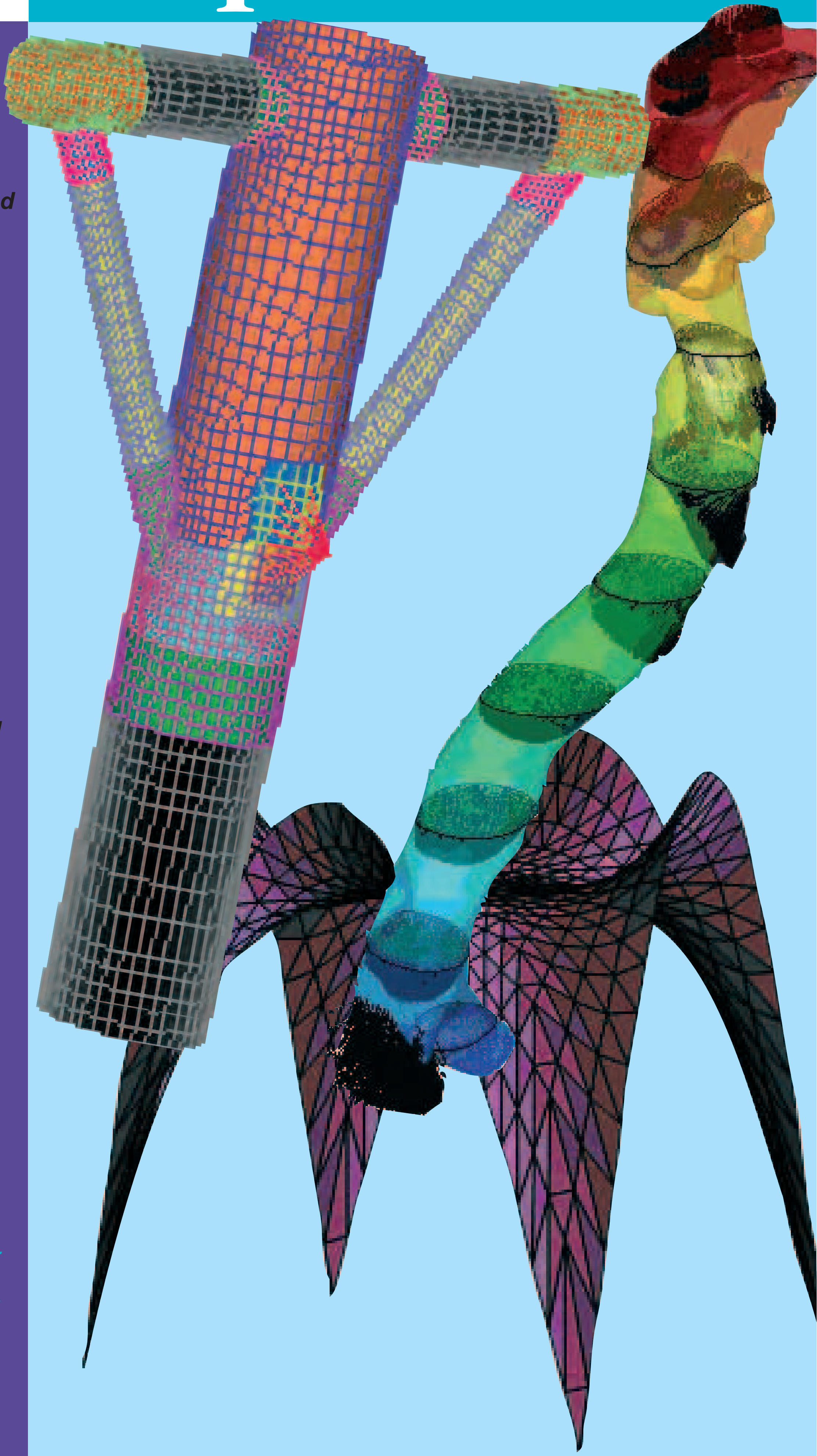
iacm expressions



Bulletin for
The International Association
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contents

editorial

Numerical methods provide a common language for the communication between different scientific and technical disciplines which traditionally have been isolated from each other. The solution of complex problems in applied sciences and engineering has brought in the need for a multidisciplinary team approach where numerical methods play the role of common denominator for many computational procedures. Indeed computational mechanics encompasses numerical methods, together with the traditional disciplines in mechanics (solids, fluids, heat transfer, electromagnetics, etc.), materials science, mathematics and computer science. Here again numerical methods act as a transversal discipline bringing together bits and pieces from adjacent areas to form a coherent computational structure capable of solving new problems involving complex coupled phenomena.

It is not surprising therefore the number of scientific meetings held in 2007 worldwide that focus on the solution of multidisciplinary problems using computational mechanics procedures. This increasing trend shows that the new culture for multidisciplinary scientific and technical work is gaining ground. This will invariably have an effect in the organizational structure of universities and research centres, as well as in the academic curricula at undergraduate and graduate levels which will surely need to adapt for providing a broader perspective for solving problems on a multidisciplinary world. This transition will not be easy as universities have a considerable inertia to changes. Big opportunities will however emerge for those organisations that can adapt faster to the new paradigms of computational engineering science.

The language of numerical methods however goes beyond the purely scientific and technical grounds. It is also the language of communication between people from different cultures and backgrounds who have a common interest in the progress of science and engineering towards a better world. Here organisations like IACM can play an important role by establishing bridges favouring the communication of scientific communities around the world via the common language of numerical methods. This opportunity is favoured by the interest of many emerging scientific groups in the five continents in participating in IACM activities. Some examples are the new IACM affiliated organisations from Malaysia, Serbia and Taiwan, the organisation of the first African Conference on Computational Mechanics in January 2009 and the increasing activity in Isfahan University in Iran in cooperation with IACM groups, as reflected in the pages of this bulletin.

Cultural interchange and mobility of scientists and ideas can indeed help to a better understanding of people, as a necessary step towards the solution of other problems affecting human life. IACM is willing to contribute, within its limited possibilities, towards achieving those challenging goals.

A final note. We are one year away from the 8th World Congress on Computational Mechanics (WCCM8) to be held in Venice (Italy) on June 30 - July 5 2008. This is going to be a major international event held in conjunction with the European Congress on Computational Methods in Applied Sciences (ECCOMAS 2008). Please put WCCM8 in your agenda. More details can be found in **www.iacm.info.**

Eugenio Oñate
IACM President

The Art of Generating Reference Solutions for Computational Schemes

by
Dan Givoli
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Israel Institute of Technology
Haifa
Israel

> "... one must be very careful in designing such reference solutions, in order to ensure that they constitute sound and reliable means of testing the scheme under consideration."

After developing and implementing a new computational scheme, one must validate and verify it, namely check that the code is correct and that the model and scheme are appropriate. The difference between validation and verification is important (see, e.g., [1]), but is not the subject of the present article, which will concentrate mainly on verification. An essential part of the process of verification is the comparison of the results produced by the code with some *reference solutions* that may be regarded as "the truth." Given such a reference solution, the error generated by the scheme can actually be calculated: this is the difference between the computed solution and the reference solution. The question considered in this article is how one can produce reference solutions for this purpose.

One obvious answer may be to look for a problem which is sufficiently simple so that it has an analytical exact solution, and apply the scheme to it. However, there are three difficulties associated with this approach. First, some schemes are designed to solve classes of problems for which no exact solution is available. Examples are abundant, especially if the problems under consideration are nonlinear. Second, even if a problem exists in the class of problems considered for which an exact solution is known, this solution may be too simple to reasonably represent other, more interesting solutions. For example, with a particular choice of the parameters a certain differential equation may have a constant solution; then verifying that the computational scheme reproduces this constant is important, but would usually say very little about the performance of the scheme in more general situations. Third, an exact solution may sometimes be available via an analytical expression but it may be too difficult to calculate in practice. This may happen, for example, when the exact solution is expressed as an infinite series which converges very slowly at certain points, or when it involves some special functions which are hard to work with numerically.

Are there other ways to generate reference solutions for computational schemes? There are, and the rest of this article suggests a number of them. It also shows that unless one is very careful, one may reach erroneous conclusions from comparing computed and reference solutions. We discuss these issues in the form of a number of brief hypothetical case studies.

Case Study 1:
Experimental Results

We were shown the results of wind-tunnel experiments for flow past a circular cylinder at moderately low Reynolds number. An unexpected periodic "mode" is observed in these results in the wake of the cylinder. We apply to this problem our new spectral code for two-dimensional time-dependent compressible Navier-Stokes equations, based on an algorithm which we have proved to be consistent and stable. Indeed, the numerical results show a periodic mode in the wake, similar to the one observed in the experiment.

In this case, the 'reference solution' is actually obtained from the results of a laboratory experiment. Using experimental data to verify computational schemes is a tricky business, and should be practiced with a lot of care. The difficulty lies in the fact that a few different processes separate the two solutions. The 'reference solution' is obtained from measurements, and thus unavoidably contains measurement noise. The measurement is applied to a real physical system, which is represented by our physical model. The latter neglects certain effects (e.g. compressibility, small asymmetries in the geometry, etc.) and concentrates on what are believed to be the most important effects. This physical model is described by a mathematical model, which may involve additional idealization. The latter is approximated via our computational scheme. This process thus involves a few sources of errors of different types. The difference between the final numerical results and the given experimental data contains all these different errors mixed together, and is thus extremely difficult to control and analyze. However, with very careful design this procedure may serve as an effective tool; see, e.g., [2].

The story appearing above about the periodic mode actually happened to S. Abarbanel and his coworkers, as is fully described in [3]. Ironically, it turned out that *both the experiment and the algorithm were wrong*; in fact the 'periodic mode' in the wake of the cylinder was spurious. This mode was triggered in the wind tunnel due to some fault in the experimental design. A similar 'mode' was generated by the computational scheme due to an improper formulation of the far-field boundary condition. The fact that these two 'modes' were similar was a pure coincidence. When the experiment and the scheme were corrected the 'periodic mode' disappeared in both. The main lesson emphasized in [3] is that even if one uses an accurate and stable algorithm there might be pitfalls. Our additional lesson is that even when the numerical results agree with the 'reference solution' we should not always jump to a conclusion on the correctness of our scheme and code.

Case Study 2:
Benchmark Computations

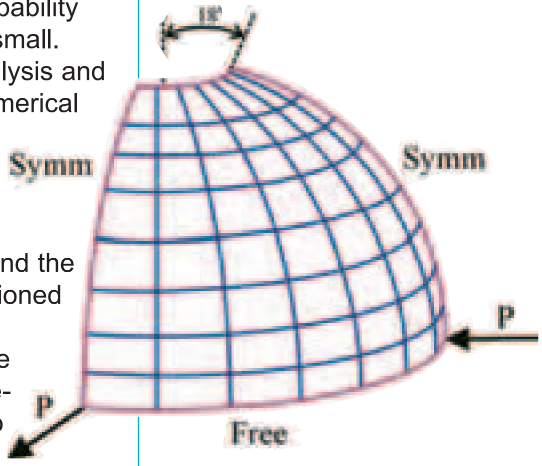
We developed a new shell finite element. To check it we apply our code to the Scordelis-Lo roof problem, to the pinched-hemisphere problem (Fig. 1) and to the pinched-cylinder problem (Fig. 2), and compare our results to those published in the literature that have been obtained by some other well established computational schemes.

Here the reference solution is not obtained from an analytic expression or from a laboratory experiment but from the numerical results produced by a collection of other computational schemes. This approach may sometimes be dangerous, because potentially the results obtained by other schemes, which serve us as a reference solution, may be all wrong. The fact that several numerical solutions match does not necessarily prove their correctness; for instance they may be all erroneous from the same reason.

In the "CFD competitions" which are held from time to time (see, e.g., [4] on the 2001 AIAA Drag Prediction Workshop) the numerical results obtained by various codes have typically shown significant variation, with several small groups of codes yielding similar results among themselves. Thus, if we ignore many of the numerical results and concentrate on a single group of results that match we may acquire false confidence in their correctness.

However, if the various numerical methods being compared are significantly different in nature, yet they all produce nearly identical results, the probability that they are all wrong is very small. Also, following very careful analysis and sufficient experience, some numerical results eventually reach the status of benchmarks. This has indeed happened with the Scordelis-Lo roof problem, the pinched-hemisphere problem and the pinched-cylinder problem mentioned above. Kim et al. [5] and many authors before them used these benchmark problems and corresponding reference solutions to check their new shell elements, in a perfectly sound way.

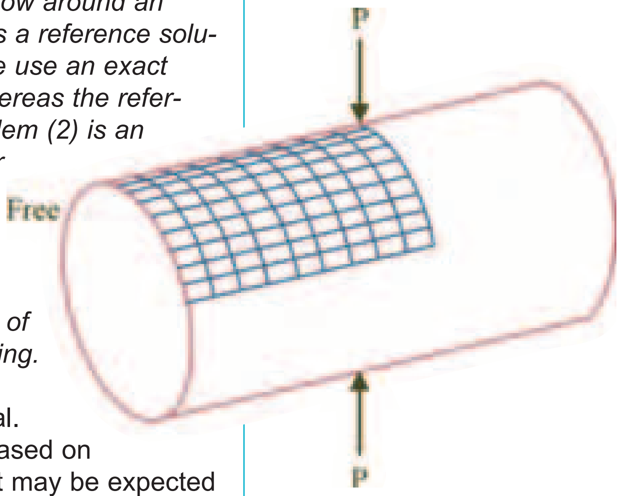
Figure 1:
The pinched hemisphere benchmark problem.



Case Study 3:
Exact and Asymptotic Solutions

We developed a new method for solving problems involving flow around obstacles of general smooth shapes. The method is based on spherical harmonic functions. We apply the method to two test problems: (1) flow around a spherical obstacle, and (2) flow around an ellipsoidal obstacle. As a reference solution for problem (1) we use an exact analytical solution, whereas the reference solution for problem (2) is an asymptotic solution for nearly-spherical obstacles (see, e.g., Van Dyke [6]). The results of test (1) are excellent. The results of test (2) are disappointing.

Figure 2:
The pinched cylinder benchmark problem



Both tests are not ideal. Since the method is based on spherical harmonics, it may be expected that it would do extremely well for spherical obstacles. Hence test (1) is not a real challenge for this method. Test (2) is much better in principle, but the difficulty is that the reference solution is asymptotic and not exact. Hence the reference solution itself contains an error which has nothing to do with our numerical scheme. It is certainly possible that a large part of the "error" observed when comparing the computational and reference solution in test (2) is due to the asymptotic solution, and thus our scheme is not necessarily to be blamed.

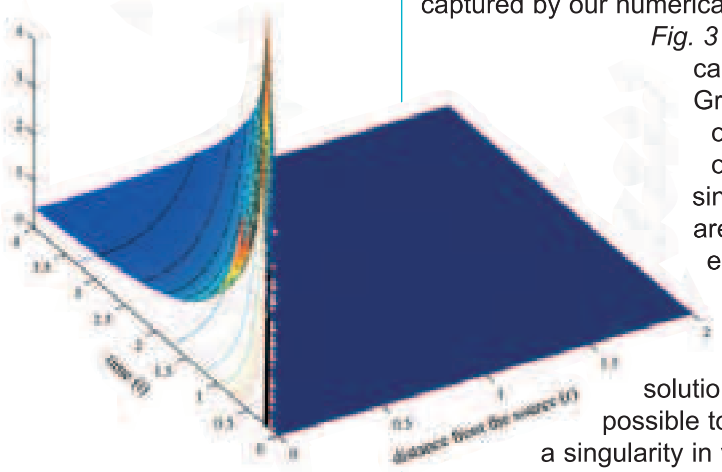
Case Study 4: Green's Functions

We developed a method for solving certain time-dependent wave scattering problems in two-dimensional unbounded domains. To test it, we apply it to a problem with a point source and no scatterer, whose solution is exactly a fundamental solution (Green's function) of the wave operator, which is available explicitly in analytic form. (See [7] for a list of Green's functions in various configurations.)

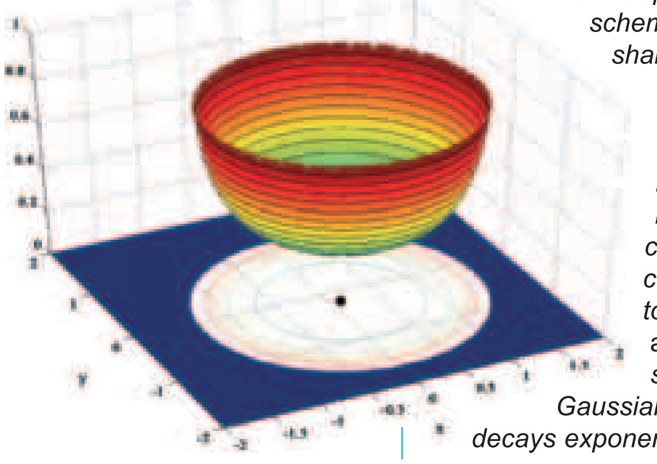
This is fine, as long as we are careful not to use a Green's function with a *singularity* (in space-time) which cannot be captured by our numerical scheme. See *Fig. 3* for a few typical examples of Green's functions of the wave operator with a singularity. If we are not careful, errors due to this singularity may pollute our numerical solution. It is usually possible to exclude such a singularity in various ways, for example by creating a "hole" around it in the computational domain.

Figure 3: *Green's functions for the wave operator in various configurations:*

3(a) *Two-dimensional space-time Green's function as a function of time and distance from the source. The function is singular along the characteristic line in space-time emanating from the source.*



3(b): *Variation in space of the same Green´s function for a fixed time.*



Case Study 5: Concocted Analytical Solutions

We developed a computational scheme for the nonlinear shallow water equations. Our code is capable of handling general forcing (inhomogeneous terms in the PDEs), boundary conditions and initial conditions. In order to check the code, we assume a certain solution, say a Gaussian function which decays exponentially in space and time, and we find the functional form of the corresponding forcing, boundary conditions and initial conditions that would yield this solution. Thus we generate an exact solution to the nonlinear shallow water equations that would serve us as a reference solution.

This technique is based on "inverse engineering." Rather than looking for the analytical solution for given forcing and boundary and initial conditions (which in most cases is an impossible task), we start from any solution of our liking, and by substituting it to all the equations, find the corresponding forcing, boundary and initial conditions. Our numerical code is, of course, oblivious to how we have acquired these functions; hence the solution that we started with serves as a perfectly legitimate reference solution. This simple technique is indeed a powerful tool in generating reference solutions for complicated problems. In many cases, the fact that a problem in strongly nonlinear, is associated with an inhomogeneous and/or anisotropic medium, has complicated geometry, etc., does not pose any hurdle with this technique. In the author's opinion (judging from the literature and from experience in industrial practice) it is not used as much as it should be to verify computational schemes.

However, this technique must not be used "blindly." In order to check a code which is supposed to solve a certain class of problems, one must be careful to choose a *representative solution* as the reference. The exponentially decaying solution in space and time given in the example above is *not* a good choice for the nonlinear shallow water equations. The shallow water equations produce wave solutions; hence any attempt to force solutions which do not bear wave behavior may give us a distorted picture on the scheme's qualities. In the example above, if the numerical solution does agree well with the exponentially decaying reference solution, this gives us some confidence in our scheme, but certainly does not tell us anything about the ability of our scheme to produce accurate wave solutions. Choosing a wave-like solution, say an eigenfunction of a "similar problem" (e.g., a linearized problem with simpler geometry), would serve as a much better reference solution.

Another example that demonstrates the necessity for choosing a *representative* reference solution is the following. Suppose we developed a scheme for solving elastostatic problems with cracks. Then we choose a global polynomial as a reference solution and find the forcing and boundary conditions that correspond to it. *Fig. 4* shows such a reference solution. Again, this is a very poor choice. The features that make crack problems hard are the discontinuity of the solution across the crack surface and the singularity at the crack tip. The polynomial solution involves neither, and hence is almost useless in checking the soundness of the computational scheme. A good choice for a reference solution may be, for example, the fundamental solution for a mode I crack in an unbounded domain. The fact that the actual computational domain is bounded is not problematic at all, since the boundary conditions imposed on the outer boundary are calculated from the known reference solution.

Sometimes this “inverse engineering” procedure is not applicable because it requires a programming effort which may not be acceptable to us. For example, suppose we developed a code that solves the *homogeneous* shallow water equations (driven by the initial conditions), and suppose the function that we have picked as our reference solution does not satisfy these homogeneous equations. Then we are obliged to extend our code to the case of the inhomogeneous shallow water equations, possibly with a complicated time- and space-dependent load term. Such an extension might be beyond what we have been set to do, especially if it is irrelevant to our real research goal.

Case Study 6:
Verification Crimes

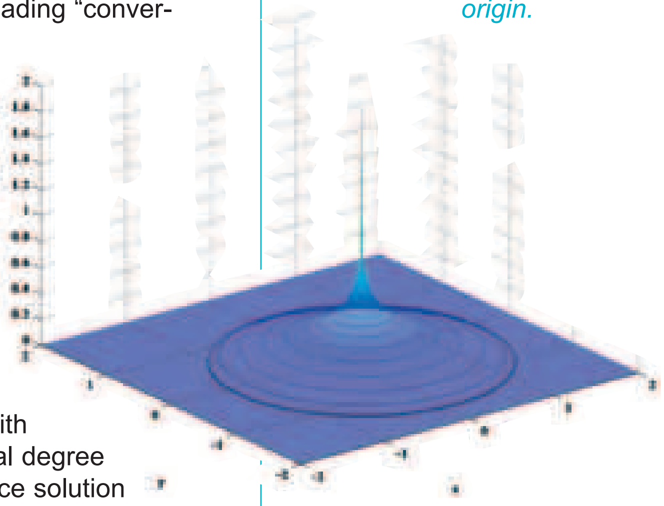
We developed a new finite element for a class of problems in static continuum mechanics. It passes the patch test, but we would like to check its performance under more complicated conditions. In order to check its h-convergence rate, we calculate the solution on a sequence S of meshes with decreasing mesh parameter h. We generate the reference solution by solving the problem with the same type of element but using a mesh twice as fine as the finest mesh in the sequence S.

This procedure is not always safe, and one should be extremely careful when practicing it. It is easy to see that some types of logical mistakes in the scheme or bugs in the code would be invisible to this procedure and would not prevent it from exhibiting misleading “convergence.” (A trivial example is a wrong factor which multiplies the stiffness matrix.)

A similar situation is related to *p*-convergence. Computing high-order solutions by using a sequence of discretizations with increasing polynomial degree *p*, where the reference solution is calculated by using a degree *p* twice as large as the largest *p* in this sequence, may sometimes lead to the wrong conclusions.

In general, one may formulate the following rule: *Avoid a reference solution that was generated by using the very same method which is being verified.* A violation of this rule may be called a *verification crime*.

If one already has strong evidence (by different means) that the scheme is convergent and that the code is correct, the procedure described above may be employed for the sake of determining the rate of convergence. Even this should be done very carefully, making sure that the asymptotic range of convergence has been reached and that the reference discretization is significantly finer than the finest discretization in the sequence S. Also, this procedure may be used as a partial diagnostics tool in the code debugging process; if the scheme is known to be convergent and yet this procedure does *not* exhibit convergence, this probably indicates that something is wrong with the code.



3(c): *Variation in space at a fixed time of the fundamental solution with loading which is an impulse in space and a step in time. Here there is a logarithmic singularity at the origin.*

> “Avoid a reference solution generated by the method being verified.”

Figure 4:
A useless reference solution: a global polynomial for an elastic plate with a crack.

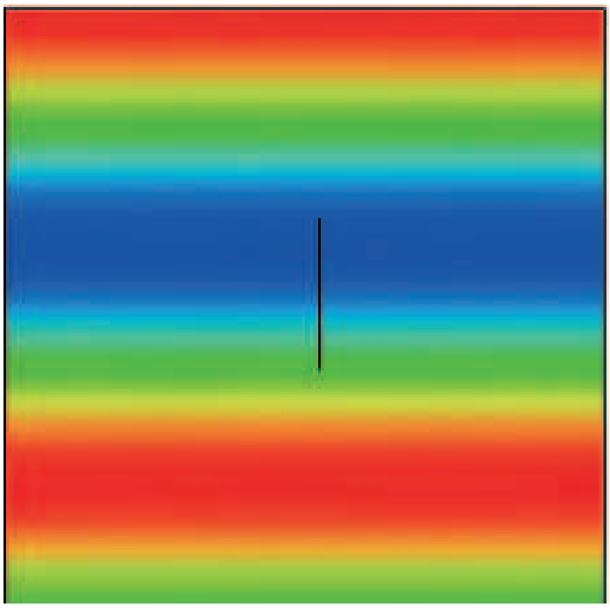
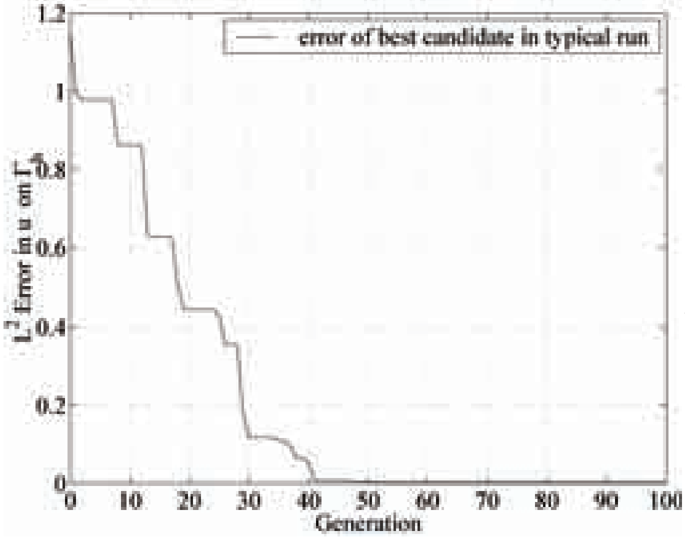
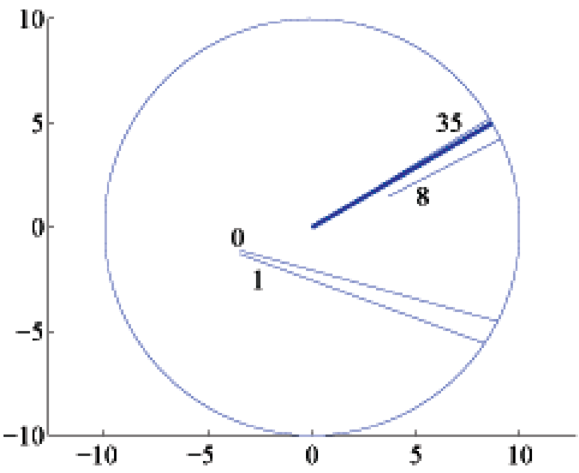


Figure 5: *Results of a crack-detection scheme, based on solving an inverse problem; Case A: Same mesh used for the reference and optimization problems ("inverse crime").*



(a) *L_2 error reduction during evolution;*



(b) *best candidate cracks obtained in various generations.*

Case Study 7:

Inverse Crimes

We developed a computational scheme to solve inverse problems in underwater acoustics. An obstacle (e.g., a submarine) is to be identified given certain "observed information" M on the solution, say the value of the solution (acoustic pressure) on a certain manifold. The scheme searches in a large discrete space of obstacle candidates and seeks, using an optimization algorithm, the obstacle that would give a solution with "observed information" as close as possible to the given data M. Finding the optimal obstacle involves solving a forward acoustics problem for each candidate obstacle, using FEM. To generate a reference solution, we first choose an obstacle; then we solve the corresponding forward problem, with a finite element mesh of the same density as used in the optimization process; then from the solution we generate the appropriate "observed information" M, which then serves as input for the computational scheme.

Indeed, although inverse problems are notoriously difficult to solve, generating a reference solution for an inverse problem becomes quite easy if one follows the procedure described above. The data needed as input for the inverse problem is extracted from the solution of a corresponding forward problem; hence all we have to do in order to generate an exact solution is to solve the forward problem for the obstacle of our choice.

However, there is one detail in the procedure outlined above which is not totally legitimate. The finite element mesh used for generating the reference solution must not be identical to the mesh used in the optimization process itself. Typically the reference mesh should be significantly finer. If one uses the same mesh for both purposes, according to [8] one commits an *inverse crime*. In this case the solution of the inverse problem can be represented *exactly* by one of the candidate forward solutions; the inverse problem then becomes artificially too easy, and cannot serve as a good test for the computational scheme. The situation is somewhat similar to the one in which we try to solve a static problem using the Galerkin method, where the exact solution happens to coincide with one of the global shape functions. See additional explanations on this issue in [8].

Figs. 5 and 6 show results generated by the method developed by Rabinovich and Givoli [9] to solve inverse problems of crack identification. The method is based on XFEM for the solution of the forward problems and on a genetic algorithm for the optimization involved in solving the inverse problem. The spatial domain is circular. *Fig. 5* (case A) corresponds to the case where the mesh used for generating the reference solution and the mesh used for identification are identical, whereas in *Fig. 6* (case B) the former is much finer. In each of the two figures, plot (a) shows the L_2 error norm on the boundary corresponding to the best candidates during the optimization process. Plot (b) shows the best cracks found, where the corresponding generation number is indicated near each crack. The target crack is plotted with a thick line.

As seen in *Fig. 5*, the optimization process for case A was very successful in identifying the crack, with the best candidates converging very quickly to cracks very near the target crack with errors less than 0.1%. However, these excellent results are far from sufficient to verify the scheme since an "inverse crime" is involved here. In case B the target crack itself generates a solution with an error of 36.7%; a discrepancy exists between the values produced by the same crack in the two different discretizations. Still, as Fig. 6 shows, the identification process succeeds in finding candidate cracks with an error level of about 15%. All the best cracks found starting from the 10th generation are in close vicinity to the target crack. The results for case B reflect the real performance of the computational scheme much better than those of case A. Nevertheless, in the first stage of the debugging process it makes sense to commit an “inverse crime” and use case A as a basic test for the correctness of the code.

Case Study 8: Spurious Modes

We developed a method for high-frequency elastic waves in bounded domains. We wish to test it on a circular domain with boundary B. As a reference solution, we use an analytical solution U obtained by solving the same governing equations in an unbounded domain. To complete the statement of the problem in the circle, we use a Dirichlet boundary condition on B, where the Dirichlet data are obtained from U.

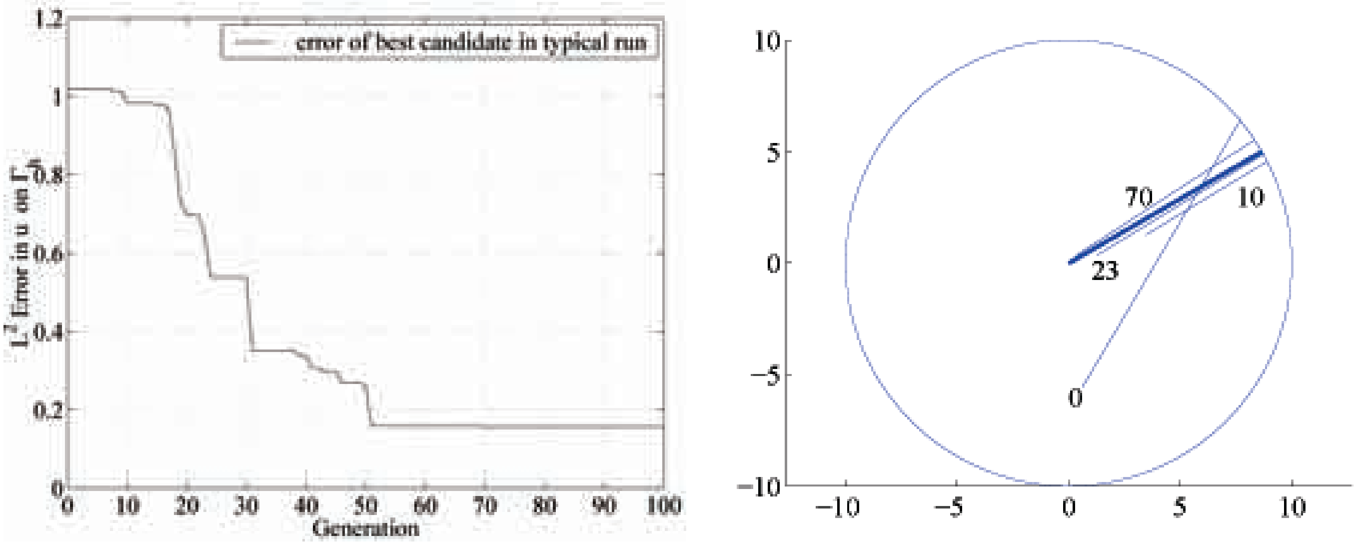
This procedure may work, but it would probably give rise to spurious oscillations in the numerical solution. The reason is that whereas the unbounded domain problem does not admit eigenfunctions (namely there are no nontrivial solutions to the homogeneous problem), the bounded domain problem does. These “modes” are supposed to be “silent” for the Dirichlet boundary condition corresponding to the unbounded domain solution U, but even the slightest interpolation error or round-off error might activate them. The same would happen with Neumann boundary condition on B. On the other hand, a mixed (Robin) type of boundary condition on B does not give rise to such parasitic modes. Hence it is much safer to use a mixed condition instead of a Dirichlet condition on B. A similar practice has been adopted by Strouboulis *et al.* [10], for example.

In conclusion, we have shown that there are various ways to generate reference solutions for testing computational schemes. We have also shown that one must be very careful in designing such reference solutions, in order to ensure that they constitute sound and reliable means of testing the scheme under consideration.

Acknowledgement

The author would like to thank S. Abarbanel and A. Mar-Or for their useful input, and I. Harari for reading the article and making very helpful comments. ●

Figure 6:
Results of a crack-detection scheme, based on solving an inverse problem; Case B: Mesh used for the reference problem is much finer than that used for the optimization.



(a) *L_2 error reduction during evolution;* ***(b)*** *best candidate cracks obtained in various generations.*

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A look back at the Extended Finite Element Method and a peek ahead ...

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After several decades of existence, it is clear that the finite element method has established itself as a cornerstone for simulation in mechanics, engineering, and science in general.

What is the recipe for such a success? I would cite among others the generality, versatility and relative simplicity of the method. It is quite impressive for instance what a three-node triangle can do for you. The mathematical foundations for the method are strong as well as its 'engineering' perception : structures are decomposed into elements tied together by nodal forces which must equilibrate themselves.

In its philosophy from the beginning the finite element relies on a strong partner: meshing technology. The mesh not only describes the boundary of the domain to be computed but also represents inner surfaces of discontinuity like voids, cracks, material interfaces, solidification front, ...

The 'meshing partner' concentrates on the discontinuity while the finite element method provides a continuous approximation over each element.

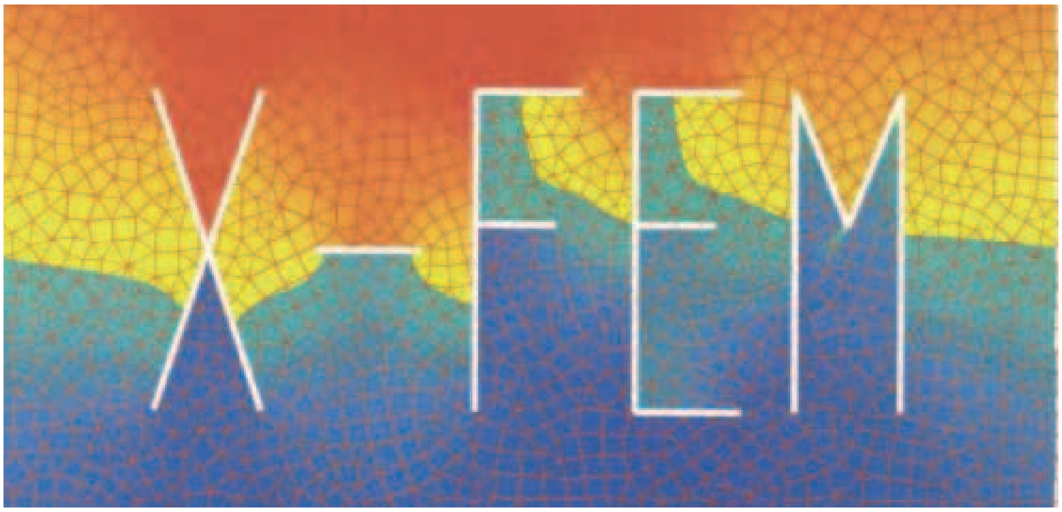
Theoretically, any domain geometry may be computed using the finite element method. This capability is often put upfront as a clear advantage over finite differences which is quickly intractable with complex geometries.

It is interesting to note that over the years, what was seen initially as a strength (theoretical capability to handle any geometry) became a source of difficulty.

With the increasing power of computers over the years, the gap between the effective computational time and the time needed to create and check meshes (human assistance needed) has dramatically increased. The meshing issue may even be so daunting that finite element simulation is abandoned as a possible design tool. For instance, as far as we know, the full simulation (we mean with true geometries) of 3D crack growth to assess structural safety under fatigue loading is not yet performed routinely in industry.

Of course, research was quite active in searching for a cure to resolve these meshing difficulties. Initially, the two major trends were on one hand the use of embedded discontinuities [1] to incorporate cracks inside the elements and on the other hand meshless methods. Meshless methods take the drastic step to remove the mesh and to replace it by a set of approximation points. Each point has a domain of influence over which continuous or discontinuous (thus allowing for crack representation) functions may be specified. The use of the meshless method for fracture mechanics was for instance developed in [2].

Figure 1:
Branched and intersecting cracks loaded at the top and bottom, colors indicate the displacement norm.



These two trends to tackle to meshing issues inherent to the classical finite element method did bring some relief but unfortunately did bring new issues as well.

The simplicity of integration and support intersection of the finite element method is lost when moving to meshless. Also, since the coding standards of meshless method differ quite a bit from finite elements, the perennial status of industrial codes is at stake.

Regarding the use of embedded discontinuities, the formulation must enforce in some way the continuity of the approximation on each side of the physical discontinuity. This is usually done using an assumed strain type approach. The stability of the existing options were studied for instance in [3].

Another trend to relief meshes started later and grew under the name of the eXtended Finite Element Method (X-FEM). The philosophy of the X-FEM is to preserve to the framework of the finite element method (thus relieving the limitations in meshless methods) and to introduce discontinuities only where they are physical (assumed strain type approaches are no longer needed). The introduction of the discontinuity is carried out using the partition of unity technique [4]. Although, the X-FEM name was coined slightly later, the first papers which may be attributed to its spirit are [5] and [6]. With these two papers, it was possible to model and grow a 2D crack without remeshing. An enrichment is used to model the crack tip (branch type discontinuity) while another enrichment (Heaviside) is used for the rest of the crack. An important fact is that the Heaviside enrichment naturally leads to classical double nodes when the crack is aligned with the mesh.

Efforts were then pushed in the direction of the stress analysis of cracked plates [7] as well as 3D cracks [8]. The success in modeling crack type discontinuities did encourage us to consider more complex discontinuities as branched cracks, intersecting cracks *(figure 1)*, voids [9] and material interfaces [10], [11] (*figure 2 and figure 3*).

The latter paper as well as [12] was the opportunity to rethink the surface representation. Initially, surfaces of discontinuity were located in a CAD fashion (a crack was given in 2D by a set of segments, a circular void was given by a center and a radius, ...). This 'Lagrangian' representation is cumbersome to handle if the surfaces evolves and is inappropriate if changes of topology in the surface occur (as it is the case for the lens-shaped crack depicted in *figure 4* for which the front breaks up into four fronts, *figure 5*). On the contrary implicit level set type representation of surfaces handles naturally changes of topology. Also, surfaces are stored as regular finite element fields (signed distance functions) and robust algorithms do exist to handle the growth under a given speed [13], [14]. The level set representation is particularly handy to model and grow 3D cracks [15], [16], [17].

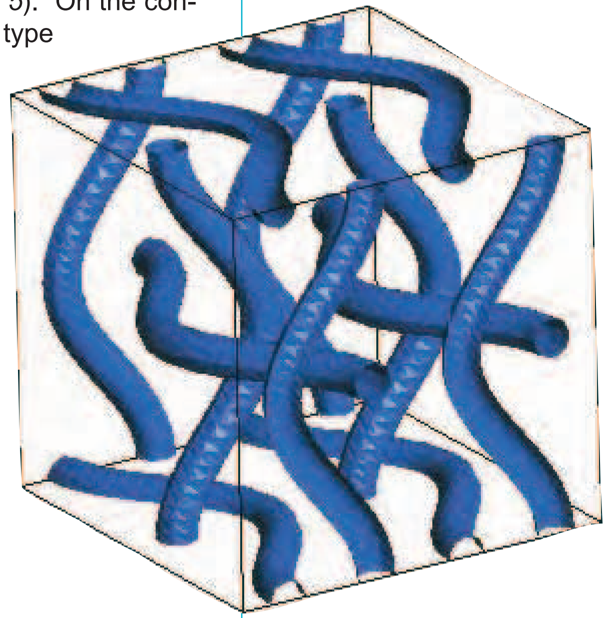


Figure 2:
An idealized woven micro-structure.

It is important to note that another prolific use of the partition of the unity was developed by another 'school' (as in painting) under the name of Generalized Finite Element Method (GFEM).
This school adds to the partition of unity use complementary ingredients as (to name a few):
- the develoment of special integration schemes (adaptive quadrature)[18],[19],
- the representation of complex discon tinuity patterns as grain boundaries [20],
- the use of hand books functions [21], [22],
- the development of a posteriori error estimator [23].

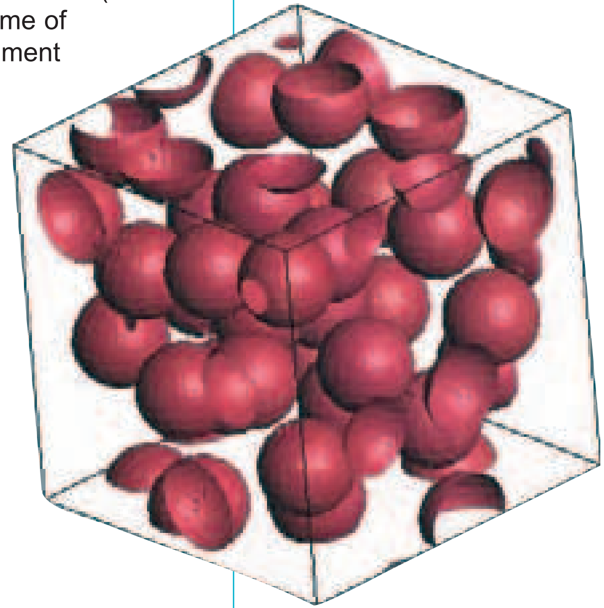


Figure 3:
A micro-structure built from random spherical inclusions.

Recent and Current developments on the X-FEM

The possibility to disconnect the mesh from the surfaces of discontinuity while keeping a clear location of these surfaces became quickly appealing as an alternative (or unique) way to handle complex geometrical situations :

> "… what was seen initially as a strength … became a source of difficulty."

- Shape and topology optimization [24]
- Inverse problems [25]
- Random shapes [26]

The performance of the enrichment regarding the convergence rates and LBB stability was also a subject of active research recently

- Two-fields variational formulations and mixed problems [27], [28]
- Optimal convergence rates, conditioning and integration issues as well as higher order implementation [29], [30].

Finally, dynamic fracture mechanics was also an intense area of research both for implicit and explicit methods [31], [32]. The papers above only represent a small fraction of the developments on the extended finite element method (the number of paper on the topic is steadily rising).

What' next ?

In order to match more and more complex geometries, the meshing tools have been creating more and more complex data structures with the following drawbacks : matrix assembly and visualization are heavy since basically they are no two same elements. The capability to handle simple meshes (uniform or octree type) while keeping a precise geometrical representation of the surfaces is very appealing (and already noticed in [33]) since:

- many elements having the same geometry, several tasks may be optimized as assembly and visualization
- octree type meshes enable the use of efficient multi-grid type solvers adaptivity is 'trivial'.

The use of simple meshes in the finite element context will I think foster a new round of exchange with methods such as finite differences and finite volumes which naturally play with simple grid (although not solely). Solid mechanics may thus benefit a lot from the fluid mechanics community implementation wise.

The reader will have noticed that the use of simple meshes and level set representations of the surfaces is orthogonal to the use of CAD surface representation. We believe that the use of simple meshes will first develop very quickly in niche applications where the CAD is not yet installed or cumbersome to use.

A clear example is the interplay with imaging. An image is a 'simple mesh' storing discontinuous data (gray level) at the element (pixel) level. These gray level may represent different phases in a media. The use of level sets for image segmentation is quite popular now in medical imaging and implemented for instance in the open source library [35]. One may thus obtain a level set representation of the interfaces and then run directly an X-FEM computation on the image grid (or a coarser grid). The *figure 6* taken from [34] illustrates these two steps in an first attempt to homogenize automatically (without the recourse to CAD and meshers) materials whose phase distributions are given by pictures. ●

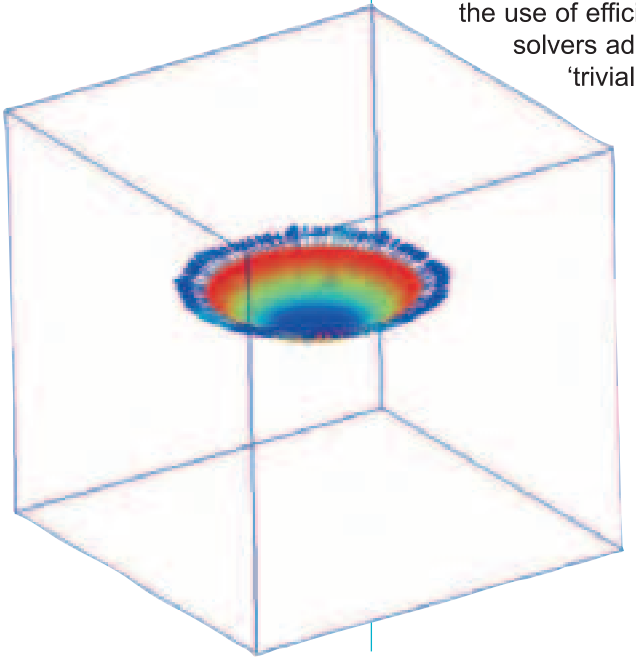


Figure 4:
A lens-shaped crack.

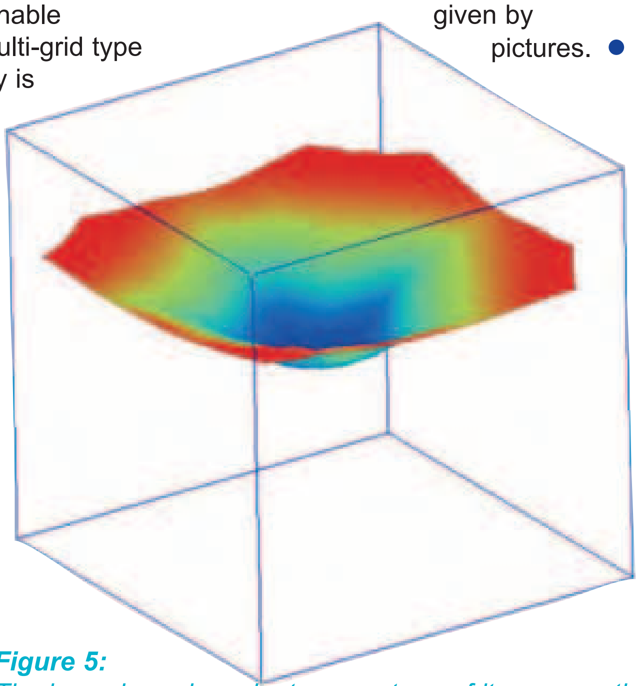


Figure 5:
The lens-shaped crack at some stage of its propagation under cyclic fatigue loading, note the change in the front topology (one curve did become four disconnected curves).

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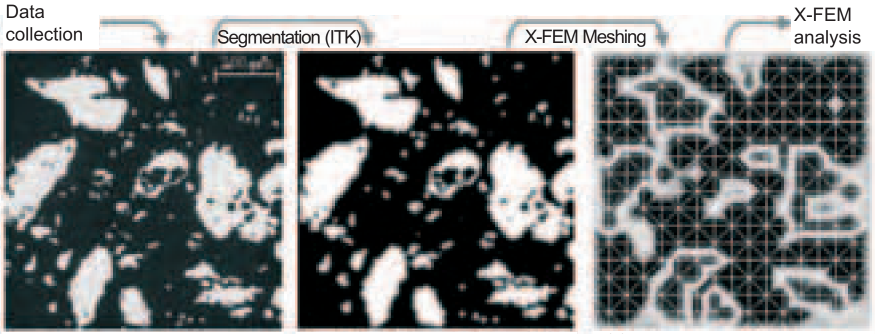

(a) Digital Image (b) Level set pixel based representation (c) X-FEM mesh with level set data embedded (detail)

Figure 6:
A digital image (a) is transformed by itk into a level set representation (b) of the interfaces. This representation is then used as is by the X-FEM computation (c) on the same grid as the one of the image (or a coarser one as it is the case in c).

The Finite Element Method for Elliptic PDEs and its Generalizations

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Introduction:

The Finite Element Method (FEM) is considered as one of the top ten numerical methods developed in twentieth century [1] and is widely used to solve various problems in engineering. In the last decade, several generalizations of the FEM have been proposed and developed to solve complex problems, which were not satisfactorily resolved by the classical FEM. We will discuss some of these generalizations in this article.

We start with a brief history of FEM, which will help (at least from the authors' perspective) to appreciate ideas behind the FEM and its generalizations. In 1696, G. W. Leibniz solved the Brachistochrone problem, in a letter to Johann Bernoulli [2], by considering the solution as a piecewise linear function and using a variational principle [3]. In 1851, K. Schellbach analyzed the Plateau problem, among others, where he represented the solution (which is a surface) by a piecewise linear function, defined on a triangular mesh [4]. It is interesting that Schellbach referred to these triangles as *elements*. It is important to note that both Leibniz and Schellbach used these techniques (and considered infinitesimally small elements) to derive the Euler equation (the governing differential equations) of their respective problems; approximating the solutions of these Euler equations was not their goal. However, the idea of using piecewise 'simpler functions' were employed in both these cases.

W. Ritz, who worked at the University of Gottingen, proposed a new numerical method in 1909 to approximate the solution of a minimization problem, and he proved the convergence of the numerical solution in the context of biharmonic and Poisson equations [5]. In contrast to FEM, this numerical method did not use piecewise polynomials and was based on global polynomials. But the idea of Ritz's proof of convergence also applies to the situation, where global polynomials are replaced by piecewise polynomials. Ritz used several ideas and results of Hilbert, who was a chaired professor of Mathematics at the University of Gottingen. It is interesting to note that Ritz did not refer to Schellbach's paper, which appeared in the same journal where Ritz published his results. Ritz was also criticized by J. W. S. Rayleigh [6] for referring to the method as a "new method", as Rayleigh had used this method in his earlier work. But it is only fair to state that Ritz wrote his 1909 paper in hurry, while he was on his death bed.

In 1915, B. G. Galerkin proposed a variant of a variational method [7], which was not related to a minimization problem and could be used for any differential equation (in contrast to Ritz's work). In 1913, I. G. Bubnov also suggested a similar (but narrower in scope) approach, and today the Galerkin's method with the same test and trial functions is known as the Bubnov-Galerkin method [8]. The same method, but with different trial and test functions, is referred to as the Petrov-Galerkin method. We note that neither Galerkin, nor Bubnov, used piecewise polynomials in their approximation.

In 1943, R. Courant proposed the use a piecewise linear function on a triangular mesh to approximate the solution of a variational problem [9]. This paper is associated with the celebrated Courant element. However, in a book, jointly written with Hurwitz in 1922 on function theory [10], he suggested, in a long footnote, the use of a sequence of piecewise linear functions on a triangular mesh to address a minimization problem. Courant never cited Schellbach in either of these works.

Prior to 1940s, the Force Method and the Displacement Method were widely used in engineering to analyze the problems of structural mechanics. These methods depended on the equilibrium principle, and not on a unified approach, like the variational principle. In late 40s and early 50s, analog computers were introduced and the members of the engineering community started to use these machines to address the structural engineering problems, especially in aero-engineering. In early 50s, there was a great push in Boeing to analyze aircraft structures, which produced only limited success. Later, a new approach was suggested by M. J. Turner (head of the Structural Dynamics Unit at Boeing), which proved to be quite successful. This new approach was published in 1956 [11], and today this paper is considered as the starting point of modern FEM. In this paper, the ideas of local approximation of the PDE as well as the assembly processes were seriously addressed. We note that the local approximation in this paper was not obtained from any variational principle. Later, Melosh in his thesis (1961-62) showed that Turner's FEM was related to a variational method [12]. He also highlighted the importance of a mathematical proof of the convergence of the approximate solution obtained from the FEM.

Though the work on the FEM in the engineering community continued and successfully addressed many important issues related to the implementation, we will end this historical tour by citing the efforts that addressed the convergence of the finite element solution. In 1962, K. O. Friedrichs [13] used piecewise linear functions on a triangular mesh and the Dirichlet variational principle to derive the system of linear equations to approximate the solutions of Dirichlet and Neumann problems on general domains. He used functional analytic methods to address the convergence of the method. It is interesting that he did not cite Courant's work; however, he mentioned Courant in a later paper. In 1963, Oganesian proved the order of convergence, *i.e.*, $O(h)$, for the piecewise linear approximation [14], which is now a well known fact. He also failed to cite Courant's work. We finally mention that in 1965, Feng Kang proposed the FEM for approximating solutions of scalar second order problems as well as of the elasticity problem [15]. He suggested several finite elements including the quadrilateral element with respect to irregular nodes. However, he did not refer to Courant, Friedrichs, Oganesian, or any engineer. We finally mention that O.C. Zienkiewicz's book [16] and his work in the area played an important role in the engineering development of FEM. For detailed historical development of FEM, we refer to [17], [18], [19], and [20].

Finite Element Method:

The FEM, as we know it today, is a finished product of efforts of mathematicians and engineers, over a span of about 150 years, some of which has been described above in the brief history. We describe the main features of FEM when applied to certain minimization problems:

(a) The FEM approximates the solution of a PDE, which is given as a variational problem: *Find* $u \in H_1$ *such that* $B(u,v) = f(v)$, *for all* $v \in H_2$, where H_1 and H_2 are Hilbert spaces, $B(u,v)$ is a bilinear form on $H_1 \times H_2$ and $f(v)$ is a linear functional on H_2. For PDEs related to the minimization of energy, $H_1 = H_2 = H$ is called the *Energy Space* and is equipped with the energy norm $\|u\| = B(u,v)^{1/2}$.

(b) Let S_h be a finite dimensional subspace of H. A Bubnov-Galerkin (B-G) method to approximate the solution u is: *Find* $u_h \in S_h$ *such that* $B(u_h, v) = f(v)$, *for all* $v \in S_h$. However, there are situations where $H_1 \mu H_2$ in the variational problem. In such cases, finite dimensional subspaces $S_{1,h}$ and $S_{2,h}$ of H_1 and H_2 respectively, are considered and the associated method : *Find* $u_h \in S_{1,h}$ *such that* $B(u_h, v) = f(v)$, *for all* $v \in S_{2,h}$, is referred to as the Petrov-Galerkin Method.

(c) Suppose the underlying domain of the PDE is decomposed, following certain rules, into non-intersecting smaller domains. These domains are called *finite elements* and the set of these elements is known as a *mesh*. The classical FEM is just a B-G method, where the functions in S_h are of special form; they are continuous functions and are polynomials on each of the finite elements. The basis elements of S_h are chosen to have compact supports. The parameter *h* is proportional to the diameter of the finite elements, and $S_h \ldots S_h^{FEM}$ is called the Finite Element (FE) subspace.

The accuracy of the finite element solution u_h is addressed by the a-priori error estimate $\|u - u_h\| \leq C \|u - \phi\|$, where ϕ is the finite element interpolant of u, the constant C is independent of u, but depends on the bilinear form *B(. , .),* when defined on $S_h \times S_h$. Thus the accuracy of the FEM solution depends on the interpolation error $\|u - \phi\|$ provided the constant C is independent of S_h and is of 'reasonable' size. The magnitude of $\|u - \phi\|$ depends on the smoothness of u, *e.g.*, we get $\|u - u_h\| \leq C \|u - \phi\| \approx O(h)$, the well known error estimate, when the double derivatives of u are square integrable.

It is clear from the error estimate that the error can be controlled by changing the parameter h. The FEM, where h is controlled to achieve a desired error is called the h-version of FEM. The error can be also controlled by keeping h fixed but changing the degree of the polynomial p, or by changing both h and p; the corresponding FEMs are known as the p-version and the h-p version of the FEM, respectively. We note that there are several important features of FEM that we did not discuss in this article, e.g, mesh generation, the assembly process, the numerical integration, the error estimation and adaptivity.

Generalization of FEM - The Meshless Method: The construction of the basis functions of S_h^{FEM}, which are piecewise polynomials with compact support, depends heavily on the mesh. However, there are problems of engineering interest, where the meshing of the domain is extremely time consuming. In late 80s, an effort started in the engineering community to construct functions $\phi_i(x)$ with compact support that did not require a mesh and had finite energy; they spanned the subspace S_h, with good approximation property, to be used in a B-G method. Today, several classes of such functions (we will refer to them as shape functions), together with the associated subspaces $S_h \equiv S_h^{MM}$, are available, and the resulting B-G methods are called the Meshless Methods (MM). For a detailed review, we refer to [21, 22].

The shape functions $\phi_i(x)$, used in MM, are constructed using a property of the S_h^{FEM}. Instead of a mesh, we start with a set of *N* points x_i in the domain, called the *particles*. Corresponding to each particle x_i, we construct a shape function $\phi_i(x)$ of compact support, such that $I^p(x) \equiv \sum_i p(x_i)\phi_i(x) = p(x)$, for all polynomials p of a fixed degree k, *i.e.*, the shape functions *reproduce polynomials of degree* k. This property ensures that the functions in the subspace S_h^{MM} accurately approximate smooth functions; for the related analysis, we refer to [22, 23].

The idea of polynomial reproducing shape functions was first addressed in an abstract setting in early 70s in [24, 25, 26] for uniformly distributed particles, and finite element basis functions were obtained as an example from this abstract framework. The problem for non-uniformly distributed particles was discussed under the topic of scattered data interpolation in many papers; we refer to the survey paper [27]. A method of constructing shape functions, which reproduced constants, was proposed by Shepard [28]. This method was generalized in several ways, see *e.g.*, [29, 30]. Today, MMs in various versions are used in practice, and have been addressed in various papers and books [31, 32, 33].

MM shares many properties of FEM and can be viewed as a generalization of the FEM. We note that the basis functions of S_h^{FEM} also reproduce polynomials. For example, the basis functions $\varphi_i(x)$ of the piecewise linear FE subspace, commonly known as the *Hat functions*, are associated with nodes x_i of a FE mesh, and they reproduce linear polynomials. Some other aspects of FEM, *e.g.*, superconvergence is also present in MM. Moreover, aposteriori error estimation approaches of FEM also work in MM.

But there are clear differences between these methods. The consequence of not using a mesh yields shape functions that are not piecewise polynomials. This gives rise to serious difficulty in computing the elements of the stiffness matrix and the load vector in MM, using quadrature. Unlike the FEM, it is necessary to increase the number of quadrature points as the size of the support of the shape functions, used in MM, decrease. Also a straight forward use of quadrature could lead to disastrous results; this phenomenon has been presented and a simple fix has been proposed in [34]. Moreover the *interpolant* $I^u(x)$, constructed from the values of $u(x_i)$, does not have the Kronecker delta (K-D) property, *i.e.*,$I^u(x_j) \mu\, u(x_j)$. We note that the FE interpolant has the Kronecker delta property. The lack of K-D property makes it difficult to implement the essential boundary conditions of the PDE in MM. Several approaches have been proposed [32] to overcome this problem. It is important to note that MM has the most potential in fluid flow problems, where re-meshing at each time step can be avoided by using the MM.

Generalization of FEM – The Generalized Finite Element Method:

The subspaces S_h^{FEM} and S_h^{MM} are based on polynomials, and thus the accuracy of the FEM and the MM depends on the approximation property of the underlying polynomials. It is well known that polynomials can accurately approximate smooth functions, but they do not perform well in approximating non-smooth functions. Loss of accuracy of FEM, in approximating non-smooth solutions, was shown in [35]. We mention that there are important classes of problems with non-smooth solutions that occur in practice, *e.g.*, problems modeling microstructure, Helmholz problems with high wave number, and crack propagation problems.

The GFEM is a B-G method, where the approximation property of S_h is not dictated by polynomials. This method was first reported as a Special FEM in [36] and was then developed and expanded into the Partition of Unity Method in [37, 38]. Later, it was referred to as GFEM in [39] and XFEM in [40]. The main idea of the GFEM is to use functions in $S_h = S_h^{GFEM}$ that globally have finite energy, and which are locally similar to the unknown solution. Often, certain a-priori knowledge of the unknown solution is available, *e.g.*, the asymptotic form of the solution in a neighborhood of a crack-tip; the GFEM can incorporate this information, locally into the functions in S_h^{GFEM}. The functions in S_h^{GFEM} are of the form $\sum_i \varphi_i\ \psi_i$. where $\{\varphi_i\}$ a is a partition of unity (PU) with φ_i having compact support, and the functions ψ_i accurately approximate the non-smooth solution, locally in the support of φ_i. The functions ψ_i can be constructed directly by using the available information, or they can be computed locally. The PU ensures the global finite energy of these functions. The GFEM has been used on a variety of problems, *e.g.*, on a problem modeling microstructure in [39] and on Helmholz problems with high wave number [41]. The related XFEM has been very successful in problems with cracks [40].

The GFEM also shares many properties with the FEM. The classical h- and p-versions of the FEM are special cases of the GFEM. Superconvergence is also present in the GFEM.

We also note that any basis of S_h^{MM} can be used as the PU in S_h^{GFEM}. But the GFEM is very different from the FEM, with respect to the numerical quadrature.

Concluding Remarks:

We did not discuss other generalizations of the FEM, *e.g.*, the Discontinuous Galerkin Method; we refer the reader to [41]. In contrast to the long history of the FEM, the effort to generalize the FEM is quite recent. Though many numerical studies are available on these generalizations, their theoretical foundation is not well developed. It is extremely important to identify areas, where these generalizations are more efficient than the FEM.

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Serbian Society for Computational Mechanics

- A Brief Overview -

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In this brief overview of the Serbian Society for Computational Mechanics (SSCM) we present the main scientific and professional activities in Serbia, with several representative illustrations and references.

The SSCM was founded on 28 June 2006, during The First South-East European Conference on Computational Mechanics held in Kragujevac, Serbia, from 28 June to 30 June 2006. The founding document was signed by a large majority of the Conference participants, among which Professors Mang, Oñaté and Papadrakakis, who enthusiastically supported the foundation of the SSCM. Recently, the SSCM has been registered with the Serbian government. The SSCM is a member of:

- IACM (International Association for Computational Mechanics),
- ECCOMAS (European Community on Computational Methods in Applied Sciences).
- Serbian Society for Mechanics.

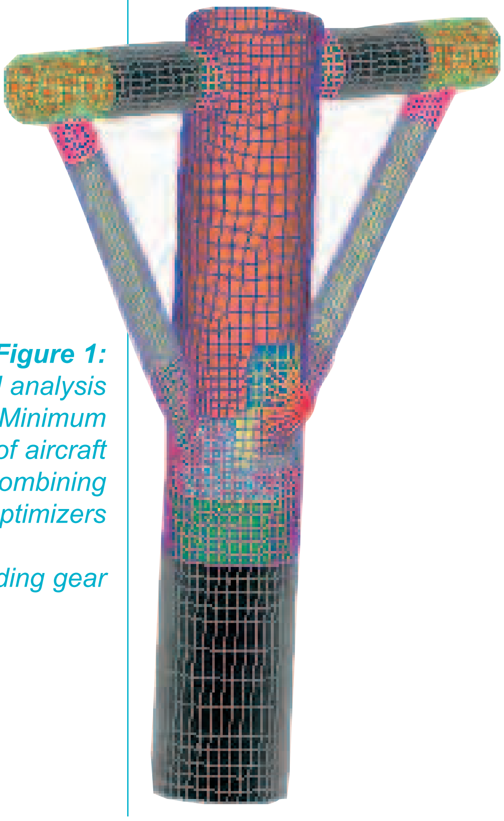


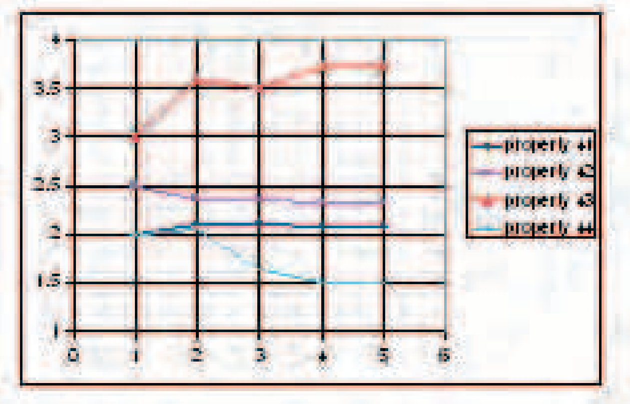
Figure 1:
A typical structural analysis at VTI Belgrade: Minimum weight design of aircraft nose landing gear combining FEM and dual optimizers

a) Part of nose landing gear

The SCCM has founded the **Journal of Serbian Society for Computational Mechanics**, which will have an international editorial board. It will be printed in English, with abstracts in Serbian at the end of each issue. At least one issue per year is planned. The SCCM will organize The Serbian Conference on Computational Mechanics every three years.

Mechanics has a long tradition in Serbia, at universities, research institutions and industry. The main research is concentrated at four university centers: Belgrade, Novi Sad, Nis and Kragujevac. In modern times, following the advances in Computational Mechanics (CM) worldwide, a significant number of researchers, particularly young investigators, have been involved in this attractive field. Computational Mechanics became the subject of teaching and research at universities, especially at the graduate level. Many M.S. and Ph.D. theses have been presented in Computational Mechanics, in the domain of development of computational methods, as well as in various applications. Research groups have been established which participate in research supported by national (Ministry of Science and Environmental Protection of Serbia) and international grants, and industry.

b) Iteration histories of thickness as the design variable



We give a brief overview of activities of the research groups (or institutions) at the four cities mentioned above, in chronological order starting from the oldest university.

In Belgrade, we have the Computational Mechanics Group at the Faculty of Mechanics of University of Belgrade (see www.matf.bg.ac.yu/~dmijuca), which is devoted to the research and development of new multifield mixed multiscale finite element procedures in solid mechanics. The Group participates in the simulation of the energy efficiency of buildings under the guidance of the DIRECTIVE 2002/91/EC. The Group is also the coordinator of the University of Belgrade activities in the International Associations for Engineering Analysis Community NAFEMS (www.nafems.org). Several state-of-the-art software packages for simulation in structural engineering and energetic efficiency of buildings, are technically supported by the Group. The main publications of the Group [1]–[4] are listed below.

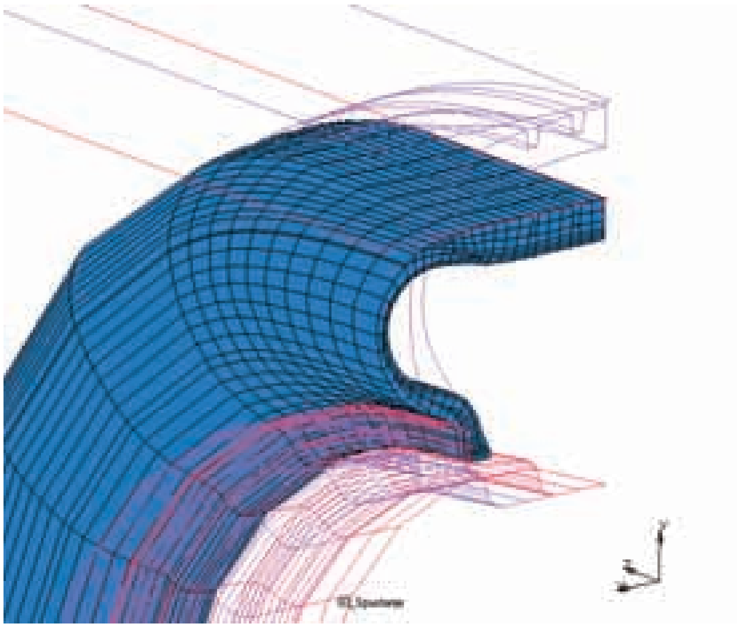


Figure 2:
Deformed configuration of a vehicle tire [11]

Besides this Group, there are individuals active in CM at technical departments (Civil, Mechanical and Electrical Engineering). In Belgrade we also have a research group in CM and its applications to aircrafts, at the VTI Aeronautical Institute, which has been active continuously over several decades. This group is involved in design of aircraft structures, analysis and optimization of large-scale structural systems including damage tolerance and fatigue life estimations. The research is based on the group's own computation methods and software. Currently, the investigation is focused on computational methods and software for crack growth using a new approach based on strain energy density. The main publications are listed as [2], [5]-[9]. A typical structural analysis example is shown in *Fig. 1.*

In Novi Sad, the research in CM is mainly performed at the Faculty of Civil Engineering and is oriented to numerical models and software for various structural behavior phenomena, with nonlinear and dynamic analysis, and soil-structure interaction problems. Some of the results in research and education in CM are summarized in ref. [10].

Figure 3:
Two characteristic shapes of the plate middle surface free vibrations, caused by the initial displacements in the form of the two first modes.
The upper plate middle surface (a) and the lower plate middle surface (b*) of the dynamic states of the sandwich double plate system (K. Stevanovic-Hedrih and her group)*

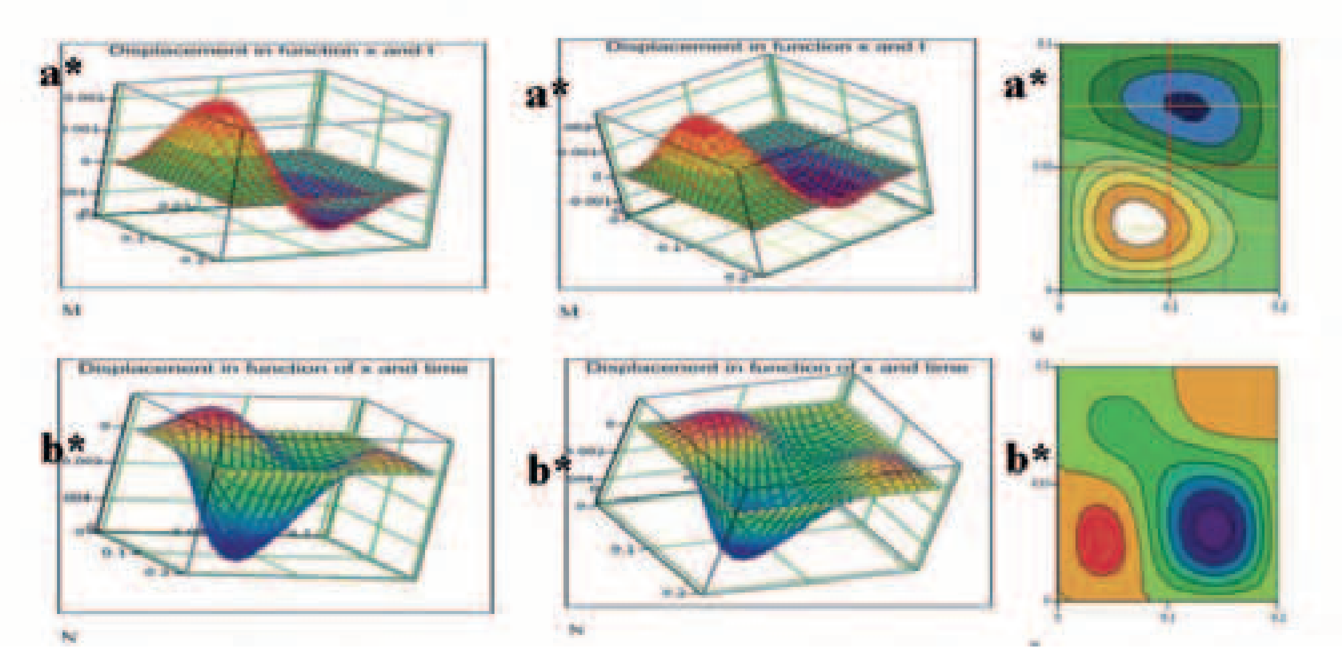
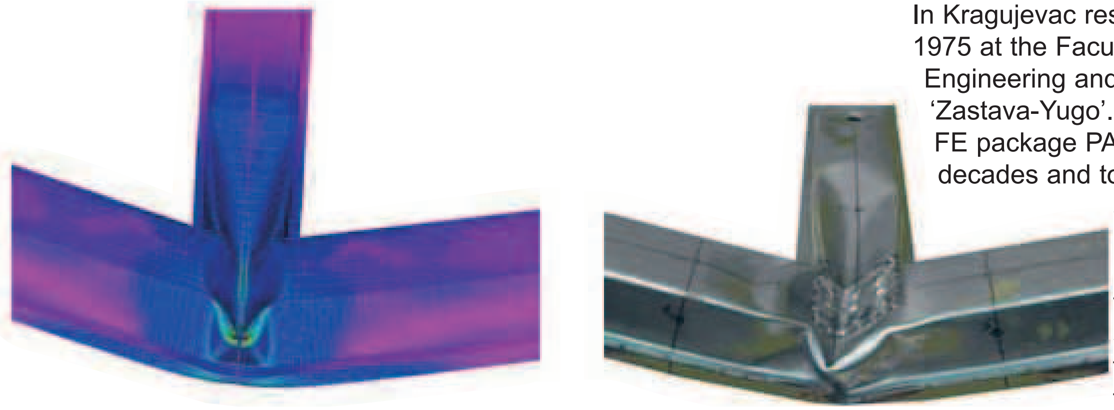


Figure 4:
Finite element solution (large strain elastic-plastic analysis) and experimentally determined deformation of a joint of car structure [Zivkovic and collaborators]



In Nis, we have two groups at the Mechanical Engineering Faculty of University of Nis. In the first group the research is directed to development of methods and software for analysis of tires under static and dynamic conditions, supported by experimental investigations. Some of the research results are noted in ref. [11]. Illustration of a FE solution is shown in *Fig. 2.* The domain of research within the second group is nonlinear dynamics, which includes: deterministic and stochastic dynamics and control of processes; theoretical and applied mechanics of rigid and solid bodies and complex hybrid structures and systems; creeping and stochastic vibrations of double plate system, parametrically excited beam, hereditary or creep material. The research results are summarized in refs. [12]-[19]. A sample solution obtained by this group is shown in *Fig. 3.*

In Kragujevac research in CM started in 1975 at the Faculty of Mechanical Engineering and at Automobile Institute 'Zastava-Yugo'. The general-purpose FE package PAK was developed over decades and today includes structural analysis, mass and heat transfer (fluid mechanics with heat transfer and diffusion), solid-fluid interaction, fracture mechanics, flow through porous media, and biomechanics (tissue, cartilage, muscle, air and blood flow, lung mechanics, biofluid-biosolid interaction). Around 40 M.S. and Ph.D. theses have been completed which include computational methods and software with applications. Based on this research, undergraduate and graduate courses have been established at the Mech. Eng. Faculty and at the Center for Multidisciplinary Studies. Current research involves development and applications of modern methods, such as discrete particle methods (DPD, EFG and SPH), multiscale methods, nanomechanics, methods in fracture mechanics and large strains. Also, image processing in connection with medical imaging and FE models, is being incorporated into the present PAK software package.

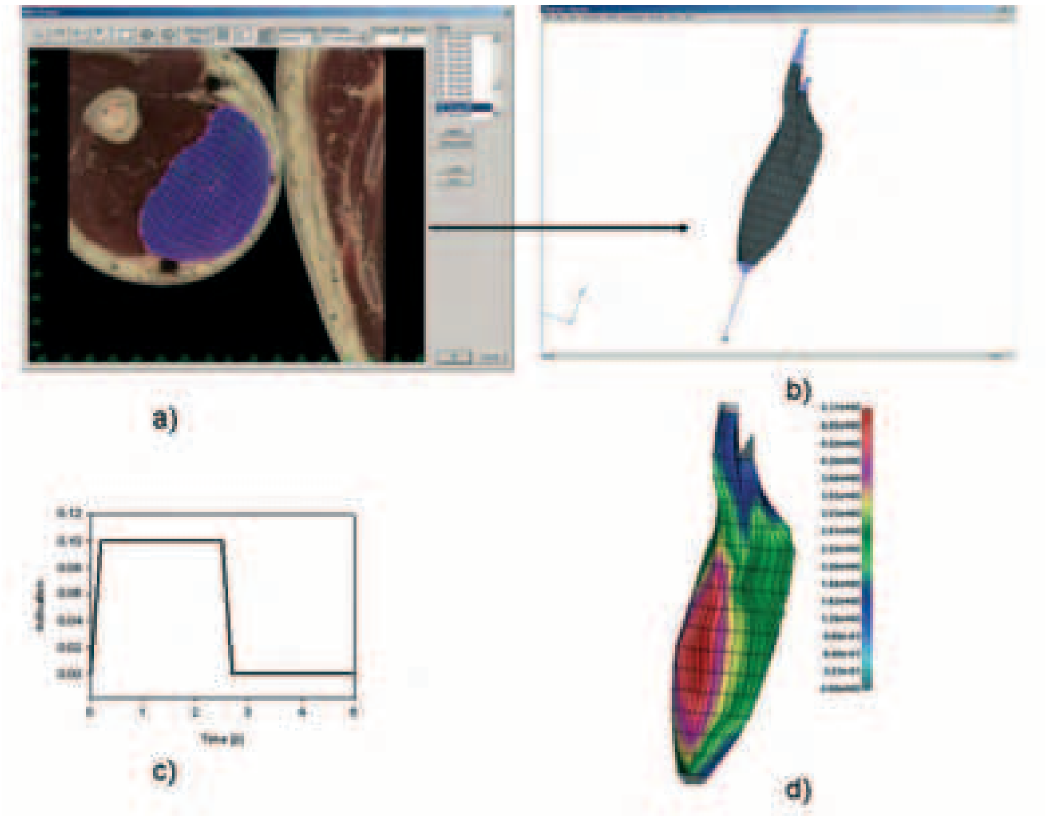
Figure 5:
Creation of 3D finite element model from muscle cross-sections data base such as Visible Human Project, and FE solution.

a) Imaging procedure and generation of 2D mesh over a cross-section;

b) 3D finite element model of the biceps brachii muscle automatically generated;

c) Activation function;

d) Displacement field under 10% internal activation (end of muscle is attached to elastic spring representing the muscle tendon).



The research is performed at the Mech. Eng. Faculty and at the Center for Scientific Research of Serbian Academy of Sciences and Arts and University of Kragujevac. Currently, over 20 young researchers and graduate students are involved in various projects. A number of international grants and collaborations are ongoing (e.g. with Harvard Univ., Univ. Texas at Houston, TU Braunschweig, Univ. Bologna, Univ. Hong Kong, CIMNE Barcelona), including several industrial grants (Institute for Water Resources ‘J. Cerni’ Belgrade, MV Engineering GmbH & Co.KG Germany, Linde Group Germany, Mannesmann Germany, ProMinent France, SIEMENS Transportation systems Graz).

The research results are partly summarized in refs. [20]-[39], and several representative solutions are shown in *Figs. 4-6.*

In summary, we can state that Computational Mechanics is well established in Serbia, and we expect that the newly founded Serbian Society for Computational Mechanics will foster this area of research and education. ●

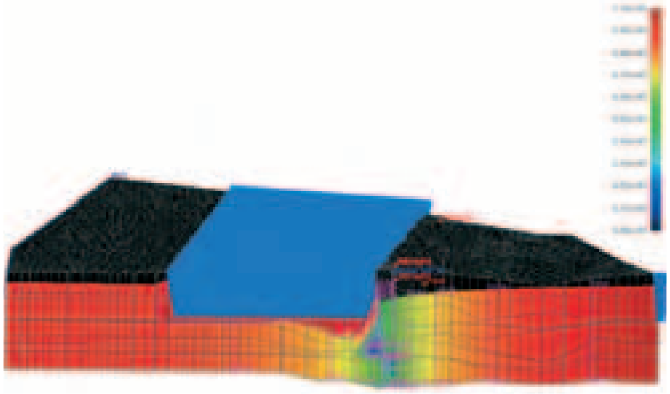


Figure 6:
Potential field for groundwater flow around Renny well, near the river Sava (Software and automatic procedures, with sub-domain concept, developed at Center for Scientific Research of Serbian Academy of Sciences and Arts and University of Kragujevac and Institut 'J. Cerni' Belgrade).

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Cultures Converse using the Numerical Methods Language

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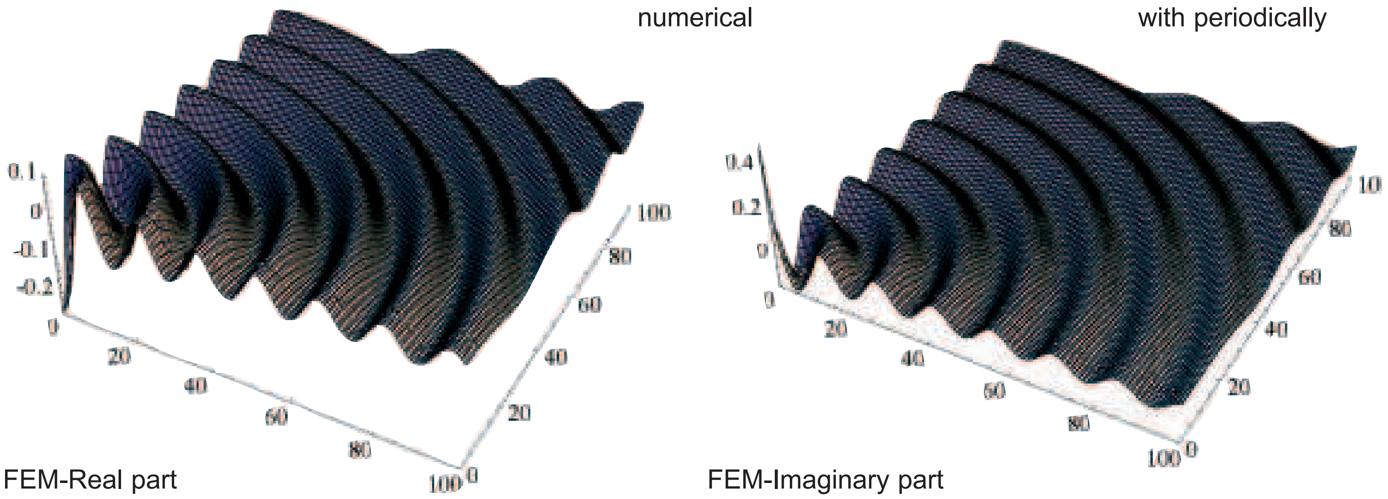
In 2000, The International Centre for Numerical Methods in Engineering at Barcelona, Spain(CIMNE www.cimne.com) decided to establish a collaborative relation with Civil Engineering Department in Isfahan University of Technology (IUT), Iran. With the background of numerical simulations formed in Swansea, naturally I was the one who was supposed to play a key role in such collaboration. The plan was to synchronize the research activities in IUT with those in abroad. Since then a number of best graduate and postgraduate students have gathered together as a research group to promote the relation. This has happened under the circumstance that industrial demands (and even the attitude of some academic fellows) with respect to numerical simulation have been just limited to the use of some commercial programs. What the group has done during the past six years is an indication of profound eager of young researchers for communicating with the rest of the world with the aid of numerical-method-language. Of course this would not be possible without such a relation with CIMNE.

This article is intended to introduce current research activities in this research group. Among several subjects that have so far been focused on, there are some that are believed to have impact on future studies. An example is a discrete transformation technique which seems to be suitable for many numerical problems. The history of the development is in close relation with our other research activities. The activities may be categorized into, error estimation and adaptivity, studies on behavior of a new discrete transformation in numerical solution of unbounded domains and semi-analytical solution of bounded ones, studies on solution techniques for material with incompressible behavior, studies on performances of meshless methods, topology optimization of structures, and some interdisciplinary issues. A summery of our new findings in each discipline is given as follows.

Error estimation

Due to its wide applications, the subject has the potential of rising new issues either in mathematics or engineering technology. Working on the area, we found an interesting transformation technique which seems to be applicable for many other areas of research.

With some experiences on recovery techniques, we were eager to know more about the performance of some of them in three dimensional problems (see [1-2]). The robustness test introduced by some pioneering scientists was employed. The task was to extend the formulation so that it would be suitable for the boundaries of the domain, like edges and corners, something that had not been done before. We came up with a new problem defined on an unbounded domain with periodically



FEM-Real part

FEM-Imaginary part

Figure 1: *Real and imaginary parts of the discrete Green's functions, in FEM sense, found for Helmholtz problem.*

decaying boundary conditions at the side faces. A characteristic like equation was found and thus an infinite number of discrete bases were available. The problem inverted to a discrete mathematical one. Now the new task was to satisfy limited number of boundary conditions with the projections of infinite number of discrete functions with unknown coefficients. To illustrate the problem, here, we bring simple relations. The main problem was finding c_i in a relation like

$$\mathbf{u}_B = \sum_{i=1}^{M} c_i \mathbf{v}_i$$

with M being a very large number compared to the dimension of vector $\mathbf{u}_B$(representing the available boundary conditions) and $\mathbf{v}_i$(representing the base vectors). To solve the problem we just assumed that the coefficients can be obtained by projection of $\mathbf{u}_B$ on $\mathbf{v}_i$ but of course with a suitable projection matrix as

$$c_i = \mathbf{v}_i^T \mathbf{P} \mathbf{u}_B$$

This assumption is consistent with conventional transformation techniques available. The projection matrix $\mathbf{P}$ was found by inserting the above relation in the first one and thus we obtained

$$\mathbf{P} = [\sum_{i=1}^{M} \mathbf{v}_i \mathbf{v}_i^T]^{-1}$$

The result was surprising and we were able to solve all problems we needed. The question regarding invertibility of the matrix has also been addressed in our works.

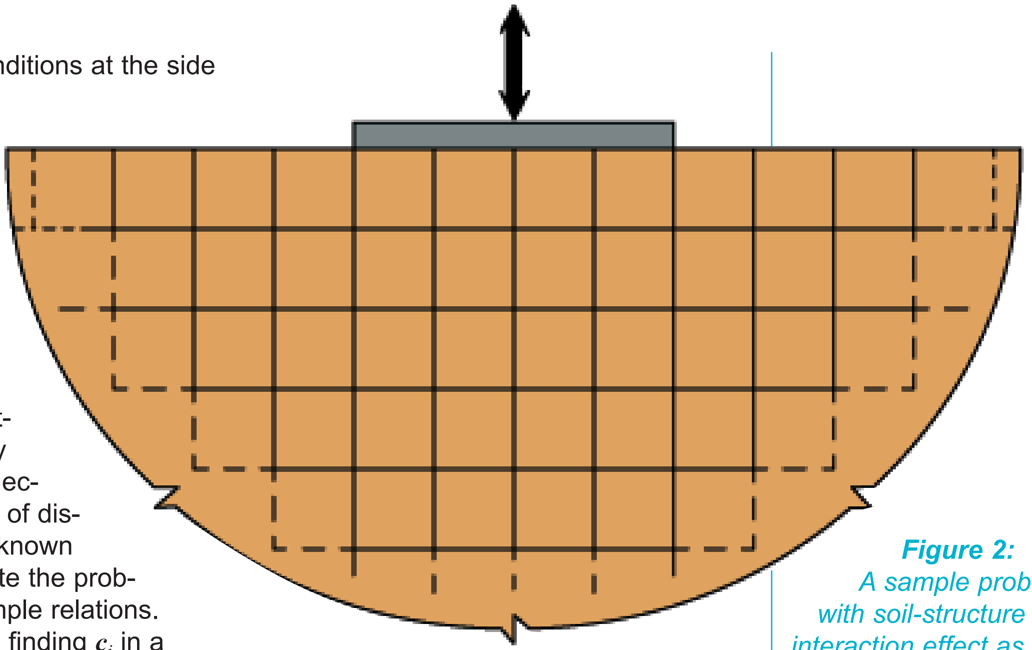


Figure 2:
A sample problem with soil-structure interaction effect as a case for application of the discrete Green's functions (the half plane is entirely covered by elements and no artificial boundary component is needed).

Since the problem had been defined on an unbounded domain (with a finite extent for satisfaction of the boundary conditions) with decaying conditions at infinity, one of the new questions was then about capability of the transformation technique in solution of general unbounded domains in physics.

Solution of discrete/continuum problems in physics

Upon observing excellent performance from the proposed transformation technique, we established a new research direction. Now we were eager to know if Green's functions (the singular ones defined on unbounded domains) could be evaluated in a discrete sense, e.g. in finite element sense. We set up a 2D problem defined on an unbounded domain, discretized with a periodic mesh pattern and excited with a harmonic point load at the origin, and then tried to solve it on a quadrant of the domain using symmetry axes (see [3]). The boundary conditions we were looking for appeared at the cut off lines

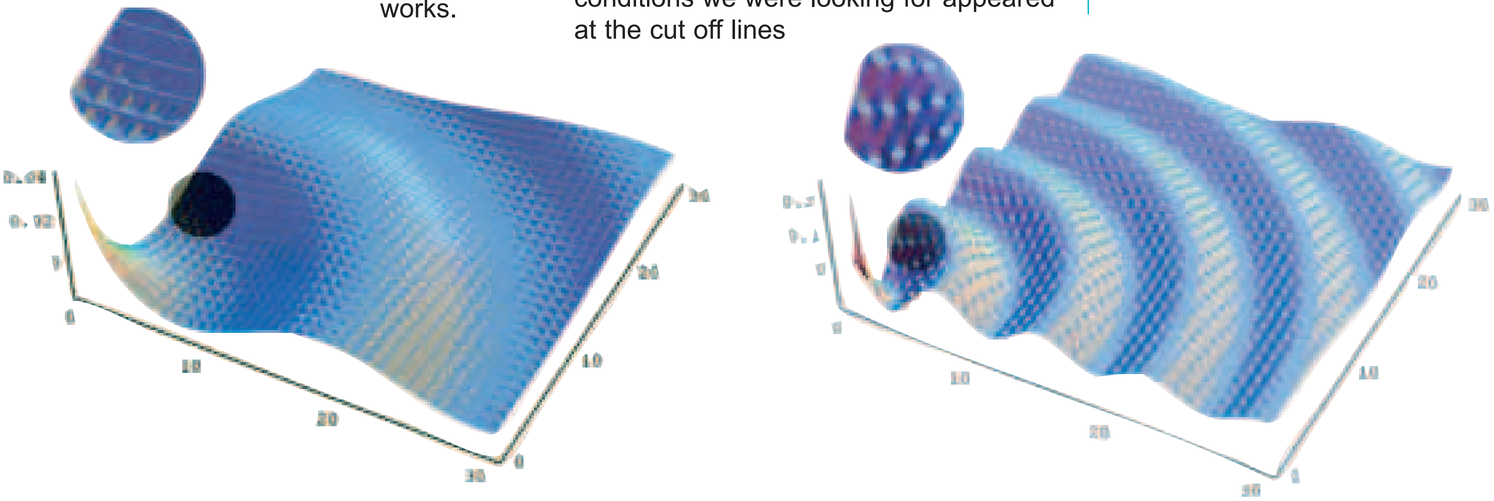
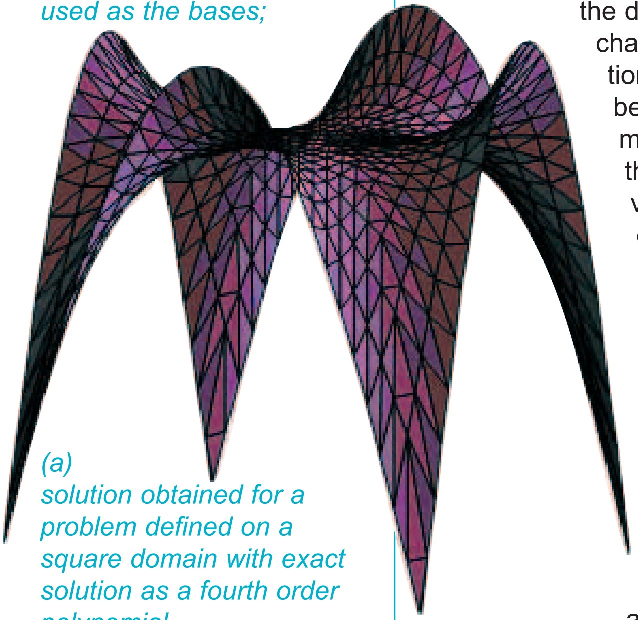


Figure 3:
Samples of discrete Green's functions found for domains with periodic material properties.

Figure 4: Numerical solution for Helmholtz equation with the aid of the new transformation technique proposed. Harmonic functions satisfying the equation were used as the bases;



(a) solution obtained for a problem defined on a square domain with exact solution as a fourth order polynomial. With 80 boundary nodes the accuracy achieved is 0.0013 % in relative energy norm;

(b) solution obtained for a problem defined on a circular domain with exact solution as a seventh order polynomial. With 80 boundary nodes the accuracy achieved is 0.003 % in relative energy norm.

along the axes of symmetry. Apart from the satisfaction of such boundary conditions, the new problem was the radiation condition which had to be considered. The radiation condition was satisfied within each cell of the mesh. This limited the number of base vectors found from the dispersion equation (the characteristic-like equation). However the number of bases was still much larger than that of the dimension of the vector of the boundary conditions. Once again the transformation technique was employed and the results were surprising.

We introduced discrete Green's functions for the solution of Helmholtz equation and elastic wave equations encountering in acoustics and geophysics *(see Fig.1)*. With such discrete Green's functions in hand, one may solve problems on unbounded domains assuming that the entire domain is discretized with elements. This capability helps those who wish to use absorbing boundary conditions for a finite region as part of an unbounded domain. The main advantage of the so defined discrete Green's functions is that they do not exhibit singularity effect. One of the applications is the modeling of soil-structure effects *(see Fig 2)*. It is obvious that as well as problems on unbounded domain, problems on bounded domains are also solvable with such discrete functions.

The research has also been extended to behavior study of domains with periodic material characteristics. We have shown that discrete Green's functions can also be found for such domains (see [4]). This has opened a new gateway towards behavior prediction of systems with multi-scale feature. Extensive studies are currently going on focusing on the subject *(see Fig 3)*.

Apart from being used in the evaluation of the discrete Green's function, the transformation may also be employed in semi-analytical solution of continuum problems. Having in hand some smooth functions as bases for a continuum, the boundary conditions can be satisfied through the transformation technique. We have also performed some studies in this regard and obtained excellent results *(see Fig. 4)*. The results are to be published.

Meshless Methods

Application of the discrete transformation and the approach used for discrete Green's function have also been shown in domains discretized with points. Finite Point Method (FPM) has been used in this regard. However, FPM suffers from some inherent instability. Therefore, separate studies have been carried out on FPM. Part of the results has been published (see [5]) but more parts are pending for being published.

Materials with incompressible behavior

Another area of our research is in close relation with the researches currently going on in CIMNE. Modeling of materials with incompressibility behavior is one of the prerequisites of the method of Particle Finite Element Method (PFEM, www.cimne.com/pfem) applied to water-structure interaction. Available methods for modeling the incompressibility behavior appear to be time consuming especially when used in explicit codes like PFEM. The methods use two-field formulations, i.e. pressure-velocity fields. As a preliminary study we have worked on a formulation with one field variables, i.e. just velocity field (see [6]). The study has been performed on linear problems and is to be extended to nonlinear ones, as PFEM requires. A new method has been proposed which is based on a split in the velocity field and the use of inter-element control volumes. The use of pressure field is relaxed by assuming a distributed body force induced by pressure. The body force is found during an iterative procedure. Although it is an iterative solution method, it is very cheap and its results are sufficiently accurate. The force-based nature of the method makes it applicable to problems like those encountering in water-structure modeling. A schematic presentation of the method, for the interaction of an elastic tube with water inside it, is shown in

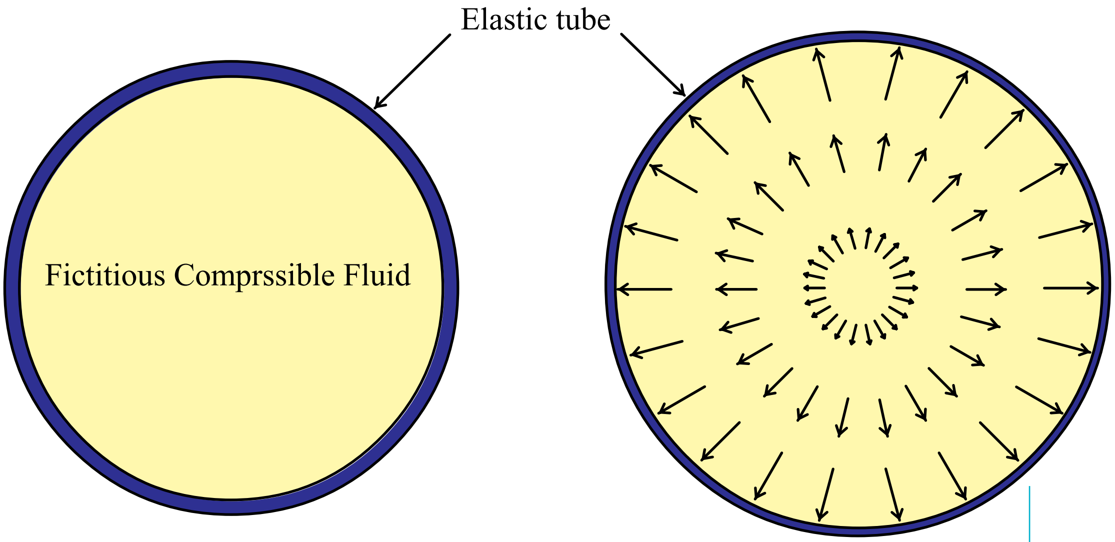


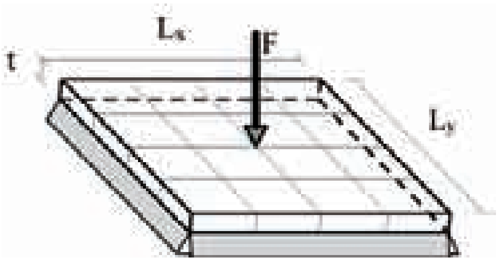
Figure 5:
Schematic presentation of the force based method for modeling of incompressible fluids in a fluid-structure interaction problem. The original material is replaced with a fictitious material and then a set of body forces are evaluated and applied to the problem to correct the material behavior.

Figure 5. At the first step of the iteration the fluid is considered compressible having an auxiliary bulk modulus. In the further steps of the iteration, body forces are found so that the fluid exhibits incompressible behavior.

Studies on topology optimization of structures

Along with the main lines of our research, we are also working on this area. Topology optimization of plate-like structures has been focused on.

> *"... motive is definitely the will of young talented researchers to communicate with the rest of the world with the language of numerical methods."*



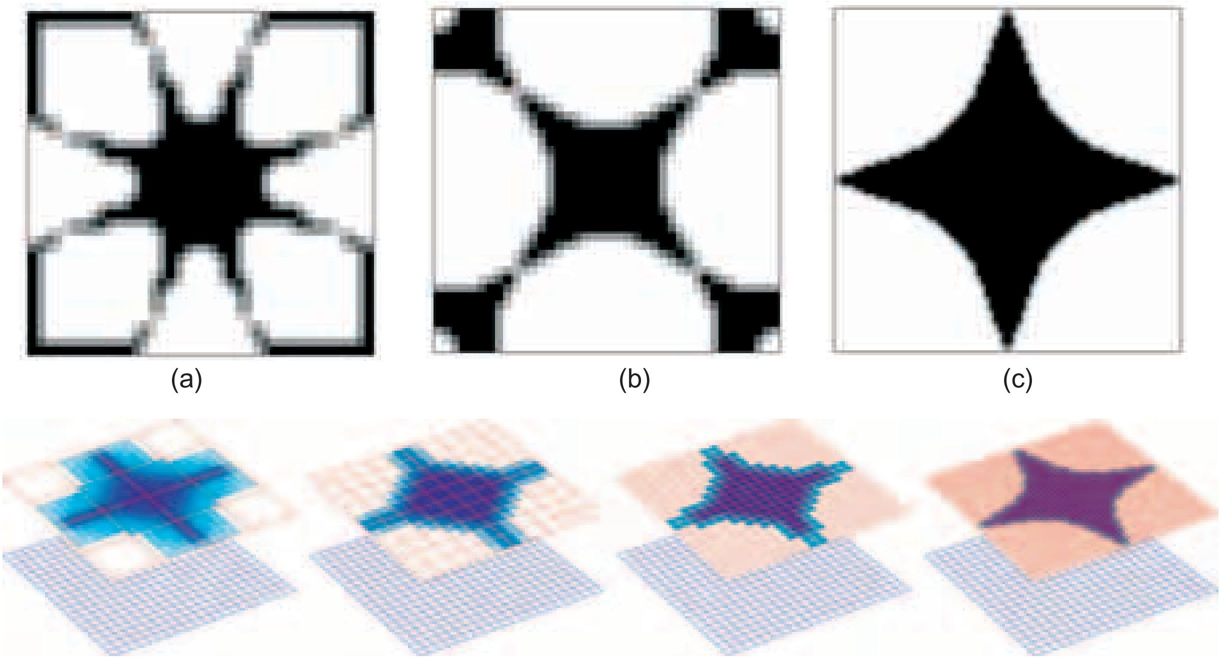

(a) (b) (c)

Figure 6:
Results of studies performed on topology optimization of a plate-like structure with a concentrated load; (a), (b) and (c) the instabilities seen due to non-uniqueness of the numerical solution; (d) schematic presentation of the proposed method for stabilizing the procedure as well as increasing the resolution of the continuous design variables.

The problem has been found very mesh dependent and exhibits sever numerical instabilities. Obtaining checkerboard patterns and non-uniqueness of the numerical solution are the representatives of the instabilities. These effects stem from non-convexity of the problem especially when artificial materials are used as the tools for obtaining material distribution. The problem has much in common with problems encountering in adaptive procedures in non-linear finite element method. Based on our experience on adaptive procedures, we have proposed a new method for removing the instabilities. The method utilizes a continuous field of design variables and uses a series of meshes to increase the resolution of the material distribution (see [7]). *Figure 6* schematically illustrates the instabilities and the remedy proposed for removing them.

What we have presented here are the topics of our research activities. Some inter-disciplinary topics are also sought by some newcomers. The research environment created is attracting the best of students. Considering that in our country the engineering fields are still on top in terms of receiving attention by students, and this is mainly due to the need for massive construction in the country, perhaps the group is one of the best in the world. Also considering the living environment around us this sounds as a miracle. The motive is definitely the will of young talented researchers to communicate with the rest of the world with the language of numerical methods. ●

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Figure 7:
Part of the research group working at Civil Engineering Department in IUT; From left to right; Mr. Moazam (M.Sc. student); Mr. Barekatein (Ph.D. st.), Mr Shamsaei (M.Sc. st.), Dr. Boroomand, Mr. Najar (Ph.D. st.), Mr. Mossaiby (Ph.D. st.), Mr. Soghrai (M.Sc. st.) and Mr. Koohi (M.Sc. st.)

Numerical Modelling of Human Upper Airway Fluid Dynamics

by:
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Abstract

In this article, realistic modelling of human upper airway fluid dynamics is explained. In addition to explaining the anatomy, disorders and importance of patient specific study of human upper airways, this article also presents some qualitative and quantitative results obtained on a realistic geometry.

Introduction

Over the last five years, there has been a significant increase in patient specific computational modelling of human body related problems. Majority of such available studies on physiological flows have attempted to understand the hemodynamics and related problems [1-5]. This is mainly due to the fact that the cardiovascular problems account for significant number of disease related deaths in the developed world. It is evident from clinical research that, some persistent respiratory problems can also develop into sever heart disease. The problems associated with the human airways include asthma, airway stenosis, sleep apnoea, throat cancer, nasal airway blockage and chronic obstructive pulmonary disease (COPD). Untreated, sleep apnoea can lead to pulmonary hypertension and sever heat disease. It is, therefore, essential to give a great deal of more attention to the human respiratory system. The number of patient specific studies on human airways is rather limited and the available studies have concentrated mainly on the lower human airways [6]. The upper human airways have received little or no attention from patient specific numerical modelling community, despite the fact that sleep apnea, throat cancer and nasal airway blockage are becoming common in both developed and developing countries.

It is clear that similar difficulties faced by blood flow appear in the human upper airway simulation. Some of the aspects may be more sever in airway fluid dynamics than blood flow simulations. For example, accurately extracting narrow portions of nasal passages from scans is extremely difficult. Often scans are polluted by the presence of mucus in the airways and some form of manual interaction to make the geometry realistic is essential. Although, in principle, some measurements are possible in a

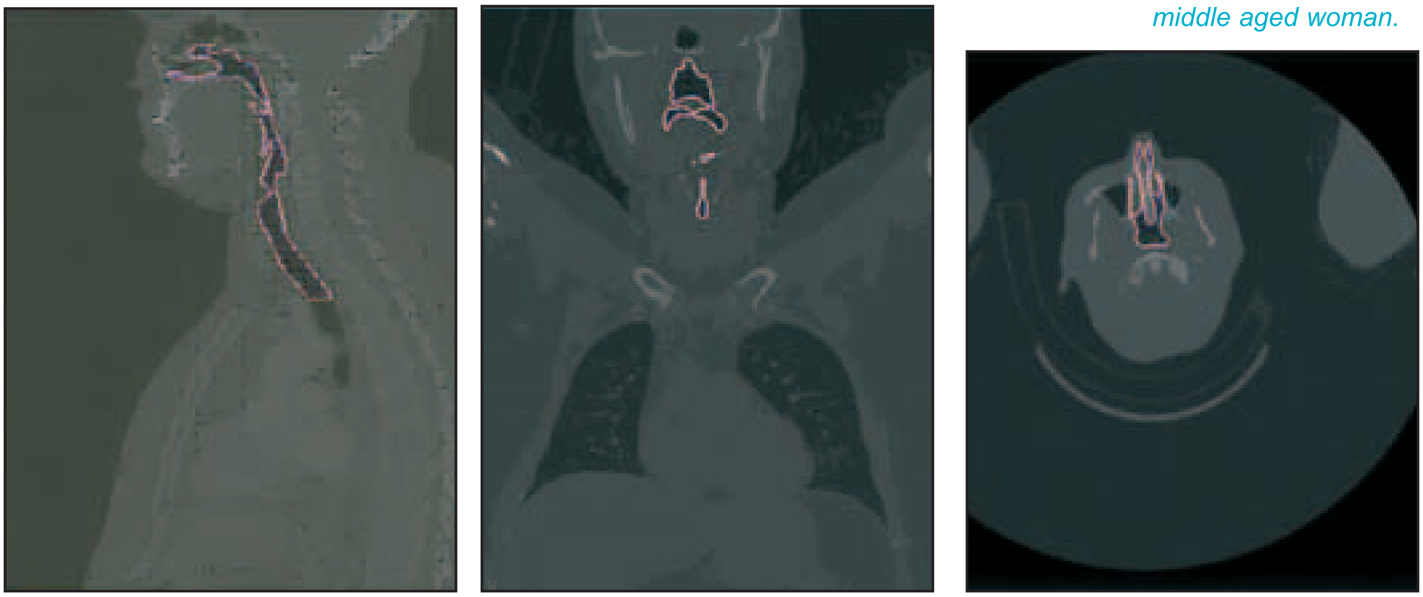

Figure 1: *CT scan of a middle aged woman.*

human upper airway, the accuracy of such measurements is likely to be poor due to the obstruction caused by the probe and complex nature of the geometry. Despite the differences in the nature of blood and airflow problems, some of the fundamental techniques used in geometrical reconstruction, meshing and solution methodology are identical. Although a huge number of articles are produced on the clinical aspects of human lower and upper airways, the understanding gained on the functions of the human upper airway is limited. For better understanding of the upper airway, its functions and disorders, patient specific numerical modelling is an ideal way forward. Unlike clinical and experimental studies, the patient specific human airway modelling can give fine details on flow pattern, pressure and wall shear stress distributions. Such details can further increase our understanding of the human airway functions.

Human Airway Disorders

The upper airway is susceptible to many diseases. We will focus on three common disorders, each of which predominantly affects one section of the airway. Nasal airway obstruction can be caused by injury altering the bony and cartilaginous structure of the nose, or by soft tissue swelling from allergy or infection. It is often treated by corrective surgery. The most important complication of such surgery is a failure to achieve the desired outcome. The surgeon will choose a particular procedure, based on experience and subjective measurements. It is our view that preoperative flow modelling could be used to determine the optimum flow rate possible by modifying the existing geometry and then to use these objective measures in planning surgery. Due to the static nature of the geometry, only airflow through such geometries is needed to determine the optimal flow rate. A major difficulty here is the production of a sufficiently high definition scan to show the very thin bony structures of the nasal passages.

The second problem of interest is that of vocal cord paralysis. This may be caused by cancer in the chest or neck or the result of surgical trauma to nerves supplying the larynx. Good quality, loud sound can only be produced when the vocal cords are closely approximated. A vocal cord, paralysed in a lateral position, results in a gap during phonation, producing a weak, breathy voice. It is not usually possible to re-innervate the larynx but insertion of a prosthesis to push the paralysed cord into an optimal position for vocalising, can allow excellent voice production. The difficulty is that, too small a prosthesis will result in a poor voice and, too large, will narrow the airway, causing breathlessness. The final decision must be a compromise between voice and airway. We believe pre-operative modelling will allow more accurate prediction of the effects of prosthesis size on both voice and airway. Although the fluid-structure interaction in this problem is important, the mechanism is normally simple. Vocal cords move up and down and laterally and medially in a systematic way and a prescribed motion may be sufficient to determine an optimal flow rate.

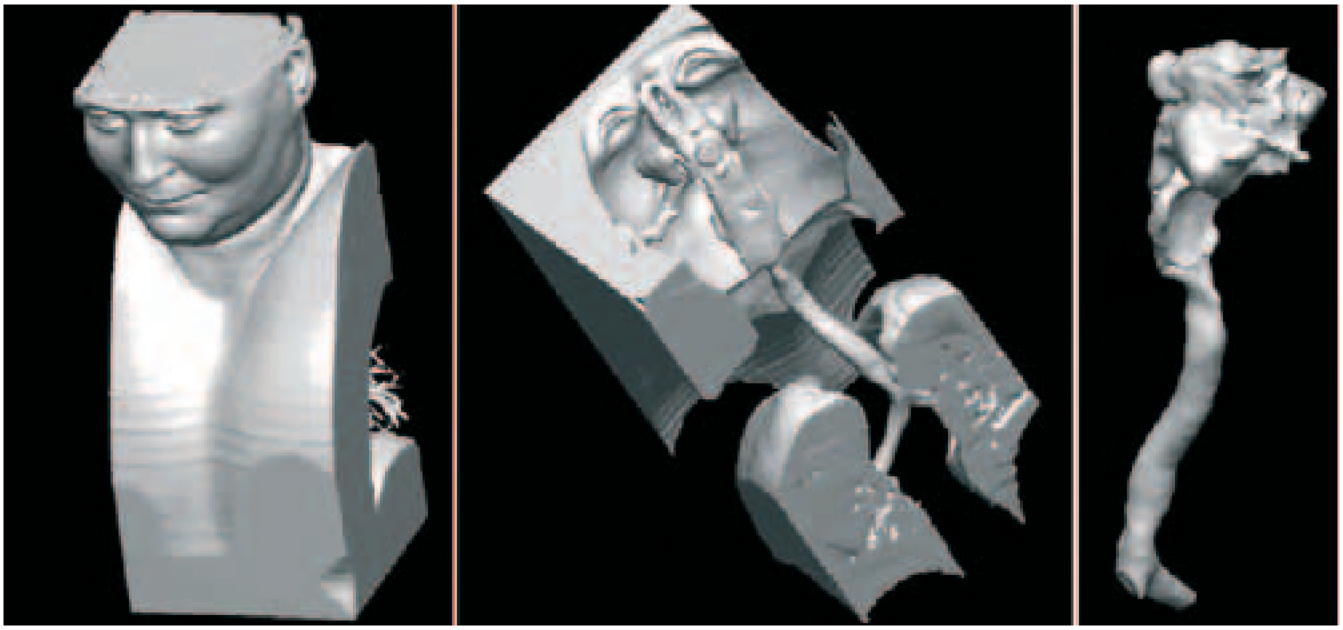

Figure 2: *MIMICS reconstruction from scans*

The geometry is not as complex as that of the nasal passages although scan resolution is still an issue.

The third, increasingly common, problem is that of sleep apnoea. This has received more attention than the previous problems due to the larger numbers affected and the concern that sleep apnoea may be an important factor in road accidents and in early death from hypertension and heart disease. However, realistic modelling of upper airway collapse has so far not been attempted. The major challenge in this problem is that of tackling the combination of fluid forces, structural movement and the neuromuscular activities contributing to airway collapse. Coupling passive material with fluid is difficult but neuromuscular actions make the problem even more complex. On the positive side, sleep apnoea is routinely investigated, providing high quality digital audiovisual data during controlled sleep studies. Thus production of a soft tissue model is possible from the experimental data.

In all three problems, the unifying factor is the study of patient specific fluid dynamics. Irrespective of other factors involved, it is essential to develop a procedure allowing repeatable fluid dynamics studies to be performed. This article is an attempt to produce procedure to carry out a patient specific fluids dynamics study in a human upper airway. In the present work, the fluid forces are determined, based upon the modelling requirement of airway collapse. Thus the main focus of the present study is to determine the pressure and wall shear stress in the airway, in particular at upper and lower oropharyngeal level.

Patient Specific Modelling

At present we use a combination of commercial tools and in house codes to extract geometry from CT scan images (DICOM format, *Figure 1*). We show the process of interactive removal of unnecessary portions of the airway in *Figure 2*. The figure on the right shows the final full airway extracted using MIMICS software. This geometry was extracted with as minimum user interference as possible. It is clear from this figure that the software has failed to identify the thin bony structures separating the sinuses from airway. As a result, the geometry included both the sinuses on the sides of the nasal passage and the ones at the forehead. *Figure 3* used full manual control on the boundaries during extraction of the geometry using AMIRA software. Once again, extracting the geometry of the nasal passage was proved to be a challenge. It appears that we need better scan resolution to more accurately extract the nasal passage geometry. However, producing higher CT scan resolution may not be possible due to the side effects of higher doses of radiation.

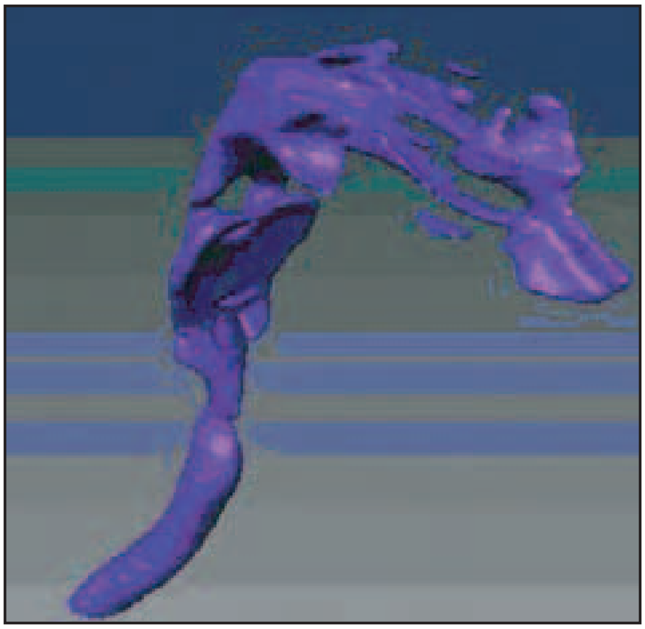

Figure 3:
Extracted full upper human airway geometry from AMIRA software.

In this demonstration study, we decided to proceed with the stl file extracted from the first option (*Figure 2*). The meshing tools, including the ones used for surface meshing is the one developed in Swansea [7]. The stl file is converted into a surface mesh and then a volume mesh was generated. It was necessary to check for any intersecting surfaces before a volume mesh was generated. The sample mesh generated for the full airway geometry, including the sinuses is shown in Figure 4 (left). As seen all the expected features of the geometry are captured. Unfortunately, this mesh was found unsuitable for carrying out calculations due to the sinuses appearing within the geometry.

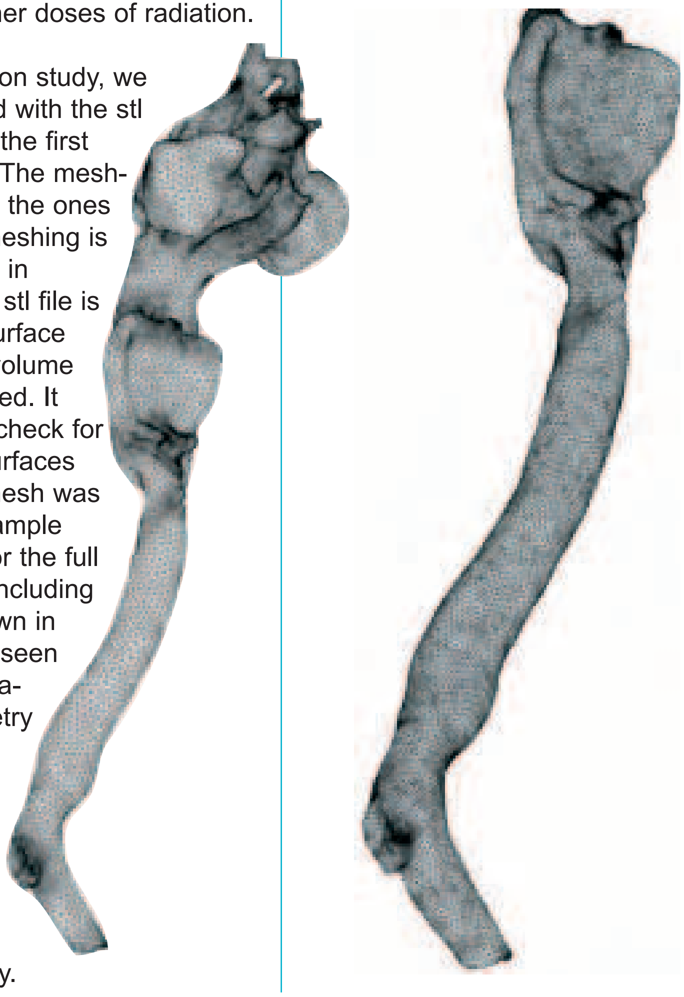

Figure 4:
Surface meshes. Initial mesh (left) and truncated mesh (right)

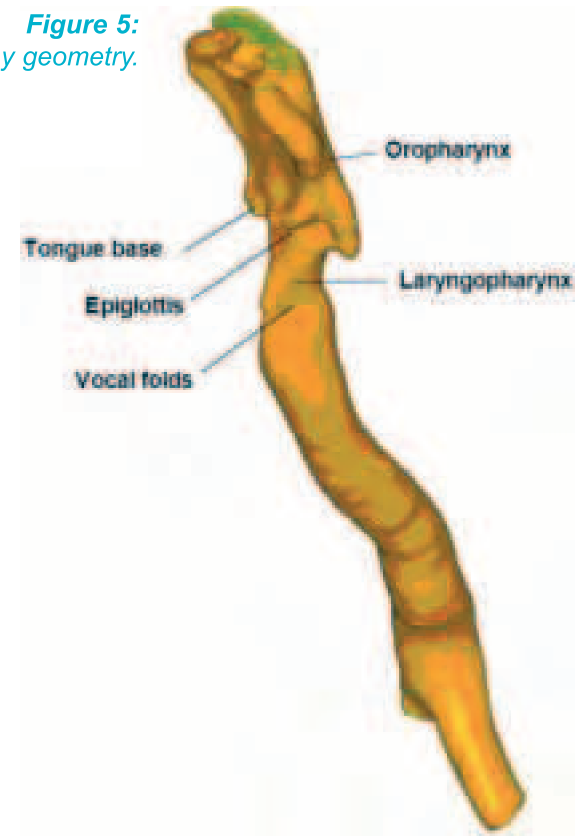

Figure 5:
Final airway geometry.

Figure 6:
Velocity vector plots at
an inhaling flow rate of 30l/m.
Vectors (left) and recirculation below vocal cords (right)

To model the flow and its effects on the airway portions expected to effect collapse, we manually truncated the geometry just above the tip of the soft pallet. Although the truncated geometry is not able to include the effects from the nasal passages, it is expected to predict the disturbance caused by epiglottis and vocal-cords. The truncated geometry was generated from a surface mesh by cutting at a required plane and projecting the surface points to a constant x_3 value. This way, a smooth surface is obtained at the inlet. After meshing the cut surface with a 2D Delaunay triangulation, the volume mesh was regenerated. *Figure 4* (right) shows the truncated mesh. Three different meshes of varying resolutions were generated to minimize the accuracy implications due to mesh size.

Figure 5 shows the geometry and important parts of the oropharynx and laryngopharynx.

Several inhalation studies were carried out and one such study at a flow rate of 30l/min is presented in *Figures 6 to 8*. The in house CBS flow solver was used in the flow calculations [8]. The vector plots in *Figure 6* clearly show a recirculation region just below the vocal cords.

Figures 7 and 8 show the pressure and shear-stress distributions. As seen the laryngopharynx area is responsible for the major part of the pressure drop. The pressure drop values obtained are close to the values normally expected. The highest shear stress was also obtained in the laryngopharynx area. This gives a clear indication that the laryngopharynx area is the one that could easily be subjected to collapse.

Future Study

It is clear that further studies are essential to enhance the understanding of human upper airway functions. To make the fluid dynamics more realistic, the nasal airway needs to be included in the study. To assess the full effect of fluid dynamic forces, the analysis should be carried out over a full breathing cycle. Even during the normal breathing cycle, the human airways are not static. For a precise model of the human airway fluid dynamics, including the dynamic variation of the structure may be necessary. Solid-fluid coupling in the human upper

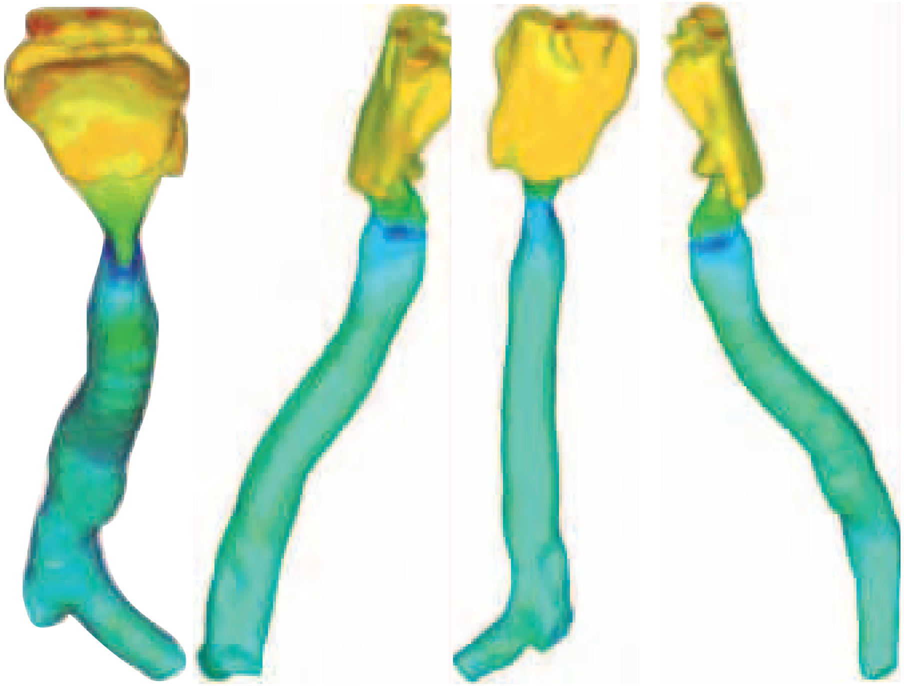

Figure 7:
Pressure distribution at a flow rate of 30l/min. Maximum pressure = 62.99 Pa, Minimum pressure = -23.69 Pa, Total pressure drop = 43.5 Pa From left to right: anterior view, side view, posterior view and side view.

airways is another area, which has a great deal of potential to further enhance the current understanding of sleep apnoea.

Acknowledgement

This work is fully funded by an EPSRC Advanced Fellowship (EP/D070554). The author also thank Mr Colin Fielder, Dr Philip Ebden and Mr. Heikki Whittet all from Singleton Hospital, Dr Keir Lewis from Swansea Clinical School and Prof Oubay Hassan and Prof Nigel Weatherill of the School of Engineering, Swansea University for their help. ●

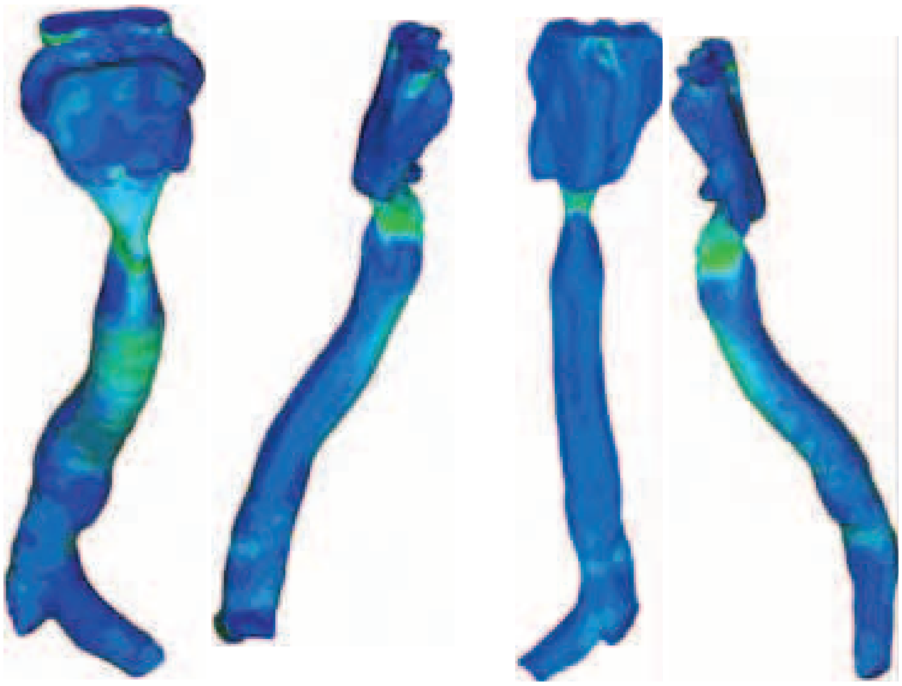

Figure 8:
Wall shear stress distribution at a flow rate of 30l/min. Maximum shear stress = 0.449 Pa. From left to right: anterior view, side view, posterior view and side view.

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USACM

Chronicle

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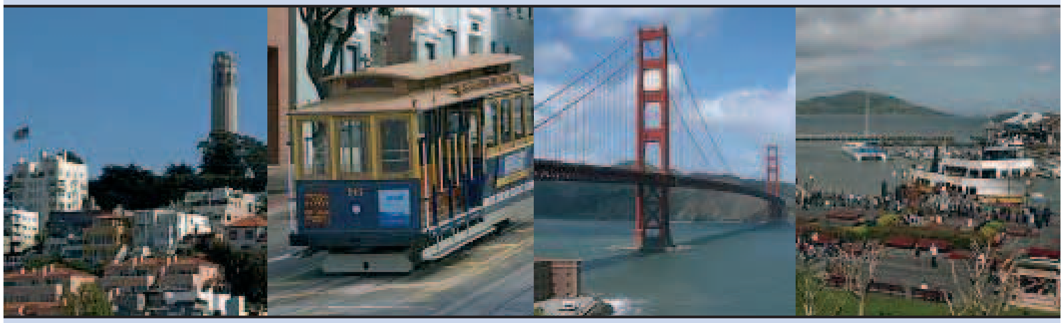


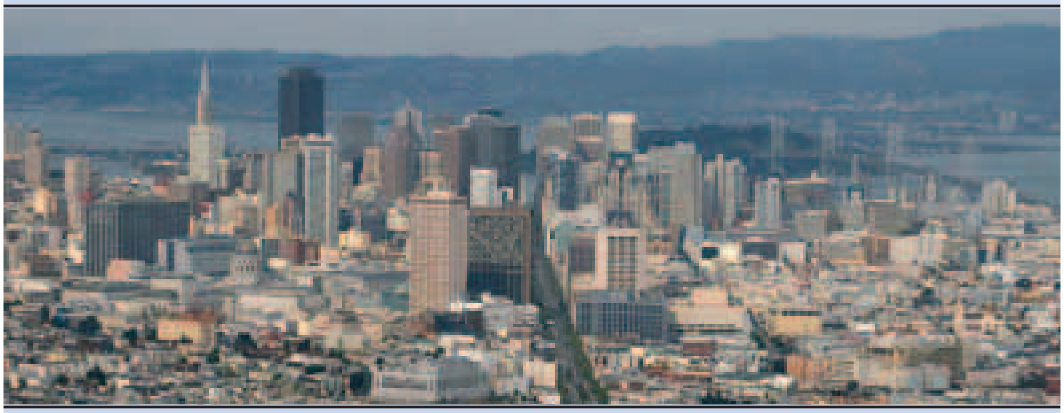
9th US National Conference on Computational Mechanics

Hyatt Regency
San Francisco, California, USA

Technical Program	July 23-26, 2007
Pre-Congress Short Courses	July 22 , 2007

Hosted by:
University of California, Berkeley

Honorary Chair: R.L. Taylor
Co-chairs: P. Papadopoulos, T. I. Zohdi



Web site:

http://me.berkeley.edu/compmat/USACM/main.html

Asociación Argentina de Mecánica Computacional

AMCA Awards - 2006

The Congress Banquet of **ENIEF 2006** gave the framework for a new ceremony of the AMCA Awards.

These awards have been instituted as recognition of scientific careers in the field of computational mechanics and are granted in three categories: Young Researchers; Scientific, Professional and Teaching Career; and International Scientific Career.

The award for Young Researchers was granted to **Victor Fachinotti**, from CIMEC- INTEC, Argentina. **Sergio Idelsohn** received the award to the Scientific, Professional and Teaching Career. S. Idelsohn has been recognized not only for his production as scientist, but also for his outstanding role in the formation of R/D groups and of the Argentine Association of Computational Mechanics. Finally, the award to the International Scientific Career, intended to recognize not only the scientific career in the field of computational mechanics but also the interaction with research centers of Argentina, was granted to **Raúl Feijóo**, from the Laboratorio Nacional de Computação Científica (LNCC), Brasil.

The jury for the AMCA Awards 2006 was integrated by: F. Basombrio, E. Dvorkin, A. Cardona, V. Sonzogni, G. Etse, J. C. Ferreri and A. Cisilino. Student papers competition

Student papers competition

Also in the banquet of ENIEF 2006, the prizes of the undergraduate student papers competition have been granted. The first place was for **Marcelo Alvarez**, from the Universidad Nacional de Rio Cuarto (Cordoba, Argentina) for his work on aerodynamics of 2D non stationary flows dominated by vorticity. The second prize was for **Thiago Alves de Queiroz**, from Universidade Federal de Goias (Brazil), for his work on mathematical modelling and comparison of numerical and perturbation methods applied to vibration of columns partially restrained on non linear soils. The third prize was granted to two students, **Roberto Godoy** and **Martin Santa Maria**, from the Universidad Nacional del Litoral (Argentina), for their work on dynamic memory management in an object oriented finite element program. ●

Figure 1:
AMCA Awards 2006 for Senior Researcher: Sergio Idelsohn

Figure 2:
AMCA Awards 2006 for Young Researcher: Victor Fachinotti

Figure 3:
AMCA Awards 2006 for International Researcher: Raúl Feijóo

Figure 4:
First prize for student papers: Marcelo Alvarez

Figure 5:
Second prize for student papers: Thiago Alves de Queiroz

Figure 6:
Third prize for student papers: Roberto Godoy and Martin Santa Maria

ENIEF 2006

XV Congress on Numerical Methods and their Applications

7-10 November 2006 - *Santa Fe, Argentina*

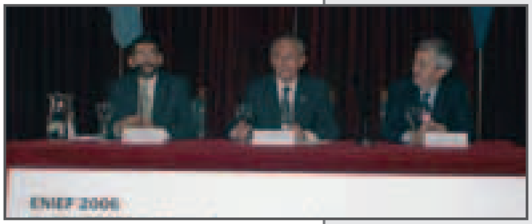


***Figure 1**: Openning ceremony of Enief 2006. V. Sonzogni, President of AMCA; M. Barletta, Rector UNL and A. Cardona, Vice-Director of INTEC*

The XV Congress on Numerical Methods and their Applications was held from November 7th to 10th , 2006 in Santa Fe city, Argentina. This new edition of the Argentine Association of Computational Mechanics (AMCA) national congress was organized by the International Center for Computational Methods in Engineering, CIMEC-INTEC (UNL-CONICET).

The congress was attended by more than 200 delegates, mainly from Argentina, Brazil and Chile, but also from Colombia, Uruguay, Venezuela, Mexico, Spain, United States, France, Italy and Belgium. Special lectures have been given by: Thomas Hughes (University of Texas, USA), Ramón Codina (Universidad Politécnica de Catalunya, Barcelona, Spain), Charbel Farhat (Stanford University, USA), Gino Bella (Universita di Roma Tor Vergata, Italy), Rainald Löhner (George Mason University, USA), Michel Bellet (CEMEF, Nize, France), Raúl Feijóo (LNCC, Brasil), Miguel Cerrolaza (Universidad Simon Bolivar, Venezuela) and Pablo Jacovkis (Universidad de Buenos Aires, Argentina) .

Full length papers were submitted to a reviewing process prior to publication. From them, 179 papers have been accepted and included in the proceedings of the congress, published as Volume XXV of the books series "Mecánica Computacional" of AMCA. This book has been compiled by A, Cardona, N. Nigro, V. Sonzogni and M. Storti. The papers of "Mecánica Computacional" are now publicly available at the website: **http://www.cimec.org.ar/ojs/index.php/mc/issue/archive** .

***Figure 2**: During the banquet: S. Idelsohn, V. Sonzogni, R. Feijoo, L. Zielonka, R. Codina, T. Hughes, M. Cerrolaza and M. Chiovetta, director of INTEC, and his wife.*

The congress took place during four days at the Universidad Nacional del Litoral main building. The technical program included: plenary lectures and ordinary and specially organized sessions, in four rooms in parallel. The opening ceremony was presided over by the rector of the Universidad Nacional del Litoral, Mario Barletta, the president of the AMCA, Victorio Sonzogni, and the vice- director of INTEC, Alberto Cardona. On Thursday the Congress Banquet took place at the Yatch Club. This social activity has been accompanied by folk dances. During the Banquet the AMCA Awards 2006 were granted. The ordinary annual assembly of AMCA took place on Wednesday.

A student paper competition was developed during ENIEF 2006. A special poster session was devoted to undergraduate students papers. The best papers received special prizes consisting in books and stages in some research centers of Argentina.
In the frame of the week of ENIEF 2006, the Second International Meeting of the CIMNE Classrooms Network was held also. This meeting was developed on Friday 10 and Saturday 11 in the Faculty of Engineering and Water Sciences (FICH) of UNL. ●

For additional information and photos please go to: **http://www.cimec.org.ar/enief2006**

***Figure 3**: Participants at ENIEF 2006*

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http://amcaonline.org.ar

ENIEF 2007

XVI Congress on Numerical Methods and Their Applications

MACI 2007

I Congress on Computational, Industrial and Applied Mathematics

The Argentine Association for Computational Mechanics (AMCA) and the Argentine Section of the Society for Industrial and Applied Mathematics (AR-SIAM), announce the **XVI Congress on Numerical Methods and Their Applications** and the **I Congress on Computational, Industrial and Applied Mathematics**.

The congresses are addressed to Engineers, Physicians, Mathematicians, Biologists and Economists and they will take place in Córdoba, Argentina from 2 – 5 October, 2007.

The first ENIEF Congress took place in 1983. Since then, fifteen ENIEF and eight MECOM (Argentinean Congress on Computational Mechanics) have been organized by AMCA. This year ENIEF2007 will take place together with MACI2007 increasing the number of people interested in attending such congresses.

Deadlines:
One page abstract: *March, 31*
Acceptance of the abstract: *April, 20*
Full length paper: *June, 15*
Acceptance of the full length paper: *July, 31*
Registration: *August, 15*

Congress Topics: Fluid Mechanics, Heat and Mass Transfer, Solid Mechanics, Structural Analysis, Mesh Generation, Visualization Algorithms, Biomechanics, Partial Differential Equations, Numerical Analysis, Industrial and Environmental Applications, Biomathematics, Modelling, Inverse Problems, Discrete Mathematics, Quantitative Finance, Optimization and Control, High Performance Computing, Fluid-Structure Interactions, Probability, Statistics and Stochastic Processes, Dynamical Systems and Acoustics. ●

For further information: http:/www.efn.uncor.edu/enief2007

NEWS

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9th World Congress
and
4th Asian Pacific Congress on Computational Mechanics

The preliminary planning for the combined WCCM IX /APCOM'10 to be held in Sydney during 2010 is progressing satisfactorily under the direction of Professor Khalili and Professor Valliappan.

Tenders for the appointment of Professional Conference Organizer (PCO) closed and a short list of the applicants has been decided for an interview. ■

APCOM'07

Third Asian-Pacific Congress on Computational Mechanics

Kyoto, Japan -

The **APCOM'07** in conjunction with **EPMESC XI** congresses will be held in **Kyoto, Japan** during **December 3-6, 2007.** The joint congresses will feature the latest developments in all aspects of computational mechanics, with many other emerging computation-oriented areas in engineering and science.

The plenary lectures will be given by the following distinguished scholars :
T. Belytschko (USA) : TBA
J.S. Chen (USA) : TBA
J. Fish (USA) : Bridging Continuum and Discrete Scales
A. Huerta (Spain) : TBA
S.R. Idelsohn (Argentina) : Recent Advances in Fluid Structure Interactions Including Free-surfaces
A. Kamal Ariffin (Malaysia) : Crack Propagation Simulation and Fatigue Reliability Challenges
W. Kanok-Nukulchai (Thailand) : TBA
N. Kikuchi (USA) : Biomechanics Related Impact Simulation by Using Coupled FEM-SPH/MPS
Y.Y. Kim (Korea) : Higher-order Beam Theory and Implementation for Automobile Pillar-Like Members
B.M. Kwak (Korea) : Developments in Robust and Reliability-based Design Optimization of Structural and Mechanical Systems
A. Leung (China) : Solution of Singular Problems Using the Fractal Finite Element Method
G.R. Liu (Singapore) : Combined Finite Element and Meshfree Techniques for Certified Solution of Mechanics Problems
W.K. Liu (USA) : TBA
H. Mang (Austria) : TBA
Ch. Miehe (Germany) : Hybrid Micro-Macro Modeling of Inelastic Materials
R. Ohayon (France) : Vibrations of Structures Coupled with Internal Fluids
E. Alantes e Oliveira (Portugal) : Dualities in Structural Mechanics
E. Oñaté (Spain) : Advances in the Particle Finite Element Method in Computational and Solid Mechanics
R. Owen (UK) : Coupled Fluid-Structure Interaction Problems in Multi-fracturing Solids and Particulate Media

Figure 1: *Naritasan Shinshoji Temple*

AUSTRALIAN ASSOCIATION FOR COMPUTATIONAL MECHANICS

The office-bearers of the new executive council of **AACM** are:

Directors:	**S.Valliappan** **G.Steven**
President:	**S.Sloan**
Vice President:	**N.Khalili**

in conjunction with **EPMESC XI**

Eleventh International Conference on Enhancement and Promotion of Computational Methods in Engineering and Science

- December 3-6, 2007

M. Papadrakakis (Greece) : Seismic Design of Structures - A Challenge for Computational Mechanics
D. Peric (UK) : Progress on Computational Strategies for Problems with Moving Interfaces and Fluid-Structure Interaction
B. Shrefler (Italy) : TBA
T. Tezduyar (USA) : Modeling of Fluid-Structure Interactions with the Space-Time and Multiscale Techniques
G. Tryggvason (USA) : Computations of the Dynamics of Heterogeneous Continuum Systems
S. Valliappan (Australia) : TBA
M.W. Yuan (China) : Advances in Computation of Large Generalized Eigenvalue Problem

In addition, over 60 minisymposia that highlight the latest trends in computational mechanics and numerous vender exhibits are scheduled.

Kyoto was the capital of Japan for over 1000 years from 794 to 1868AD. In addition to beautiful imperial villas, Kyoto is home to about 400 Shinto shrines and 1,650 Buddhist temples which are dotted around the city. Innumerable cultural treasures and traditional crafts, as well as beautiful spring cherry blossoms and autumnal colors, attract visitors to Kyoto, both from Japan and abroad. The congress period coincides with the perfect time for viewing the beautiful deep red hues of the Japanese maple's foliage.

Important Dates

Deadline for abstract submissions	June 1, 2007
Final selection of abstracts	July 1, 2007
Deadline for submission of full length papers	August 1, 2007
Deadline for submission for visualization contest	August 1, 2007 ■

2006 Congress Medalist

Ivo Babuška

by Karel Segeth

Professor Ivo Babuška was awarded the 2006 Congress Medal at the 7th World Congress on Computational Mechanics in Los Angeles, July 16-22, 2006.

Figure 1:
Professor Ivo Babuška

The Congress Medal, also known as the Gauss-Newton Award, is IACM's highest award and honors lifetime achievement in Computational Mechanics.

Ivo has held the Robert Trull Professorship at the Institute for Computational Engineering and Sciences (ICES) at the University of Texas at Austin since 1995. Prior to joining ICES, Ivo was affiliated with the Institute for Physical Science and Technology and the Department of Mathematics of the University of Maryland at College Park. Ivo's time in Maryland began with a visiting position in 1968, the same year he was appointed professor at Charles University in Prague.

Ivo was born in Prague, March 22, 1926. He studied civil engineering at the Czech Technical University in Prague and received the M.S. degree in 1949 and Ph.D. in Technical Science in 1951. In 1955 he received the Ph.D. degree in mathematics from the Mathematical Institute of the Czechoslovak Academy of Sciences in Prague (formerly known as the Central Mathematical Institute) and in 1960 he received the Doctor of Science degree, which was in Czechoslovakia, and still is in the Czech Republic, the award for the highest scientific achievement.

From 1955 to 1968 he was the head of the Department of Constructive Methods of Mathematical Analysis (originally named the Department of Partial Differential Equations) of the Mathematical Institute of the Czechoslovak Academy of Sciences.

Ivo's background in applied and numerical analysis brought him to the finite element method. Among his achievements in finite elements are the *p*-version, the Babuška -Brezzi inf-sup condition, *a posteriori* error estimation and adaptivity, and the partition of unity method (GFEM). He has received numerous honors for his research including honorary doctorates from Charles

Figure 2:
2006 Congress Medal - Gauss-Newton Award

University and Helsinki University of Technology, Fellowship in IACM and the United States Association for Computational Mechanics (USACM), elected membership in the U.S. National Academy of Engineering, Honorary Diploma of the Czech Society of Mechanics, Honorary Foreign Member of the Czech Learned Society, Honorary Editorship of the journals *Applications of Mathematics* and *Numerische Mathematik*, and the Medal De scientia et humanitate optime meritis, the highest award granted by the Academy of Sciences of the Czech Republic. Asteroid number 36060 was named "Babuška" in Ivo's honor!

At the age of 81, Ivo is still a vibrant force in scientific research. He enthusiastically mentors students and post-docs at ICES, hosts visitors there, travels and publishes extensively, lectures throughout the world, and frequently delivers the ICES Forum, informal presentations on advanced topics and historical perspectives.

Ivo is the second mathematician to be awarded the Congress Medal. The other is Franco Brezzi, the 2004 Medalist. This is not the only thing they have in common. They are inextricably linked through the celebrated Babuška-Brezzi condition.

Ivo's influential work spans mathematics and engineering. These days he is actively engaged in Verification and Validation (V&V), a subject of considerable importance in engineering practice.

He recently gave a series of lectures on V&V for faculty colleagues at ICES in preparation for their writing a team research proposal. He is a frequent and enthusiastic attendee at ICES research seminars, where he asks numerous probing and incisive questions to speakers.

He and his lovely wife Renata are active participants in the social activities of ICES and the University of Texas at Austin. His energy and intellectual powers seem to remain unabated at the elegant age of 34.

This article is based in part on K. Segeth, "Professor Ivo Babuška is Eighty," *Applications of Mathematics, Vol. 51*, No. 2, 89-92 (2006). We thank the Mathematical Institute of the Academy of Sciences of the Czech Republic for permission to use it in preparing this article. ●

Figure 3:
Prof. Ivo Babuška receiving his award in Los Angeles

Joint

VIII World Congress on Computational Mechanics (WCCM VIII)

and

V European Congress on Computational Methods in Applied Science & Engineering (ECCOMAS V)

June 30 to July 5 2008

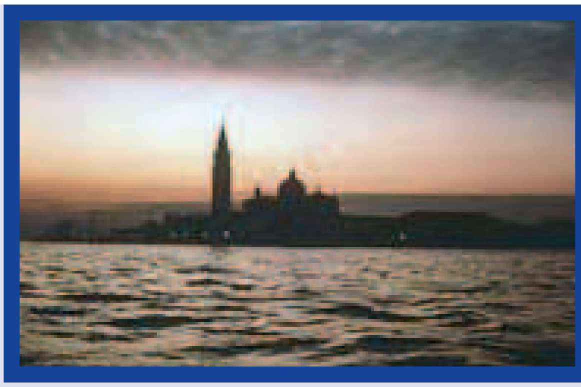
The joint **VIII World Congress on Computational Mechanics (WCCM VIII)** and **V European Congress on Computational Methods in Applied Science and Engineering (ECCOMAS V)** will be co-organized by the University of **Padua** and the Politecnico of **Milan** in Venice, from **June 30 to July 5 2008**, under the auspices of the **International Association of Computational Mechanics (IACM)**, the **European Community on Computational Methods in Applied Sciences (ECCOMAS)**, the Italian Association of Theoretical and Applied Mechanics (AIMETA) and the Italian Society of Applied and Industrial Mathematics (SIMAI).

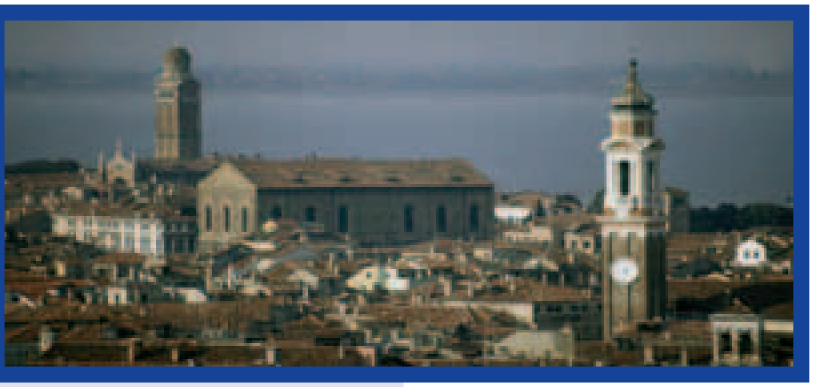
In accordance with the tradition of previous issues of IACM and ECCOMAS Congresses, the congress will be open to the latest developments in all aspects of computational mechanics, and is especially intended to broaden the fields of application of the discipline to include new computation oriented areas in engineering and sciences.

The congress will be structured in Minisymposia organized by leading scientists from all over the world on topics at the current front of research in computational mechanics and applied mathematics. Particular importance will be given to plenary and semi-plenary lectures intended to provide an interdisciplinary forum for information and discussion on some of the most advanced subjects.

The congress will be held at the Lido di Venezia Congress Center, located in the Complex formed by the Palazzo del Cinema and the former Venice Casino. The Palazzo del Cinema and the nearby Casino represent a conference centre offering over 3,000 visitor places and spacious exhibition areas. The lido di Venezia is an island which limits the lagoon of Venice towards the Adriatic sea. There are frequent links from other parts of the city including a ferryboat from the Tronchetto car terminal.

Venice is easily accessible by road, by train or by air, arriving either at Marco Polo international airport or Nicelli airport on the island itself. In the immediate vicinity of the congress center there are 1.600 hotel rooms available, offering a range of 2-star to luxury accommodation. Further there are many hotels in Venice itself.





WCCM VIII & ECCOMAS V

The venue represents the perfect place for those who want to meet colleagues and at the same time mix cultural tourism and a vacation by the sea. Venice is considered among the most beautiful and best preserved historical cities in the world, unique in the fact that it is the only city in the world built on water. The city has earned the name of *La Serenissima*, the most serene, as throughout the city's remarkably stable history Venice favoured neutrality and peace when possible. Today the city's peaceful atmosphere is due to the complete absence of cars; boats provide the only means of transport along a system of over 150 canals. For those who prefer to explore the city on foot, more than 430 bridges connect the canals and streets together. There are numerous museums and over 200 churches to explore. San Giorgio Maggiore, Giudecca are separate islands, as are Torcello, Murano (where glass is produced), and Burano (where lace is historically made). There are over 100 other islands in the lagoon.

The organization of the joint

VIII World Congress on Computational Mechanics (WCCM VIII) and V European Congress on Computational Methods in Applied Science and Engineering (ECCOMAS V),

to be held in Venice from June 30 to July 5 2008,
is progressing according to the planned schedule.
You are invited to visit the Congress website
http://www.iacm-eccomascongress2008.org
for updated information.

So far, more than **one hundred proposals for Minisymposia**
have been already accepted.
The updated list of Minisymposia is available at

http://www.iacm-eccomascongress2008.org/frontal/Invited2.asp

conference notices

Workshop on Computational Mechanics 2007

JMC 2007

August 23-24 2007

The **Chilean Society for Computational Mechanics** (its Spanish acronym is SCMC) announces the **Workshop on Computational Mechanics 2007** to be hosted by the Universidad de Chile at Santiago the Chile city during **August 23-24 2007**.

The SCMC invites to visit its web page www.scmc.cl. The visitor of the web will find information about the SCMC and the previous organized workshops as well as news of the Workshop on Computational Mechanics 2007 (JMC 2007).

Workshop secretariat:
Prof. Ramón Frederick
e-mail: rfrederi@cec.uchile.cl.
Phone: 56-(0)2-978 4448
Fax: 56-(0)2-698 8453.
www.scmc.cl

12th IACMAG Conference GOA-India - 1-6 October 2008

(Tentative)

The **International Association for Computer Methods and Advances in Geomechanics (IACMAG)** organizes its conferences about every three years. The conference was started in 1972 and the most recent (11th IACMAG) was held in Turin, Italy, from 19th to 24th June 2005.

Previous conferences were held at USA, Germany, Canada, Japan, Austria, Australia and China. Details of these conferences are available at **http://www.iacmag.org/index1.html**.

We are planning to hold the conference preferably in GOA-India. Tentatively, it will be held during 1-6 October 2008.

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http://www.civil.iitb.ac.in/~dns
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Honorary president
O.C.Zienkiewicz

Honorary Chairmen
B.D.Reddy,E.Oñate,H.Mang

Conference Chairmen
A.G.Malan, P.Nithiarasu

Important Dates
Mini-Symposia: 10 Jan'08
Abstract: 30 Apr'08
Conference website
www.africomp.com

AfriComp'09

1st African Conference on Computational Mechanics Sun City, South Africa, 12-15 Jan'2009

Africa is the second largest continent while being the oldest inhabited territory on earth. South-Africa in particular, is home to the leading African economy. It is the world's largest producer of both gold and diamonds and offers first world skills and infrastructure.

We are pleased to announce the first International, African Conference on Computational Mechanics (Africomp) to be held in Sun City in South Africa. The Sun City resort is 2 hours drive from Johannesburg. It has a unique African rhythm unlike any other. It houses four world-class hotels including the magnificent world renowned Palace of the Lost City. The Palace glitters with splendour beautifully set in its own rain forest surround.

AfriComp is a bi-annual conference which is aimed at bringing together international researchers engaged in the broad field of computational mechanics and to stimulate research in Africa. Technical papers are invited on topics from any area of computational mechanics. Proposals are also invited for mini-symposia organised by individual researchers (composed of at least 5 papers).

As this is the first conference of its kind in Africa, a special Gold Medal will be awarded. This is to recognise an African who has made major contributions to Computational Mechanics. Further, an O.C.Zienkiewicz prize and certificate will also be awarded to the best paper presented at the conference.

iacm news

Association of Computational Mechanics Taiwan

We are pleased to inform you that the "Association of Computational Mechanics Taiwan" has been formed. The following are the key persons of the association:Chairman - **Y. B. Yang**, Vice Chairman - **Chung-Yue Wang**, Executive Director - **David Chen.** For further information contact **ybyang@ntu.edu.tw**

Australian Association for Computational Mechanics

The office-bearers of the new executive council of AACM are: Directors - **S. Valliappan** & **G. Steven**, President - **S. Sloan,** Vice President - **N. Khalili**

Dean of Mechanical Engineering

As of 1 May **Rene de Borst** has taken up the position of Dean of Mechanical Engineering at Eindhoven University of Technology.

20 years of CIMNE

The International Centre for Numerical Methods in Engineering **(CIMNE)** at Barcelona, Spain, celebrates its 20th anniversary (1987-2007). A number of scientific events are planned over 2007 in commemoration of the anniversary year.
See **www.cimne.com** for details.

ECCOMAS Thematic conferences

The European Community in Computational Methods in Applied Sciences **(ECCOMAS)** organises 22 Thematic Conferences in 2007 in different fields of Computational Mechanics. For a full list of ECCOMAS conferences visit **www.eccomas.org**

Honourary Fellowship and SEMNI Award to Prof. E. Oñate

Prof. E. Oñate has been awarded an Honourary Fellowship from the University of Wales at Swansea. He has also received the Award from the Spanish Association for Numerical Methods in Engineering (SEMNI).

86 birthday of Prof. Zienkiewicz

Prof. O. C. Zienkiewicz celebrated his 86 birthday anniversary on May 18th during his annual visit to CIMNE at the Technical University of Catalonia (UPC) in Barcelona, Spain. Prof. Zienkiewicz has held the UNESCO Chair of Numerical Methods in Engineering at UPC since 1989.

Figure: *(from left to right)*
E. Oñate, O.C. Zienkiewicz, S. Idelsohn (sitting down), R. Codina, B. Suárez, C. Felippa. H. Zienkiewicz, P. Diez

Best Ph.D. Thesis Awards from ECCOMAS

The ECCOMAS Award for the best Ph.D. Thesis in an European University have been granted to: **Dr. Santiago Badia** from Technical University of Catalonia, Barcelona, Spain, for his thesis on *"Stabilized Pressure Segregation Methods and their Application to Fluid-Structure Interaction Problems"* and to **Dr. Per Carl Johan Heintz** from Chalmers University for his thesis on *"Finite Element Procedures for the Numerical Simulation of Crack Propagation and Bilateral Contact".*

INSA Fellowship to Professor Tarun Kant

We are very glad to inform you that **Prof. Tarun Kant,** Department of Civil Engineering, has been elected a Fellow of the Indian National Science Academy (INSA) this year in 2006. Please join us in congratulating him for this significant professional recognition.

Professor HH Mathur Excellence Award in Research in Applied Sciences, 2006

The following facultys have been selected to receive the Prof. H.H. Mathur Excellence Award in Applied Sciences for research excellence during the year 2006, within the Indian Institute of Technology, Bombay.

a) **Prof. Tarun Kant** (Civil Engineering Department) IIT
b) **Prof. N.K. Naik** (Aerospace Engineering Department IIT

Error Omission

Expressions 20 Page 24 Figure 3

Apologies to: **Prof Pinhas Bar-Yoseph** (third on the right) for the ommission of his name in figure 3 caption.It should read as follows:
J. Fish, R. Ohayon and P. Bar-Joseph at the reception.

conference diary planner

9 - 11 July 2007 **ECCOMAS Thematic Conferences on Meshless Methods**
Venue: Porto, Portugal *Contact:* www.eccomas.org

16 - 20 July 2007 **ICIAM07 - International Congress on Industrial and Applied Mathematics**
Venue: Zurich, Switzerland *Contact:* www.iciam07.ch

23 - 26 July 2007 **9th US National Conference on Computational Mechanics**
Venue: San Francisco, USA *Contact:* me.berkeley.edu/compmat/USACM/main.htm/

5 - 7 September 2007 **COMPLAS 2007 - 9th International Conference on Computational Plasticity. Fundamentals and Applications**
Venue: ***Barcelona, Spain*** *Contact:* www.cimne.com

12 - 17 August 2007 **SMiRT19 - Structural Mechanics in Reactor Technology**
Venue: Toronto, Canada *Contact:* www.engr.ncsu.edu/smirt-19

23 - 24 August 2007 **JMC 2007 - Chilean Workshop on Computational Mechanics 2007**
Venue: Santiago, Chile *Contact:* www.scmc.cl

27 - 29 August 2007 **EURO:TUN 2007 - ECCOMAS Thematic Conference on Computational Methods in Tunnelling**
Venue: Viena, Austria *Contact:* www.eccomas.org

17 - 19 September 2007 **Structural Membranes 2007 - III Int. Conference on Textile Composites & Inflatable Structures**
Venue: Barcelona, Spain *Contact:* congress.cimne.upc.es/membranes07

18 - 21 September 2007 **CIVIL-COMP 2007 - Civil, Structural and Environmental Engineering Computing**
Venue: St. Julians, Malta *Contact:* http://www.civil-comp.com/conf/cc07.htm

22 - 24 September 2007 **ADMOS III - International Conference on Adaptive Modeling and Simulation**
Venue: Göteborg, Sweden *Contact:* admos07@cimne.upc.edu

2 - 5 October 2007 **ENIEF'2007 - XV Congress on Numerical Methods and their Applications**
Venue: Sante Fe, Argentina *Contact:* cimne.org.ar/enief2006

17 - 19 October 2007 **ECCOMAS VipIMAGE 07 - Vision and Medical Image Processing**
Venue: Porto, Portugal *Contact:* www.eccomas.org

22 - 26 October 2007 **Pan-American Conference for Non-Destructive Testing**
Venue: Buenos Aires, Argentina *Contact:* http://www.aaende.org.ar

3 - 6 December 2007 **APCOM'07 Asian-Pacific Association for Computational Mechanics together with**
Venue: Kyoto, Japan *Contact:* www.apacm.org/apcom07-epmescXI

3 - 8 January 2008 **PLASTICITY 2008**
Venue: Kailua/Kona, Hawaii *Contact:* http://www.neat-plasticity.com/

7 - 11 January 2008 **WSCS 2008 - Winter School on Computational Science**
Venue: El Passo, Texas Contact: http://www.math.utep.edu/wscs_2008/

7 - 11 January 2008 **PACAM X - Pan American Congress of Applied Mechanics**
Venue: Cancun, Mexico *Contact:* tattard@csufresno.edu

14 - 16 May 2008 **SUSI 2008 - Structures Under Shock and Impact**
Venue: Algarve, Portugal *Contact:* http://www.wessex.ac.uk/conferences/2008/

1 - 6 June 2008 **EngOpt 2008 - International Conference on Engineering Optimisation**
Venue: Rio de Janiero, Brazil *Contact:* www.engopt.org/*Contact:*

18 - 20 June 2008 **ACI/CANMET Conference on High Performance Concrete Structures and Materials**
Venue: Manaus, Brasil *Contact:* venus.ceride.gov.ar

30 June - 5 July 2008 **8th World Conference on Computational Mechanics and Engineering**
5th ECCOMAS Congress on Computatioal Methods in Applied Sciences
Venue: Venezia, Italy *Contact:* www.iacm.info / www.eccomas.org

1 - 6 October 2008 **12th IACMG Conference**
Venue: Goa, India *Contact:* www.12iacmag.com

12 - 15 January 2009 **AfrCCM'09 - 1st African Conference on Computational Mechanics**
Venue: Sun City, South Africa *Contact:* http://www.afrccm.com/