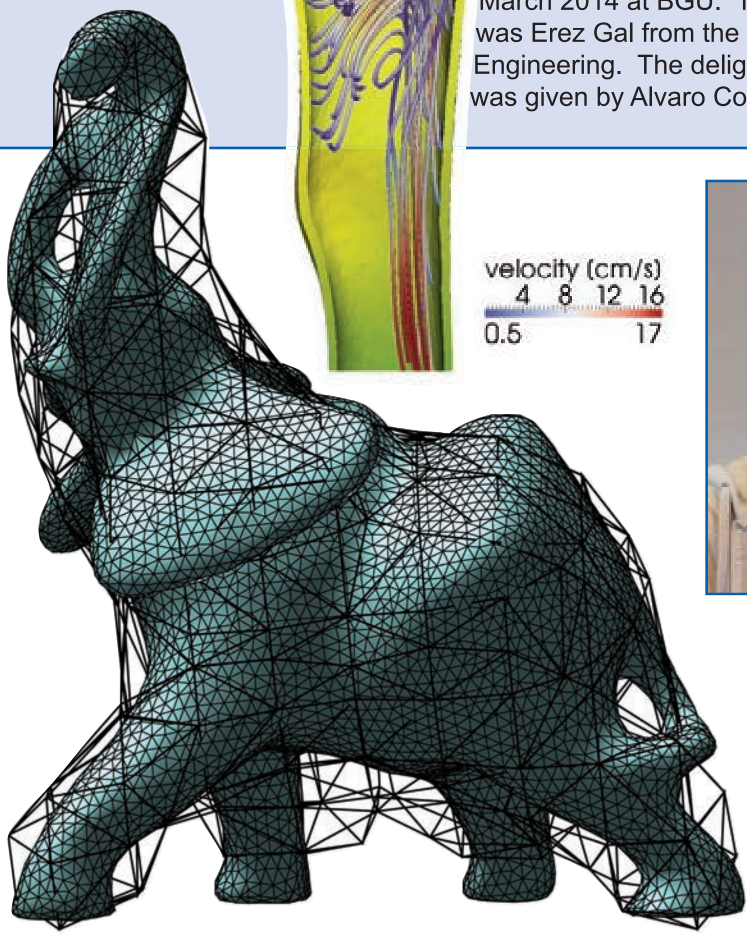


***Figure 4:***
*(right) A conforming tetrahedral mesh obtained by deforming the background universal mesh. This is a figure from the lecture of Adrian Lew at ISCM-37*

***Figure 5:***
*(above) Brigit Mittelman gives a talk at ISCM-37*

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Engineering Dept. at the Federal University of Rio De Janeiro, Brazil, who talked about large scale Finite Element simulation of gravity currents. *Figure 6* shows Prof. Coutinho lecturing, and *Figure 7* shows a figure from his talk.

Michael Engelman, from Ansys Inc., USA, who is a council member of IACMM, gave an interesting Keynote Lecture on human body models for CFD simulations. *Figure 8* shows Dr. Engelman lecturing. *Figure 9* is a group photo of the Invited Speakers with the IACMM Council and the local organizers.

The Symposium also included 9 other contributed lectures. These included a talk by Hagen Wille, a student from the group of Ernst Rank in the Technical University of Munich on uncertainty quantification for patient-specific simulation of human femurs. See *Figure 10* for a figure from this talk.

The 38th IACMM Symposium also marked the 20th anniversary of IACMM, which was founded in 1995 by Pinhas Bar-Yoseph, Dan Givoli and Isaac Harari. A modest ceremony to celebrate this event was held during the lunch break. See *Figure 11*.

Recently there have been some changes in the executive council of IACMM. Amiel Herszage completed a 5-year term as the Secretary/Treasurer. On February 15 he was replaced by Emanuel Ore, who was the previous Sec/Treas. This nomination is temporary, since on October 15 it is planned that Slava Krylov will take office in this capacity. On July 1, after more than 8 years in office, Dan Givoli was replaced by Zohar Yosibash as President of IACMM. ●

**Figure 6:**
*(above) Prof. Alvaro Coutinho lecturing at ISCM-38*

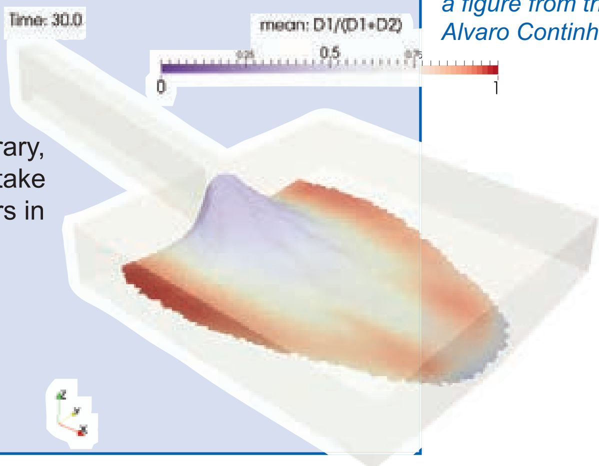


**Figure 7:**
*(below) Total deposition of sediments on a model basil: a figure from the lecture of Alvaro Continho at ISCM-38*

**Figure 8:**
*(above) Dr. Michael Engelman lecturing at ISCM-38*

**Figure 9:**
*(below) A group photo taken at ISCM-38. From left: Amiel Herszage, Michael Engelman, Isaac Harari, Dan Givoli, Alvaro Coutinho, Erez Gal (local organizer), Robert Levy (head of hosting dept.) and Zohar Yosibash*

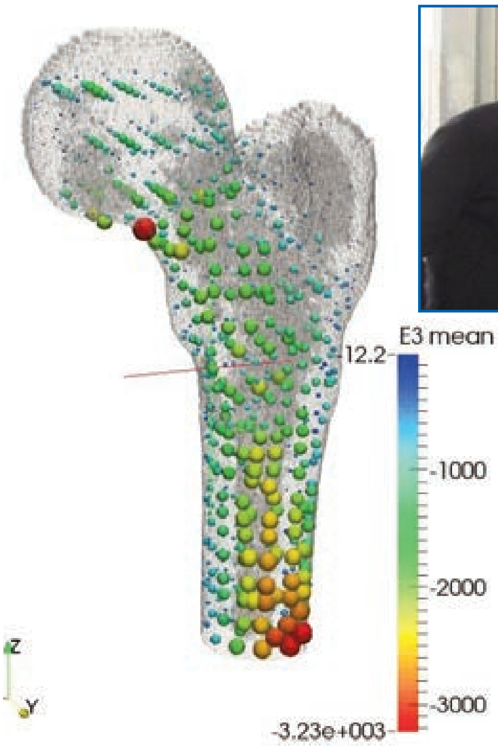


**Figure 11:**
*(above) Erez Gal (right, local organizer) and Dan Givoli (president of IACMM) prepare for the ceremony celebrating the 20th anniversary of IACMM*

**Figure 10:**
*(left) Mean and variance of principal strains in a human femur: a figure taken from the talk of Hagen Wille at ISCM-38*

## The 21st International Conference on Computer Methods in Mechanics & The 3rd Polish Congress of Mechanics, 8-11 September 2015, Gdańsk

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The 21st International Conference on Computer Methods in Mechanics (CMM), organized jointly with the 3rd Polish Congress of Mechanics (PCM), took place in Gdańsk on **8-11 September 2015.** All of the information about the PCM-CMM-2015 Congress is available at the website **http://www.pcm-cmm-2015.pg.gda.pl/**.

The decision to merge the CMM & PCM scientific events in 2015 was made conjointly by the Board of Polish Association for Computational Mechanics (PACM) and the Board of Polish Society of Theoretical and Applied Mechanics (PSTAM). The bi-annual CMM conferences held since 1974 are mainly focused on computational methods applied to the problems of mechanics and engineering practice. The idea of PCM dates from 2005 and the recent intention of the fusion of PCM and CMM was to present a state-of-the-art knowledge in the wide do of mechanics including inter-disciplinary problems, and to trigger a discussion and debate on development perspectives of mechanics and related fields.

The following institutions were organizers of the Congress: Polish Society of Theoretical and Applied Mechanics, Polish Association for Computational Mechanics, Institute of Fundamental Technological Research of the Polish Academy of Sciences (PAS), Committee on Mechanics of the PAS, Committee on Civil Engineering and Hydroengineering of the PAS, Committee on Machine Building of the PAS, Institute of Fluid-Flow Machinery of the PAS and Gdańsk University of Technology.

Honorary patronage of the Congress was held by: Minister of Science and Higher Education of the Republic of Poland, Marshal of the Pomorskie Voivodeship, Rector of Gdańsk University of Technology, Director of the Institute of Fluid-Flow Machinery PAS. The sponsorship of the Congress assured its high organization level, these were: Energa Group, Ministry of Science and Higher Education of the Republic of Poland, and SOFiSTiK. The media patronage was held by Acta Energetica Quarterly.

The Congress President was Prof. Michał Kleiber, Congress Vice-President – Prof. Włodzimierz Kurnik, Chairman of the Scientific Committee – Prof. Tadeusz Burczyński, Vice-Chairman of the Scientific Committee – Prof. Krzysztof Wilde, Chairmen of the Permanent Congress Committee – Prof. Arkadiusz Mężyk and Prof. Zbigniew Kowalewski, Honorary Chairman – Prof. Witold Gutkowski. The Congress Honorary Committee consisted of 16 members, International Advisory Board – 26 members, and Scientific Committee – 60 members. In the opening ceremony the GUT was represented by the Vice-Rector for Scientific Research, Prof. Józef Sienkiewicz, the representatives of scientific associations were Prof. Viggo Tvergaard (President of IUTAM) and Prof. Ekkehard Ramm (President of ECCOMAS).

The Organizing Committee was mainly composed of workers of the Department of Structural Mechanics, Faculty of Civil and Environmental Engineering, GUT. The Organizing Committee Chairman was Prof. Jarosław Górski, the Secretaries were Dr. Karol Winkelmann and Mr. Łukasz Smakosz. Dr. Agnieszka Sabik and Dr. Marek Skowronek fulfilled important roles in the team. The 19-member Organizing Committee featured the Vice-Chairmen: Prof. Paweł Kłosowski and Prof. Jacek Pozorski (IFFM, PAS). The Congress of Mechanics instigated a

***Figure 1:***
*Before the opening ceremony of PCM-CMM-2015 Congress (from left to right): Prof. Jarosław Górski (Chairman of OC), Prof. Krzysztof Wilde (Vice-Chairman of SC), Prof. Józef Sienkiewicz (Deputy Rector for Science, GUT), Prof. Michał Kleiber (Vice-President of European Academy of Sciences and Arts), Prof. Tadeusz Burczyński (Chairman of Committee on Mechanics PAS), Prof. Ekkehard Ramm (President of ECCOMAS), Prof. Viggo Tvergaard (President of IUTAM), Prof. Zbigniew Kowalewski (President of PSTAM), Prof. Mieczysław Kuczma (President of PACM)*

***Figure 2:***
*The O.C. Zienkiewicz Medal Awarding Ceremony (from left to right): Prof. Tadeusz Burczyński, Prof. Tomasz Łodygowski, Prof. Waldemar Rachowicz, Prof. Ekkehard Ramm, Prof. Michał Kleiber, Prof. Mieczysław Kuczma*

broad interest among scientists and engineers of Polish and international affiliations. There were 650 registered participants at the Congress website (Poland – 518, abroad – 132), then 531 submissions (Poland – 441, abroad – 90), and finally 510 participants took part in the Congress who gave 495 presentations in 9 parallel sessions at the GUT and the IFFM, PAS.

The diversity of the Congress topics is mirrored in the titles of 11 general lectures: **Jorge Ambrósio** (Technical University of Lisbon, Portugal), Interaction Between Mechanical Systems and Continuum Mechanics Models in the Framework of Biomechanics and Vehicle Dynamics; ***Marc Geers*** (Technical University of Eindhoven, The Netherlands), Multiscale Mechanics of Metamaterials; ***Reinhold Kienzler*** (University of Bremen, Germany), Consistent Plate Theories - a Matter Still Not Settled?; ***Tomasz Kowalewski*** (IFTR PAS, Poland), Nanoscale challenges of fluid mechanics; ***Zbigniew Kowalewski*** (IFTR PAS, Poland), Experimental Attempts for Creep and Fatigue Damage Analysis of Materials - State of the Art and New Challenges; ***Mieczysław Kuczma*** (Poznan University of Technology, Poland), Shape Memory Materials and Structures: Modelling and Computational Challenges; ***Tadeusz Kurtyka*** (CERN, Switzerland), Advanced Mechanics in High Energy Physics Experiments; ***Waldemar Rachowicz*** (Technical University of Kraków, Poland), Finite Element Method Simulations of Linear and Non-linear Elasticity Problems with Error Control and Mesh Adaptation; ***Ekkehard Ramm*** (University of Stuttgart, Germany), Hierarchic Isogeometric Analyses of Beams and Shells; ***Alfredo Soldati*** (University of Udine, Italy), Computation and Physics of Turbulent Dispersed Flows; ***Viggo Tvergaard*** (Technical University of Lyngby, Denmark), Finite Strain Analyses of Deformations in Polymer Specimens.

The Congress was composed of 25 Mini-Symposia, proposed by renowned scientists from Poland and abroad, covering all submitted oral presentations. Three jubilee sessions were organized during the Congress: the 80th birthday of **Prof. Janusz Orkisz** and the 80th birthday of **Prof. Zenon Waszczyszyn**, as well as the 60th anniversary of scientific work of **Prof. Czesław Woźniak**. Another session was to commemorate **Prof. Józef Joachim Telega**, who passed away 10 years ago. An important event was the O.C. Zienkiewicz Medal Awarding Ceremony that took place in the Polish Baltic Philharmonic Hall in Gdańsk, before the concert of the Gdańsk Chamber Orchestra conducted by Prof. Paweł Kukliński. The Medal was established by the PACM in 2007, and was named in the name of **Professor Olgierd Zienkiewicz**, the prominent British – of Polish descent – academic, mathematician, and civil engineer. The 2015 laureates are:

- ***Prof. Tomasz Łodygowski*** – for the whole of activity
- ***Prof. Waldemar Rachowicz*** – for outstanding achievements during recent 2 years
- ***Prof. Ekkehard Ramm*** – for foreign scientists of particular merit for the development of computational mechanics in Poland.

The awards were presented by Prof. Michał Kleiber (Commander of the Medal Chapter) and Prof. Tadeusz Burczyński (Chancellor of the Medal Chapter), during the ceremony conducted by Prof. Mieczysław Kuczma (President of PACM). The Prof. Jan Szmelter Award for young researchers was included in the Congress programme. The Jury chaired by Prof. Paweł Kłosowski awarded two authors for the best oral presentations and one author for the best poster. The laureates were: **Tomasz Gajewski** (Poznan University of Technology, Poland), **Richard Ostwald** (Technical University Dortmund, Germany), and **Marek Paruch** (Silesian University of Technology, Poland), respectively.

The two-page abstracts of 504 presentations were printed in two 500 page volumes of the Congress proceedings plus at the Congress website and were reviewed by the Scientific Committee members of the Congress. Participants had the opportunity to submit extended papers to the post-conference book, to be published by CRC/Balkema (Taylor & Francis Group) in March 2016. A separate editorial procedure classified approximately 132 papers.

The PCM-CMM-2015 Congress was a successful, well-organized scientific event. The fusion of PCM and CMM into a joint scientific event proved effectively feasible and fruitful and will be continued in the future. The next, 22nd International Conference on Computer Methods in Mechanics will take place in Lublin in 2017, and a joint event of the 23rd CMM and the 4th Polish Congress of Mechanics will be held in Cracow in 2019. ●

## Short Course on Mechanics of Random and Fractal Media

The Short Course on Mechanics of Random and Fractal Media was held at the Poznan University of Technology on **25-26 June 2015** in Poznań, Poland. The instructor of the course — Prof. Martin Ostoja-Starzewski from the University of Illinois at Urbana-Champaign, USA — gave 12 lectures concerned with, inter alia, the stochastic geometric models of microstructures, mesoscale bounds for random elastic linear and nonlinear media, as well as mechanics of fractal media via dimensional regularization. The course was organized by a team of PACM members (Mieczysław Kuczma, Magdalena Łasecka-Plura, Katarzyna Rzeszut, Monika Chuda-Kowalska) and supported by the Rector of Poznan University of Technology, Prof. Tomasz Łodygowski. Some 20 young scientists from the Czech Republic, Germany and Poland participated in the course. ●

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## 12th National Conference on Computational Structural Mechanics

From **May 18 to 22, 2015**, CSMA organised its biannual conference. For more than 20 years, it has been held in the Giens peninsula (on the French Riviera) as a way to both ensure beautiful weather conditions, and feel the pulse of research in the field of computational mechanics

***Figure 1:*** *Views of the stunning Giens Peninsula*

The conference was co-organised by a consortium of West of France's laboratories under the supervision of **Laurent Stainier** (GEM) with laboratories **LGCGM** (Rennes), **LAMPA** (Angers), **LaSIE** (La Rochelle), **GEM** (Nantes), **LIMATB** (Lorient) & **LBMS** (Brest). It is therefore easy to understand that reduction of models and multiscale should be key players of general preoccupations. Hence the key topics: coupling, biomechanics, identification, numerical methods, multiscale, vibrations, stochastichs, rupture, contact, HPC, mesh, enriched elements, multiphysics, dynamics, damage, optimisation, applications, behaviour, process, thin structures, stability. In addition, there were five symposia organised by the researchers in order to throw light onto some major trends: Theoritical aspects of computational mechanics (9 papers), From the high fidelity model to its real-time command (30), Fluids and complex flows (9) Mechanics of architectured materials (7), Sea and seaside (5). The conference also included six plenary sessions, plus one centred on our best young researchers, another dedicated to software demonstration and yet another gathering about fifty poster presentations. Not to mention what is so delightful about Giens: the emphasis on friendliness and social interactions. The conference programme was established with almost 250 proposals selected by a panel chaired by **G. de Saxcé** *(LML-Lille)* attended by an industrialist, **S. Andrieux** *(ONERA)* & **L. Stainier** *(GEM)* representing the organisation laboratories. The 2015 conference gathered almost 350 participants and received support from the following companies: ALINEOS, ALTAIR, DCNS, EDF, SAFRAN.

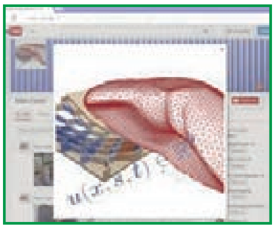


***Figure 2:*** *From E. Cueto's presentation showing the simulation of surgical gestures*

### *Plenary Sessions*

The presentation of **A. Gravouil** *(LaMCoS-Lyon)*, *Heterogeneous Asynchronous Time Integrators for Structural Dynamics*, suggests using the best digital plan by adapting it to the situations: eg. explicit in the case of contact and implicit for current matters. The coupling must be assured thus for example by an asynchronous plan associated with a decomposition of domains where from a lot of problems but a very significant gain in times of calculation. **M. Ortiz** *(Caltech)* presented *Multiscale modeling and simulation of solids* which as a starting point of a just analyse, the modelling of the physics is more important than the modelling of the data. The simulations will not be better than the used material ls models. For example, if we are interested in the modelling of the fracture, it is essential to make coexist at least 3 timescales and 3 scales of space. One promising proposal was the resolution 'Optimal Transportation Meshfree'.

***Figure 3:*** *From G. Cailletaud's presentation on the Modelling of 3D printing*

The young "catedrático" **E. Cueto** *(AMB-Saragosse)* developed, *dans Computational vademecums for virtual surgery* the simulation of surgical gestures. Certainly, a lot of problems were resolved: real time, materials laws, contact, modelling of the cut, the dynamics, the interactivity. A collection on the rules of the art will open new possibilities with industrial, medical applications. The presentation de **J.-F. Remacle** *(University of Leuwen, Rice University)*, *GPU accelerated spectral finite elements on all-hex meshes*, approaches meshes with quadrangles in 2D and hexahedrons in 3D. The presentation reviews: grouping of triangles (2) to make a quadrangle or of tetrahedrons (5, 6 or 7) to make a hexahedron, or division of a triangle in 3 quadrangles (by adding 4 points) or of a tetrahedron. In a more realistic and wise way, it is necessary to know how to content itself with hex-dominating meshings. Secondly, the presentation invited us to use GPU processors, much cheaper, but which require new less greedy algorithms in memory. In his presentation, *Numerical Modelling of 3D printing*, **G. Cailletaud** *(CdM-Evry)* detailed a process used more and more in industry. The CdM's works for SAFRAN are precursory in this multidisciplinary approach which reveals needs for modelling, for bank material, of optimization as shown in examples presented, essentially concentrated on aeronautical applications and the thermal-metallurgy-mechanics sequence. For **E. Rouhaud** *(LAMSIS-Troyes)* and **L. Roucoules** *(LSIS-Aix-en-Provence)* who presented *In Silico Manufacturing Processes?* the modelling of the manufacturing processes is one of the keys to better understand, optimize, even reduce the number of the extremely expensive tests. In this context, there are also the peripheral actions in the simulation but more important: the management of the interfaces product-process, the knowledge management, the directed design manufacturing are so many domains justifying the term in-silico.

***Figure 4:*** *The poster prize was called Thierry Charras Prize in memory of our friend*

### *Mini-Symposia & Thematic Sessions*

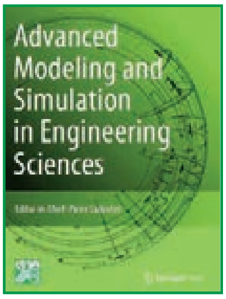
The amount of presentations (more than 200 of them, many of which of very high quality) reflects us the energy and openness of our laboratories.

**"Theoritical Aspects of Computational Mechanics" Symposium:** P. Alard (LMGC-Montpellier), J.-J. Marigo (LMS-Palaiseau) & A. Hamdouni (LaSIE-La Rochelle), - 9 conferences distributed in 3 sessions.
**"From the High Fidelity Model to its Real-Time Command" Symposium:** F. Plestan (IRCCYN-Nantes) & F. Chinesta (GEM-Nantes). Victim of its success because using the techniques of Reductions of models, it collected more than 30 communications and was, therefore transferred to Posters session.
**"Fluids and complex flows " Symposium:** R. Valette (CEMEF-Sophia), A. Ammar (LAMPA-Angers), and has gathered 9 conferences distributed in 3 sessions. This symposium shown researchers' contributions in the numerical domain, concerning the flows occurring in a complex environment.
**"Mechanics of architectured materials" Symposium:** R. Dendievel (SIMAP-Grenoble), D. Favier (3SR-Grenoble), & G. Rio (LIMATB-Lorient) and has gathered 7 conferences distributed in 2 sessions.
**"Sea and Seaside" Symposium:** C. Berhault (SEM-REV-Nantes), F. Schoefs (GEM-Nantes) & P. Le Tallec (LMS-Palaiseau), and has gathered 5 conferences distributed in 2 sessions.
**Twenty-One thematic Sessions:** Gathered by the Scientific Committee: "Multiscale", "Rupture" (both with 15 conferences,) "Optimisation" (12), "Coupling", "Enriched Elements", "Numerical methods", "Stochastics", "Vibrations" (9), "Applications", "Biomechanics", "Behaviour", "Contact", "Identification", "Mesh", "Processes" (6), "HPC", "Dynamics", "Damage", "Multiphysics", "Stability", "Thin Structures" (3).

***CSMA Prize***
The best two PhDs defendes in 2014 are **R. Bouclier** (LaMCoS-Lyon) for *Isogeometric locking-free NURBS-based solid-shell elements for nonlinear solid mechanics* and **N. Spillane** (LJLL-Paris) for *Robust domain decomposition methods for symmetric positive definite problems*. Those two prize-winners come after **L. Boucinha** (LaMCoS-Lyon) for *A priori Model Reduction through separations of space-time variables – Application to transient elastodynamics* and **M. Jebahi** (I2M-Bordeaux) for *Discrete-continuum coupling method for simulation of laser-induced damage in silica glass*.
***Software Session***
About twelve research softwares were presented. In an atmosphere of excitement, the champions of the field gave demos: CAST3M, LMGC90, SALOME-MECA, EuroPlexus. ALTAIR & DYNAS+ were also present. More specific tools were also presented.
***Poster Session and Thierry Charras Prize***
Introduced by **N. Moës** *(GEM-Nantes)*, this session allowed one to communicate research in a new way: the classical 20 minutes' presentation was replaced by a 2 hour question time where the researcher answered questions. This year, the organisers decided to give the Thierry Charras prize to: *Interpolation of inverse of operators for the reduction of models* by **O. Zahm** *(PhD student at GEM-Nantes)*
***Social Interaction***
It is part and parcel of the conference and hugely contributes to the delight and the warmth enjoyed by every one: the residence, the opening and closing cocktail receptions, the dinner, the day trip to Porquerolles are the little side orders without which the taste of Giens wouldn't be the same! And they facilitate studious conversations that sometimes last very long over a drink shared by PhD students, assistant professors and professors. ●

# Prospects

## 2017 Conference
The organizing committee will be a Parisian team implantée on the Paris-Saclay Campus et gathering the new IMSIA (CEA, EDF, ENSTA), ONERA and the LMS, The 13th conference will also be held in Giens during May.

## AMSES Journal



In June 2012, the CSMA launched a new international journal: AMSES , "Advanced Modeling and Simulation in Engineering Sciences". The first paper was published on January 2014. Quickly published, this open-access peer-reviewed scientific journal, is published by Springer and widely funded by CSMA. It shall encompass issues of modelisation, simulation, but also interactions with trials, which are essential to modelisation, characterisation and validation – not to mention related subjects. The ambition of AMSES is always to become as quickly as possible, one of the reference's journal in the field of computational mechanics.

## As a Conclusion
The Giens conference has long been a must-go event which displays the dynamism in computational mechanics research by gathering the younger researchers, scientific leaders and the industry. Even hiding itself behind fondamuntal presentations, application is the fuel of research, supporting most of the fields tackled in Giens.

*The French community gave itself some objectives of which we shall retain:*
*Favor the innovation and the scientific breakthroughs and to look for the good balance*
*between fundamental and application, what can seem contradictory but is simply and only complementary!*

## Annual Conference

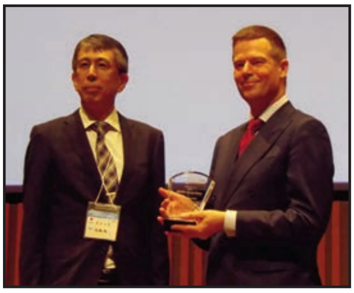


***Figure 1:*** *Prof. René de Borst receiving the JSCES Grand Prize from Prof. Seiichi Koshizuka, the president of the JSCES*

The 20th JSCES's Annual Conference on Computational Engineering and Science, chaired by Dr. H. Watanabe (MSC Software Corporation, Japan), was held during **June 8-10, 2015**, at Tsukuba International Congress Center. The conference was held as one of the 20th Anniversary events of the JSCES. Over 500 people participated and 336 topics were presented in the conference. Fruitful discussions were exchanged in 31 organized sessions associated with a plenary lecture, a special event for young engineers, graphic awards and special symposia.

The plenary lecture entitled "Computational Mechanics of Interface Phenomena and Evolving Discontinuities" was given by Professor René de Borst of University of Glasgow, UK. In his lecture, he presented an elegant enhancement of the cohesive-surface model to include stress triaxiality, which still preserves the discrete character of cohesive-surface models. He also outlined how the cohesive-surface approach to fracture can be extended to multi-phase media, in particular fluid-saturated porous media. Prof. de Borst also received "The JSCES Grand Prize 2015", for his outstanding contributions in the field of computational engineering and sciences, at the following ceremony *(Figure 1)*.

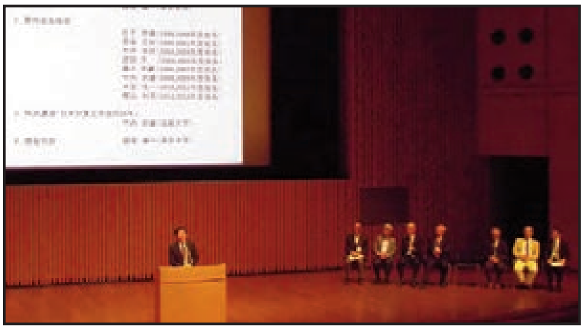


***Figure 2:*** *The 20th Anniversary Ceremony*

The 20th Anniversary Ceremony of the JSCES took place at the main hall in presence of the successive presidents, Dr. Mikio Shoji, Prof. Nobuyoshi Tosaka, Prof. Hideomi Ohtsubo, Prof. Hiroshi Takeda, Prof. Norio Takeuchi, Dr. Koichi Ohtomi and Prof. Kazuo Kashiyama *(Figure 2)*. After short addresses from each guest, a special lecture entitled "20 years of the JSCES" was delivered by Prof. Norio Takeuchi. Some of the meeting memos of the arrangement committee and valuable pictures taken before the establishment of the society were shown. The ceremony renewed the memories of the past 20 years and refreshed our resolutions for the years to come.

***Figure 3:*** *One scene from the Course Lectures for Creating Future Visions of Young Scientists and Engineers*

A special event for young engineers, "Course Lectures for Creating Future Visions of Young Scientists and Engineers", was held at lunchtime of the second and third day *(Figure 3)*. This year, topics on their academic backgrounds and research motivations under the program title of "Special lectures of engineers and scientists from Tsukuba Science City" were presented by six guests; Dr. Motofumi Usui from the Japan Aerospace Exploration Agency (JAXA), Dr. Tomohiro Sawada from the National Institute of Advanced Industrial Science and Technology (AIST), Dr. Takuzo Yamashita from the National Research Institute for Earth Science and Disaster Prevention (NIED), Dr. Susumu Ejima from the Japan Automobile Research Institute (JARI), Dr. Junichi Suzuki from the National Institute for Land and Infrastructure Management (NILIM) and Dr. Toshio Osada from the National Institute for Materials Science (NIMS). Many students and young researchers, who are about to set out in a long career, had fruitful discussions with the senior researchers. ●

## The 2nd Japan Spain Workshop on Computational Mechanics

The 2nd Japan Spain Workshop on Computational Mechanics was held at Chuo University on **October 15, 2015.** Five speakers from each country presented their recent achievements and exchanged inspiring ideas in a very friendly atmosphere *(Figure 4)*. ●

***Figure 4:*** *Participants of the 2nd Japan Spain Workshop on Computational Mechanics*

## *Summer Camp for Students*

"The summer camp for students 2015" hosted by JSCES was held at the seminar facility located in mountainside of Mt. Tsukuba during **September 19-20, 2015**. 31 students and 13 members from the JSCES attended the camp and had fruitful discussions. The main objective of this camp is to enhance mutual friendship among the graduate students as the candidate of young researchers in the field of computational mechanics.

During this camp, 5 keynote speakers gave talks about their research backgrounds; also 16 students presented their ongoing researches. The best presentation awards were given to two students *(Figure 5)*. All attendees enjoyed exchanging their experience and idea in a beautiful late summer atmosphere *(Figure 6)*. ●

***Figure 5:***
*Winners of the best presentation awards (Mr. Yuto Soma (left) and Mr. Gai Kubo, Prof. Seiichi Koshizuka at the middle)*

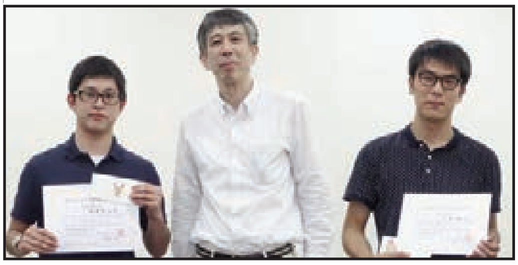


***Figure 6:***
*Participants of the JSCES summer camp 2015 held at the beautiful mountainside of Mt. Tsukuba*

## *IWACOM-III*

The 3rd International Workshops on Advances in Computational Mechanics (IWACOM-III), chaired by Prof. Daigoro Isobe and vice-chaired by Prof. Shigenobu Okazawa, was held at Ryogoku, Tokyo during **October 12-14, 2015**. This conference, too, was held as one of the 20th Anniversary events of the JSCES. The conference contained 9 workshops, each with the latest and hottest topics in the field of computational mechanics. Over 50 speakers from abroad including 2 plenary lecturers (Prof. Wolfgang Wall and Prof. Antonio Huerta), and about 100 speakers from Japan delivered their talks. The number of participants was 207.

The biggest objective of this conference was to provide chances to young researchers for intensive discussions about their own selected topics and identify future directions for the development of related modeling strategies and computational techniques. During two days of fruitful discussions in the workshops, a reception party and a banquet were held as social events. In particular, the participants experienced an exciting evening at *Hananomai* restaurant which had *dohyo* in center, watching *sumo* wrestling events and enjoying *chankonabe*, a Japanese stew commonly eaten by the sumo wrestlers *(Figures 7 & 8)*.

The next IWACOM, IWACOM-IV, is planned to be held around 2020, the year of Tokyo Olympic Games. ●

***Figure 7:***
*Gathering around chankonabe*

***Figure 8:***
*Praising good fight after sumo wrestling match (Profs. Antonio Huerta and Wolfgang Wall at the middle)*

*For all inclusions under*
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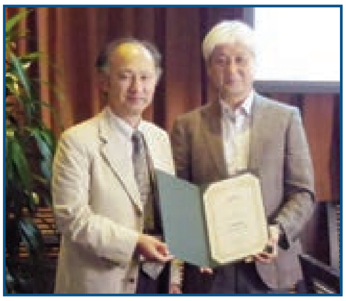
The JACM is a union of researchers and engineers working in the field of computational mechanics mainly in Japan. JACM is a loosely coupled umbrella organization covering 29 computational mechanics related societies in Japan through communication with e-mail and web page (http://www.sim.gsic.titech.ac.jp/jacm/index-e.html). The members of JACM organized 3 mini-symposia at PANACM 2015 held in Buenos Aires, Argentina in Aril 2015, and 6 mini-symposia at USNCCM13 in San Diego, USA in July 2015. The JACM members also organize a total of 23 mini-symposia for WCCM & APCOM 2016 to be held in Seoul, Korea.

***Figure 1:***
*Professor S. Yoshimura (President of JACM) discussing about the present status of JACM.*

***Figure 2:***
*Group photo taken at the 2015 annual meeting of JACM*

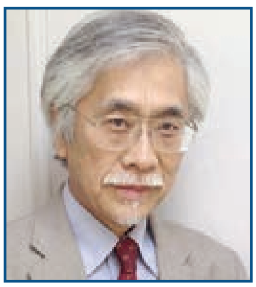
On 28th July, 2015, the 2015 JACM annual meeting with the award ceremony was held in San Diego, USA on the occasion of the USNCCM13 *(figures 1, 2 and 3)*. At the meeting, the JACM members discussed the current status of the JACM and future plans, especially about a cooperation with Korean computational mechanics associations to strongly support WCCM & APCOM 2016.



***Figures 3:***
*JACM award winners (Dr. M. Koishi (left) and Professor S. Takagi) with Professor Yoshimura in the award ceremony*

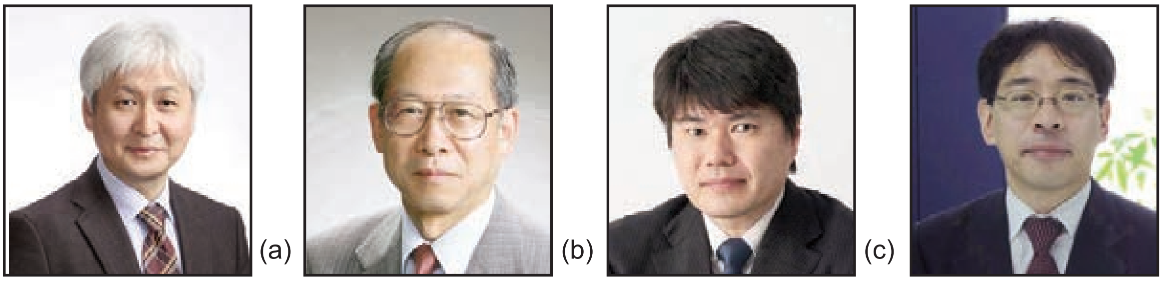
***The 2015 JACM award winners are listed below.***


(a)


(b)

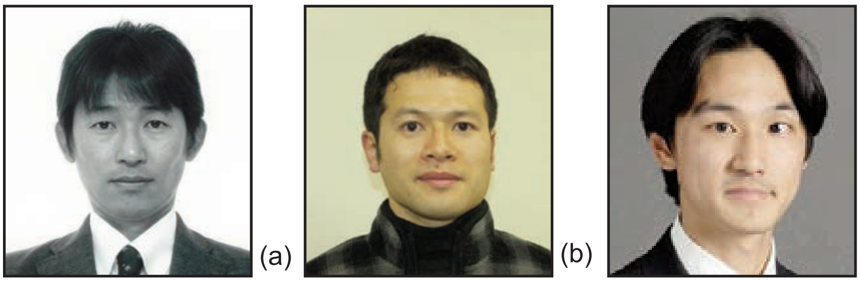

(c)

***Figures 4:***
*The JACM 2015 Computational Mechanics Award winners: Professor H. Kanayama (Japan Women's Univ.) (a), Professor T. Hisada (UTokyo) (b) & Professor H. Liu (Chiba Univ.) (c)*



(a) (b) (c) (d)

***Figure 5:***
*The JACM 2015 Fellows Award winners:*
*Dr. M. Koishi (Yokohama Rubber, Co. Ltd.) (a), Professor K. Shingu (Nihon Univ.) (b), Professor S. Takagi (UTokyo) (c), Dr. T. Fujisawa (Prometech Software, Inc.)*



(a) (b) (c)

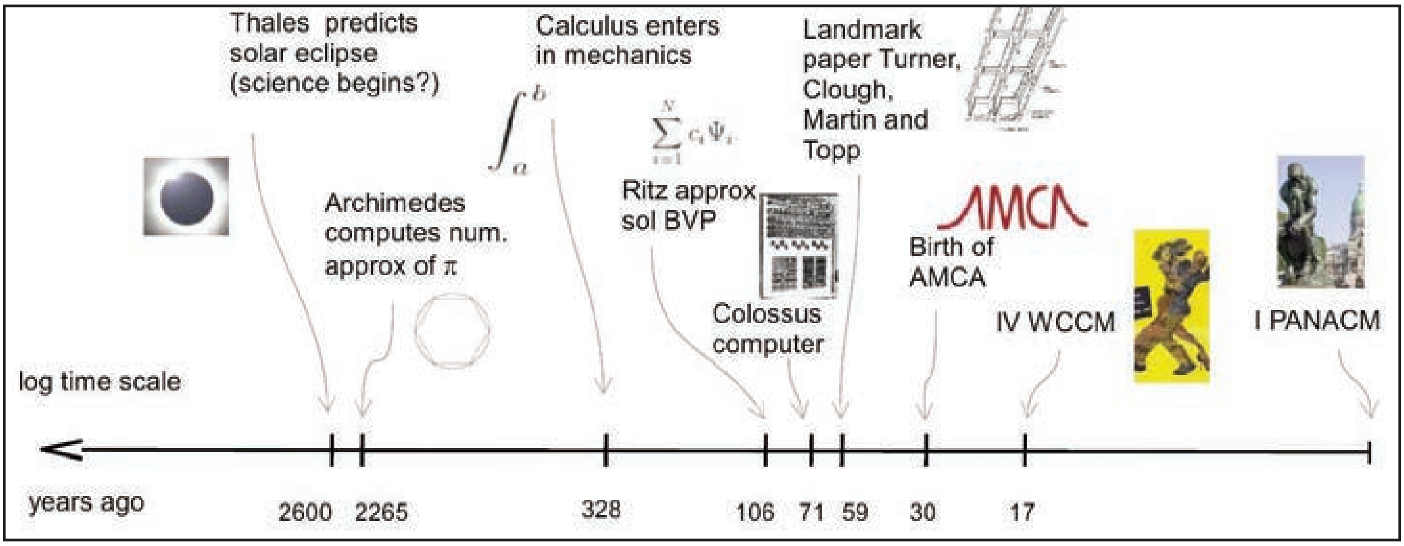
***Figures 6:***
*The JACM 2015 Young Investigators Award winners: Professor K. Iwamoto (Tokyo Univ. of Agriculture and Technology) (a), Professor A. Takezawa (Hiroshima Univ.) (b), Professor Y. Tadano (Saga Univ.) (c)*

Recently Japan has initiated a new national supercomputer development project. The new supercomputer will be a successor of Japan's current flagship computer, the K Computer. The project, which is now called the FLAGSHIP 2020 project, was launched by the Ministry of Education, Culture, Sports, Science and Technology (MEXT) in April 2014. Under the project, the RIKEN AICS (Advanced Institute for Computational Science) will start to develop and begin operations of the new supercomputer in FY 2020. The basic design will be carried out based on the concept of "co-design", an approach under which system design and applications are developed collaboratively.

The new flagship computer, which is now tentatively named "Post K Computer", will be used to work on innovative solutions to current scientific and social issues. In December 2014, a total of nine projects for developing software applications to solve important scientific and social issues using the Post K Computer were selected. They are scheduled to continue till 2020.
*Their titles are as follows:*

***Category of Realization of Healthy and Long-life Society:***
*Issue 1.* Construction of Infrastructure for Innovative Drug Design based on Functional Control of Bio-molecule Systems
*Issue 2.* Integrated Computational Bio-science to Support Taylor-made and Preventive Medical Care
***Category of Disaster Prevention and Mitigation and Environmental Problems:***
*Issue 3.* Construction of Integrated Prediction System of Earthquake / Tsunami Complex Disasters
*Issue 4.* Improvement of Prediction of Meteorology and Global Environments Using Observatory Big Data
***Category of Energy Problems:***
*Issue 5.* Development of New Infrastructural Technology for Highly Efficient Generation, Conversion, Storage and Utilization of Energy
*Issue 6.* Realization of Innovative Clean Energy Systems
***Category of Strengthening of Industry Competitiveness:***
*Issue 7.* Innovation of New Functional Devices and High Performance Materials for Supporting Next-Generation Industries
*Issue 8.* Development of Innovative Design and Manufacturing Processes Leading Near Future MONODUKURI
***Category of Advancement of Basic Science:***
*Issue 9.* Discovery of Fundamental Law and Evolution of a Universe

Many of JACM members are involved in the above projects. We hope that their achievements will be presented in upcoming IACM congresses and thematic conferences. ●




# AMCA celebrates
# $11110_2$ years

Born in 1985, the Argentine Association for Computational Mechanics celebrates 30 years of activity.

Following the First Symposium on Numerical Methods in Continuum Mechanics, in Buenos Aires, 1977, and the First and Second National Meeting of Researchers and Users of the FEM (ENIEF), in Bariloche, 1983 and 1984, the Argentine Association for Computational Mechanics was created in 1985 when the First Argentine Congress on Computational Mechanics (MECOM) was held in Santa Fe-Paraná, cities.

Sergio Idelsohn was elected as its first president conducting it through many years and contributing greatly to its international insertion.

AMCA was one of the first national associations integrating the IACM. It has participated in the organization of several international congress, such as the IV WCCM of the IACM in 1998; and the Fourth PACAM (Pan American Congress of Applied Mechanics) in 1995; several editions of the CILAMCE (Iberian Latin Congress of Computational Methods in Engineering); and recently the First Pan-American Congress on Computational Mechanics, PANACM 2015. ●

***Figure 1:***
*R. Clough and J. C. Heinrich assisting at the birth of AMCA in 1985*

*Remark:* *In the top image, the figure 2600 in the Time Line seems to be a vague reference, but it is the exact elapse: the eclipse took place on 28 May 585 BC. Since then, almost 2600 years passed until the Anniversary Workshop.*

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*http://www.amcaonline.org.ar*

# Anniversary Workshop

## Future Trends in Computational Mechanics

In the frame of the AMCA Anniversary a Workshop on Future Trends In Computational Mechanics was held in Santa Fe, Argentina, November 16-17, 2015.

Four lecturers have been invited:

*Gustavo Buscaglia*, Universidad de São Paulo, São Carlos, Brazil, Some challenging issues in the simulation of biological problems

*Eduardo N. Dvorki*n, Sim&Tec, Argentina, Contribution of Computational Simulations to the technological development of Argentina.

*Rainald Löhner*, George Mason University, USA, Fluid-Structure Interaction simulations on High-Performance Computing platform: What lies ahead

*Sergio Idelsohn*, CIMNE, Spain and CIMEC, Argentina, Trends in Computational Mechanics that may have Future.

A panel discussed each of the workshop topics, for which the following researchers have been invited: Mariano Cantero, Alberto Cardona, Enzo Dari, Guillermo Etse, Fernando Flores, Axel Larreteguy, Angel Menendez, Oscar Moller, Norberto Nigro, Marta Rosales, Gustavo Sanchez Sarmiento, Ruben Spies, Mario Storti, Domingo Tarzia and Marcelo Venere. ●

***Figure 2:***
*AMCA Anniversary Workshop*

***Figure 3:***
*Lecturers: (left to right) R. Löhner, S. Idelsohn, E. Dvorkin and G. Buscaglia*

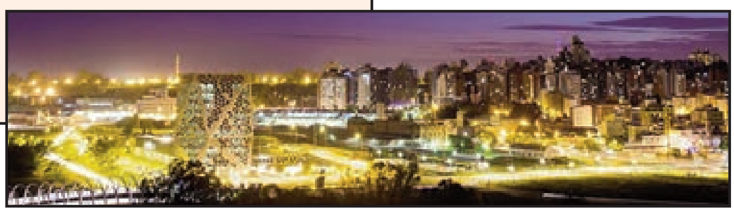
## CALL FOR PAPERS

### ENIEF 2016

### XXII Congress on Numerical Methods and their Applications

*Córdoba, Argentina, 8-11 November 2016*

The Argentine Association for Computational Mechanics (AMCA) announces the XXII Congress on Numerical Methods and their Applications (ENIEF 2016), which will be held in Córdoba, Argentina, organized by the Technological National University (UTN) at Córdoba, Argentina.
*Email:* enief2016@frc.utn.edu.ar
*Web:* http://www.frc.utn.edu.ar/enief2016/ ●



abmec
Associação Brasileira de Métodos Computacionais em Engenharia

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***Gray Farias Moita***
*gray@dppg.cefetmg.br*

CILAMCE 2016

XXXVII IBERIAN LATIN AMERICAN CONGRESS ON COMPUTATIONAL METHODS IN ENGINEERING
BRASILIA - DF BRAZIL

## XXXVII Ibero Latin American Congress on Computational Methods in Engineering

**Brasília, Brazil**

**November 6 – 9, 2015**

The Ibero Latin American Congress on Computational Methods in Engineering (CILAMCE) is a series of annual meetings, promoted by the Brazilian Association of Computational Methods in Engineering (ABMEC). Since 1977, CILAMCE has provided a forum for engineers, students, re-searchers and other active professionals in the field of numerical methods, coming from Brazil and others countries, to discuss and to explore the state-of-the-art of recent applications of computational methods in several engineering branches.
The framework of CILAMCE is multi-disciplinary and scientists from all over the world are encouraged to contribute to the confer-ence. The technical program includes plenary speakers and mini-symposia sessions with contributing papers on pre-defined topics.

## XII Symposium of Computational Mechanics (SIMMEC 2016)

The Brazilian Association of Computational Methods in Engineering (ABMEC) and the Federal University of Jequitinhonha and Mucuri Valleys are pleased to announce the 2016 edition of the Symposium of Computational Mechanics (SIMMEC). SIMMEC is a multidisciplinary technical-scientific event organised since 1991 in different Brazilian universities. SIMMEC is promoted by ABMEC and is second most important Brazilian event in the field of Computational Mechanics. The aim of SIMMEC is to share the latest developments in computational mechanics and related areas. SIMMEC is also an opportunity for discussions and networking of professionals, researchers and students in the field.

In 2016, XII SIMMEC will be held in the UNESCO World Heritage City of Diamantina, Brazil, from **25 to 27 May 2016**. The event will host technical sessions as well as keynote lectures given by national and international specialists from the academy and industry (Boston University, UFPE, UFMG, Embraer and Wikki Brasil). Two short-courses opened to all attendees will be offered on subjects of common interest. The visitors will be also invited to the social events in the pleasant city of Diamantina.

XII SIMMEC

The topics of the Symposium will be: Numerical Analyses in Manufacturing Processes; Bioengineering; Dynamics and Vibrations; Solid and Fluid Mechanics;

After 35 successful meetings, 36th Ibero-Latin American Congress on Computational Methods in Engineering will be held from 6 to 9 November 2015, in Brasília, Brazil, and is hosted by the Graduate Program in Integrity of Materials on Engineering of the University of Brasília (UnB).

Brasília, capital of Brazil, dream of Dom Bosco, commanded by Juscelino Kubitschek, 21th Brazilian President, idealized by the architects Lucio Costa and Oscar Niemeyer, is reference in modern architecture and Unesco World Heritage Site. Brasília is the 4th largest city in Brazil and center of political power. The city is located in west center of the country, near from others Brazilian states capitals.

On behalf of the organizing committee of CILAMCE 2015, it is a great pleasure to invite you to the XXXVII Ibero-Latin American Congress on Computational Methods in Engineering. We look forward to welcoming you in Brasília. For more information please visit the website ***2016.cilamce.com.br*** ●

Numerical Methods; Finite Element, Boundary Element and Finite Volume Methods; Modeling of Thermal Systems and Heat and Mass Transfer; Optimization; Design of Machines; Computational Simulation and Artificial Intelligence.

Abstract submission will open on December 2015, until February 2016. For more information, visit the website: ***doity.com.br/simmec2016***. ●

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## *Simulating in the Rain:*
## *GACM Colloquium 2015*
*hosted at*
***RWTH Aachen University***

From **July 20-24, 2015** the RWTH Aachen University, Germany, became the site of the 6th GACM colloquium, the colloquium of the German Association on Computational Mechanics (GACM). Nearly 300 participants followed the invitation of conference chairpersons Dr. Stefanie Elgeti and Dr. Jaan-Willem Simon to a full week of compelling talks, interesting discussions, and a necessary dose of diversion.

One key idea of the GACM colloquium is to address the future generation of researchers. This is a shared goal with a conference type that has only recently found its path into ECCOMAS conference family. In Aachen, the organizing committee had the special pleasure of hosting the GACM colloquium in conjunction with the 3rd ECCOMAS Young Investigators Conference (ECCOMAS YIC). As a contrasting complement, the conference was furthermore held in direct sequence with the 3rd Aachen Conference on Computational Engineering Science (AC.CES), organized by the graduate school AICES and traditionally focusing on invited speakers with international prestige. In total, this formed the YIC GACM AC.CES 2015.

The YIC GACM AC.CES was attended by participants from 33 countries; most of them European, but some as far away as New Zealand or Japan. Almost every participant contributed a presentation to the scientific program, leading to 44 parallel sessions and minisymposia. In addition, the scientific program featured three young investigators plenaries as well as six plenaries by senior speakers invited to AC.CES. A poster session within the frame of AC.CES was open to those participants who felt not quite ready for a presentation yet. In order to provide easy access to the scientific program for all participants, RWTH Aachen University offered professional child care throughout the conference.

In addition to the scientific program, the GACM colloquium focuses on enhancing the dialogue and the networking between the young investigators, with an extensive

***Figure 1:***
*ECCOMAS president Prof. Ekkehard Ramm during the opening ceremony*

***Figure 2:***
*The audience during the opening ceremony*

***Figure 3:***
*GACM president Prof. Wolfgang Wall during the opening ceremony*

social program as a catalyst. In Aachen, the social program consisted of a public lecture by Dr. Fabian Hemmert on "Staying Human in the Digital Age", a Journal Club, a movie night, where the movie group of RWTH Aachen University showed the movie "Moneyball", and a Science Slam. During the Science Slam, a group of six brave men, consisting of both conference participants and members of the organizing committee, showed their talent in scientific comedy, giving the audience a very memorable evening full of entertainment and surprises. Special thanks go to Prof. Wolfgang Wall, current GACM president, for showing he is young at heart by taking on the challenge and participating in the Science Slam. Already proving that scientists can be both successful and funny, this event led up to the appearance of a professional in both aspects: the special conference guest Dr. Mayim Bialik, alias Dr. Amy Farrah Fowler on the US sitcom "The Big Bang Theory". YIC GACM AC.CES conference badges, which secured exclusive entrance to her talk, quickly became a much envied accessory in all of Aachen; in retrospect, over 20,000 people would click "like" on Facebook for this event. Furthermore, the insightful and engaging talk by Dr. Mayim Bialik lead to press coverage on the YIC GACM AC.CES in major newspapers all over Germany.


***Figure 4:***
*The audience bids Mayim Bialik farewell*

Overall, the 6th GACM colloquium was a great success with Aachen weather strongly contradicting the provocative title. The next colloquium, to be held in 2017 in Stuttgart, is now eagerly anticipated!

*Organizing committee of*
***GACM YIC AC.CES 2015***

***Figure 5:***
*Conference dinner in the historic coronation hall*

KSCM
KOREA SOCIETY FOR COMPUTATIONAL MECHANICS

## WCCM XII & APCOM VI

*for all inclusions under*
***KSCM***
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mkkim1212@skku.edu

WCCM XII & APCOM VI will be held in Seoul, Korea on **July 24-29, 2016**. The conference venue is COEX complex, a business and cultural hub located in the heart of "Gangnam" district. This massive complex consists of 12 buildings including World Trade Center Seoul, City Airport Terminal, three 5-star hotels, musical theater, COEX aquarium, Asia's largest underground shopping center, and COEX convention center hosting 200 exhibition and 2,000 conferences every year including G20 Seoul Summit and 2002 FIFA World Cup.

Currently, more than 220 mini-symposium proposals have been accepted and Call-for-abstract is on the way. Please be aware of the following important dates for participating in this wonderful event.


- Deadline for one-page abstract: ***January 24, 2016***
- Acceptance notice: ***January 30, 2016***
- Deadline for early registration: ***March 31, 2016***

For more information, please visit conference website **http://wccm2016.org/** or contact the secretariat of WCCM XII & APCOM VI **secretariat@wccm2016.org.**

The Korean Society for Computational Mechanics (KSCM) was founded in 2011 to stimulate, foster, and promote various activities such as education and research and practice in computational mechanics and organize conferences in Korea for the dissemination of knowledge concerning computational mechanics as an affiliate of IACM. Recently, KSCM has formed the new executive council members for 2015-2017 as follows:

***President:***
Prof. Chae, Soo Won (Korea University)
***Senior Vice-President:***
Prof. Kim, Yoon Young (Seoul National University)
***Vice-Presidents:***
Prof. Kim, Cheol (Kyungpook National University), Prof. Lee, Chang-Ock (KAIST), Prof. Lee, Haeng Ki (KAIST) and Prof. Lee, Tae Hee (Hanyang University)
***Auditors:***
Prof. Cho, Maenghyo (Seoul National University) and Prof. Kim, Byung Soo (Chungnam National University)
***Secretaries:***
Prof. Kim, Moon Ki (Sungkyunkwan University) and Prof. Lee, Ik Jin (KAIST). ●

## USNCCM13 Held in San Diego, California

*Figure 1: Opening reception at the Manchester Grand Hyatt*

The 13th U.S. National Congress on Computational Mechanics was held in San Diego, California, **July 26-30, 2015** at the beautiful Manchester Grand Hyatt. Over 1300 participants participated in over 100 minisymposia spanning 4 days. It also featured three plenary and five semi-plenary speakers. Five pre-congress short courses were also offered. Graduate students participated in a poster competition which included over 90 posters.

A new feature of the USNCCM13 was the Women Researchers Forum, sponsored by Elsevier and USACM, attended by approximately 50 female researchers designed to discuss topics of interest and facilitate networking opportunities. All women researchers at all career stages (from students to leading experts) were invited. ●


*Figure 2: Women Researchers Forum sponsored by Elsevier*

## USACM 2015 Awards Presented

USACM presented awards at the USNCCM13 banquet to the following:

John von Neumann Medal: Antony Jameson, Stanford University, for pioneering contributions to computational fluid dynamics, particular to advances in the study of compressible flow over aircraft and the optimal design of air foils

The Belytschko Medal: Stewart Silling, Sandia National Laboratories, for developing and demonstrating, peridynamics, a new mechanics methodology for modeling fracture and high strain deformation in solids

Thomas J.R. Hughes Medal: Douglas Arnold, University of Minnesota, for seminal contributions as a research mathematician and educator specializing in computational mathematics, interdisciplinary research, numerical analysis, FEM, PDEs, mechanics, the interplay between these fields, and FE exterior calculus.

Gallagher Young Investigator Award: Vikram Gavini, University of Michigan, for his pioneering work developing multi-scale methods for density-functional theory calculations at continuum scales, electronic structure studies on defects in materials, and quantum transport in materials.

USACM Fellows: Yuri Bazilevs, UC-San Diego; Sanjay Govindjee, UC-Berkeley; Assad Oberai, RPI; Abani Patra, University of Buffalo. ●

## USACM Upcoming Conferences

- **Multiscale Methods and Validation in Medicine and Biology III**, Los Angeles, CA, February 25-26, 2016. http://mmvmb3.usacm.org/
- **Advances in Mathematics of Finite Elements**, Austin, TX, March 21-22, 2016. http://amfe2016.usacm.org/
- **IUTAM Symposium on Integrated Computational Structure-Material Modeling of Deformation and Failure under Extreme Conditions**, Baltimore, MD, June 19-22, 2016. http://iutam2016ics.usacm.org/
- **Recent Advances in Computational Methods for Nanoscale Phenomena**, Ann Arbor, MI, August 29-31, 2016 (see USACM website for further information)
- **Isogeometric and Meshfree Methods**, La Jolla, CA, October 10-12, 2016. http://iga-mf.usacm.org/
- **14th U.S. National Congress on Computational Mechanics (USNCCM14)**, July 17-21, 2017, Montreal, Canada. http://14.usnccm.org/ ●

# conference diary planner

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| **5 - 10 June 2016** | **ECCOMAS Congress 2016**<br>*Venue:* Crete Island, Greece *Contact:* http://eccomas2016.org/ |
| **8 - 10 June 2016** | **XII SIMMEC - XII Symposium of Computational Mechanics**<br>*Venue:* Diamantina, Brazil *Contact:* doity.com.br/simmec2016 |
| **19 - 21 June 2016** | **IUTAM - Comp.Structure-Material Modeling of Deformation & Failure Under Extreme Conditions**<br>*Venue:* Baltimore, U.S.A. *Contact:* http://iutam2016ics.usacm.org/ |
| **19 - 23 June 2016** | **EngOpt 2016 - Int. Conf. Engineering Optimization**<br>*Venue:* Iguassu Falls, Brazil *Contact:* www.engopt.org |
| **11 - 14 July 2016** | **ICCMS2016 - VI Int. Congress on Computational Mechanics & Simulation**<br>*Venue:* Bologna, Italy *Contact:* http://conference.mercatura.pt/mechcomp2016/ |
| **24 - 29 July 2016** | **APCOM 2016 - 6th Asia Pacific Congress on Computational Mechanics**<br>*Venue:* Seoul, Korea *Contact:* http://www.wccm-apcom2016.org/ |
| **24 - 29 July 2016** | **WCCM XII - World Congress on Computational Mechanics**<br>*Venue:* Seoul, Korea *Contact:* http://www.wccm-apcom2016.org/ |
| **21 - 26 Aug 2016** | **24th International Congress of Theoretical & Applied Mechanics**<br>*Venue:* Montreal, Canada *Contact:* http://www.ictam2016.org/ |
| **10 - 12 Oct. 2016** | **Isogeometric & Meshfree Methods**<br>*Venue:* La Jolla, CA, U.S.A. *Contact:* http://iga-mf.usacm.org/ |
| **8 - 11 Nov. 2016** | **ENIEF 2016 - XXII Congress on Numerical Methods & their Applications**<br>*Venue:* Córdoba, Argentina *Contact:* http://www.frc.utn.edu.ar/enief2016/ |
| **5 - 7 April 2017** | **FEF 2017 - 19th International Conference on Finite Elements in Flow Problems**<br>*Venue:* Rome, Italy Contact: http://www.iacm.info/vpage/1/0/Events/FEF |
| **6 - 7 April 2017** | **SYMCOMP 2017 - Int. Conf. Numerical & Symbolic Computation: Developments & Applications**<br>*Venue:* Minho, Portugal *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **15 - 17 May 2017** | **VII International Conference on Computational Methods in Marine Engineering**<br>*Venue:* Nantes, France *Contact:* http://congress.cimne.com/marine2017/ |
| **15 - 17 May 2017** | **MultiBioMe 2017 - Multiscale Problems in Biomechanics & Mechanobiology**<br>*Venue:* Corsica, France *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **6 - 9 June 2017** | **SMART 2017 - 8th Conference on Smart Structures and Materials**<br>*Venue:* Madrid, Spain *Contact:* http://www.eccomas.org/vpage/1/14/2017/ |
| **12 - 14 June 2017** | **COUPLED PROBLEMS 2017 - VII Int. Conf. on Coupled Problems in Science & Engineering**<br>*Venue:* Rhodes Island, Greece *Contact:* http://congress.cimne.com/coupled2017/ |
| **14 - 16 June 2017** | **CFRAC 2017 -V Int. Conf. Computational Modeling of Fracture & Failure of Materials & Structures**<br>*Venue:* Nantes, France *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **19 - 21 June 2017** | **X-DMS 2017 - eXtended Discretization Methods**<br>*Venue:* Umeå University, Sweden *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **26 - 28 June 2017** | **ADMOS 2017 - VIII International Conference on Adaptive Modeling and Simulation**<br>*Venue:* Lombardy, Italy *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **30 June - 1 July 2017** | **MDA 2016 - 1st International Conference on Materials Design and Applications 2016**<br>*Venue:* Porto, Portugal *Contact:* www.fe.up.pt/mda2016 |
| **11 - 14 July 2017** | **2nd International Conference Mechanics of Composites**<br>*Venue:* Bologna, Italy *Contact:* https://sites.google.com/a/gcloud.fe.up.pt/mechcomp2016/ |
| **17 - 21 July 2017** | **USNCCM14 - 14th U.S. National Congress on Computational Mechanics**<br>*Venue:* Montreal, Canada *Contact:* http://14.usnccm.org/ |
| **21 - 23 Aug. 2017** | **Modern Finite Element Technologies - Mathematical and Mechanical Aspects**<br>*Venue:* Bad Honnef, Germany *Contact:* http://www.eccomas.org/vpage/1/14/2017 |
| **5 - 7 Sept. 2017** | **COMPLAS 2017 - XIV International Conference on Computational Plasticity**<br>*Venue:* Barcelona, Spain *Contact:* http://congress.cimne.com/complas2017/ |
| **26- 28 Sept. 2017** | **PARTICLES 2017 - V International Conference on Particle-based Methods**<br>*Venue:* Hannover, Germany *Contact:* http://congress.cimne.com/particles2017/ |
| **9 - 11 October 2017** | **STRUCTURAL MEMBRANES 2017 - VIII Int. Conf. on Textile Composites & Inflatable Structures**<br>*Venue:* Munich, Germany *Contact:* http://congress.cimne.com/membranes2017/ |
| **11 - 15 June 2018** | **ECCM - ECFD Conference 2018**<br>*Venue:* Glasgow, UK *Contact:* http://www.eccomas.org/vpage/1/13/Upcoming-ECCM-ECFD |