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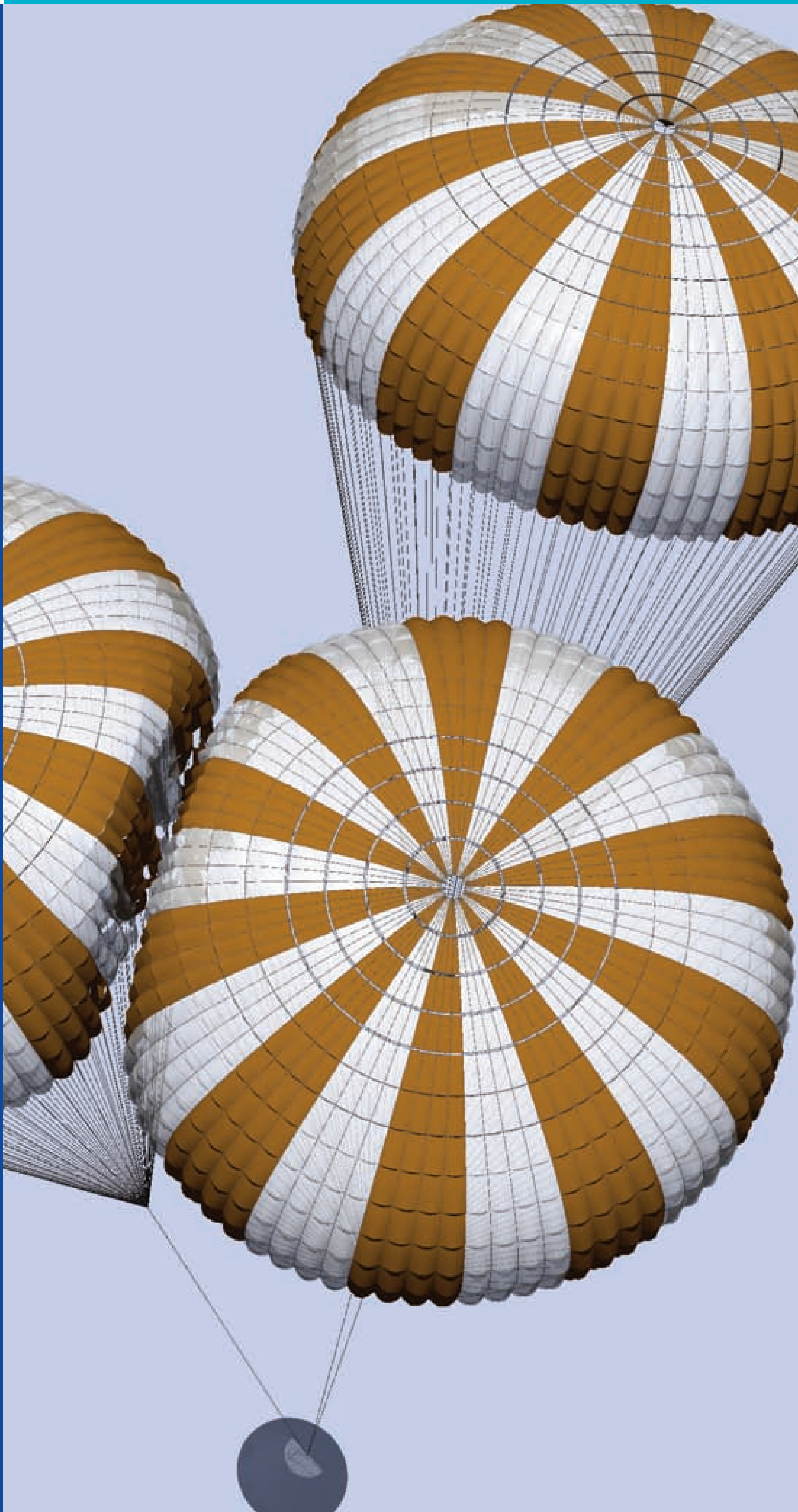

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contents

editorial

This issue of Expressions will be practically coincident with the 10th World Congress on Computational Mechanics organized by the IACM in the city of Sao Paulo on 8-13 July 2012. Previous editions of this global event took place in Austin (1980), Stuttgart (1990), Tokyo (1994), Buenos Aires (1998), Vienna (2002), Beijing (2004), Los Angeles (2006), Venice (2008) and Sydney (2010). Some 2000 participants will participate in WCCM X in Sao Paulo.

On behalf of the IACM I thank the effort of the organizers of the Sao Paulo congress, and in particular the involvement of Prof. Paulo Pimenta as Chairman of the congress and his co-workers for making of WCCM X another successful IACM event.

WCCM XI will take place in Barcelona, on July 20-25 2014 in conjunction with two major ECCOMAS conferences: the 5th European Conference on Computational Mechanics (ECCM V) and the 6th European Conference on Computational Fluid Dynamics (ECFD VI).

World congresses on Computational Mechanics are the major events organized by the IACM. They aim to gathering researchers, developers and practitioners in the broad field of computational methods in engineering and applied sciences. The participation in the WCCMs has progressively increased from some 500 participants in the first meeting in Austin to the 2000 participants in Sao Paulo, with a peak of 3000 participants in WCCM VIII in Venice in 2008.

The support and involvement of the international computational mechanics community to WCCMs is a sign of the vitality of the field. This is nowadays more apparent when we are facing a deep economic crisis that affects all countries in the world, directly or indirectly.

The topics covered in the WCCMs have also evolved. The traditional areas in computational solid and fluid mechanics have been progressively extended to cover a broader spectrum reaching basically all fields of applied sciences and engineering.

New prominent topics include bio-medicine, nano-technology, blending of particle-based methods and traditional finite element methods, distributed computing in multicore machines, virtual reality for display of simulation results and integration of computational methods and software into embedded systems incorporating data acquisition systems and data mining methods, wireless sensors, info-mechanical systems and devices and artificial intelligence techniques.

WCCMs are a meeting point for multicultural and multi-disciplinary relations among the IACM community in academia and industry worldwide. They are also a forum for interchange of state of the art information in the different fields and an opportunity for young scientists to meet with senior colleagues, thereby opening a world of opportunities in research, university and industrial activities.

Eugenio Oñate
Editor of IACM Expressions

FSI Modeling of Spacecraft Parachutes

by
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Rice University
Houston

Computer modeling of parachutes involves all the numerical challenges of fluid–structure interaction (FSI). The aerodynamics of the parachute depends on the canopy shape and the deformation of the canopy depends on the aerodynamics forces, and the two systems need to be solved in a coupled fashion. Because the parachute FSI is in a category where the structure is light (compared to the air masses involved in the parachute dynamics) and very sensitive to changes in the aerodynamics forces, the coupling technique, which determines how the coupling between the equation blocks representing the fluid, structure, and mesh moving is handled, requires extra care.

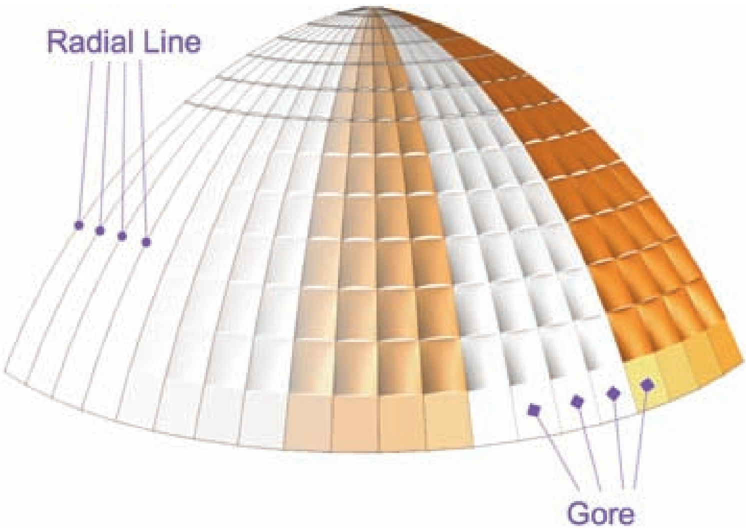

Figure 1:
Parachute radial lines and gores

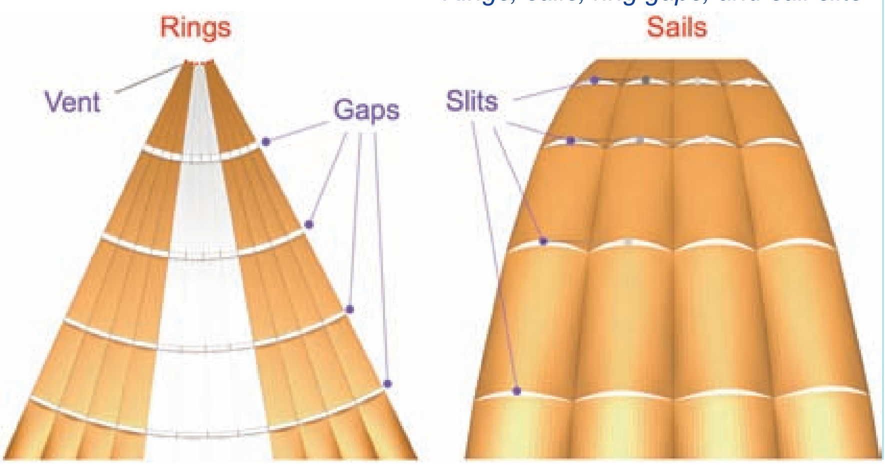

Figure 2:
Rings, sails, ring gaps, and sail slits

Spacecraft parachutes are typically very large ringsail parachutes that are made of a large number of gores, where a gore is the slice of the canopy between two radial reinforcement cables running from the parachute vent to the skirt (see *Figure 1*). Ringsail parachute gores are constructed from rings and sails, resulting in a parachute canopy with hundreds of ring gaps and sail slits (see *Figure 2*). The complexity created by this geometric porosity makes FSI modeling inherently challenging.

Spacecraft parachutes are typically used in clusters of two or three parachutes (see *Figure 3*), and the contact between the parachutes is a major challenge specific to FSI modeling of parachute clusters.

The core technology used in the parachute FSI computations of the Team for Advanced Flow Simulation and Modeling (T★AFSM) <www.tafsm.org> <www.jp.tafsm.org> is the Stabilized Space–Time FSI technique [1]. The T★AFSM parachute FSI computations started as early as 1997 with axisymmetric computations and goes as far back as 2000 for 3D computations. In the early years of parachute modeling with the space–time FSI technique, the coupling technique was block-iterative (see [1, 2] for the terminology), and later a more robust version of that, which significantly increased the coupling stability (see [2]). In 2004 and later, the space–time FSI computations were based on the quasi-direct coupling and direct coupling techniques [1, 2], which yield significantly more robust algorithms for FSI computations where the structure is light. These techniques are for the general case of nonmatching fluid and structure meshes at the interface, which is what we prefer in parachute computations, but reduce to monolithic techniques when the meshes are matching. Today, the quasi-direct coupling is the favored coupling technique in the FSI computations of the T★AFSM.

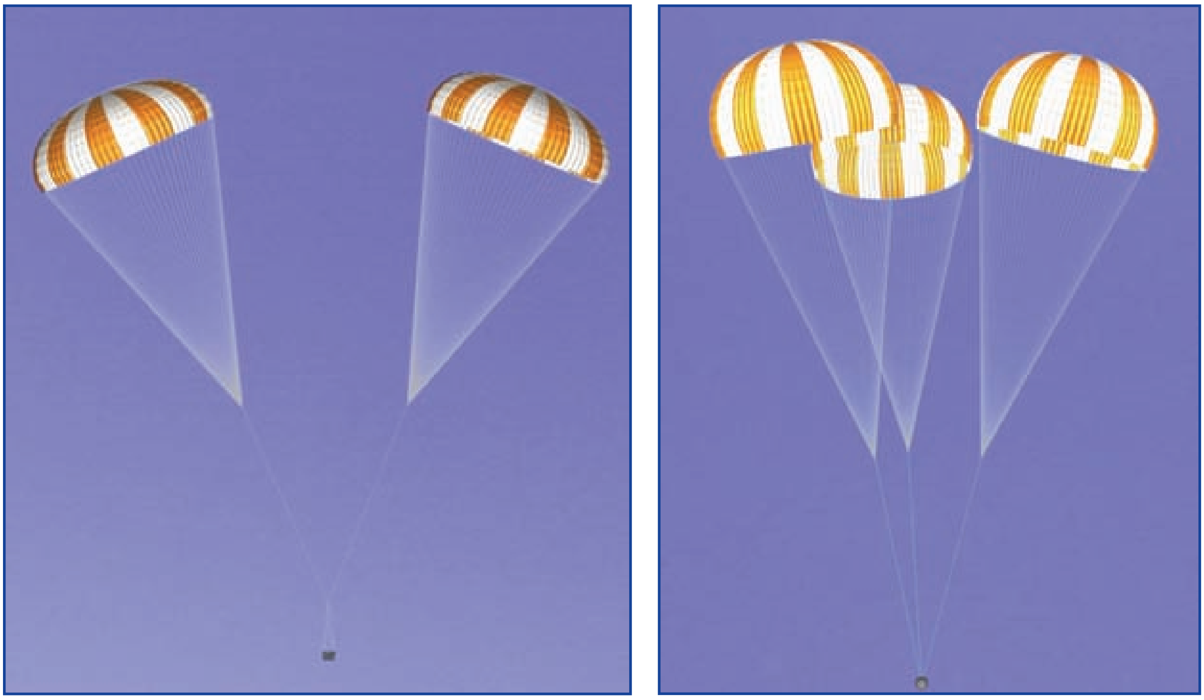

Figure 3:
Clusters of two and three parachutes

The Homogenized Modeling of Geometric Porosity (HMGP) was introduced in [3], and its new version, "HMGP-FG," was introduced in [4]. The HMGP helps us bypass the intractable complexities of the geometric porosity by approximating it with an equivalent, locally varying homogenized porosity, which is obtained from an HMGP computation with an n-gore slice of the parachute canopy. *Figures 4 and 5* summarize the HMGP-FG. For details, see [3, 4]. Even in the fully open configuration, the parachute canopy goes through a periodic breathing motion where the diameter varies between its minimum and maximum values. The shapes and areas of the gaps and slits vary significantly during this breathing motion (see *Figure 6*). It was shown in [5] that the porosity coefficients have very good invariance properties with respect to these shape and area changes.

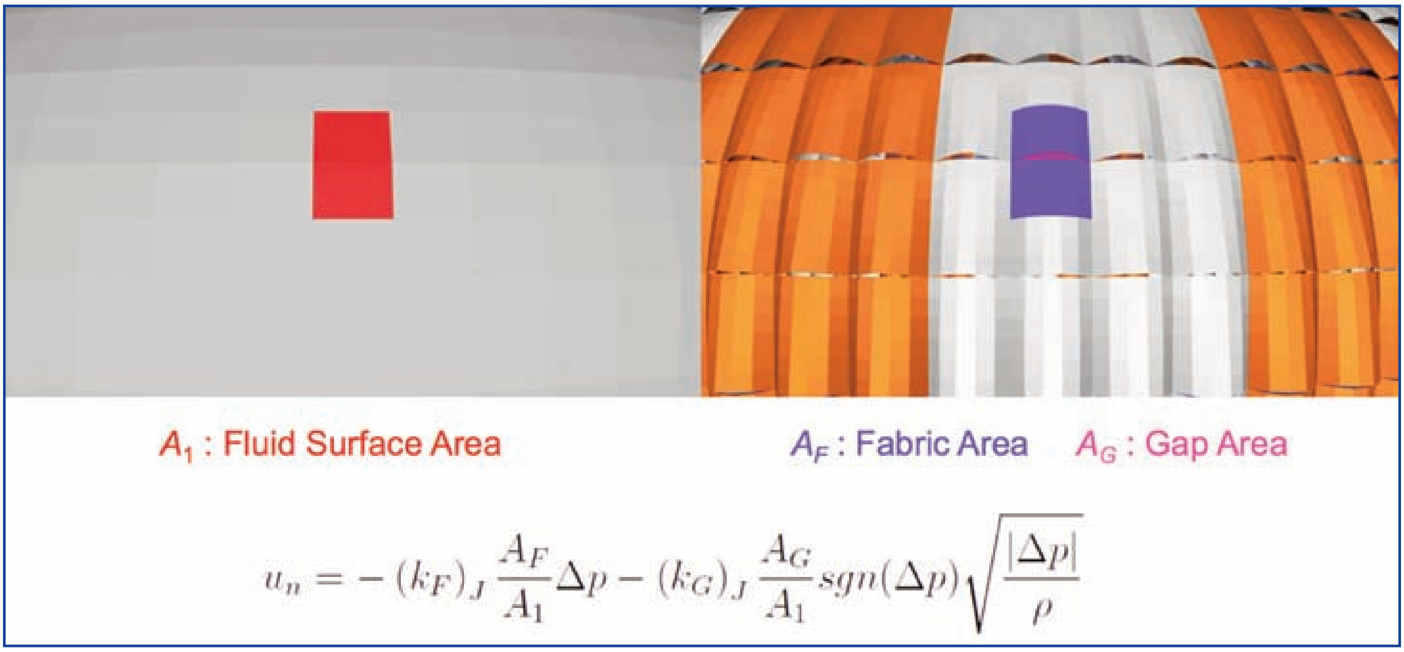

Figure 4:
In the HMGP-FG, the normal velocity crossing the parachute canopy under a pressure differential $\triangle p$ is modeled by using two homogenized porosity coefficients $(k_F)_J$ and $(k_G)_J$. For details, see [3, 4]

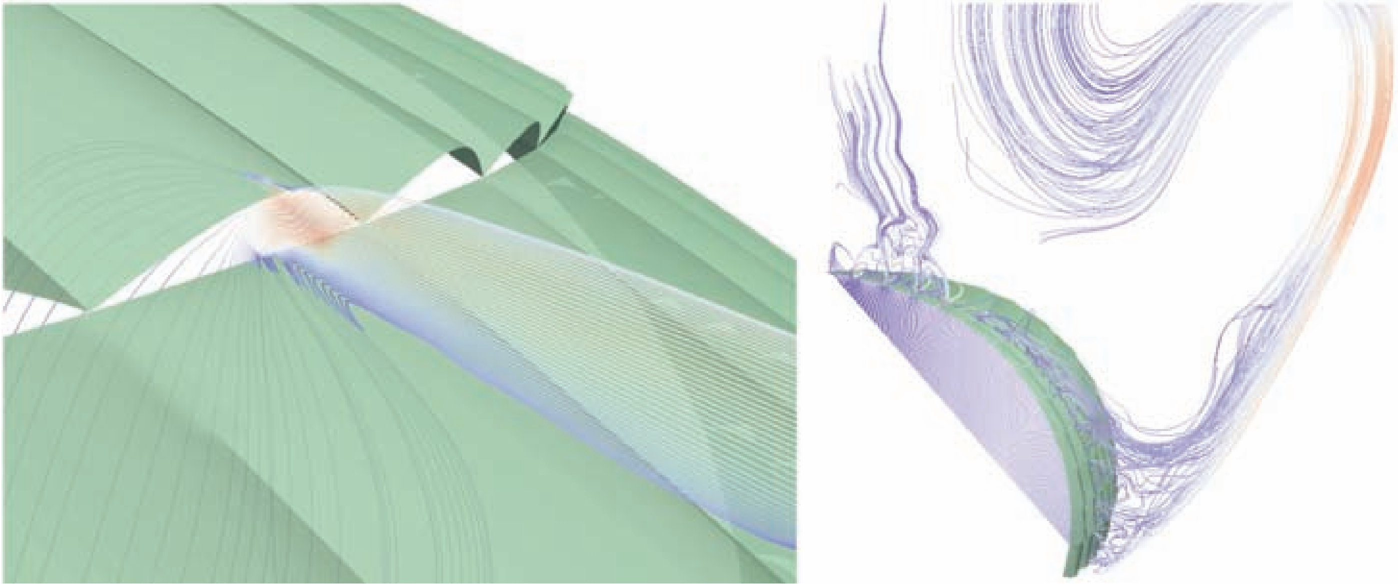

Figure 5:
The two porosity coefficients are calculated from a one-time fluid mechanics only computation with an n-gore slice of the parachute canopy, where the flow through all the gaps and slits is resolved

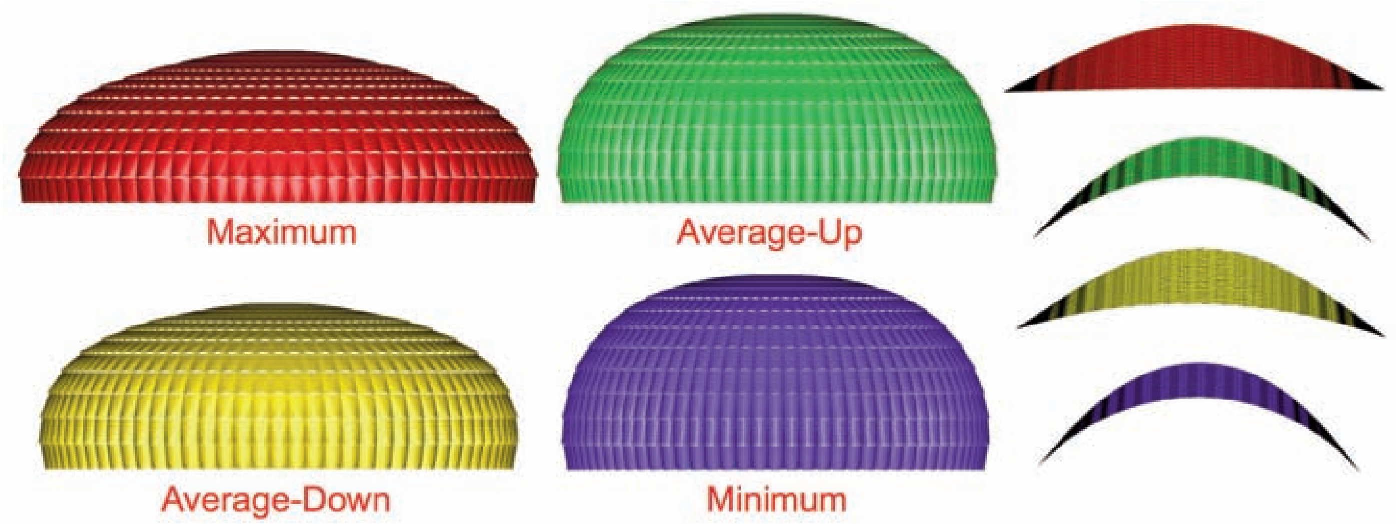

Figure 6:
The shapes and the areas of the slits vary significantly during the canopy breathing motion

	Descent Speed (ft/s)	Relative Horizontal Speed (ft/s)	Breathing Period (s)	Swinging Period (s)
Test Data	<10% Diff	Comparable	<10% Diff	<10% Diff
Computation	21.4	4 to 13	6.7	16.4

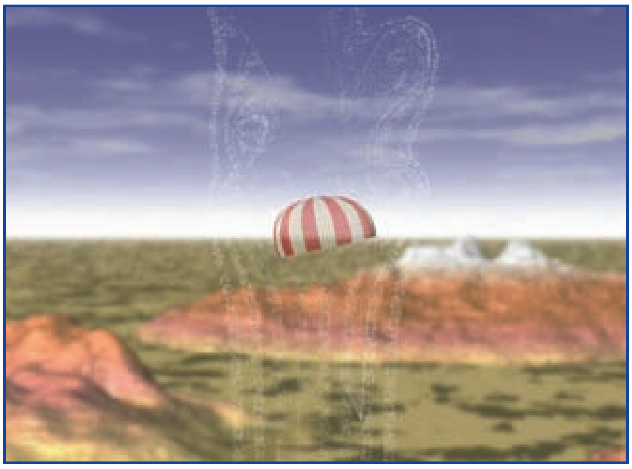

Figure 7:
Parachute and flow field at an instant during the computation and the comparison with the test data

Comparing our computed results to data from drop tests with a base parachute design helps us gain confidence in our parachute FSI model. *Figure 7* shows the parachute shape and flow field at an instant during the computation and the comparison with the test data.

Figure 8:
A simulation-based parachute design study, where the objective is to evaluate the aerodynamic performance of the parachute as a function of the suspension line length. See [6] for details of the study

With confidence gained from comparing our results with test data, we can carry out simulation-based parachute design studies [4, 6], such as evaluating the aerodynamic performance of the parachute as a function of the suspension line length (see *Figure 8*) or in response to removing one of the sails of the canopy (see *Figure 9*).

Figure 9:
A simulation-based parachute design study, where the objective is to evaluate the aerodynamic performance of the parachute in response to removing the 5th sail. The virtual smoke shows the vortex patterns in the parachute wake. See [4] for details of the study

The contact between the canopies of a spacecraft parachute cluster is a computational challenge that we have addressed recently (see [7, 8]) with a contact algorithm where the objective is to prevent the structural surfaces from coming closer than a minimum distance. The Surface-Edge-Node Contact Tracking technique was introduced in [1] for this purpose, in [7, 8] evolved into a conservative version that is more robust, and is now an essential technology in the parachute cluster computations we carry out. *Figure 10* shows a cluster of two parachutes at an instant during the FSI computation when the parachutes are in contact, and *Figure 11* shows a cluster of three parachutes at three different instants during the FSI computation, with contact between two of the parachutes. See [7, 8] for details.

This article shows that parachute FSI modeling can contribute valuable information and analysis to the spacecraft parachute design process, and in particular the parachute cluster computations show that spacecraft parachute modeling can now be done under actual conditions.

A comprehensive review of the core and special space–time FSI techniques used in spacecraft parachute modeling can be found in [9]. The readers can also find material on this subject, and some movies, at our Web sites <www.tafsm.org> <www.jp.tafsm.org>.

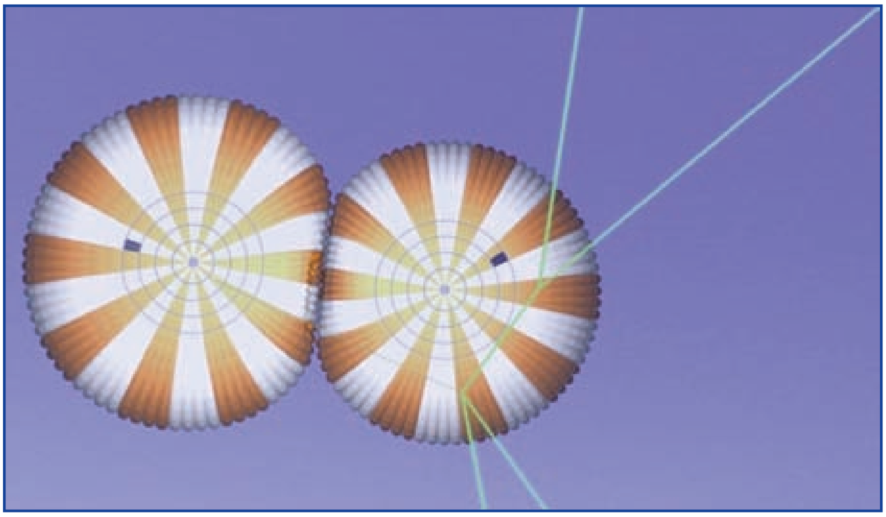

Figure 10:
A cluster of two parachutes at an instant during the FSI computation. See [7, 8] for details

This research was supported by NASA Johnson Space Center and is an outcome of much collaboration with and guidance from NASA engineers, especially Ricardo Machin. Many current and former members of the T★AFSM contributed to this research; they are the coauthors of the articles cited. ●

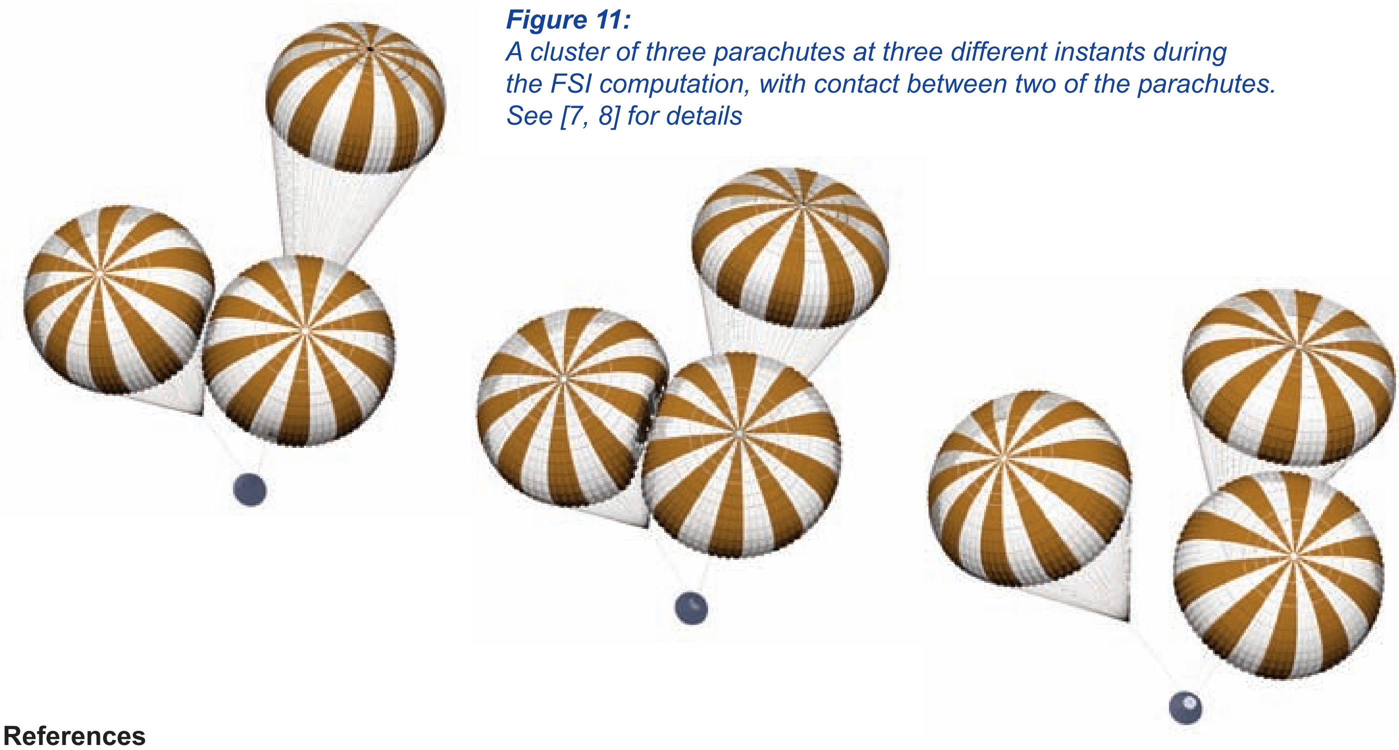

Figure 11:
A cluster of three parachutes at three different instants during the FSI computation, with contact between two of the parachutes. See [7, 8] for details

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Numerical Modeling of Highly Heterogeneous Media

by
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Heterogeneities in oil reservoirs

Oil production in Mexican reservoirs is on decline, primary recovery is in the last stages and it has become necessary to resource to enhanced oil recovery (EOR) techniques. Research in these aspects is very active and numerical modeling is playing an important role. Several research projects on numerical simulation are being developed, e.g., simulation of enhanced techniques such as water and gas injection, and in situ combustion.

Some Mexican oil reservoirs are better described as Naturally Fractured Vuggy Carbonate Reservoirs, it is acknowledged that to have access to remaining hydrocarbons present in these mature fields is necessary to meet greater reservoir characterization challenges than those existing when these reservoirs started their productive life. It is important to consider other alternatives for reservoir characterization that describe heterogeneities better than traditional procedures especially if pressure maintenance or an EOR process will be undertaken. Some NFR have different scales, poor fracture connectivity and disorderly spatial distribution of fractures. Vugs effect on permeability is related to this connectivity.

To describe the complex heterogeneities of these reservoirs several theories have come in to play, noteworthy the Theory of Fractals, see [3]. In the simplest case, we shall describe some aspect of the theory and illustrate some numerical methods of interest.

The random function path to fractal reservoirs

Let X be a function of two variables, $X \equiv X(x,\omega)$: X is a random function if for $x \in R^N$, the function $X(x,\cdot)$ is a random variable.

Let *M* be the spatial domain occupied by the porous medium, for a given ω ; is simply a deterministic *R*-valued function on R^N; which is refereed to as a realization of the function X.

$$X(\cdot,\omega): M \subset R^N \to R$$

Let us consider the basic equation of single-phase flow [2],

$$\frac{\partial(\phi\rho)}{\partial t} = \nabla \cdot \left(\frac{\rho}{\mu} K \nabla p\right) + q$$

Here ρ the density of the fluid per unit volume and μ its viscosity. Also ϕ is the porosity, and *K* the absolute permeability tensor of the porous medium.

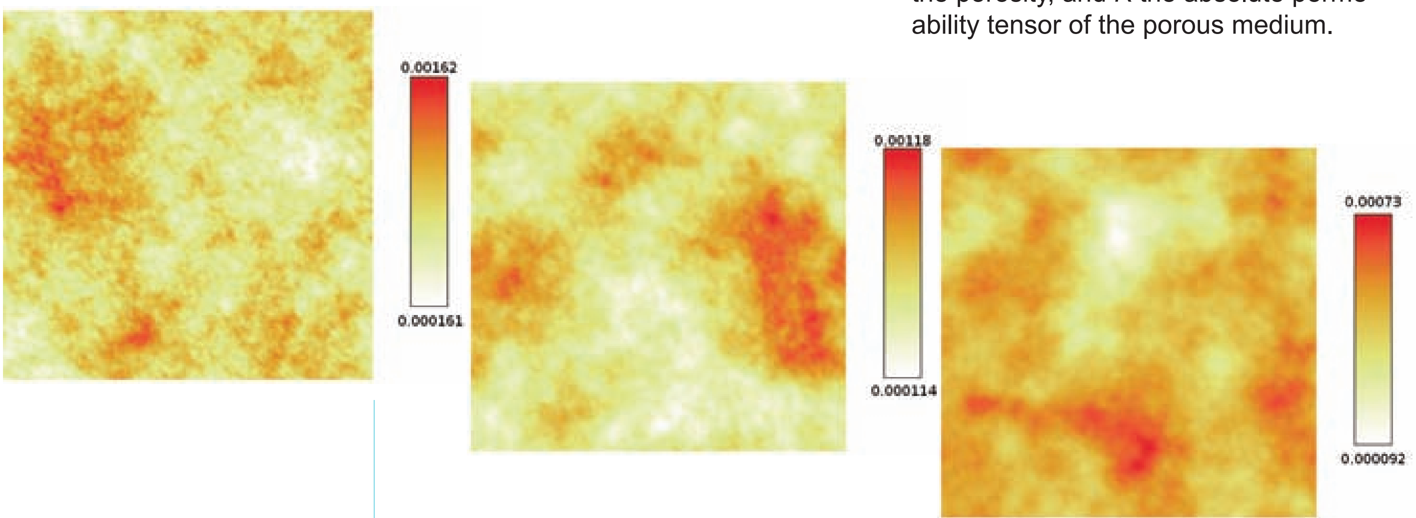


Figure 1:
Profiles obtained by spectral synthesis for different values of H.

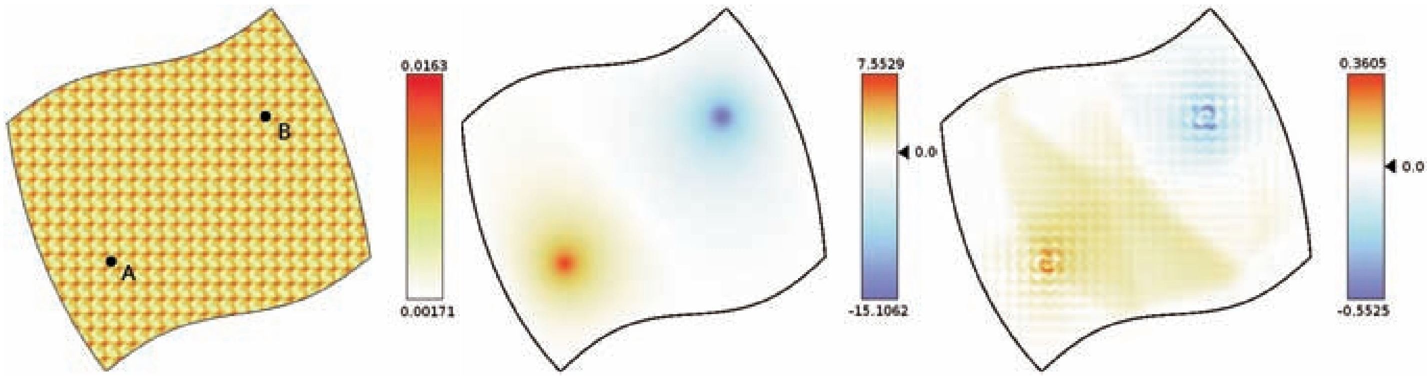


Figure 2:
The solution ***p*** *does not reproduce the local variation of* $\boldsymbol{p}^{\varepsilon}$ *.*

" ... the problem is to generate realizations of porosity and permeability with prescribed geostatistical properties. "

We assume that the medium is isotropic, so $K = kI$; where I is the identity tensor.

We focus on porosity and permeability since these properties characterize the porous medium. It is customary to model these properties $\phi=\phi(x), k=k(x)$, as random functions. In this context, we shall refer to a reservoir as fractal, if the level sets of these random functions have fractional Hausdorff dimension [1].

Consequently, for flow simulation, the problem is to generate realizations of porosity and permeability with prescribed geostatistical properties [3]. There are several algorithms to generate realizations of random functions with fractal properties [4]. For instance, using spectral synthesis we generate profiles of permeability in *Figure 1*.

With this approach the flow equations remain unchanged. What is necessary is to upscale permeability to grid size for numerical simulation. An appealing method is that of homogenization [5].

For the steady state equation,

$$-\nabla\cdot\left[a\left(\frac{x}{\varepsilon}\right)\nabla p^{\varepsilon}\right]=q \qquad x\in\Omega,$$
$$p^{\varepsilon}=0 \qquad x\in\partial\Omega,$$

we assume a is a *Q*-periodic function ($Q\subset R^{N}$ is the unit cube, $a(y+me_i)=a(y)$ for all $y\in Q$, $m\in Z$, and e_i denotes the *i*-th canonical vector). Instead of solving the equation above, the homogenization method obtains the solution *p* such that $p^{\varepsilon}\to p$ as $\varepsilon\to 0$. *p* is obtained by solving a problem with constant coefficients,

$$\sum_{i=1}^{N}\sum_{j=1}^{N}\bar{a}_{ij}p_{x_ix_j}=q \qquad in \qquad \Omega,$$
$$p=0 \qquad in \qquad \partial\Omega,$$

where $\bar{a}_{ij}$ are the homogenized coefficients.

For example, *Figure 2* shows the differences between p and its differences with p^{ε}. In this case, q is a difference of two Gaussian functions with centers at A and B. This is a cartoon of an injection-production system. Due to the variability Of $\left(\frac{x}{\varepsilon}\right)$,it is necessary to use fine grid to compute p^{ε}. In actual applications this is computationally prohibited.

Fractional continuous media

An alternative approach is to consider fractal media as a fractional continuous media, see [6]. The procedure consists on replacing the fractal medium with fractal mass dimension by some continuous medium that is described by fractional integrals.

Let W be a set in R^3 with Hausdorff dimension D: If D is not an integer, the set is fractal. The *D-mass* of W is defined by the fractional integral

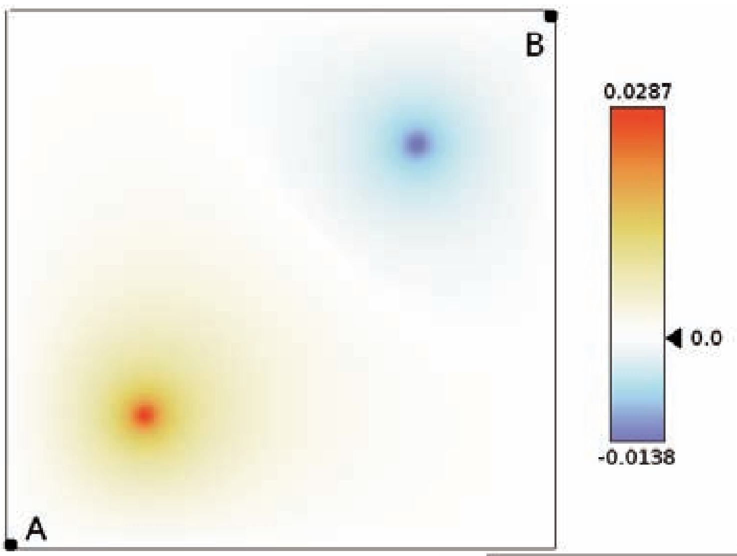
$$M_D(W,x_0)=\int_W \rho(x)dV_D, \qquad x_0\in W,$$

$$dV_D=c_3(D,x)dx \qquad c_3=\frac{2^{3-D}\Gamma(3/2)}{\Gamma(D/2)}\frac{1}{|x-x_0|^{3-D}}$$

where ρ is density. Note that if $D = 3$; the expression $M_D(W, x_0)$ coincides with the euclidean case. One can derive a fractional version of the Gauss Theorem and proceed as customary in Continuum Mechanics to obtain the continuity equation

$$\frac{\partial \phi}{\partial t}+\frac{2^{D-d-1}\Gamma(D/2)}{\Gamma(3/2)\Gamma(d/2)}|x|^{3-D}\nabla\cdot(|x|^{d-2}\rho u)=q$$

Here, *d* corresponds to the exponent associated to the boundary of the fractal continuous medium.



Assuming Darcy's law, $u=-k\nabla p$ and steady state we have the equation

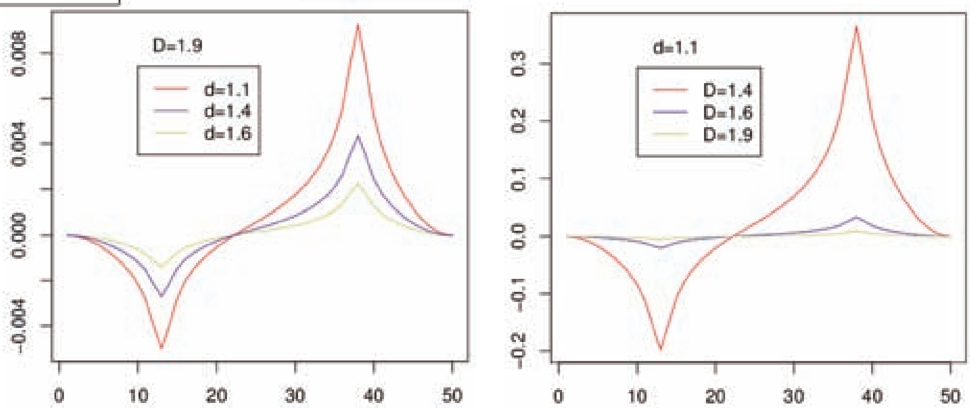
$$-\nabla\cdot(a(x)\nabla p)=f(x),$$

where

$$f(x)=\frac{\Gamma(d)}{\Gamma(d)2^{D-d-1}}\|x\|^{D-2}q(x), \qquad a(x)=\|x\|^{d-1}\rho k$$

As before, we solve the equation in an injection-production system. In *Figure 3* we show the solution as well as the profile along the diagonal for several values of Hausdorff dimension. In this elementary setting the model serves its purpose, heterogeneity of the porous medium is associated to Hausdorff dimension and it has the expected effect in fluid flow. ●

Figure 3: *Solution obtained with* ***D = 1.9,d = 1.1,*** *and the behavior of the solutions by varying the parameters* ***D*** *and* ***d***



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The Key to Tracing the Postbuckling Response of Structures with Multi Critical Points

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The postbuckling response of structures with multi winding loops is a complex physical phenomenon. Depending on the history of loading, the stiffness of the structure may be softening or stiffening, the equilibrium path may be stable or unstable, and the structure itself may be on a stage of loading or unloading. All such phenomena are typified by the occurrence of critical points such as the limit points and snap-back points in the load-deflection curves (*Figure 1*), which often makes the iterations difficult to converge to the desired path [14]. In this article, some key issues that are crucial to the successful tracing of the postbuckling response of a structure using an incremental-iterative approach will be highlighted [9].

Concerning the finite element equations used, the first requirement is that the (linearized) finite element should be rigid-body-qualified, such that no artificial forces will be generated upon rigid rotations.

Secondly, the *corrector* used for recovering the element forces from the element displacements should be made as accurate as possible, since this is the phase that governs the accuracy of the solution.

Thirdly, the *predictor* used for computing the structural displacements for given load increments, which are approximate by nature due to unavoidable linearization, should be accurate to the level not to misguide the direction of iterations.

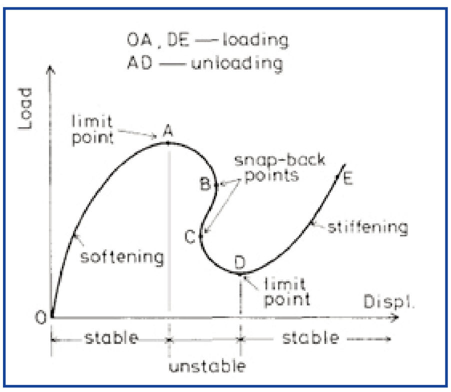


Figure 1: *General characteristics of a nonlinear structure*

As for the incremental-iterative scheme for searching the equilibrium points, it is required to be: (1) numerically stable when encountering the limit points, (2) adjustable in load increments to reflect the stiffness variation, and (3) self-adaptive in changing the loading direction. In this article, we shall assume that the updated Lagrangian (UL) formulation is adopted, in that all the equations of the structure at the current configuration C_2, which is to be solved, are expressed with reference to the last calculated configuration C_1.

Quality of nonlinear finite elements

All nonlinear theories for structures should be linearized, if a solution is to be obtained in terms of the load-deflection curves by the finite element approach. In this regard, an incremental-iterative approach (i.e., solution scheme) has to be adopted to remove the unbalanced forces resulting from approximations due to linearization of the theory, updating of geometry and member forces of the structure, or any other sources involved in the procedure. Let us assume that a precise procedure has been adopted for updating the geometry and nodal forces of the structure, as this is the most fundamental part of an analysis. The unbalanced forces $\{R\}$ should originate from linearization of the theory or derivation of the element stiffness matrices $[k]$ from the virtual work or energy equations via nodal representations. Here we use the term "linearized" or "linearization" to refer to the fact that the finite element of concern here is initially stressed or acted upon by a set of nodal forces $\{{}^1f\}$ at each intermediate incremental step. We shall focus our discussion on how to solve the geometrically nonlinear and postbuckling response of an elastic structure, with the effects of material nonlinearity or yielding excluded.

By the UL formulation, one can work on the virtual work equation or its variants to derive the equation of equilibrium for the finite element, in which the elastic effect is represented by the elastic stiffness $[k_e]$ and the instability effect by the geometric stiffness $[k_g]$ [13; 7]. In this part of derivation, some terms appearing in the virtual work equation or encountered in the finite element formulation are unavoidably omitted simply because they are of "higher-orders". As a matter of fact, care must be taken in omitting the so-called higher-order terms, because some of them may appear physically in pair, combine to represent a rigid rotation effect, and therefore cannot be omitted in an arbitrary manner [4; 8; Chapters 4 & 7 in 7].

Aside from the solution scheme to be described later, rigid rotation is an issue central to the successful tracing of the winding, postbuckling response of a structure using the incremental-iterative procedures. In comparison, it is relatively easier for the elastic stiffness $[k_e]$ to satisfy the rigid rotation property, but the same is not true for the geometric stiffness $[k_g]$, if the neglect of higher-order terms has not been handled in a delicate way with the rigid rotation effect kept in mind [Chapters 4 & 7 in 7].

What we like to point out here is that if the rigid rotation effect is not properly represented by the nonlinear finite element, especially by the geometric stiffness $[k_g]$, then unbalanced forces $\{R\}$ will be induced upon rigid rotations, which can hardly be eliminated by further iterations using the same rigid-body-defective stiffness. Eventually, the iterations are likely to diverge when further increments are conducted or when the rigid rotations are accumulated to a certain level.

Sometimes we called this phenomenon a result from the *lack of a proper direction of iterations* [3]. A nonlinear finite element with such rigid-rotation defects can still be used for "slightly nonlinear" problems, but is not suitable for use in problems of which the postbuckling response may involve extremely large rotations.

Rigid body rule

A simple way to test if a nonlinear finite element can accommodate rigid rotations is by the rigid body rule [6]. To illustrate this rule, let us consider a bar subjected to a compression *P* and sitting on the earth in *Figure 2*. When the earth undergoes a rigid rotation , the line of action of force *P* rotates with the rotation, but its magnitude remains unchanged. An overall result is the preservation of equilibrium of the bar in the rotated position.

The same conclusion holds for the bar if it is subjected to and equilibrated by a set of forces, i.e., $\{^1f\}$, including the axial forces, shear forces, and bending moments at C_1, as is the case for the 2D beam shown in *Figure 3*.

Based on the above observation, the rigid

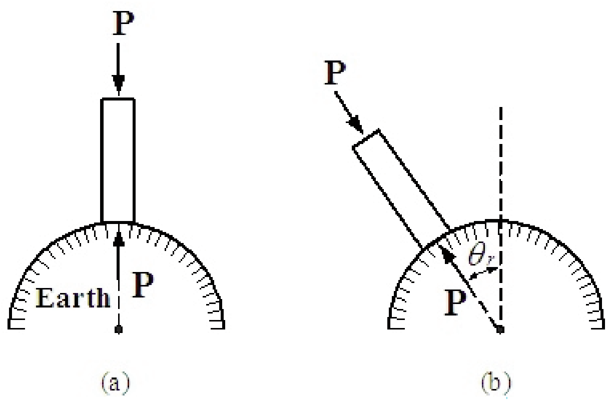


Figure 2:
A stressed bar before and after rigid rotation

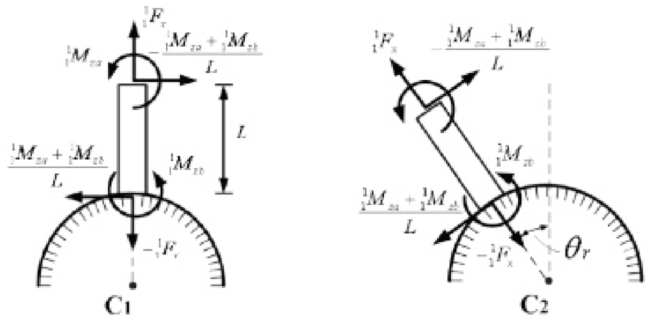


Figure 3:
2D stressed beam before and after rigid rotation

body rule can be stated as follows: For a bar initially acted upon by a set of forces $\{^1f\}$ in equilibrium at C_1, it should remain in equilibrium after the rigid rotation at C_2, with no change on the magnitudes of the acting forces. It should be noted that *no limit* has been placed on the magnitude of rotation for the rigid body rule to be valid. It is easy to conceive the rigid body rule for the 3D beam element or other types of finite elements that are initially acted upon by a set of nodal forces $\{^1f\}$.

The rigid body rule described above is a universal one, which serves as the *minimum* condition for testing the legitimacy of a nonlinear finite element, with initial nodal forces.

One simple reason for this is that the stiffness equation derived for each finite element, if reasonably derived, should work for any types of deformations $\{u\}$, including the bottom line of rigid displacements $\{u_r\}$. The other reason for a nonlinear element to be rigid-body qualified is that at each incremental step of a nonlinear analysis, a large portion of the displacements of the finite elements belongs to rigid rotations [10; 11; 12], as illustrated in *Figure 4*.

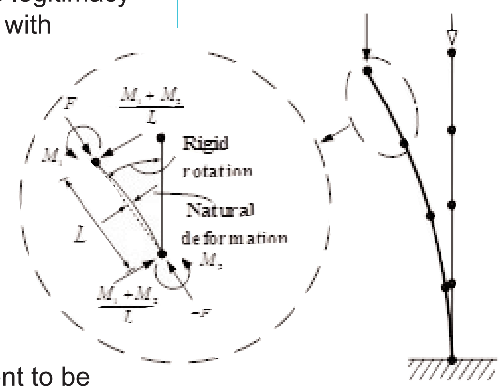


Figure 4:
Element displacements decomposed as rigid rotation and natural deformation

" Using finite elements that are rigid-body qualified, the GDC method, along with the GSP, can be employed to solve the load-deflection postbuckling paths of elastic structures involving multi critical points and large rotations."

In conducting the rigid body test, all the terms involved in the finite element equation should be considered, including the elastic stiffness $[k_e]$, geometric stiffness $[k_g]$, initial forces $\{^1f\}$ at C_1, and resulting forces $\{^2f\}$ at C_2, [6; 9; 10; 11]. First, we know that a reasonably derived elastic stiffness $[k_e]$ will generate zero forces upon rigid rotations $\{u_r\}$. It follows that the elastic stiffness term $[k_e]$ can be excluded, and the rigid body rule becomes the one for testing the legitimacy of the geometric stiffness $[k_g]$ derived for a finite element.

The procedure of testing is quite simple. One first assumes a rigid rotation field $\{u_r\}$ (small in magnitude for convenience and as the minimum condition to be satisfied). Then, based on the element equation [6 for instance], one can sum up the initial nodal forces $\{^1f\}$ at C_1 (in the form of *Figure 3(a)*) with the forces generated by the geometric stiffness $[k_g]$ during the rigid rotation, i.e., $[k_g]\{u_r\}$ to obtain the resulting forces $\{^2f\}$ at C_2. If the resulting forces $\{^2f\}$ obtained are consistent with the form shown in *Figure 3(b)*, then the rigid body test is passed. Otherwise, it is not. For the case where the rigid body test is not passed, the terms that have been missing or over-regulated can often serve as the clue for tracing the errors or mistakes involved in deriving the finite element equation.

Predictor of incremental-iterative analysis

One basic step in finite element analysis is to assemble all the element stiffnesses $[k]$ to obtain the structural stiffness $[K]$. With the structural stiffness $[K]$ made available, one can conduct the incremental-iterative analysis by first applying a load increment $\{^2P\}$-$\{^1P\}$ on the structure and then solving the structural equation for the displacement increments $\{U\}$ of the structure. Such a step has been referred to as the predictor stage of an incremental-iterative analysis [8; 7]. Here, we like to note that the structural equation used in the predictor is born to be non-exact or approximate, as it has been derived as the result of linearization from the original nonlinear theory.

Furthermore, since this stage affects only the speed of convergence or the number of iterations, it does not add much to the accuracy of solution by trying to improve the exactness or the level of nonlinearity of the stiffness matrices $[k]$ used in this part of analysis. Unfortunately, this has been the point of focus of numerous previous researches. For the purpose of successfully tracing the postbuckling response of structures, however, it is required that the structural stiffness matrices $[k]$ used in the predictor be rigid-body qualified in order not to misguide the direction of iteration [3].

Corrector of incremental-iterative analysis

Once the structural displacement increments $\{U\}$ are solved for a load increment $\{^2P\}$-$\{^1P\}$ in the predictor, we can obtain the displacement increments $\{u\}$ for each element of the structure. With this, we are ready to compute the nodal forces $\{^2f\}$ for each element at the updated, deformed configuration C_2. Such a stage has been referred to as the corrector of an incremental-iterative nonlinear analysis [8; 7]. Since the corrector governs the accuracy of the solution by an incremental-iterative procedure, it should be carried out in a very careful, precise way.

To calculate the nodal forces $\{^2f\}$ at C_2, it is conceptually easier to divide the element displacements $\{u\}$ into two parts as the rigid displacements $\{u_r\}$ and natural deformations $\{u_n\}$.

First, the initial nodal forces $\{^1f\}$ existing on the element at C_1 when undergoing the rigid displacements $\{u_r\}$ can be treated as those acting at C_2 with reference to C_2 according to the rigid body rule.

Second, the elastic force increments $\{f\}$ generated at the incremental step by the natural deformations $\{u_n\}$ can be computed as $\{f\} = [k_e]\{u_n\}$.

Summing up the above two parts yields the resulting forces $\{^2f\}$ at C_2. Such a procedure of calculation is simple, but is amazingly accurate. It has been successfully used as the corrector in tracing the postbuckling response of various structures containing winding loops, namely, with multi critical points.

After the element forces $\{^2f\}$ are made available and the geometry of the structure is updated, the total resistant (internal) forces $\{F\}$ at the structural nodes can be computed accordingly. As a consequence, the unbalanced forces $\{R\}$ at the newly deformed configuration can be computed as the difference between the total applied loads $\{^2P\}$ and the total resistant forces {*F*}. Then another iteration involving the predictor and corrector should be conducted to eliminate the unbalanced forces {*R*}.

However, another issue arises concerning how to perform the iterations, namely, by keeping the applied loads $\{{}^2P\}$ constant or allowing them to vary, because it will affect the capability of the iteration scheme to bypass the limit points and therefore to trace the postbuckling response involving multi-critical points, as will be described below.

Path-tracing scheme - generalized displacement control (GDC) method

As was stated by Yang and Shieh [14], an incremental-iterative scheme used to trace the postbuckling response of structures with adjacent equilibrium paths, which may involve multi critical points, such as limit points and snap-back points, and large rigid rotations accumulated from previous incremental and iterative steps, should possess the following properties:

(1) numerical stability in passing the limit points,

(2) automation in adjusting the load increments to reflect the stiffness variation, and

(3) automation in reversing the loading direction for loading and unloading stages.

To overcome the numerical instability associated with the limit points, an incremental-iterative scheme should *not* be performed at *constant loads*, as is the case with Newton-Raphson method (see *Figure 5*). The *generalized displacement control (GDC) method* devised by Yang and Shieh [14] is capable of dealing with the limit points, as iterations are not performed at constant loads. Besides, it utilizes the *generalized stiffness parameter* (GSP) as a guiding parameter for adjusting the load increments and for reversing the loading directions in an automatic manner.

General stiffness parameter

Let us introduce first the GSP. This parameter is defined as the dot product of the tangent vectors $\bar{u}$ and $\bar{v}$, respectively, of the load-deflection curve shown in *Figure 6* at the start and the end of the current incremental step, but is inversely normalized with respect to the dot product of the tangent vectors for the first

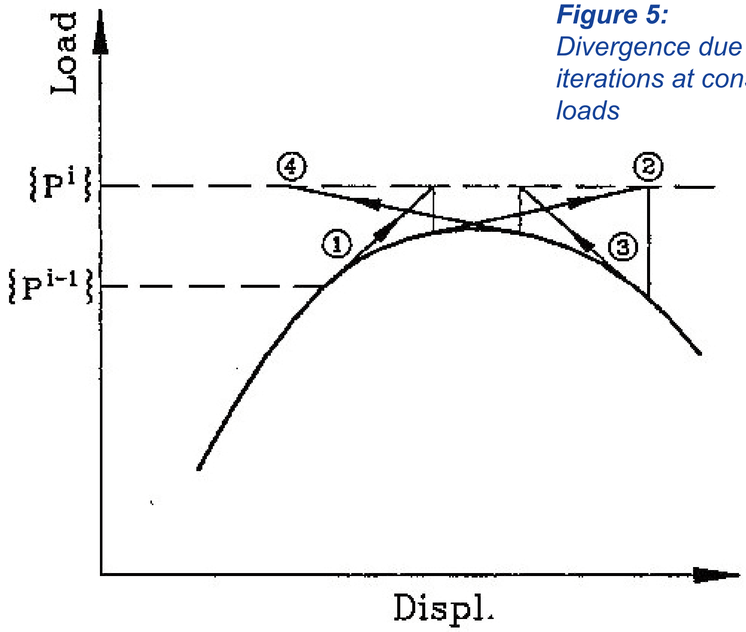


Figure 5:
Divergence due to iterations at constant loads

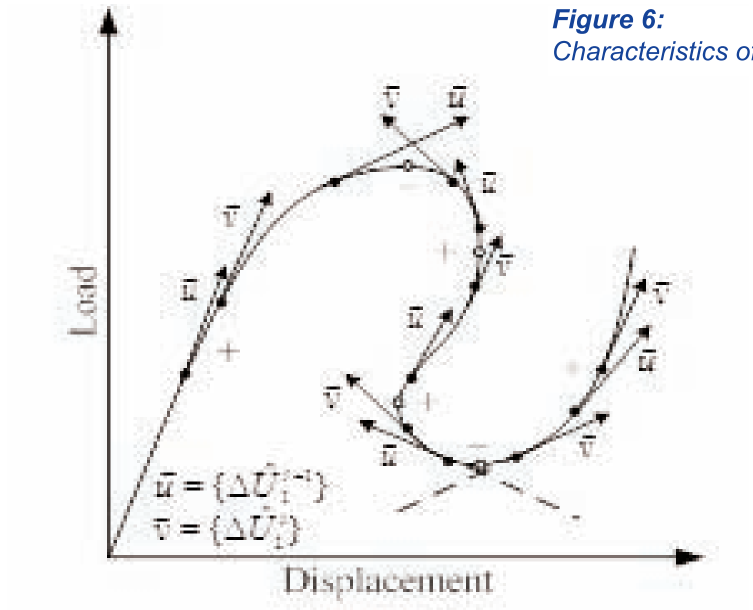


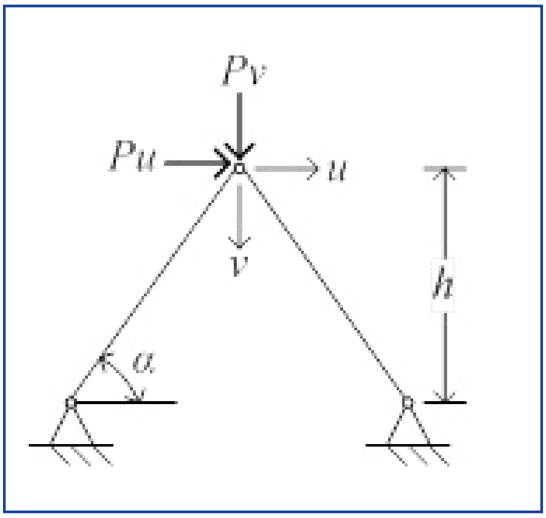
Figure 6:
Characteristics of GSP

incremental step [14]. From *Figure 6*, it is easy to see that the two tangent vectors form an *obtuse angle* only when passing a limit point, which means a *negative* dot product, and that for all the other cases, they form an acute angle, which means a *positive* dot product. Since “passing a limit point” means a change in loading direction, thus when a negative sign is detected for GSP, the loading direction should be reversed, namely, from “loading” to “unloading” after passing the first limit point, and from “unloading” to “loading” after passing the second limit point as for the case shown in *Figure 6*, and so on. This feature of the GSP has enabled the GDC method to overcome automatically all the limit points encountered in the winding, postbuckling path of a structure, a special feature that makes the GDC method outperform the arc length method.

To those researchers who have got acquainted with the GDC method, they regard this method as a much more reliable one for tracing the postbuckling response of structures [2]. It should be added that in a numerical analysis, it is unlikely that an iterative step will hit “right” at a limit point, a well-known singularity problem that cannot be avoided mathematically, as there always exist some round-off or truncation errors in the numerical process.

The other feature with the GSP is that the dot product of the two tangent vectors of the current incremental step has been inversely normalized with respect to that of the first incremental step. In this way, the GDP represents the stiffness of the structure at the current incremental step with respect to the first incremental step. As a matter of fact, the GSP starts with unity and becomes smaller when the structure softens and greater when the structure hardens, and becomes close to zero when approaching a limit point. In this way, the variation of the structural stiffness is automatically taken into account in determining the load increment at each step, which makes the GDC method a very efficient scheme. Furthermore, unlike the current stiffness parameter proposed by Bergan [1], the GSP remains bounded in regions near the snap-back points (or any other regions), rendering the GDP a stable scheme for getting through the snap-back points.

Figure 7:
Two-member truss



Final remarks

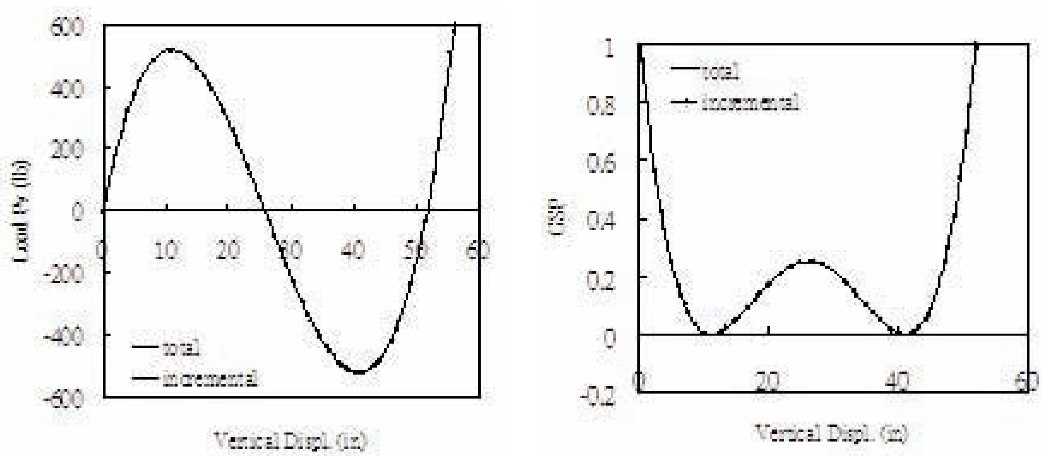
Using finite elements that are rigid-body qualified, the generalized displacement control (GDC) method, along with the general stiffness parameter (GSP), can be employed to solve the load-deflection postbuckling paths of elastic structures involving multi critical points and large rotations. Details of the incremental-iterative procedure have been given in [14].

However, for those who are newly trying to adopt this method, it is suggested that they work first on the two-member truss shown in *Figure 7*. The reason is that it is relatively easier to debug any logistic or coding errors in the implementation of the procedure when solving the two-member truss, since each computational quantity can be physically interpreted as this truss contains only two degrees of freedom. Besides, the postbuckling response of the truss has been analytically made available by Pecknold et al. [5].

From the point of numerical stability, the two-member truss represents one of the most challenging problems, due to the existence of adjacent equilibrium paths, multi limit points and snap-back points, loading, unloading, and reloading, all of which should be dealt with in a large-rotation domain.

For the case of a vertical load, the results for the load-deflection response and for the GSP vs. the vertical deflection of the truss have been shown in *Figures 8(a) and (b),* respectively.

Figure 8:
Two-member truss without imperfection:
(a) P_v vs. v, *(b) GSP vs. v*



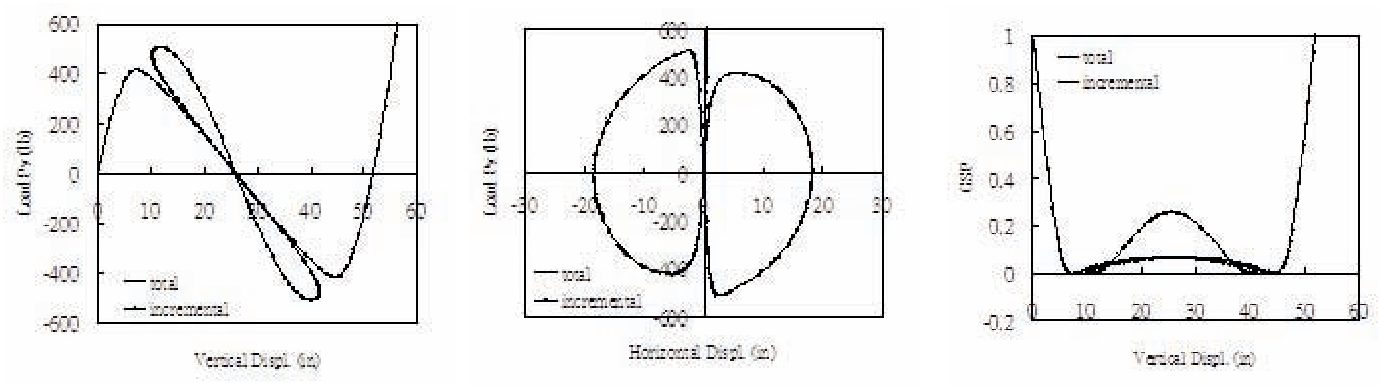
For the case of vertical and horizontal loads, the results for the truss are shown in Figures 9(a)-(c) for the following: (a) P_v vs. v, (b) P_v vs. u, (c) GSP vs. v. The special features of the GSP can be appreciated from *Figures 8(b)* and *9(c)* for the two cases considered. If a newly developed analysis program can handle the postbuckling behavior of the two-member truss, then most likely it can deal with the postbuckling behavior of other complicated structures.

The research reported herein on the postuckling response of elastic structures, including the rigid body rule, nonlinear finite element quality, predictor and corrector, and solution schemes, has been sponsored by a series of research projects by the National Science Council, Taiwan, including the ones with grant nos. NSC-75-0414-P-002-21, 78-0410-E002-30, 80-0410-E002-18, 80-0410-E002-59, and 81-0410-E002-05.

Such a long-time financial aid is gratefully acknowledged. ●

Figure 9:
Two-member truss with horizontal imperfection (P_u=0.05P_v):

(a) P_v vs. v, *(b) P_v vs. u, (* *c) GSP vs. v*



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The CM Questions of the Month

by
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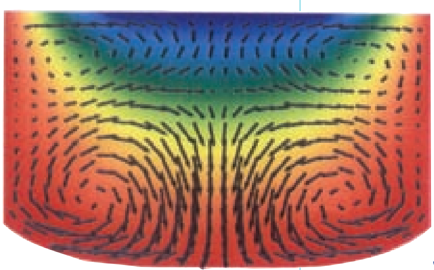
During the last four years, the author of this article has been editing an electronic newsletter on Computational Mechanics (CM), distributed twice a month to more than 400 subscribers who constitute the Israeli CM community (about 50 of them are full members of the Israel Association for Computational Methods in Mechanics – IACMM). This newsletter includes a section called "The Question of the Month," which is a riddle on CM subjects that the readers are asked to solve. Each month the answer to the Question of last month is published, along with the names of those readers who answered it correctly, and a new Question is posed. Sometimes interesting discussions develop, as readers comment on the Questions and on the answers.

The Questions, which span all areas of CM, are composed with an educational goal in mind. Some of the questions may be trivial to some of the readers, who have different backgrounds in industry and academia, but hopefully there is always something new to learn. Sometimes the Questions are quite theoretical, while occasionally they are very practical. Some of the readers who frequently send me their answers and comments are internationally distinguished researchers (like Achi Brandt, Roland Glowinski, Rafi Haftka and Eli Turkel to name just a few; there are others but I will stop here in fear that I will forget someone). Their participation in the discussion on the Questions is an important contribution to the educational benefit of this "game", and encourages other members of the community to participate as well.

In the following you will find a selection of Questions, their Answers, and in some cases comments that were made on them by readers. In order to give you, the reader of this article, a chance to think about the Questions before looking at their answers, we first write down all the selected questions, and only then their associated answers and comments.

Question 1: October 2008 Question of the Month: Equipping an Incompressible Code with Capability to Handle Buoyancy

You have in your working environment an incompressible flow code (it does not matter what method it is based on), which is used routinely for problems in hydrodynamics. The code is truly incompressible, namely assumes given constant density and does not include any temperature effects. One day, you suspect that a certain industrial process that you are working on involves Rayleigh-Benard instability, in which temperature plays a crucial role. Rather than buying a new code, you decide to change the existing code in order to be able to simulate the Rayleigh-Benard convection. ***What is the easiest way to do this, namely the way which would require minimal changes in the existing code?***



Rayleigh-Benard convection in a process of crystal growth from the melt. Temperature and velocity distributions are shown in a vertical plane of the crucible. Figure taken from Givoli, Flaherty and Shephard, Modelling Simul. Mater. Sci. Eng. 4 (1996) 623–639.

Question 2: April 2009 Question of the Month: Measuring Closeness of a Matrix to Being Singular

Many computational methods lead to a linear algebraic problem, where a system of linear algebraic equations has to be solved. The matrix appearing in this system must not be singular, otherwise the system cannot be solved. However, sometimes the matrix is not singular but "almost singular", and in such cases the solution of the system may become problematic, and special care must be taken.

[1] *Roshka is an imaginary character who appears quite a lot in the Questions, and represents the naïve engineer who has yet a lot to learn about computational methods. Roshka will appear again in another question below.*

The question arises: *how do we measure the closeness of a matrix to being singular?*

Our friend Roshka[1] has an idea: he calculates and looks at the determinant of the matrix. Since the determinant of a singular matrix is zero, the determinant might be regarded as a measure of the closeness to singularity; the smaller the determinant is (in absolute value) the closer the matrix is to being singular.

The question is: ***Why is Roshka's idea a bad idea? And what better idea would you suggest to measure how close a matrix is to being singular?***

Question 3: September 2009 Question of the Month: Discontinuous Galerkin

In recent years, the class of methods called Discontinuous Galerkin (DG) has emerged and has become popular among those developing new Finite Element (FE) techniques. One of the properties of DG is that the solution (elastic displacement, temperature, etc.) is not required to be continuous across element boundaries, and so may have "jumps" on the interfaces between neighboring elements. This is so even though the exact solution is known to be continuous. In contrast, the standard FE method produces numerical solutions which are continuous by construction. (Of course, the derivatives of the primary solutions – stresses, heat fluxes, etc. – are discontinuous even in the standard FE method. But here we are talking about the primary solution – elastic displacement, temperature, etc.)

This property of the DG may look strange – it may seem non-beneficial to allow the approximate solution to be discontinuous when we know that the exact solution is continuous.
What is the explanation and motivation for this?

Boris Galerkin (1871-1945)

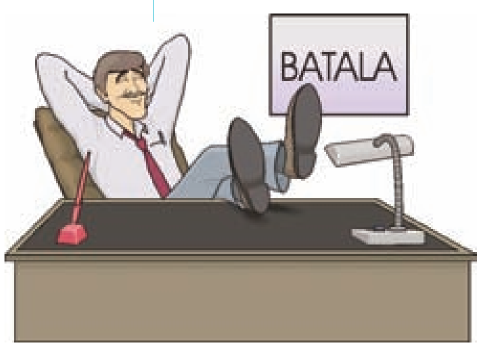
Discontinuous Galerkin

Question 4: October 2009 Question of the Month: Wave Resolution

Imagine that you are a group leader in the computational engineering company BATALA[2] (Benchmarks And Theoretical Analysis for Low-tech Applications).
Roshka is a junior member of your group. Here is a dialogue between the two of you:

Roshka: About this wave problem that you gave me to solve, related to the new project...
You: Yes, how about it?
Roshka: It goes very well. Remember, you told me to solve it for many various wave-lengths, the smallest being 0.001 meter and the largest being 1 meter.
You: Right.
Roshka: So I started with the 1 meter wave-length. I created a mesh with 20 elements per wave-length, because I read in an old report that there is a rule of thumb saying that 10 elements per wave-length should be good enough, and I wanted to be safe.
You: But you should check that...
Roshka: Not to worry! You remember that for the 1 meter wave-length (and for this wave-length only) we have some experimental results? Well, I compared the numerical results to the experimental results and the agreement is excellent!
You: Very good.
Roshka: So in principle this is the end of the story. I will go on and solve the problem for all the wave-lengths from 1m down to 0.001m, and in each case I will take 20 elements per wave-length. The mesh for the smallest wave-lengths will be quite dense, but it's not too terrible. I'll finish on Monday and then leave for my ski vacation.
You: Yet another vacation?! You just returned from one! Anyway, I hate to disappoint you, Roshka, but what you suggest to do will most probably *not* give us good results.

Explain why you said this to Roshka.



[2] *In Hebrew, the word "Batala" means idleness, the state of doing nothing. It usually refers to resting during a vacation.*

Answer to question 1: Equipping an Incompressible Code with Capability to Handle Buoyancy

The first thought that one might have is that one has to turn the code into a compressible code. After all, Rayleigh-Benard instability is caused by buoyancy effects, namely hot fluid becomes less dense and thus tends to go up (against gravity) while cold fluid becomes more dense and thus tends to go down. Thus, density becomes variable and the fluid is not incompressible any more.

However, turning an incompressible code into a fully compressible code is a nightmare... First of all, the velocity and pressure on one hand and the temperature on the other become fully coupled (through the equation of state that connects the energy equation to the momentum equations), and one has to solve for the temperature field simultaneously with the other variables. This involves some major technical changes in the code. Second, the properties of numerical schemes (stability and accuracy) for compressible and incompressible flows are totally different, and thus the "switch" from incompressible to compressible requires a lot of caution and is far from being "automatic".

Alex Yakhot

Amiel Herszage

Simon Brandon

Alex Gelfgat

What may save the day is the so-called Boussinesq approximation, which is valid in many applications (for example, it is heavily used in crystal growth applications). It is based on approximating the change in the density due to the temperature by the first-order term in a Taylor series around the nominal density. In this case the equations to be solved are not modified at all, except for a "buoyancy forcing term" in the right-hand-side of the relevant momentum equation which is a linear function of the temperature. This has the advantage that the density remains a given constant in the governing equations. Moreover, there is no full coupling between the temperature and the other variables. Thus, we can first solve for the temperature distribution (maybe using a separate, thermal code), and then solve separately for the velocity and pressure fields using our slightly modified incompressible code.

Correct answers were obtained from: *Simon Brandon, Alex Gelfgat, Amiel Herszage, Stephane Seror, David Sidilkover, Alex Yakhot.*

Answer to question 2: Measuring Closeness of a Matrix to Being Singular

Using the determinant to measure the closeness of a matrix to being singular is a very bad idea from several reasons. First, the determinant depends on the size of the entries of the matrix in a misleading way. Here is a demonstration of this. Consider a N×N diagonal matrix with entries equal to 0.1 on the diagonal. This matrix is as "perfect" as the identity matrix, and is not close to being singular at all. However, its determinant is $D=0.1^N$. If N is a large number, D will be a small number. Even for N=6 we will already get $D=10^{-6}$, and if N is a million (which is not so rare for CM applications), D will be an extremely tiny number. From looking at this tiny number one might wrongly conclude that the matrix is close to singular. Moreover, one would conclude that a matrix like that with N=million is closer to being singular than such a matrix with N=1, which is of course nonsense.

Related to this, the determinant D is a bad measure also because it depends on the engineering units that we use to write down the entries of the matrix. Suppose, for example, that the matrix entries have units of length. Then we will get two very different results for D if we use meters or millimeters as our units!

The standard way to measure "closeness to singularity" is through the Condition Number of the matrix. The condition number can be computed as the ratio of the maximum singular value of the matrix to the minimum singular value. (The "singular values" of a matrix are real positive values related to the Singular Value Decomposition (SVD) of the matrix; see books on numerical linear algebra.) For matrices with simple structure (called "normal matrices"), such as real symmetric matrices, the notions of singular values and eigenvalues coincide (up to a sign), and then the condition number is the ratio of the largest eigenvalue and smallest eigenvalue (in absolute values).

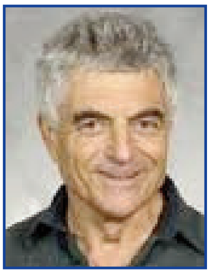
The condition number really measures how the solution of the system Ax=b changes when we slightly change the matrix A (or the vector b). Thus it is a measure of the sensitivity of the matrix. A singular matrix has infinite sensitivity, and an infinite condition number. A perfect matrix has condition number 1.

Hillel Tal-Ezer

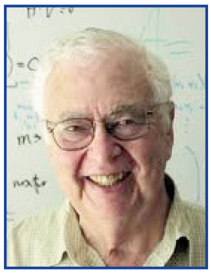
Kosta Volokh

Correct answers were obtained from: *Rami Ben-Zvi, Hillel Tal-Ezer, Amiel Herszage, Pavel Trapper, Eli Turkel, Kosta Volokh, Asher Yahalom, Zvi Zaphir.*

Comment:
Achi Brandt[3] comments that although my answer is indeed the standard one, it is not the best answer. The condition number may grow arbitrarily upon rescaling of equations and unknowns. Besides, it is not a good measure of how easy it is to numerically invert a matrix accurately; for example a non-singular diagonal matrix can have any condition number, but is trivial to invert or to solve with. The best answer is that the "closeness to singularity" is measured not by the condition number of the matrix itself, but by the the condition number of another matrix, called the "bi-normalized matrix". See details in the 2004 paper of Oren Livne and Gene Golub, "Scaling by binormalization," Numerical Algorithms 35: 97–120, 2004 (and see the interesting dedication!).



Achi Brandt



Gene Golub (1932-2007)

Answer to question 3: Discontinuous Galerkin

To fix ideas, let us consider the problem of steady-state heat conduction. (Analogous arguments can be given to problems in elasticity.) Suppose we have a finite domain (the body) in which the steady-state heat equation holds. We assume that along a part of the boundary of the body the temperature is given (a Dirichlet boundary condition) whereas on another part of the boundary the normal heat flux is given (a Neumann boundary condition). Now, let us construct a mesh of finite elements in this domain.

What is our goal?
We want to find a numerical solution that has the following 5 properties:

A. In each element, the solution satisfies (exactly or approximately) the equation of steady-state heat conduction.
B. On the part of the external boundary where the temperature is given, the solution satisfies (exactly or approximately) this boundary condition.
C. On the part of the external boundary where the normal heat flux is given, the solution satisfies (exactly or approximately) this boundary condition.
D. The temperature (namely the solution itself) should be (exactly or approximately) continuous across element borders.
E. The normal heat flux (related to the solution gradient) should be (exactly or approximately) continuous across element borders.

Erich Treffz (1888-1937)

Obviously, no numerical method would generally satisfy all five requirements exactly, because this would mean that we have found the analytical solution of the problem, and thus there is no need for a numerical method. So in general, at least some of the five requirements are to be satisfied approximately. The standard finite element (FE) method satisfies A, C and E approximately and B and D exactly. More precisely (and we will not discuss this issue here, which has to do with variational formulations) we say that A, C and E are satisfied weakly (or "in a weak sense") while B and D are satisfied strongly (or "in a strong sense").

There are special FE methods in which the type of satisfaction of A-E is different. For example, FE methods in which A (the differential equation in each element) is satisfied exactly are called Trefftz methods.

The *balance* of the satisfaction of all 5 requirements – some of them weakly and some of them strongly – has a major effect on the quality and behavior of the numerical

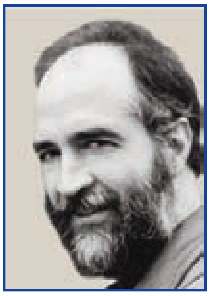
[3] *Prof. Achi Brandt, from the Weizmann Institute of Science, Israel, is the main inventor of the Multigrid method.*

method. If one is not careful and tries to enforce too many requirements strongly this may result in a bad numerical method that yields poor numerical solutions! One way in which this is manifested is the phenomenon known as “locking” that some of you may be familiar with. It is maybe surprising at first, but can be understood after some reflection, that a strong satisfaction of a certain requirement (from A-E) is not necessarily better than a weak satisfaction of this requirement.

Now we come to Discontinuous Galerkin (DG) methods. In these methods both D and E are satisfied weakly. Thus, not only the normal heat flux but also the temperature is not continuous across element borders. The continuity of both temperature and normal heat flux is enforced in a weak sense. Does this look strange? Yes – if you are very accustomed to the standard FE method. But if you think about this a little, there is nothing particularly “sacred” about property D that makes it more important than all other properties. Enforcing it weakly is not more “strange” than enforcing any other property weakly.

It turns out that DG methods are associated with particularly good balance among the five requirements, and as a result they tend to be more well behaved than the standard FE method in some situations.

All this is just “hand waving” and general talk. Here are some more concrete details on the advantages of DG methods. RBZ quotes from Bernardo Cockburn’s lecture notes on DG for convection-dominated problems (http://www.math.umn.edu/~cockburn/LectureNotes.html):


Bernardo Cockburn


Rami Ben-Zvi

The main features that make DG methods attractive are:

* their formal high-order accuracy,
* their nonlinear stability,
* their high parallelizability,
* their ability to handle complicated geometries (e.g., hanging nodes in general and within hp-adaptivity), and
* their ability to capture the discontinuities or strong gradients of the exact solution without producing spurious oscillations.

There is a lot to explain about each of these properties, but we shall stop here. PT points out another important advantage of taking the primary field (temperature) to be discontinuous. In some cases this allows one to invert some matrices on the element level rather than on the global level, which saves a lot of computational effort.

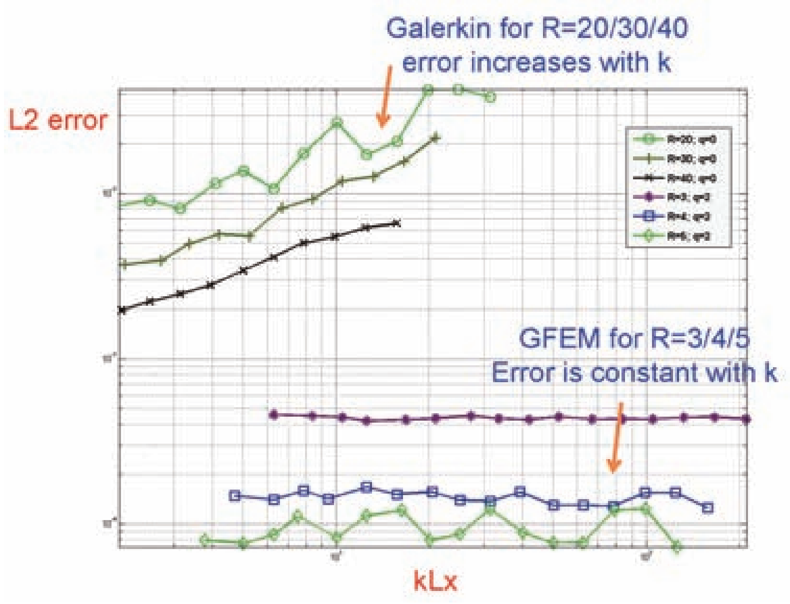
Correct answers were obtained from: *Rami Ben-Zvi, Pavel Trapper.*

Answer to question 4: Wave Resolution

What I had in mind is the so-called “pollution effect” that is caused by dispersion error. It turns out that keeping a fixed number of elements (or grid points) per wave length is not a safe procedure in general, even for simple linear wave problems. The rule of thumb saying that one needs about 10 elements per wave length is good for relatively long waves, but as the waves get shorter (or their frequency increases) one needs more and more elements per wave length to maintain the same level of accuracy!

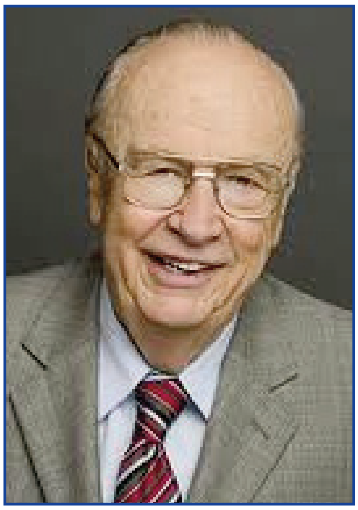
Eli Turkel, together with his coworkers, was one of the pioneers to discover and research this phenomenon. In his 1985 paper with Bayliss and Goldstein (J. Computational Physics, Vol. 59, pp. 396-404, 1985) they show that with a 2nd-order-accurate numerical method the number of required grid points per wave length λ increases like $1/\sqrt{\lambda}$. Moreover, they show in this paper that the pollution becomes smaller for higher-order methods, and that with a really high-order method it becomes negligible. Thus, ET comments, “for a spectral scheme Roshka is in fact correct!”

Figure taken for the MSc thesis of Ido Gur, Dept. of Aerospace Eng., Technion, 2011. The L2 error is shown as a function of the wave number for a fixed resolution R (fixed number of nodes per wave length). The three curves at the top correspond to the Galerkin FE method: the error increases with the wave number – this is the pollution effect. The three bottom curves correspond to a GFEM-based scheme: the error remains constant as the wave number is increased.



At around the same time, Babuška and his coworkers analyzed this phenomenon in more detail and coined the name “pollution effect” to it. ET comments: “In fact (this effect) goes back to a much earlier paper of Kreiss and Oliger who showed that (in the time domain) one needs more points per wave length – again as a function of the accuracy of the scheme – for longer periods of time, because of phase errors. In frequency space this is equivalent to the pollution effect.” Finally, ET notes: “Despite that these facts are known for over 20 years, most papers when doing a convergence study assume that the number of points per wavelength is fixed for various wave lengths. So Roshka is in good company.”

Eli Turkel



Ivo Babuška

RG in his answer relates in detail to exactly the same effect, and explains what Roshka needs to do: “In order to achieve the same global error (for all wave lengths) as for the 1m wave length, Roshka needs to set an appropriate resolution for each wave length that he solves so that the total accumulated error will be limited to that of the 1m problem. The resolution for the 0.001m wave length should be much higher in order to get the same global error.”

AY and ZZ proposed two correct answers that were different from the above. AY points out that if the problem Roshka is dealing with is nonlinear, then complex wave phenomena are expected – for example, interaction among waves of different wave lengths – and there is no guarantee that the simple rule that Roshka adopted would be good enough. ZZ relates to the effect of damping: “With FEM, it is very difficult to determine the full damping matrix. Therefore it is usual to assume that the damping matrix is proportional to the mass and stiffness, i.e., Rayleigh damping. As long as the frequencies are low and the damping is relatively small, this is fine. As the frequencies increase proportional damping is not valid anymore, and a more appropriate damping simplification is usually not available. Therefore high-frequency acoustic problems are usually solved by energy methods and not by FEM.”

Correct answers were obtained from: *Ran Ganel, Eli Turkel, Asher Yahalom, Zvi Zaphir.*

A second collection of Questions and their answers will appear in a forthcoming issue of IACM Expressions. ●

Lord J.W.S. Rayleigh (1842-1919)

Challenges of Computational Modelling in Production and Medical Technology

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Computational modelling – here with reference to production and medical technology – has the potential to develop into a field of research of not only scientific relevance. Model-based therapy (e.g. simulation-assisted surgery) is still a vision for the next decades but will, if it is put into practice, revolutionize standard medical technology and treatment. This will have a direct societal impact and finally change the attitude towards computational mechanics.

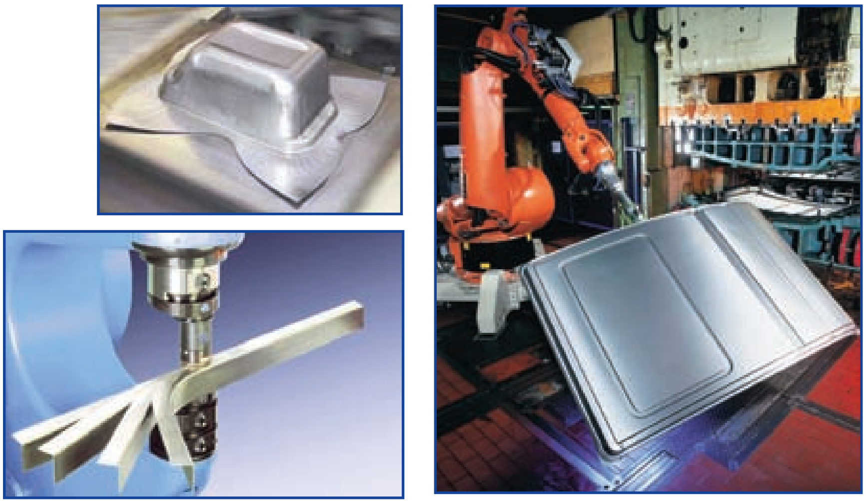


Figure 1: Examples for work pieces manufactured by forming processes

Another rewarding field of application is production technology where economic competition requires to shorten production cycles enormously. Computational modelling is the only way to reduce experimental effort. However, it is only accepted as alternative development tool if it provides realistic results. This again calls for better models and methods – finally for a deep knowledge of computational mechanics.

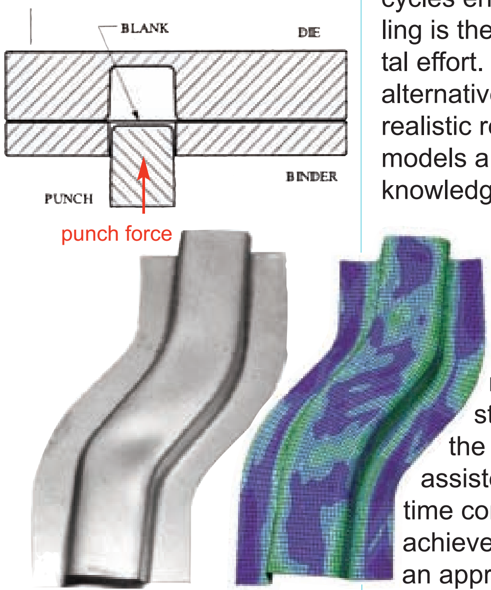


Figure 2: Springback of an S-rail

The first part of the present article deals with the simulation of innovative forming processes. The further development of medical technology, e.g. new stent designs, is discussed in the second part. Simulation-assisted surgeries will require real time computation. The latter can be achieved by means of model reduction, an approach which has to be explored much further in the context of non-linear solid mechanics.

I. Production technology

Forming of metallic sheets (*see Fig. 1*) is an important production process needed e.g. in the car and aircraft industry. Increasing requirements are posed on the variability of the products as well as the duration of the production cycles. For this reason it is highly attractive to replace experiments by simulation, also for the purpose to improve the process methodology. However, suitable computational methods which reliably and efficiently provide realistic forming results are still lacking. The challenges from the computational view are, to name only a few, the presence of large deformations, various phenomena of inelasticity (e.g. plasticity, damage), initial and evolving anisotropy, rate and temperature dependence, extreme aspect ratios as well as complex contact situations. Clearly, a considerable amount of scientific work has been invested in parts of these problems (see e.g. [1,2,3]). Nevertheless, a holistic approach in which computation and experiment are on equal footing is not yet available. Which steps are required?

The first issue is the **material modelling**. Starting from the very simple rheological model of a spring put in series with the parallel combination of a friction and a Maxwell element, already allows to simulate typical phenomena of cyclic behaviour such as the Bauschinger effect and ratchetting. The logical and direct extension of this 1D model to 3D and finite deformation [4] including an anisotropic yield potential [5,6] leads to a very general constitutive law which enables to model non-linearly isotropic, kinematic as well as distortional hardening. These phenomena are strongly correlated with the effect of springback (*see Fig. 2*). To quantify the latter is extremely important for industrial processes because it causes elastic unloading after removal of the work tools. This changes the final shape of the product. Obviously it is one important task of numerical computation to compute this final geometry in advance and help to steer the process in such a way that its outcome yields the desired geometry.

Finally, it is of crucial importance to predict damage and failure (forming limit diagrams) to make a statement about the formability of a specimen [7] (*see also Fig. 3*). An interesting aspect is to increase this formability (i.e. sharper corners, smaller radii) by combining standard quasistatic with high speed forming. Electromagnetic forming has been proven to be a successful strategy for this purpose. This represents also a very interesting challenge for the computational part [8] (*see also Fig. 4*).

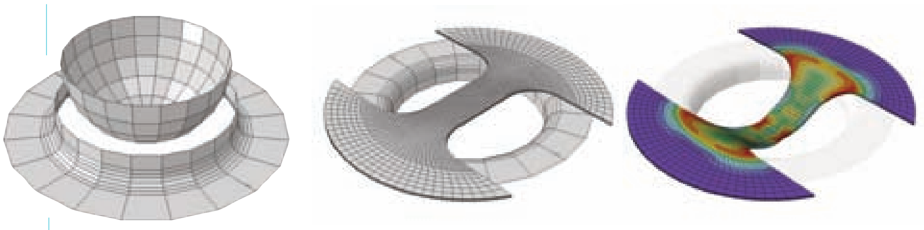


Figure 3:
Simulation of the Nakazima stretching test – used to determine forming limit diagrams

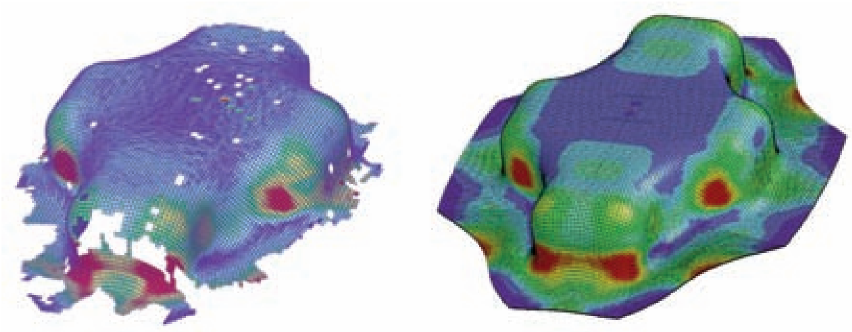


Figure 4:
Distribution of major strain after forming (left: experiment, right: simulation), experimental result provided by IUL (Dortmund, Germany)

Higher temperatures lead to a more pronounced rate-dependent material behaviour. In contrast to standard forming processes where the temperature does not rise very much beyond room temperature, so-called ring rolling processes represent typical situations where rate and temperature dependence play an important role (*see Fig. 5*).

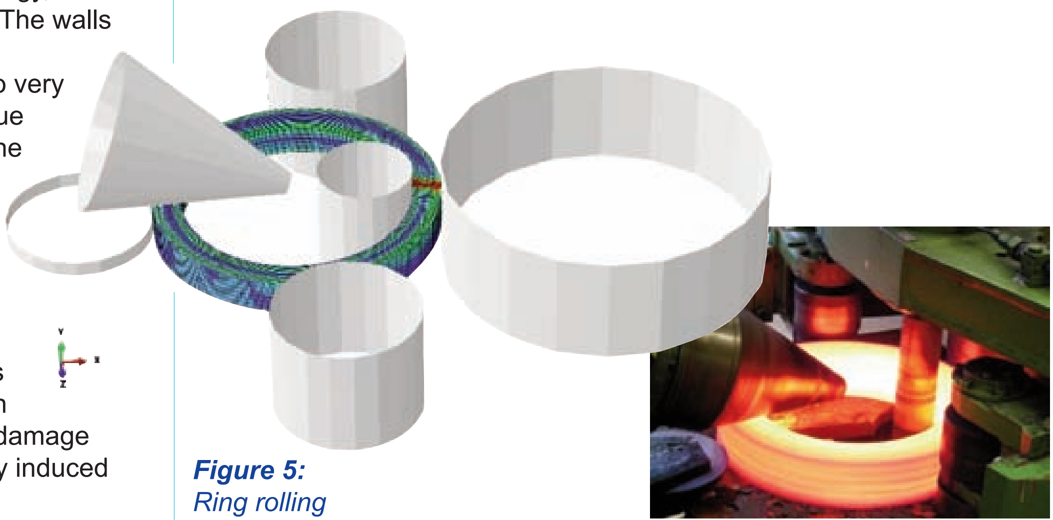


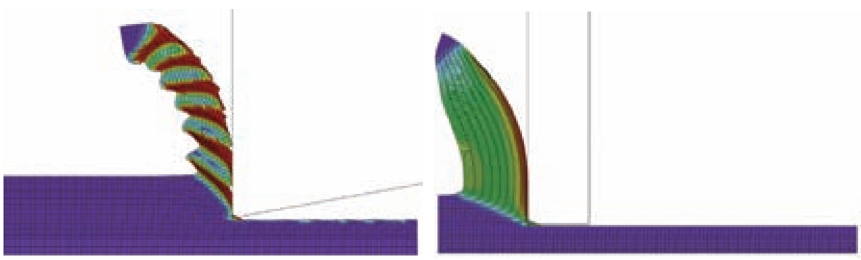
Figure 5:
Ring rolling
(experiment and simulation)

Another good example, though further away from production technology, is the repeated start of spacecraft. The walls of the cooling channels in a combustion chamber undergo very high temperature gradients due to the extreme difference of the temperature in the hot gas inflow and the coolant. The constitutive formulation for the material of the cooling channel (e.g. Narloy-Z) has to take that into account [9]. The number of possible starts of the spacecraft is very much depending on the amount of damage accumulating due to thermally induced inelastic deformation.

In fact, almost all previously described aspects come together in the simulation of cutting processes (*see Fig. 6*). Depending on the ratio of thermal expansion with respect to heat capacity and on the speed of the process one might observe adiabatic shear bands which lead to segmented cutting processes (*Fig. 6a*). Slightly different conditions, be it a different ratio of the crucial thermal parameters or a lower velocity of the process, lead to a completely different result of the cutting process (*Fig. 6b*).

Certainly it would be additionally very interesting and scientifically challenging to incorporate the microstructure of the materials involved in the process (see e.g. [10]). However, today's state of the art is still characterized by the fact that even though micro-macro models are available they are generally not applied to process simulation. Additionally it has to be admitted that such multi-scale models do not necessarily require less material parameters. Although most parameters are physically-based it is difficult to exploit this advantage since suitable experimental methods from material science are still under development.

Figure 6:
(a) Segmented cutting process, *(b) Continuous cutting process*



But the material modelling is only one side of the coin. Its importance in process simulation is often overestimated whereas the influences of geometry and boundary conditions on the result of the production process are not investigated with sufficient care. At the structural level, the issue of **finite element technology** comes into play. Forming processes are characterized by bending of thin structures, the material behaviour of which is dominated by plasticity. Working with a deviatoric flow rule which is for most metallic materials a very good assumption leads to plastic incompressibility. These two situations – bending of thin structures and plastic incompressibility – are known to lead to severe artificial stiffening phenomena ("locking") if standard low order finite element formulations are used. Nevertheless, low order formulations show many advantages, especially in the context of non-linear problems: e.g. high robustness with respect to severe mesh distortion, small bandwidth of the tangential stiffness matrix, simple meshing and remeshing. For this reason, the use of low order finite element formulations is still advisable – if the locking problem can be overcome.

Figure 7: *Forming results computed by means of Q1STs*

This was the starting point for the research field of finite element technology (see the milestone works [11,12]). Development progressed via "classical" shell formulations (including rotational degrees-of-freedom) (e.g. [13]) to so-called solid-shell elements [14,15] which include only displacement degrees-of-freedom. The element family Q1SP(e,s,b) (solid, solid-shell, solid-beam, see [14]) as well as its extension Q1STs described in [15] have proven its efficiency in many situations (*see Fig. 2 and Fig. 7*). Important advantages are the reduced number of Gauss points i.e. increased computational efficiency, the robustness with respect to severe mesh distortion, the absence of locking even for extreme aspect ratios and finally the simplicity of the formulation.

Let us finally come to the issue of **contact** simulation. From the point of view of the authors the situation is very unsatisfactory. Naturally, so-called academic codes such as FEAP (Finite Element Analysis Program, developed at the University of California at Berkeley, USA) are not designed to offer the full instrumentarium of computer aided engineering. Thus, they are usually not suitable to carry out complex process simulations. On the other hand, commercial finite element program systems do not well support the implementation of user subroutines. This holds in particular for contact modules. For this reason, scientists and practical engineers have to deal with the commercially available contact options which are not well explained and in many cases, especially in implicit simulations, slow down the computation enormously. How to find a way out of this dilemma is not clear yet. In any case, much more interaction between scientists from the computational mechanics community and engineers from industry is necessary to steer the commercial finite element software development into a fruitful direction.

II. Medical technology

Also for applications of medial technology, e.g. stent implantation, sophisticated material modelling has to be combined with powerful finite element technology and contact modelling. Stents are implanted in the blood vessel to hold it open and avoid regrowth of biological material (*see Fig. 8a*). This is to avoid heart attacks, strokes or thrombosis. In the last decade so-called self-expanding stents made of the shape memory allow Nickel-Titanium (NiTi) were brought on the market. Here, one exploits the effect of pseudo-elasticity which means that a specimen made of NiTi can undergo relatively large reversible strains (up to 10% equivalent engineering strain). An even newer development are shape memory polymer stents where the transition from rubbery (high temperature) to glassy (low temperature) behaviour is exploited *(see Fig. 8b,* [16]). Interestingly, the material model developed in [4] can be suitably rewritten to yield the pseudo-elastic behaviour [17].

NiTi stents are also a good example for very sophisticated thin structures posing high challenges on finite element technology. The finite element discretization depicted in Fig. 8c shows that parts of the structure are beam-like others solid-like. The stents are therefore a perfect playground for the finite element family Q1SP (in general eight-node elements) which lets us easily combine solid with solid-beam elements (*see Fig. 8c*). An additional very important issue but quite open point of research is the interaction between blood flow, blood vessel and stent.

Besides the goals to replace experiments by simulation and to improve implant technology we aim at model-based therapy. This means that numerical simulation shall be used to provide additional important information to the surgeon which is otherwise not available. An example is the FESS (functional endoscopic sinus surgery) (*see Fig. 9*) where the surgeon is in danger to penetrate dangerous areas such as the orbit or the brain. Running an accompanying simulation in real-time which incorporates realistic models of the biological materials and structures can provide important information – e.g. about the forces needed to carry out certain operation steps. Especially interesting are also the effects of cutting operations. Simulation is intended to be used to predict these effects which otherwise would not be known to the surgeon.

To achieve a simulation in realtime the original model has to be reduced. For this purpose model reduction shall be applied. The class of methods based on singular value decomposition has been shown to be especially attractive for applications requiring short simulation time but also a high degree of accuracy. These methods work in the way that the subspace of dimension n (e.g. a finite element model with n degrees-of-freedom) is projected onto a subspace with smaller dimension m << n (often called black box). The transformation matrix computed for this purpose can be decomposed of eigenvectors of the tangential stiffness matrix (modal basis reduction method), Ritz vectors (load-dependent Ritz method) or the transformed eigenvectors of a so-called correlation matrix (proper orthogonal decomposition – POD). The combination with a non-linear finite element computation is e.g. discussed in [18]. The POD method is for all three material models which have been investigated (hyperelastic, viscoelastic, elastoplastic) the one with the best accuracy and the shortest CPU time. The relative error of the POD for an academic example (block under compression) is in the range from 10^{-9} (hyper- and viscoelastic) to 10^{-5} (elastoplastic). Using 15 bases for a 20 x 20 x 20 mesh, the CPU effort can be reduced to 1%. The following figures show the typical development of a reduced model from real medical data. CT data (*Fig. 10a*) are segmented depending on the gray scales

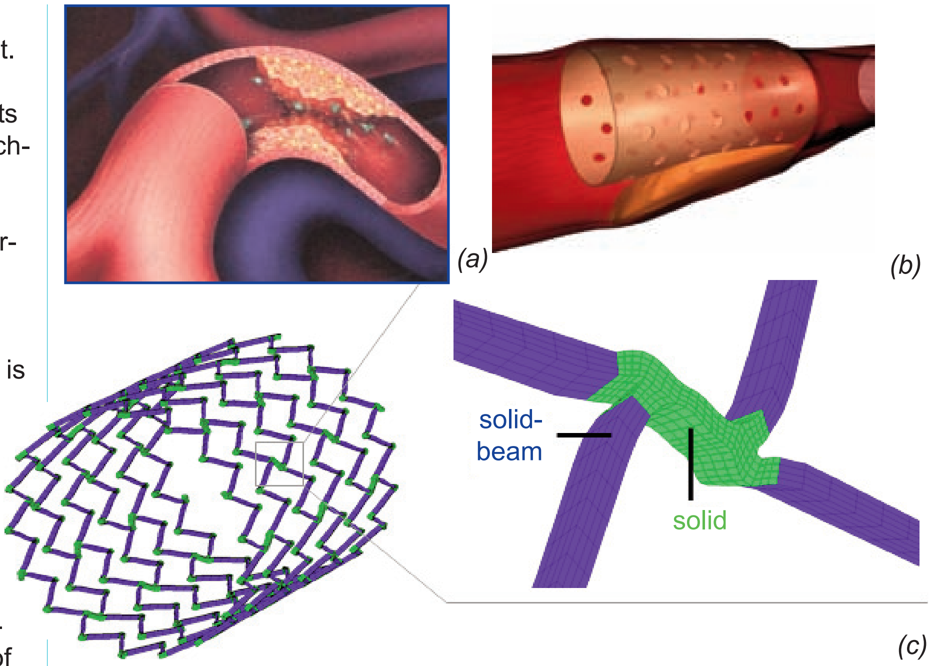


Figure 8:
(a) Blood vessel with plaque,
(b) Shape memory polymer stent implanted in a blood vessel,
(c) Discretized structure of a NiTi stent (green: solids, blue: solid-beams)

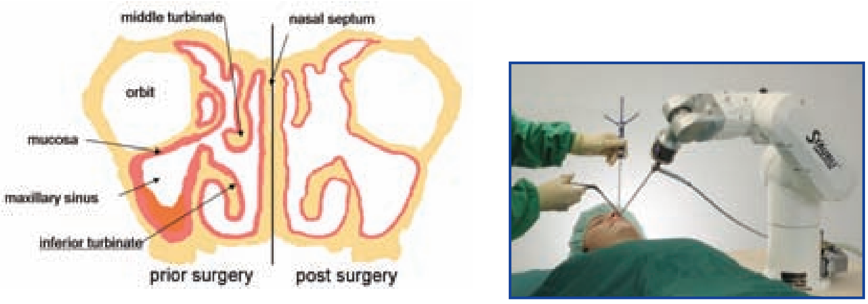


Figure 9:
Nasal area after prior and post FESS, roboter-assisted minimally invasive surgery

(*Fig. 10b*). It is in this way possible to differentiate between tissue, bone and air. Modern finite element software already allows the transfer of these data into a finite element model (Fig. 10c) which is then reduced to a black box model with only a few degrees-of-freedom.

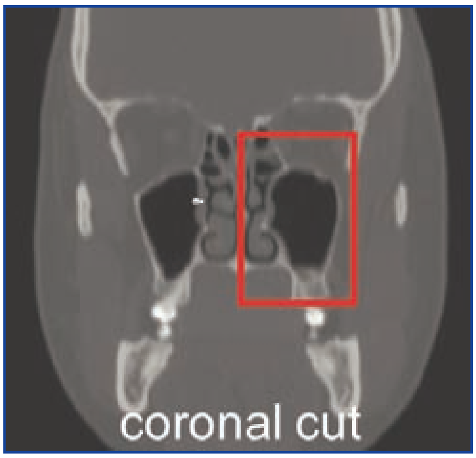


Figure 10a:
Picture from CT data

Conclusions

Certainly it is still a long way till computational mechanics enters practical life as described above. Reaching this goal requires still major qualitative progress in non-linear material, finite element and contact modelling – in a very broad sense. Scale bridging should not be restricted to the micro and the macro level. In fact, the black box can be seen as the so-called holo level which shall enable a holistic investigation of complex production processes or medical interventions. This is in the opinion of the authors a fascinating and thankful goal for the future. This future has just started.

Figure 10b:
Segmented data

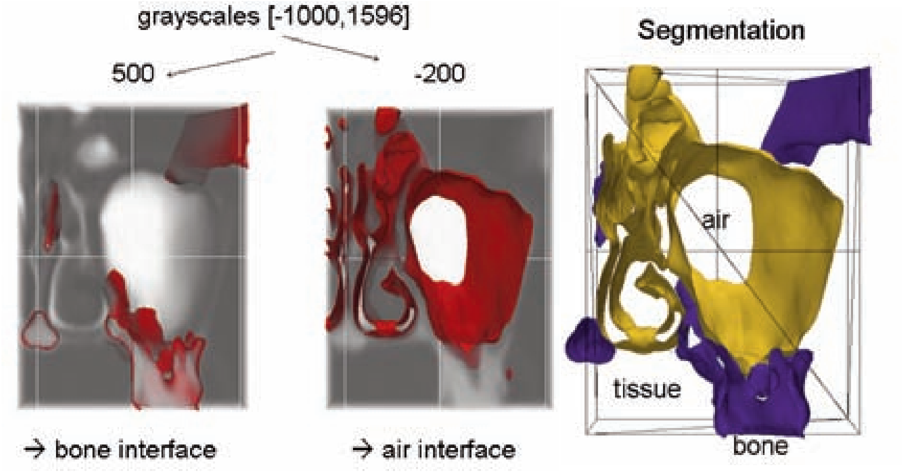
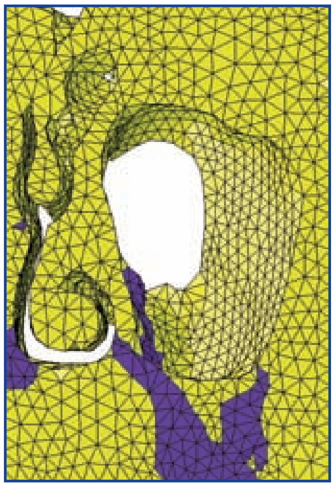
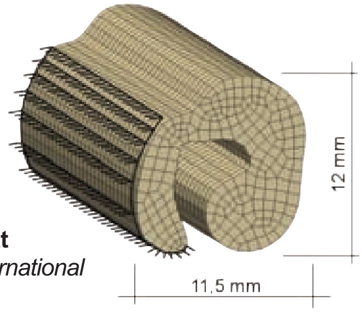


Figure 10c:
Total finite element mesh and part of the finite element mesh





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Novel Strain-Energy Based Coupled Elastoplastic Damage-Healing Models and Computational Algorithms for Geomaterials

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During earth moving processes, some soil motions, such as rolling and gliding, can cause significant amount of soil spillage. These soil motions, as a consequence, decrease the soil-carrying capacity of earth-moving equipment and therefore increase the costs of earthwork operation. Moreover, the rolling and gliding motions generate higher frictional contact between the surfaces of soil particles and the earth-moving equipment blade, resulting in faster blade wear and higher energy consumption by the tractor. In order to improve the operational efficiency, extensive laboratory experiments and field testing of various designs for earth-moving equipment must be performed by the equipment manufacturers. A computational framework that can simulate soil motions during the earth-moving operations will enable the equipment design to be more economical and versatile, which can ultimately benefit the construction and agriculture industries.

To develop a rigorous computational framework to account for complex and instantaneous motions of cohesive soils, physics-based comprehensive material models of soils are much warranted. In the past three decades, there has been a large body of soil plasticity models for saturated and partially saturated soils, as well as analyses of strain localization and shear band for soils. However, there has been no published literature on *healing* (recovery of elastic stiffness) models for granular cohesive soils due to compression (compaction) and water suction, which would provide considerably more physical mechanism to account for partial or complete recovery (healing) of cohesive/frictional bonds among granular soil particles under compaction or confinement subsequent to prior soil damage. There is a fundamental need for physical and reliable modeling of the progressive *coupled* elastoplastic damage and healing mechanisms in cohesive soils under complex and cyclic loading during real-world earth moving processes.

The real starting point of CDM occurred when Kachanov [1] published the first paper on the creep of metals by introducing a field variable ψ called "phenomenological continuity parameter". The concept of effective stress within the framework of CDM was later introduced by Rabotnov [2]. The basic development of continuum damage mechanics continued during the 1970s, more than one decade after the historical development of fracture mechanics. In the 1980s, the framework of damage mechanics was built upon a significantly more rigorous basis using the thermodynamics [3-7] and micromechanics [8-9]. Moreover, applications of continuum damage mechanics to engineering problems expanded dramatically as many researchers became involved in this discipline, such as the applications to the modeling of creep damage, fatigue damage, elasticity coupled with damage, creep-fatigue interaction, ductile plastic damage, and damage in composite materials. We refer to [10-12] for comprehensive reviews on damage mechanics in engineering materials.

Experimental evidence from different fields shows that some materials can be repaired or healed in various ways such as chemical, physical or biological phenomena, leading to progressive recovery of internal material defects. In this study, the healing effect can occur when the cohesive soil is under compression (compaction). The proposed novel healing mechanism is different from the idea proposed by [13] which generalized the continuum damage mechanics with healing processes to predict the damage and irreversible deformation processes for a self-healing fiber-reinforced lamina. Further literature review of self-healing materials can be found in [14].

".... a ... need for physical and reliable modeling of the progressive coupled elastoplastic damage and healing mechanisms in cohesive soils under complex and cyclic loading ...."

Characterization of Strain-Energy Based Hybrid Isotropic Damage

We first characterize the progressive degradation of mechanical properties of soils due to damage by means of a simple isotropic damage mechanism. To this effect, we ascribe to the notion of equivalent *tensile* strain ξ^{+} as the (undamaged) energy norm of the *tensile* strain tensor. The proposed isotropic damage mechanism is called "hybrid" since the computation of this equivalent tensile strain involves the *principal* tensile direction of the total strain tensor. This definition is at variance with that employed by [15] as the J_2 -norm of the strain tensor.

Accordingly, we set

$$\xi^{+} \equiv \sqrt{\Psi^{0}(\boldsymbol{\varepsilon}^{+})} = \sqrt{\frac{1}{2}\boldsymbol{\varepsilon}^{+} : \mathbf{C}^{0} : \boldsymbol{\varepsilon}^{+}},$$

where $\varepsilon^{+} \equiv \mathrm{P}^{+} : \varepsilon$. The fourth-order tensor $\mathbf{P}^{+}$ denotes the "Mode I" *positive* (tensile) projection tensor. We now characterize the state of damage in soils by means of a damage criterion $\phi^{d}(\xi_t^{+}, g_t) \leq 0$, formulated in the strain space. It is noted that the numerical value of g_t would be lowered due to the incremental healing (if any) from the previous time step. For the isotropic damage case, we define the evolution of the damage variable d and the damage threshold g_t by the rate equations.

Characterization of Strain-Energy Based Hybrid Isotropic Healing

Similar to the characterization of damage in the previous subsection, we characterize the progressive recovery of mechanical properties of soils due to healing by means of a simple isotropic healing mechanism. We use the notion of equivalent *compressive* strain ξ^{-} as the energy norm of the compressive strain tensor.

We set $\xi^{-} \equiv \sqrt{\Psi^{0}(\boldsymbol{\varepsilon}^{-})} = \sqrt{\frac{1}{2}\boldsymbol{\varepsilon}^{-} : \mathbf{C}^{0} : \boldsymbol{\varepsilon}^{-}}$

where $\varepsilon^{-} \equiv \mathrm{P}^{-} : \varepsilon$. The fourth-order tensor $\mathbf{P}^{-}$ denotes the "Mode I" *negative* (compressive) projection tensor with components.

We characterize the state of healing in soils by using a healing criterion

$\phi^{h}(\xi_t^{-}, r_t) \leq 0$, with the functional form:

$\phi^{h}(\xi_t^{-}, r_t) \equiv \xi_t^{-} - r_t \leq 0$. Here, r_t is the *healing threshold* at the current (positive) time t.

It is noted r_t will be *lowered* in value due to the *incremental* damage (if any) from the previous time step. For the isotropic healing case, we define the evolution of the healing R and the healing r_t by the rate equations.

Net (Combined) Effect of the Hybrid Isotropic Damage and Healing

We propose the micromechanics-motivated *incremental* scalar form to compute this net effect of damage-healing, d^{net}. The characterizations of damage and healing as discussed in the previous sections can be considered as the *predictor formula* in our damage-healing algorithm. Once the associated damage or healing variables are computed at the time step n (damage and healing will not occur at the same step), we apply the so-called c*orrector formula* to calculate the variable of *net effect* of damage and healing, d^{net}, at the time step (n+1).

Characterization of Effective Plastic Response and Tangent Moduli

In accordance with the notion of effective stress, the characterization of the plastic response should be formulated in the *effective stress space* in terms of effective stresses $\bar{\boldsymbol{\sigma}}$ and $\bar{\boldsymbol{\sigma}}^{\mathbf{p}}$. Therefore, for the classical situation in which the yield function is postulated in the stress space, we replace the homogenized Cauchy stress tensor $\boldsymbol{\sigma}$ by the effective stress tensor $\bar{\boldsymbol{\sigma}}$ so that the elastic-damage domain is characterized by $f(\bar{\boldsymbol{\sigma}}, \mathbf{q}) \leq 0$. Here, $\mathbf{q}$ represents the internal plastic variables and the corresponding evolution can be found below. With the assumption of an associative flow rule, rate-independent plastic response is characterized in the strain space by the constitutive equations (cf. [3-4]).

Characterization of Strain-Energy Based Anisotropic Damage Evolution

In order to build into the formulation the notion of irreversibility, we introduce a damage criterion with the function form:

$$\phi^{D}\left(\boldsymbol{\varepsilon}^{+} \otimes \boldsymbol{\varepsilon}^{+}, G_t\right) \equiv \zeta^{+}\left(\boldsymbol{\varepsilon}^{+} \otimes \boldsymbol{\varepsilon}^{+}\right) - G_t \leq 0,$$

where G_t is an internal variable that furnishes the "radius" of the damage surface at the current time. The damage process is characterized in terms of the irreversible, dissipative equations of evolution.

Characterization of Anisotropic Healing Evolution

We introduce a healing criterion in the strain space with the following function form:

$$\phi^H\left(\varepsilon^-\otimes\varepsilon^-,R_t\right)\equiv\zeta^-\left(\varepsilon^-\otimes\varepsilon^-\right)-R_t\le 0,$$

where R_t is an internal variable that furnishes the “radius” of the healing surface $\phi^H\left(\varepsilon^-\otimes\varepsilon^-,R_t\right)=0$ at the current time. The healing process is characterized in terms of the corresponding irreversible equations of evolution.

Computational Algorithms: Two-Step Operator Splitting Methodology

Attention is focused on the local hybrid isotropic elastoplastic-damage-healing rate constitutive equations. In accordance with the notion of operator split, we consider the innovative, additive decomposition of the original problem of evolutions into the *elastic-damage-healing part* and the *plastic part*.

Numerical Examples of Soil Compression, Excavation and Compaction

A one-dimensional driver problem according to the proposed damage-healing mechanism is performed first by the Matlab codes. Other numerical examples are subsequently performed for soil compression, excavation and compaction by using two different models; i.e., the hybrid isotropic *damage* model, and the hybrid isotropic *damage-healing* model. The numerical results from the two distinct models are carefully compared to illustrate the effects of *healing* mechanism.
These two models are implemented into the existing NMAP meshfree code [16] developed based on the semi-Lagrangian formulation with stabilized nonconforming nodal integration; cf. [17-18].

For the purpose of demonstrating the healing effects, the earth-moving process is systematically performed, including the lifting, dumping and compaction of cohesive granular soils. In order to properly handle large deformation and excessive particle motion of soils, these simulations are implemented into an existing NMAP meshfree code. In the following simulations, the Drucker-Prager associative multi-surface plasticity formulation is employed to model the soil behaviour for the sake of simplicity; cf. [18-20]. The blade of the bulldozer is treated as a rigid body and thus represented by two

Figure 1:
Comparisons of deformations of soils for various stages of the earth-moving process simulations between the hybrid isotropic damage model (left column) and the hybrid isotropic damage-healing model (right column)

contact surfaces in black color. To model the contact between soil particles and the blade surfaces, meshfree smooth contact algorithm [21-22] is employed. A layer of soils with the dimension 4 x 2 m is discretized into 41 x 21 x 861 uniformly distributed particles. The natural contact algorithm of [23] is applied to model the contact between the soil particles and the ground surfaces. The bulldozer blade is controlled:

(i) to move horizontally to the right for 0.3 m,
(ii) to lift the soils vertically for 3 m,
(iii) to move horizontally to the right for 1.8 m,
(iv) to rotate 45 degrees to dump the soils over the wall, and then
(v) to rotate back to move forward and downward to compact the soils in the ground hole.

The comparisons of progressive de formations at various time steps between the *hybrid isotropic damage-only model* and the *hybrid isotropic damage-healing model* are displayed in *Figure 1*. In these figures, the blue solid circles represent the soil particles with no damage ($d^{net} = 0$), the red solid circles symbolize the soil particles with full damage ($d^{net} = 0.95$, the preset upper bound damage in these simulations), and the solid circles in other colors (such as green, yellow and orange) signify partial damage between 0 and 0.95.

From *Figure 1*, for both the damage-only model and the damage-healing model, it is observed that the soil *shear bands* are formatted under the pushing-lifting of the bulldozer blade. However, once the *healing mechanism* is triggered, the subsequent soil motions and deformations are different for the two models. Most of the soil particles from the lower triangle under the shear band slide out of the blade before subsequent dumping. This is induced by the hybrid isotropic damage-only model, without any healing mechanism. By contrast, in *Figure 1*, the shear bands are partially healed under compression such that the soil particles from the lower triangle under the shear band are *not* squeezed out. The healing effect can be clearly observed when the soil compaction is performed. The color of most soil particles in the ground hole gradually changes from red (full damage) to green (low damage) due to the healing mechanism when the soil particles are under blade compaction. By contrast, without the healing effect, the color of most soil particles in the ground hole still remains red (full damage) even when the soil particles are under compaction.

"…. change of effective stress due to matric suction in the formulation is considered and the governing incremental damage and healing evolutions are coupled and characterized through the effective stress concept in conjunction with the hypothesis of strain equivalence."

Closing Remarks

We can readily extend the computational algorithms to handle strain-energy based elastoplastic anisotropic damage and healing models, and perform numerical simulations for such anisotropic damage-healing models accordingly. Full details are presented in [24-25].

Further, improved two-parameter volumetric-deviatoric strain-energy based coupled elastoplastic damage and healing models and computational algorithms have been proposed recently in [26] for earth moving processes. The volumetric and deviatoric elastic-damage-healing predictor and the effective plastic corrector are implemented within the RKPM meshfree codes. Numerical examples under earth excavation, transport and compaction are presented in [26] to illustrate salient features of soils such as shear band and partial recovery of soil stiffness due to compaction by the new two-parameter damage-healing models.

Moreover, innovative strain-energy based coupled elastoplastic hybrid isotropic damage and healing models for partially saturated soils have been developed and implemented for numerical simulation of earth pushing processes. In particular, change of effective stress due to matric suction in the formulation is considered and the governing incremental damage and healing evolutions are coupled and characterized through the effective stress concept in conjunction with the hypothesis of strain equivalence; cf. [27]. ●

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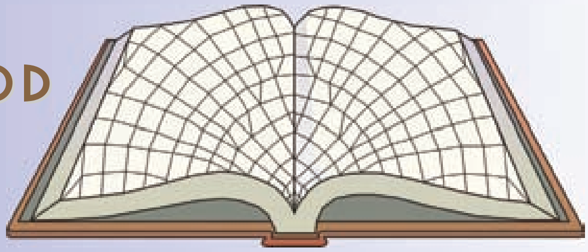
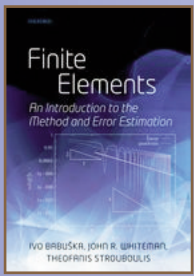
FINITE ELEMENTS: AN INTRODUCTION TO THE METHOD AND ERROR ESTIMATION



Ivo Babuška, John R. Whiteman & Theofanis Strouboulis

Oxford University Press, Oxford, UK, 2011

BOOK REVIEW



ISBN-10: 0198506694
323 pages, soft cover, $55 (List Price).
Contents: Preface, 1. Introduction, 2. Formulations of the Problems, 3. Finite Element Methods, 4. Interpolation and its Error, 5. a priori Estimates of the Error of the Finite Element Solution in the Energy Norm, 6. Functionals and Superconvergence, 7. a posteriori Error Estimates, A Note on Verification, Epilogue, Appendix A, Bibliography, Index

This is an excellent mathematical book on error estimates for the Finite Element (FE) method. To the best of my knowledge, no other book covers the subject of FE error analysis in such a thorough and complete way. The three authors, who are well known mathematicians that have made seminal contributions to both the mathematical and engineering literature, should be congratulated for this important achievement.

In the Preface, the authors explain their motivation for writing this book: "... we feel that there is a need for a book that presents the main theoretical ideas of the FE method and the analysis of its errors in an accessible way, and that demonstrates the interrelationship between the theory and the computed numbers... Further, the book should require the minimum of pre-requisites for understanding the basic theory presented... Finally, it should address the numerical computation of typical simple engineering problems..."

Being "accessible" is a relative term. It is true that the book aims at attracting readers lacking formal mathematical education, and that the text includes engineering examples that demonstrate the theory. However, I would not say that this book is an easy reading material for the average engineer who is interested in the theoretical aspects of the FE method. Large parts of this book are written in a mathematically technical style that requires mathematical maturity. The style used in these parts is significantly more technical than that of some other major books on FEs, such as "The Finite Element Method" by Hughes [Dover, 2000], "Numerical Solution of Partial Differential Equations by the Finite Element Method" by Claes Johnson [Dover, 2008], as well as the two books by Szabó and Babuška – "Finite Element Analysis" [Wiley, 1991] and "Introduction to Finite Element Analysis: Formulation, Verification and Validation" [Wiley, 2011]. (The latter will be reviewed in the next issue of IACM Expressions.) It is perhaps slightly less mathematically technical than "Finite Elements" by Oden *et al*. [Prentice-Hall, 1981] and certainly more accessible than "The Finite Element Method for Elliptic Problems" by Ciarlet [SIAM, 2002].

I think that the present book will be easily accessible only to those engineers, or engineering graduate students, who are very strongly mathematically oriented. On the other hand, this is an ideal book for graduate students *in applied mathematics* who are interested not only in the theory of FE error estimation but also in how it is applied in practice. No doubt that for readers who do posses the necessary mathematical maturity this book will be a great asset. Such readers will not only be exposed to the state of the art of FE error estimation theory, but will also learn how confidence in the numerical results can be obtained from this theory.

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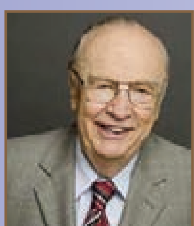
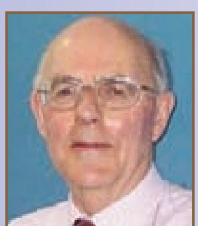


Ivo Babuška



John R. Whiteman

Theofanis Strouboulis

In order to present the basics of FE error estimation in a deep and thorough way, the authors restrict themselves to linear scalar elliptic PDEs. More precisely, the book deals only with linear elastostatics in 1D (rod in tension/compression), which is analogous to 1D heat conduction, and with 2D heat conduction. I think that this is a prudent choice, because it enables one to concentrate on the fundamental understanding of the basic theory. This book paves the way for the reader to later understand FE error estimation in a more advanced context.

The seven chapters can be viewed as divided into three groups: introductory material on the FE method and on interpolation errors (chap. 1-4), *a priori* error estimates (chap. 5 and 6) and *a posteriori* error estimates (chap. 7). Chapter 1 introduces the extremely important notions of reliability of computations, validation and verification. Chapter 2 discusses the strong and weak forms of the problem and the equivalent minimization problem. On pp. 26-27 the authors prove the equivalence of the weak formulation and the minimization formulation; this is the first time I see an “elementary” proof for this equivalence that does not require the technique of the calculus of variations. Chapter 3 presents the Galerkin FE method. The shape functions discussed include piecewise linear and piecewise parabolic functions. The latter are hierarchical, not nodal, functions; their advantages are explained (pp. 74-75). Benchmark problems are defined, which are referred to in later chapters of the book. The chapter ends with a discussion on the best approximation property. Chapter 4 discusses interpolation and its error; this is a topic in approximation theory which of course plays a vital role in FE error analysis.

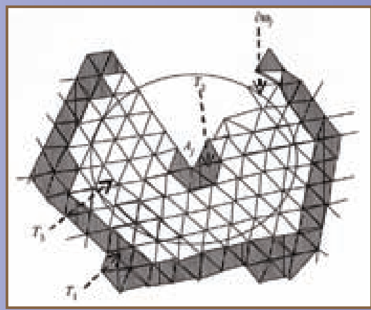


Figure 1:
Neighborhood of a geometrical singularity (reentrant corner), and associated notation. This figure appears in the book as Fig. 5.5 on p. 170

The four first chapters mentioned above occupy about half of the book and constitute an introduction to the main subject: error estimation. Chapter 5 presents *a priori* error estimates in the energy norm. The proof of the standard error estimate does not make a direct use of the best approximation property (as opposed to the classical Strang and Fix approach); the advantage is apparently in the potential to extend the proof to more complicated cases. The error estimate is demonstrated for several examples in a clear way. Then error estimates for 2D problems involving geometrical singularities (e.g., reentrant corner) are discussed and applied to the benchmark problems. See Fig. 1, which is taken from the book. Chapter 6 deals with estimates for errors measured by functionals different than the energy norm. Superconvergence (for the solution's derivative) in 1D and 2D is explained. Local and global errors are discussed. See Fig. 2, taken from the book. Pollution is only mentioned briefly since it is outside the scope of this book.

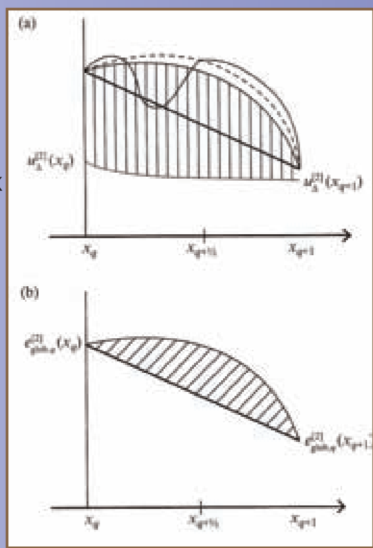


Figure 2:
Illustration of local and global errors. This figure appears in the book as Fig. 6.3 on p. 187

Chapter 7 discusses *a posteriori* error estimates, using the notions of error indicators and error estimators. The success of the error estimator is measured by the effectivity index. (Here I will give a single relating to the style of presentation: the effectivity index is defined by the mathematical expression given by eq. (7.4c) on p. 219, in terms of previously defined quantities, but it is not mentioned in the surrounding text. Later it is used in tables of results of numerical experiments. An engineer that is not used to the lack of textual explanations of such basic concepts may find the exposition difficult to follow.) The chapter includes a discussion on recovered functions, not as a tool for flux-recovery methods but as a means of computing estimators. The estimators discussed include (a) residual-based estimators (with or without flux jumps), (b) subdomain (patch) estimators, (c) averaging-based estimators (including the celebrated ZZ estimator), and (d) the Richardson estimator. Section 7.3 is a very nice summary that provides a comparison of the properties of all these types of estimators.

The book is well structured. Every chapter starts with a nice short Summary that surveys the content of the chapter. The book contains many examples, which are usually special cases for the theory discussed. It is also scattered with exercises – some of them purely mathematical (e.g., to prove a certain inequality), and some are more engineering-like, with numerical values and even engineering units. Quite a few figures with sketches and graphs as well as tables with results of examples are provided, which illustrate the theory very effectively. Some sections end with interesting “morals” that point to practical conclusions drawn from the discussion and examples.

In summary, this is a superb book on FE error analysis, that is well suited for applied mathematicians, and partly also for readers with engineering background provided that they posses sufficient mathematical maturity, or if the book is used as a course textbook with appropriate guidance.". ●

ACMT

ASSOCIATION OF COMPUTATIONAL MECHANICS

Third International Symposium on Computational Mechanics (ISCM III)
in conjunction with
Second Symposium on Computational Structural Engineering (CSE II)



Figures 1, 2 & 3:
ISCM III-CSE II
Conference Organizers:
YB Yang *- ybyang@ntu.edu.tw*
President
LJ Leu *- ljleu@ntu.edu.tw*
Vice President
CS David Chen *- dchen@ntu.edu.tw*
Secretariat General
of Association of Computational Mechanics Taiwan (ACMT)

The third International Symposium on Computational Mechanics (ISCM III) in conjunction with second Symposium on Computational Structural Engineering (CSE II) was held in National Taiwan University, Taipei, Taiwan during December 5-7, 2011. The objectives of ISCM III-CSE II are to discuss the latest development and application of computational methods in all aspects of engineering and science with a special emphasis on mechanics.

When counted from the side of the ISCM, this conference was the third in the sequence organized by the International Chinese Association for Computational Mechanics (ICACM), of which Prof. Mingwu Yuan has been the President. The first ISCM was held under the effort of Prof. Yuan in Beijing in 2007. Following the first successful meeting, the ICACM board decided to hold the ISCM every two years. The second ISCM was held in Hong Kong and Macau in 2009 in collaboration with EPMESC XII by Prof. Andrew Leung of City University of Hong Kong and Prof. Vai Pan Iu of University of Macau. The aim of the ISCM is to bring together scientists in the computational mechanics community to exchange the latest ideas of researches through the symposium.

On the other hand, the first International Symposium on Computational Structural Engineering (abbreviated as CSE) was held in Shanghai in 2009, co-organized by Tongji University and Vienna University of Technology. The aim of CSE is to provide a forum for scientists, developers, and engineers to review novel research findings, to assess the suitability of new models, and to evaluate the robustness of advanced computational methods for investigation of the life-cycle of structures.

Figures 4 & 5:
ISCM III-CSE II Conference Venue

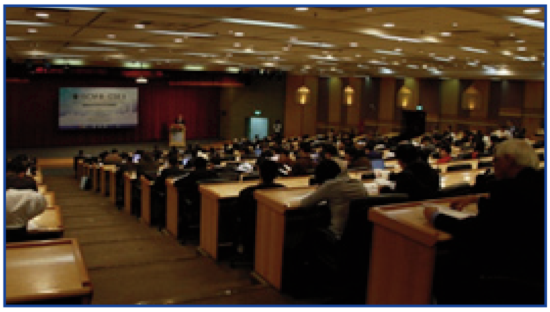
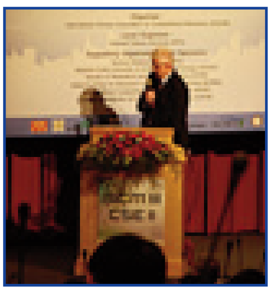
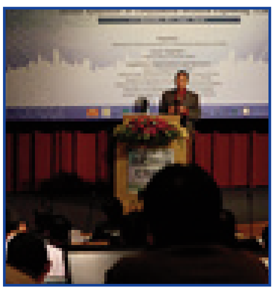


Figure 6:
Welcome speech by the Conference Chair, Prof. YB Yang

Figure 7:
Open plenary by Prof. Herbert Mang



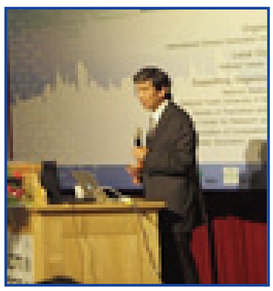
Figures8, 9, 10 & 11:
Plenary speeches by:
Prof. Wing-Kam Liu



Prof. Jun-Zhi Cui

Prof. Subrata Mukherjee

Prof. JS Chen



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TAIWAN (ACMT)

(From one of our plenary speakers from USA) I rank ISCM III-CSEII top 10% of all the international conferences that I have ever attended. Congratulations!

Judging from the fact that the ISCM and CSE have some overlapping in topics and participants, we therefore decided to have a joint conference for them in Taipei, Taiwan. The joint event attracted more than 300 participants, coming from 20 countries and regions, including Austria, Australia, Brazil, China, Germany, Greece, Hong Kong, India, Indonesia, Iran, Japan, Korea, Macao, Netherlands, Singapore, Slovakia, Taiwan, U.K., U.S.A., Vietnam.

The joint conference featured 5 plenary lectures, 6 semi-plenary lectures, 56 invited talks and 192 regular presentations. The plenary speeches were given by Prof. Herbert Mang (Vienna University of Technology), Prof. Jun-Zhi Cui (Chinese Academy of Engineering), Prof. Wing-Kam Liu (Northwestern University), Prof. Subrata Mukherjee (Cornell University) and Prof. Jiun-Shyan Chen (University of California, Los Angeles).
The semi-plenary speeches were given by Prof. J. N. Reddy (Texas A&M University), Prof. Manolis Papadrakakis (National Technical University of Athens), Prof. G. Yagawa (Tokyo University), Prof. Jiann-Wen Woody Ju (University of California), Prof. Ping Hu (Dalian University of Technology) and Prof. Xiong Zhang (Tsinghua University).

One of the biggest events in this conference was the organization of the Minisymposium in Honor of the 70th Birthday of Prof. Herbert A. Mang, former President of the Austrian Academy of Sciences and Professor of Vienna University of Technology. Parallel to the minisymposium, a Birthday Celebration Party co-organized by Prof. Josef Eberhardsteiner (Vienna University of Technology) was held at 85F in Taipei 101 to celebrate Prof. Mang's 70th Birthday.

The ISCM III-CSE II was a great success and we thank all the participants all over world to make it a truly memorable event. The great supports and participation from the officials of IACM and its affiliated associations, Prof. G. Yagawa, Prof. Wing-Kam Liu, Prof. MW Yuan, Prof. JS Chen, Prof. Manolis Papadrakakis, are very much appreciated.

Figures 12, 13 14, 15 & 16: *Selected photos taken from Prof. Herbert A. Mang 70th Birthday Celebration Party at Taipei 101.*

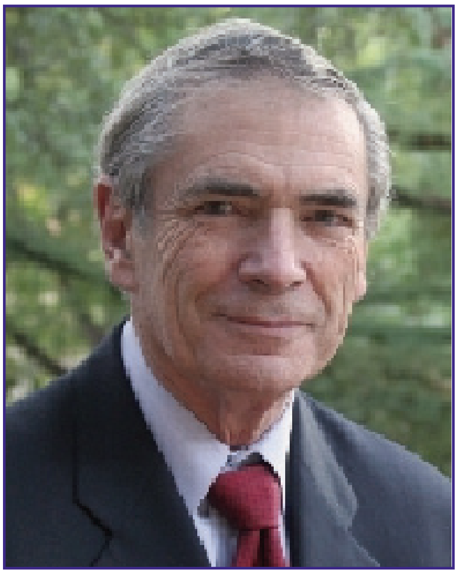
USACM

USACM Announces New Award

USACM announces the establishment of the J. Tinsley Oden Medal to be given in recognition of outstanding and sustained contributions to computational science, engineering, and mathematics. These contributions shall be in the form of important research results that significantly advance the understanding of theories and methods of computational science, engineering and mathematics that have broad applicability to computational mechanics. This award replaces the USACM Computational and Applied Sciences Award.

A founding member and past president of both USACM and IACM, J. Tinsley Oden is also the founding Director of the Institute for Computational Engineering and Sciences (ICES) at the University of Texas, Ausitn. The Institute supports broad interdisciplinary research and academic programs in computational engineering and sciences, involving four colleges and 18 academic departments within UT Austin. He is an author of over 600 scientific publications: books, book chapters, conference papers, and monographs, including 50 books he has authored or edited. These include *Contact Problems in Elasticity*, the six-volume series: *Finite Elements, An Introduction to the Mathematical Theory of Finite Elements*, and several textbooks, including *Applied Functional Analysis and Mechanics of Elastic Structures*, and *A Posteriori Error Estimation in Finite Element Analysis*. His most recent book, *Introduction to Mathematical Modeling: A Course in Mechanics*, was published in 2011. His treatise, *Finite Elements of Nonlinear Continua*, published in 1972, subsequently translated into Russian, Chinese, and Japanese and published in a Dover edition in 2007, is cited as having not only demonstrated the great potential of computational methods for producing quantitative realizations of the most complex theories of physical behavior of materials and mechanical systems, but also established computational mechanics as a new intellectually rich discipline that was built upon deep concepts in mathematics, computer sciences, physics, and mechanics.

Figure 1: *Professor J. Tinsley Oden*



Dr. Oden is a member of the U.S. National Academy of Engineering and the American Academy of Arts and Sciences. He is a representative of IACM on the IUTAM Working Party 5 on Computational Mechanics and serves on numerous organizational, scientific and advisory committees for international conferences and symposia. Oden has received many honors and awards for his research and writings, including six honorary doctorates, the IACM Gauss-Newton Medal, the USACM von Neumann Medal, the Zienkiewicz Medal, the von Karmen Medal, the Timoshenko Medal, and many others. He is an Editor of *Computer Methods in Applied Mechanics and Engineering* and serves on the editorial board of 27 scientific journals. ●

USACM Announcements

- 12th U.S. National Congress on Computational Mechanics (USNCCM12) will be held **July 22-25, 2013**, in Raleigh, NC, USA. Proposals for minisymposia are currently being accepted. . Please see the website (12.usnccm.org) for further details.

- Plan to attend the 22nd International Workshop on Computational Mechanics of Materials (IWCMM XXII), **September 24-26, 2012** in Baltimore, MD, USA (http://iwcmm22.jhu.edu/).

- Workshop on Nonlocal Damage and Failure: Peridynamics and Other Nonlocal Models, will be held **March 11-12, 2013**, in San Antonio, TX, USA. The website (nfd2013.usacm.org) contains more information.

Thematic Conference:
Multiscale Methods and Validation in Medicine and Biology I

USACM held its first thematic conference on Multiscale Methods and Validation in Medicine and Biology I: Biomechanics and Mechanobiology, at the Embassy Suites in Burlingame, CA, February 13-14, 2012. The conference, organized by Professors Suvranu De, William Klug, and Wing Kam Liu, hosted a total of 92 attendees from the US, Europe and Asia. The two-day meeting featured over 70 presentations in the following areas:

Figure 2:
Lecture presented at Multiscale Methods and Validation in Medicine and Biology I: Biomechanics and Mechanobiology

Mechanobiology at the molecular, cellular, tissue and organ levels,
Multiscale mechanics of biological macromolecules in health and disease
Multiscale biofluid mechanics and mass transport,
Multiscale mechanics of biological membranes, films and filaments,
Multiscale mechanics of adhesion,
Biomolecular motors and force generation,
Mechanics of bionanoporous materials

Two parallel sessions were held on each day to accommodate the talks. Each talk was 20 minutes in length and each session featured a 30-minute Round Table Discussion period. In addition, seven poster presentations were made. During the first day lunch, Dr. Grace Peng from the National Institutes of Health made a presentation on 'Thoughts on the Future of Multiscale Modeling'. With an opening reception, conference dinner, and lunches each day, there was ample time for participants to discuss the research being presented. ●

A second conference is planned for 2014 in the San Francisco Bay Area.

Figure 3:
Informal discussion during a break at Multiscale Methods and Validation in Medicine and Biology I: Biomechanics and Mechanobiology

USACM Partners with SIAM on SIAM UQ12 Conference

The USACM served as a cooperating organization with SIAM on the 2012 SIAM Conference on Uncertainty Quantification (SIAM UQ12), which was held April 2-5, 2012 in Raleigh, NC. Other cooperating organizations were the American Statistical Association (ASA) and the Statistical and Applied Mathematical Sciences Institute (SAMSI). This was the first-ever conference dedicated entirely to the emerging field of UQ. Roger Ghanem (University of Southern California) served as the USACM representative on the organizing committee, and USACM members received a discounted registration price.

The conference was a tremendous success; the four-day length and 487 registered attendees far exceeded the numbers originally planned for. The format included six plenary lectures, six mini-tutorials, nine parallel sessions of technical presentations over the four days, an evening poster session, and an evening "forward-looking" panel session. There was also a meeting of the SIAM Activity Group on UQ, which is cooperating closely with the new USACM UQ Specialty Committee. SIAM UQ will now become a biennial conference series. USACM will again be cooperating with SIAM on SIAM UQ14, to be held in Spring,2014. ●.

ACME Association of Computational Mechanics in Engineering - UK

20th UK ACME

Conference on Computational Mechanics in Engineering

The UK Association for Computational Mechanics in Engineering (ACME) was founded with the aims of promoting research in computational mechanics in engineering within the UK, and establishing formal links with similar organisations in Europe and the International Association for Computational Mechanics (IACM). The main activity of ACME involves the organisation of the Annual Conference, which has been held in a UK university since 1993.

The 20th ACME Annual Conference was held at the School of Mechanical, Aerospace and Civil Engineering, the University of Manchester from 27th-28th March 2012. The Conference attracted over 100 researchers from over 35 universities. Among the participants, 15 were from outside UK, including Australia, China, Ireland, Netherland, Spain, Turkey and USA, which added a strong international flavour to this UK national conference.

During the two-day conference, 84 presentations were given on a wide range of topics, from computational solid mechanics to CFD and fluid-structure interaction, from computational structural engineering to geomechanics and wave propagation, from materials constitutive modelling to complicated damage and fracture behaviour under impact and fire, from newest numerical methods and algorithms to advanced application of complicated materials, structures and processes in different scales. Four invited plenary lectures were given, by Prof. Guirong Liu from Cincinnati, USA on smoothed finite element methods, Associate Prof. Chongmin Song from Sydney, Australia on scaled boundary finite element method, Prof. Keneth Morgan from Swansea, UK on adaptive remeshing

Figure 1: (above left and right) On the plenary lecture of Prof Rene de Borst

Figure 2: Lively discussion after Prof Guirong Liu's plenary lecture

Figure 3:
The Crisfield Prize and the Best Postdoctoral Researcher Award winner, Dr Hou Man from UNSW

Figure 4:
The Best PhD Award winner, Mr Jack Hale from Imperial College of London

Figure 5:
The Best PhD Award winner, Mr Graeme Edwards from Glasgow University

of CFD problems, and Prof. Rene de Borst from Glasgow, UK on multiscale fracture modelling, respectively. A total of 88 four-page papers are published in the conference proceedings (both online and paperback).

At the end of the Conference, four prizes were awarded to young researchers who presented the best papers, selected by a judging panel comprising senior academics. The Crisfield Prize and the Best Postdoctoral Researcher Award went to Dr Hou Man from the University of New South Wales, the Best PhD Awards to Mr Graeme Edwards from Glasgow University and Mr Jack Hale from Imperial College of London, and the Zenkiewicz Best PhD Thesis Prize to Dr Sundararajan Natarajan from Cardiff University.

The Conference was preceded by the 2nd ACME School on the afternoon of 26th March, in which three lectures on special topics were given to over 50 participants, by Prof. Carlo Sansour from Nottingham, Prof. Stephane Bordas from Cardiff and Dr Dongfang Liang from Cambridge, respectively.

After the conference, Prof Carlo Sansour, the President of ACME UK, commented that "the meeting was a great success" and congratulated Dr Zhenjun Yang for "the excellent organisation of the conference and in particular, the good selection of the keynote speakers."

Dr Zhenjun Yang
University of Manchester

Figure 6:
Conference dinner in the magnificent old Christie Library (1898) of the University of Manchester

Figure 7:
Prof Carlo Sansour, Dr Chongmin Song and Dr Zhenjun Yang

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65th Birth anniversary of

Sergio Idelsohn

MECOM 2012 will be inaugurated on November 13th, this time in the beautiful northern Argentine city of Salta. Salta, a city famous for its empanadas (pasties), wines and folklore, among so many other things, lies at a point where the mountains meet with the forest, leaving a dream valley behind. There, researchers from many parts of the world will gather to share good moments and exchange scientific opinions. On this occasion, we are fortunate to honor one of the distinguished citizens that Argentina has given to the world on his 65th birth anniversary, our dear friend, colleague and professor, Sergio Rodolfo Idelsohn Barg. It is difficult to describe in a few words the contribution that Sergio has made over his academic life, which includes almost two thirds of his lifetime. However, we have accepted the challenge.

Figure 1: *Sergio Idelsohn*

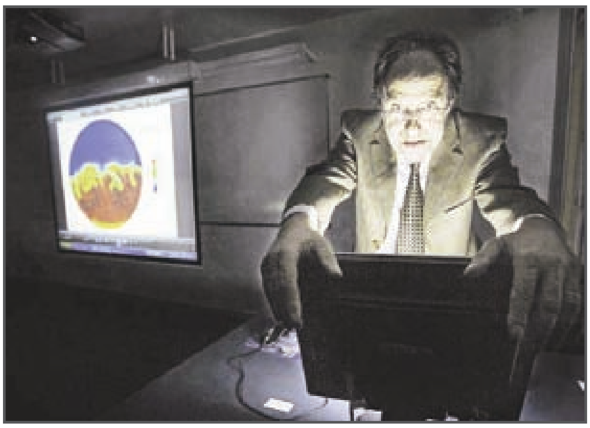
Sergio Idelsohn is an Argentine scientist specialized in the field of computational mechanics. He started his career in solid mechanics when, as a PhD student at the University of Liege, he came in contact with plates and shells. Later, back in Argentina, he focused on applications of the finite elements method in heat transfer and fluid mechanics, areas in which he has been working up to the present. However, throughout his active scientific career, he deeply explored different methods and made valuable contributions to each of them, such as finite volume, finite elements and, lately, particle methods. In his opinion, the latter methods are the ones that best adapt to problem solving in fluid mechanics, where fluids interact with a free surface, when the mixture of diverse fluids is simulated or when they interact with some structures.

Figure 2: *Sergio with Olek Zienkiewicz*

Dr. Sergio Idelsohn was born in the city of Paraná on November 15, 1947. He got his degree of Mechanical Engineer at the National University of Rosario (UNR) in 1970 and his Ph D in Engineering at the University of Liege, Belgium, in 1974.

He has held several positions, such as Tenured Professor at the UNR since 1989, CONICET Scientific Researcher since 1981, reaching the maximum researcher category (Senior Researcher) at a very early age. He was Director of the Regional Center of Research and Development (CERIDE), Santa Fe (1985-1987 and 2003-2006). He was Guest Professor at the Institute for Advanced Study at Princeton (USA); at the University "Pierre et Marie Curie" (France), and at the Polytechnic University of Catalonia (Barcelona, Spain). From 1985 to 2005, he was president of the Argentine Association of Computational Mechanics, an organization that had its origin in the visionary ideas of several Argentine scientists of that time, with Sergio Idelsohn among them. Since 1980, when the city of Santa Fe adopted him as a citizen, he worked hard to create, establish and strengthen the current International Center for Computational Methods in Engineering. Another of Sergio's values is his ability to make friends, which helped him gain the affection of many of the authors of the most prestigious books published in the field of Computational Mechanics, professor Olgierd Zienkiewicz among them.

Figure 3: *Sergio Idelsohn in front of his Real Time project*



At present he is a researcher at the Institució Catalana de Recerca i Estudis Avançats (ICREA), developing his activities at the International Center for Numerical Methods in Engineering, (Centro Internacional de Métodos Numéricos en Ingeniería, CIMNE), Barcelona, Spain. Every year, Sergio and his wife, Lelia Zielonka, are welcome in Argentina, and particularly Santa Fe, where they stay for about two months. Lelia was the secretary at CIMEC during all the years that they lived in Santa Fe most of the time. During those two months, Dr Idelsohn works as Professor at the Faculty of Engineering and Hydrological Sciences of the National University of the Littoral in Santa Fe. He has published more than one hundred scientific articles in international journals and is the author of several book chapters, such as Chapter 9 in Implicit Finite Element Methods (1984). In 1987 he received one of the most important awards in his scientific life, the Houssay award, a prize granted to the author of the best scientific works conducted in Argentina. He was elected "Fellow" of the American Academy of Mechanics in 1996 and of the International Association of Computational Mechanics in 1998. In 1993 he received the Konex Award in the field of Industrial, Chemical and Electromechanical Engineering.

He also received the Award of the National Academy of Sciences of Argentina in 1997 and of the International Association of Computational Mechanics in 2002. In 2006 he was granted the AMCA Award of the Argentine Association of Computational Mechanics for his sustained research, teaching, and professional activities. In 2007 he received the Elsevier Scopus Award for the number of times his works were cited in the previous ten years. In 2009 he was given the Sociedad Española de Métodos Numéricos en Ingeniería (SEMNI) Award, in recognition to a professional and international trajectory in the Hispanic speaking world. In February 2010 the European Research Council gave him a grant worth millions to develop numerical simulation systems to perform real-time calculations.

As Professor Idelsohn states, the challenge lies in a change of paradigm in the way of thinking about the problems. "Although computers are very fast at present, calculations in engineering take between 10 and 20 hours. If we need to calculate, for example, the consequences of a crack in a dam, these periods are unacceptable. Therefore, the project that received ERC funding consists of doing the calculations in real time. We will not need to wait for so many hours for the work of a computer while water flows out", explained the researcher during an interview in Santa Fe. Then he asserted that: "With this method we might do the calculations at the same time that the dam failure occurs. Thus, determining how water will descend, where it will reach, whether the nearby cities will have to be preventively evacuated, is very useful to prevent the contingency. The advantage of real time calculation lies in those cases in which natural phenomena occur very rapidly, and rapid decisions need to be made as well. Our work proposes a method for doing those calculations in real time.

To conclude, happy birthday dear Sergio, and many thanks for all that you have given to us.

by
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JSCES

General Assembly Meeting

Figure 1:
Special lecture by Professor Kozo Fujii in the JSCES Symposium

The JSCES, which was incorporated under a new regulation about government-affiliated public corporations two years ago, hold the third general assembly meeting of the JSCES in May 24, 2012. On this occasion, Dr. Koichi Ohtomi (Toshiba Corporation) stepped down as the President of the JSCES, and Dr. Kazuo Kashiyama (Professor, Chuo University) took over it.

Prior to the deliberation in the assembly, a special symposium was held, in which Dr. Kozo Fujii (Professor, Institute of Space and Astronautical Science, Japan Aerospace Exploration Agency: JAXA/ISAS) presented a plenary talk entitled "Product Innovation with HPC/CFD ~ Concept Revolution from Geometry Design to Control Device Design~" *(Figure 1).*

On the same day, inviting Dr. M. Shoji (the second president), who founded Shoji Medal, we had the award ceremony for awarding JSCES prizes to senior and young researchers and practitioners. This year's recipients are:

Annual Conference

The 17th JSCES's Annual Conference on Computational Engineering and Science, chaired by Prof. N. Takano (Keio Univ.), was held on May 29-31, 2012, at Kyoto Kyoiku Bunka Center (Kyoto, Japan). The conference lasted three days and was attended by about 560 participants. About 400 papers with full lectures were presented by researchers, graduate students and practitioners in the conference composed of 8 tracks and 36 minisymposia. Among them, two special symposia were organized by the conference organizing committee for intensive discussions for specific fields of research. One is "Disaster Prevention/Reduction ~Present Situation and Proposition in Computational Mechanics~" *(Figure 3)* and the other is "Innovation of Materials for Structures and Applications for Manufacturing". The plenary talk was given by Professor Olivier Pironneau at the University of Paris VI (Pierre et Marie Curie) who presented the paper "Optimal Shape Design for Airplane Aerodynamics". He is also the recipient of "The JSCES Grand Prize 2012" for his outstanding contributions in the field of computational engineering and sciences *(Figure 4)*.

Figure 3:
Special symposium "Disaster Prevention/ Reduction ~Present Situation and Proposition in Computational Mechanics~"

The JSCES took this conference as an occasion to promote young researchers by awarding "Best Paper Award" to speakers with respectable presentations and papers, and "Visualization Award" to speakers with illustrative figures placed in their papers. Also, five sponsoring software venders and distributers provided separate "Lunch-on Seminars" during lunchtime, in which their activities were presented to the audience being lunch boxes served. All these events in this conference were quite successful. The significance of JSCES's annual conference has been determined as an established setting for the exchange of ideas in the field of computational engineering and science, and for the enlightenment of state of the art in this field. The effort will continue to have the next year's conference in Tokyo, June 2013. ●

Figure 4:
Prof. O. Pironneau (recipient of The JSCES Grand Prize 2012) (30th of May, 2012)

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Prof. Norio Takeuchi *(The JSCES Award)*, Dr. Keizo Ishii *(The JSCES Award)*, Prof. Takahiro Yamada *(Kawai Medal)*, Dr. Ryusaku Sawada *(Shoji Medal)*, Dr. Kazuki Shibanuma *(Outstanding Paper Award)*, Dr. Zixian Zhang and Prof. Ichiro Hagiwara *(Outstanding Paper Award)*, Dr. Ikumu Watanabe *(Young Researcher Award)*, and Dr. Takeshi Akita *(Young Researcher Award) (Figure 2)*. ●

Figure 2:
Group shot of recipients of The JSCES Award, Kawai Medal, Shoji Medal, Outstanding Paper Award and Young Researcher Award

International Forum & the JSCES's Grand Prize for 2011

Due to the Higashi Nihon Daishinsai (Great East Japan Disaster), many important events planned for the first half of the last year were canceled. In particular, a plenary lecture at the 16th JSCES's Annual Conference was post-poned until December 6, 2011, on which the JSCES could have the opportunity to organize "the 1st International Forum for Nonlinear Computational Solid Mechanics". In this special meeting, Professor Peter Wriggers (Leibniz Universitaet Hannover, German) presented the paper "3D error controlled adaptive multiscale extended finite element methods for crack simulations" (co-authored by P. Wriggers, S. Loehnert, D.S. Mueller-Hoeppe, M. Holl, C. Hoppe, H. Clasen) as a plenary speaker and was awarded The JSCES's Grand Prize 2011 after his lecture *(Figure 5)*. In the same forum, two invited speakers gave their talks about the recent trends and advances in multiscale modeling and analyses. One was "Multi-scale structural health monitoring: challenges for microcrack identification" presented by Prof. Tmonari Furukawa (Virginia Polytechnic Institute and State University, USA) and the other "Multiscale analysis: numerical material testing with micro-scale information and material modeling" by Prof. Kenjiro Terada (Tohoku University). *Figure 6* shows a group shot at the convivial party after the forum. ●

Figure 5:
Prof. P. Wriggers (recipient of The JSCES Grand Prize 2011) with Prof. K. Ohtomi (former President ofJSCES) (6th of December, 2011)

Figure 6:
Group shot of participants of the 1st International Forum for Nonlinear Computational Solid Mechanics (6th of December, 2011)

JSCES Future Events

In this manner, the JSCES, which has over 800 IACM members, is directing various international activities as an IACM affiliated society in Japan, promotes exchanges in individual associations and societies on computational mechanics. This year, the JSCES plans to organize the Sixth Korea-Japan Workshop in Kyoto, Japan and the first Spain-Japan Workshop in Barcelona, Spain. The JSCES will also provide a special educational event named "Summer School on Basics and Applications of Flow Simulation by FEM". These events will be reported in the next issue. ●

JACM NEW ELECTED COUNCIL

The Japan Association for Computational Mechanics (JACM) elected a new executive council in March 2012. After three years as president of JACM, Prof. Noriyuki Miyazaki, Kyoto University left the board. The new executive council members for 2012-2014 are as follows :

Figure 1:
Prof. Shinobu Yoshimura (President)

President :
Prof. Shinobu Yoshimura,
The University of Tokyo,
yoshi@sys.t.u-tokyo.ac.jp,
http://save.sys.t.u-tokyo.ac.jp/prof/index.html

Vice Presidents :
Prof. Takayuki Aoki,
Tokyo Institute of Technology,
taoki@gsic.titech.ac.jp, http://www.sim.gsic.titech.ac.jp/English/Member/taoki.html,
and
Prof. Shinji Nishiwaki : Kyoto University,
shinji@prec.kyoto-u.ac.jp,
http://www.osdel.me.kyoto-u.ac.jp/english/members/index.html

JACM NEWS

JACM officially started on December 17, 2002. The purpose of JACM is to establish the communication network over the scientists related to computational mechanics. The JACM differs from ordinary societies, but is rather a loosely coupled union of 26 societies in Japan related to computational mechanics. Please visit the web-site at **http://www.sim.gsic.titech.ac.jp/jacm/index-e.html** to see our activities.

In 2012, JACM supports two international events held in Japan.

The first event was “Lectures on Computational Fluid-Structure Interaction” held on 5-6 March, 2012 at University of Tokyo, Japan, whose co-chairs are Professors Yoichiro Matsumoto of University of Tokyo, Tayfun Tezduyar of Rice University, Shinobu Yoshimura and Kenji Takizawa of Waseda University, Japan. The other lecturers are Profs. Yuri Basilevs of UCSD and Takeo Kajishima of Osaka University, Drs. Tomohiro Sawada of AIST, Satsuki Minami of University of Tokyo and Satoshi Ii of Osaka University.
Over 90 participants including researchers and students from academia as well as engineers from industries attended the workshop.

The workshop had two objectives.
The first day is an “FSI Exchange” where the lecturers focus on computational FSI techniques and exchange information on what challenges are faced and how the challenges addressed.
The second day of the workshop was short-course style, where the lectures focus on “FSI Fundamentals”. All the lectures are very stimulating and informative not only for the participants but also for the lecturers.

for all inclusions under ***JACM*** *please contact:*
Shinobu Yoshimura
jacm-jim@save.sys.t.u-tokyo.ac.jp

Figure 2:
Prof. Takayuki Aoki
(Vice-president)

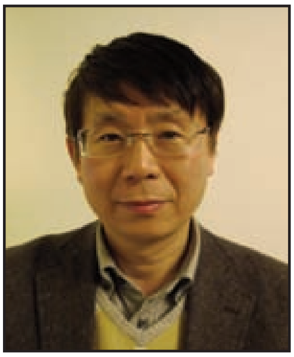

Figure 3:
Prof. Shinji Nishiwaki
(Vice-president)

Figure 4:
Prof. Hiroshi Okada
(Secretary General)

Secretary General :
Prof. Hiroshi Okada :
Tokyo University of Science,
hokada@rs.noda.tus.ac.jp,
http://www.rs.noda.sut.ac.jp/me/laboratories/okada_laboratory.html

Figure 5:
Profs. Yoichiro Matsumoto, Tayfun Tezduyar and Takashi Yabe (Tokyo Institute of Technology) in Panel Discussion of FSI Workshop

The second event is International Computational Mechanics Symposium 2012 to be held in 9-11 October, 2012 in Kobe, which is 25th anniversary event of Computational Mechanics Division of Japan Society of Mechanical Engineers.

Besides a number of mini-symposia, it will have invited plenary talks by Professors Jack Dongarra of University of Tennessee, J. S. Chen of UCLA, Roger Ohayon of CNAM and Genki Yagawa of Toyo University. The symposium also includes a technical tour to the world's fastest supercomputer, K-computer. Deadline of Extended Abstract submission is July 15, 2012.

In more detail, please visit the website,
http://www.jsme.or.jp/conference/cmdconf12/index.html

Figure 6:
Night View of Kobe International Port

conference diary planner

1 - 5 July 2012	**EngOpt 2012 : 3rd Int. Conf. on Engineering Optimization**			
	Venue:	*Rio de Janeiro, Brazil*	*Contact:*	*http://www.engopt.org*
8 - 13 July 2012	**WCCM 2012 - 10th World Congress on Computational Mechanics**			
	Venue:	*Sao Paulo, Brazil*	*Contact:*	*http://www.wccm2012.com*
9 - 13 July 2012	**ESMC 2012 8th European Solid Mechanics Conference**			
	Venue:	*Gratz, Austria*	*Contact:*	*www.esmc2012.tugraz.at*
17 - 20 July 2012	**VECPAR 2012 : High-Performance Computing for Computational Science**			
	Venue:	*Kobe, Japan*	*Contact:*	*http://nkl.cc.u-tokyo.ac.jp/VECPAR2012/*
6 - 10 Aug 2012	**CLAM 2012 : IV Congreso Latinoamericano de Matemáticos**			
	Venue:	*Cordoba, Argentina*	*Contact:*	*http://www.famaf.unc.edu.ar/clam2012/*
9 - 10 Aug 2012	**CADI 2012 : I Congreso Argentino de Ingeniería**			
	Venue:	*Mar del Plata, Argentina*	*Contact:*	*info at cadi.org.ar*
4 - 9 Sept 2012	**ECT2012: 8th Int. Conf. on Engineering Computational Technology**			
	Venue:	*Dubrovnik, Croatia*	*Contact:*	*http://www.civil-comp.com/conf/ect2012.htm*
10 - 13 Sep 2012	**ICPP : International Conference on Parallel Processing**			
	Venue:	*Pittsburgh, USA*	*Contact:*	*http://www.icpp2012.org*
10 - 14 Sept 2012	**ECCOMAS 2012 - 6th European Cong. on Computational Methods in Applied Science & Eng**			
	Venue:	*Vienna, Austria*	*Contact:*	*http://eccomas2012.conf.tuwien.ac.at*
18 - 21 Sept 2012	**FDM2012 : Fracture and Damage Mechanics**			
	Venue:	*Xi'an City, China*	*Contact:*	*http://fdm.engineeringconferences.net/*
24 - 26 Sept 2012	**IWCMM XXII - 22nd International Workshop on Computational Mechanics of Materials**			
	Venue:	*Raleigh, NC, USA*	*Contact:*	*http:12.usnccm.org*
2 - 5 Oct 2012	**CAIM 2012 : III Congreso Argentino de Ingeniería Mecánica**			
	Venue:	*Buenos Aires, Argentina*	*Contact:*	*http://www.caim2012.frba.utn.edu.ar/*
9 - 11 Oct 2012	**International Computational Mechanics Symposium 2012**			
	Venue:	*Kobe, Japan*	*Contact:*	*http://www.jsme.or.jp/cmd/*
23 - 25 Oct 2012	**VII COBIM : Congreso Bolivariano de Ingenieria Mecanica**			
	Venue:	*Cusco, Perú*	*Contact:*	*vii.cobim at pucp.edu.pe*
13 - 16 Nov 2012	**MECOM 2012 : X Congreso Argentino de Mecánica Computacional**			
	Venue:	*Salta, Argentina*	*Contact:*	*http://www.unsa.edu.ar/mecom2012*
24 - 28 Feb 2013	**FEF 2013 : Finite Elements in Flow Problems**			
	Venue:	*San Diego, USA*	*Contact:*	*http://www.tafsm.org/TH70/*
11-12 March 2013	**Workshop on Nonlocal Damage and Failure: Peridynamics and Other Nonlocal Models**			
	Venue:	*San Antonio, USA*	*Contact:*	http://nfd2013.usacm.org
29 - 30 May 2013	**MARINE VI: Marine Engineering.**			
	Venue:	*Hamburg, Germany*	*Contact:*	*http://congress.cimne.com/marine2013*
3 - 5 June 2013	**International Conference on Adaptive Modeling and Simulation - ADMOS 2013**			
	Venue:	*Lisbon, Portugal*	*Contact:*	*http://www.lacan.upc.edu/admos2013*
12 - 14 June 2013	**SEECCM III : South-East European Conference on Computational Mechanics**			
	Venue:	*Island of Kos, Greece*	*Contact:*	*http://www.seeccm2013.org.*
17 - 19 June 2013	**COUPLED V: Coupled Problems in Science and Engineering.**			
	Venue:	*Ibiza, Spain.*	*Contact:*	*http://congress.cimne.com/coupled2013*
22 - 25 July 2013	**NCCM12 - 12th U.S. National Congress on Computational Mechanics**			
	Venue:	Baltimore, USA	*Contact:*	http://iwcmm22.jhu.edu/
3 - 5 Sept 2013	**COMPLAS XII: Computational Plasticity. Fundamentals and Applications.**			
	Venue:	*Barcelona, Spain.*	*Contact:*	*http://congress.cimne.com/complas2013*
18 - 20 Sept 2013	**PARTICLES III: Particle-based Methods. Fundamentals and Applications.**			
	Venue:	*Stuttgart, Germany.*	*Contact:*	*http://congress.cimne.com/particles2013*
9 - 11 Oct 2013	**MEMBRANES V: Textile Composites and Inflatable Structures.**			
	Venue:	*Münich, Germany.*	*Contact:*	*http://congress.cimne.com/membranes2013*