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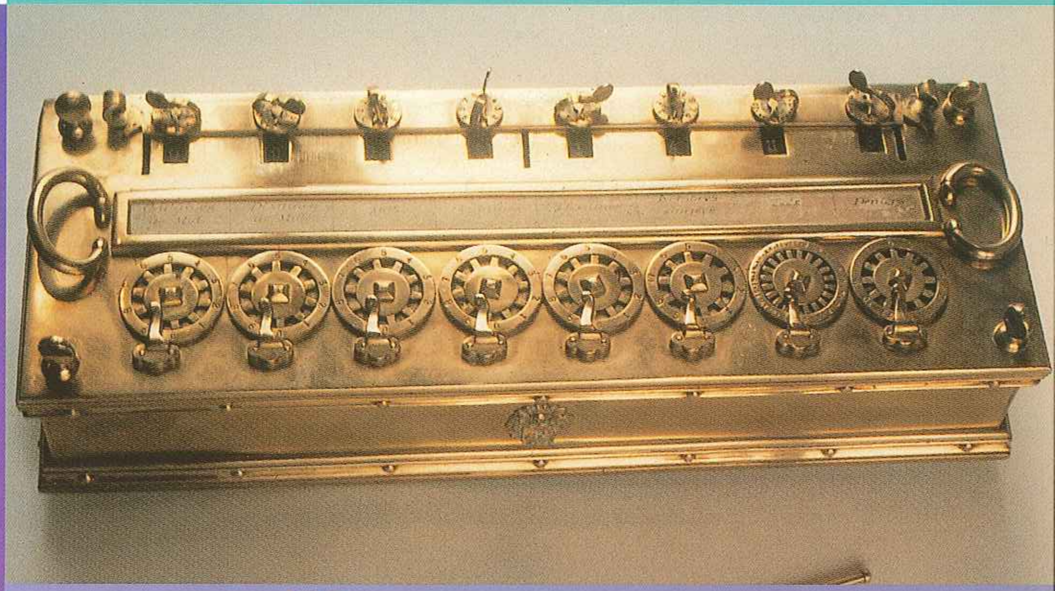

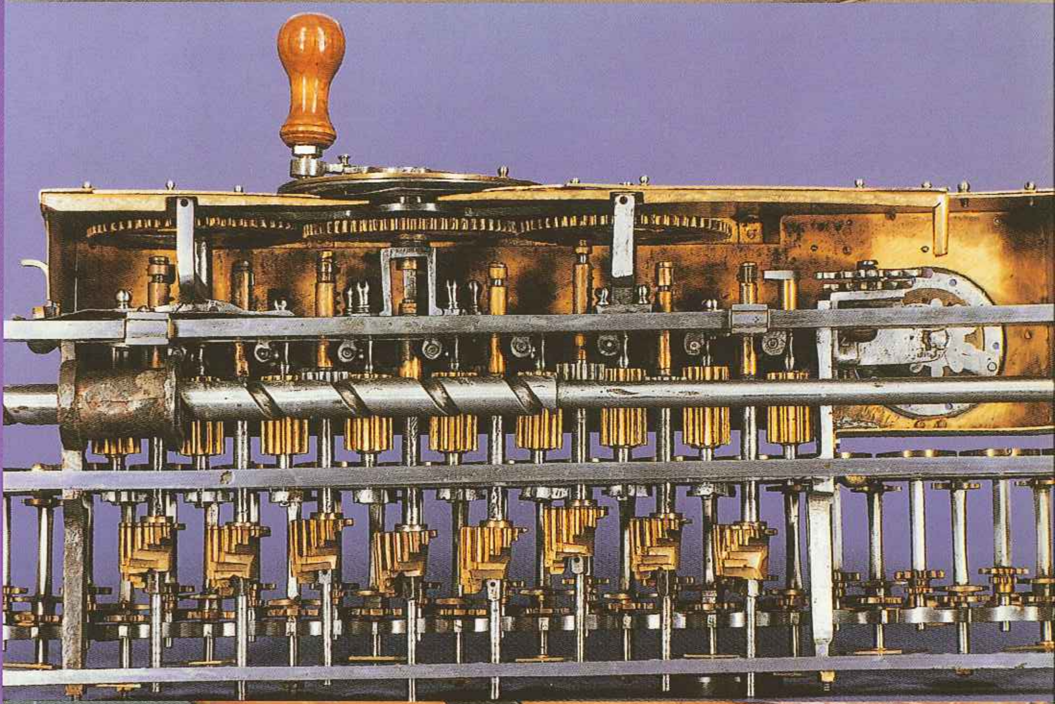

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by Erwin Stein and Karl Popp

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editorial

Does Supercomputing have a Future?

I recently attended a meeting of the U.S. National Academy of Engineering held at the Lawrence Berkeley Laboratories. The theme of the meeting was the title of this editorial. Various scientists from academia, industry and government laboratories gave their views on the topic. There were very diverse opinions expressed and the discussions were very lively. Obviously, this topic bears on Computational Mechanics. At one time finite element programs such as NASTRAN and DYNA3D were reputed to use more supercomputer CPU cycles than any other software. However, today´s computing landscape is substantially different from what it was in earlier days of Computational Mechanics. I have been actively involved in computing for 35 years. Over this time platforms of choice have evolved from mainframes and supercomputers, to minicomputers and minisupercomputers to workstations to the presently ubiquitous PC's. The conquest of the microprocessor and the ascendancy of networking technologies have changed the face of computing in general and supercomputing in particular.

What is a contemporary supercomputer? Today´s supercomputer paradigm is parallelism in which thousands of processors are linked by high-speed networks. Typically, the processors are commodity microprocessors, but there are exceptions in which very high-performance custom processors are also being used, such as for the 40 teraflop supercomputer being built by NEC in Japan for weather forecasting and atmospheric sciences. The scale of contemporary supercomputers is mind boggling: The proposed supercomputer for the Los Alamos National Laboratories has a footprint of 40 meters by 65 meters! It will be located on the second floor of a building specifically designed and built to house it. The first floor will contain the cooling and power systems! The price tag - approximately one billion dollars. There are smaller versions being built and several are already in use at various U.S. national laboratories such as Lawrence Livermore and Sandia. These are the so-called ASCI machines. One was decommissioned within three years because it had become obsolete. Microprocessor technology is still marching along according to Moore´s Law — speed and memory double approximately every eighteen to twenty-four months. This creates a fundamental dilemma for supercomputing: Given the enormous cost of building a supercomputer and the rapidity of microprocessor obsolescence, can supercomputing be economically justified? On a wide scale, the answer seems to be no. However, for critical scientific questions and national defense, the answer appears to be yes.

As far a Computational Mechanics is concerned the microprocessor seems to have captured the field. Small parallel microprocessor systems are also becoming widely used in larger engineering organizations. I would define "small" as a hundred processors or fewer, but that number will probably grow in the future. It is interesting to note that parallelism has become a pervasive technology despite the fact that among the numerous computer companies formed to develop and market parallel machines none succeeded. This is a vivid example of the difference between a successful technology and a successful business.

It is amazing what one can do these days on a single-processor lap-top computer. Nevertheless, the appetite for more speed and memory, if anything, is increasing. There always seems to be some calculation that one wants to do that exceeds available resources. In the 35 years I have been computing this seems always to have been the situation. It makes me think that computers have always and will always come in only one size and one speed: "Too small and too slow." This will be the case despite supercomputers becoming the size of football fields!

Tom Hughes
IACM President

Trends in Computational Structural Mechanics

After dinner talk
delivered by
Karl S. Pister
23 May 2001
at the
Trends in Computational Structural Mechanics Conference
Lake Constance
Organised by
Wolfgang A. Wall and colleagues
under the auspices of the
German Association of Computational Mechanics

Ladies and Gentlemen, it is my pleasure to have this chance to speak at the Conference, bearing in mind that we have been admonished not to pay special attention to the birthday of our colleague, Professor Ekkehard Ramm. In observance of that constraint, I bring a special recognition that is independent of birthdays. It is a well-known fact that Professor Ramm is the leading expert in Europe on the famous Golden Gate Bridge in the San Francisco Bay Area. Acting upon the acclamation of a group of structural engineers in California, who shall remain unnamed, I am delighted to present to Ekkehard a symbol of his recognized expertise, a photo taken during the construction of the bridge sometime in the 1930's. I note in passing that this occurred before he was born, thus is not connected in any way with his birthday or its celebration.

Now let me begin my "official" remarks. On October 8, 1926, at a meeting of the Structural Division of the American Society of Civil Engineers in Philadelphia, Pennsylvania, Professor Harald Westergaard, then Professor of Theoretical and Applied Mechanics at the University of Illinois, Urbana, presented a paper entitled: **"One Hundred Fifty Years Advance in Structural Analysis"**. I would like to begin using excerpts from his presentation. I quote:

"The ancient bridges, the vaults, arches, and flying buttresses of the great medieval cathedrals, and the riggings of sailing vessels at the height of their development, bear witness of structural insight on the part of the builders; but the art of structural analysis, except for small beginnings, is only about 150 years old."

That would place its age today at 225 years old. Westergaard continues with the statement:

"Structural analysis is based on the physical properties of materials; its method is mathematical; its purpose is design. It came into existence by a meeting of physics, mathematics, and engineering."

Figure 1: *Delegates arriving for the dinner*

The discussion of the paper contained some interesting comments. S. Timoshenko, then Professor at the University of Michigan, wrote:

"It is a consequence of the ancient structural project at Babel (as the story goes), that linguistic barriers have hampered the progress of science. These barriers have become of slight concern to the English speaking peoples with reference to many of the languages, especially French and German, but, unfortunately, the Russian barrier is not so easily surmounted. The writer takes this opportunity to help remedy this, and to elaborate the reference made to the Russian tradition."

Timoshenko then goes on to mention the names and contributions of a number of well-known figures in the history of mechanics: Daniel Bernoulli, Euler (neither were Russian, but Swiss, with a very rich Russian patroness), Jouravski (shear stresses in beams), Golovin (curved bars), Kriloff and Boobnov (theory of the structure of ships) and Jassinsky (theory of elastic stability).

It is interesting to note in passing that Timoshenko failed to mention the name of Galerkin. However, in his treatment of the evolution of the Theory of Elasticity, Westergaard remarked:

"Much work has been done during the last ten or fifteen years on the subject of the flexure of slabs. Two names should be mentioned: A. Nadai in Germany and B. Galerkin in Russia."

Today few would connect the major contributions of these researchers with flexure of slabs, although Nadai's book, ***Die Elastischen Platten***, written in 1925, is of historical interest.

In describing the development of the theory of statically indeterminate structures Westergaard identified leading principles and their discoverers. In as much as these principles connect directly to contemporary theories of structures and of solids I will note them. First, the appearance of the Maxwell-Mohr equations and their systemization by Mueller-Breslau, followed by Castigliano's principle of least work. He then identifies the work of a fellow Dane, Ostenfeld, who, in 1925, published a book entitled ***Die Deformationsmethode.*** Here he described the equations of elasticity as having the same form as the Maxwell-Mohr equations except that loads and deformations had changed places. Finally, he calls attention to "W. Ritz in a notable paper published in 1908 gave emphasis to a principle of minimum which lends itself particularly well to approximate solutions." One might observe that in 1926, when Westergaard presented his review of structural analysis, most of the necessary elements to enable the birth of the field of computational structural mechanics were available, save one critical element - how to actually do the computing, even for structural systems whose degrees of freedom were of relatively low order. There surely were heroic attempts to deal with what can be called the "curse of dimensionality". In the field of structural analysis the method of Hardy Cross, moment distribution, stands out. While for continua, the method of relaxation of Sir Richard Southwell must be mentioned.

Without wishing to do an injustice to other work which occurred between 1926 and sometime in mid-twentieth century, let me jump ahead to that time. The term "structural mechanics", not to mention "computational structural mechanics", did not appear in the literature until some time after the mid-nineteen hundreds. Certainly, at the time I was a graduate student a half-century ago, those terms did not yet exist. Continuum mechanics, mechanics of solids, theory of plates, theory of shells, and structural theory were largely, if not entirely separate fields of study with only minimal connection, either in terms of researchers in these fields or unifying underlying structure. Computation meant using a hand crank calculator, or if one were lucky, an electric calculator. "Numerical analysis" was a course given in mathematics, largely disconnected from any engineering applications.

If one characterizes the disparate nature of the subject at that time by examining books, the following would appear:

Love's *Theory of Elasticity*
Timoshenko's *Theory of Elasticity, Theory of Plates and Shells, Theory of ElasticStability*
Mushelishvili's *Theory of Elasticity* (translated by Radok)
Sokolnikoff's *Theory of Elasticity*
Grinter's *Theory of Structures*
Lamb's *Hydrodynamics*

Continuum mechanics was still largely a very abstract area of applied physics, often infused with the tensor formalisms of Levi-Cevita and McConnell. The work of Truesdell and his collaborators was only beginning to emerge at this time.

In the area of computation for structures Newmark at Illinois was a pioneer in the application of computational methods to structural problems, particularly in the area of structural dynamics.

A book by Salvadori and Baron at Columbia was another landmark in computational methods for structures. All of this, however, would experience a dramatic change as a consequence of unrelated, yet highly synergistic occurrences which I will turn to shortly. I still recall the time when I first gave a course in Plates and Shells, together with my late colleague, Egor Popov. I started the course with theory of plates. I remember telling my students that it seemed strange to teach a course on elastic plates that was unconnected to the theory of elasticity! One of the most useful resources at that time was Girkmann's ***Flaechentragwerke.***

The invention first of the vacuum tube and then transistorized digital computers opened the door to numerical analysis at an unprecedented scale. However, left alone, it probably would not have dramatically changed mechanics of solids and structures. What was required were new insights as to how both continua, as well as structures (still disparate entities) could be modelled for purposes of analysis and design. Happily, this occurred independently in at least two places: The appearance of the paper **"Stiffness and Deflection Analysis of Complex Structures"** by Turner, Clough, Martin and Topp - which led ultimately to the birth of the term ***"finite element method"*** was one occurrence. To this I would add the papers on Energy Theorems by Argyris and Kelsey, leading to the birth of the term ***"matrix displacement method"***. It would take years for these two terms to be united. Note that in the beginning finite elements were very physical in concept. It would take some years before the mathematical structure would emerge and develop. Here I must pause for an historical interjection: I offer proper recognition of Euler and Courant on the one hand and Zienkewicz on the other. Oleg did not discover the finite element method at the beginning. I recall a seminar that he presented at Berkeley in the 1950's in which he solved anelastic torsion problem using Southwell's relaxation method. I give him credit, however, for being a very fast learner, as his most recent three-volume edition of his now renowned work with Bob Taylor testifies.

The forces of finite element methodology, digital computation and burgeoning research in mechanics of solids and structures led to a noteworthy event at Berkeley in the late 1950's - the adoption of the name ***"structural engineering and structural mechanics"*** for a division of our department of civil engineering. That is the first time I recall seeing the term ***"structural mechanics"***, however I am open to challenge on this very local view of the world. Probably the term had multiple origins of which I am unaware.


Figure 2: Karl Pister


Figure 3: Ekkehard Ramm receiving his picture award

> "... I still have a clear memory of the vigorous discussion that took place over the question: "Is there a scholarly, intellectual basis that supports the adoption of the term `computational mechanics' as an academic discipline?"."

Computational mechanics presents a different story for me. In the early 1980's at the request of Nick Perrone, who then headed ONR's research program in mechanics, together with the late Mel Baron, I co-chaired a National Research Council study on computational mechanics. Although I have long forgotten what the report of that committee contained, I still have a clear memory of the vigorous discussion that took place over the question: "Is there a scholarly, intellectual basis that supports the adoption of the term `computational mechanics' as an academic discipline?" While there still may exist lingering doubts in the academies of the world over the resolution of this question, I would be surprised to find a challenger here present. This group would not be surprised to know that a young researcher on the committee by the name of Tinsley Oden was the champion of the significance of this new discipline of computational mechanics.

Finally, in the last decade the evolution of networked computers, from ARPAnet to Internet to Internet II, together with email and websites, has gone a long way to removing the linguistic barriers which Timoshenko described in Westergaard's paper.

In my opening remarks I made brief reference to a poem familiar to German people - der Erlkoenig. It is only fitting that I should also close with a poem - one that is probably familiar to no one among us save myself. Although nearly four decades old, I believe it still has great relevance, especially to this conference. It appears in the Proceedings of the Fourth International Congress on Rheology, held at Brown University in August 1963. Written by Barry Bernstein, and titled "Rheol-logic" it does not mention structural mechanics but has a lot to do with the continuing evolution of computational structural mechanics. ●

Rheol-logic

The tensor tramps across the page,
and fields of functions stage by stage
Inform the reader in the know
Of how the stress affects the flow.

No cone or plate need shear a goo
To find the laws of nature true,
But all is known to those who think
And nothing flows but printers' ink.

For by the rules of logic rheol,
To which the erudite appeal,
By word and wit and cogitation
Come true and trusty revelation.

You need not stir a can of paint
To find what is or see what ain't.
Just follow through the mathematics
Of stress and flow and creep and statics.

Yet stay before you open the books,
It's not so easy as it looks.
No spring, no dashpot leads you on
No molecules to lean upon.

Just tensors, fields, and energies,
Just talk and inequalities
In utmost generality.
All else is but banality.

How many heads have spun and reeled
Confronted by a classic field?
How oft have students felt upset
By new, unheard-of alphabet?

The rational assured mechanic
May drive a simple soul to panic,
When concepts new and old are flung
Both here and there in Caesar's tongue.

But hold before you seek a tryst
To meet your psychoanalyst.
Just learn the ways of secret cults
To seek some new and grand results.

New terms you think to add and state
Your try your best to complicate,
And should a problem make you weary
You turn instead to newer theory.

And as you think you wield your pen
You write and publish, talk, and then
When all is done and seems perfections,
You print additions and corrections.

Figure 4 and 5:
Delegates enjoying a light moment at the dinner

The Top 10 Computational Methods of the 20th Century

by
Dan Givoli
Technion
Israel Institute of Technology

In the January/February 2000 issue of the journal *Computing in Science & Engineering*, a joint publication of the American Institute of Physics and the IEEE Society, the guest editors J. Dongarra and F. Sullivan put together a list they entitled "Top Ten Algorithms of the Century." Their goal was "to assemble the 10 algorithms with the greatest influence on the development and practice of science and engineering in the 20th century".' In the May 2000 issue of *SIAM News*, B.A. Cipra briefly described these 10 algorithms. They are: (1) the Monte Carlo method, (2) the Simplex method, (3) Krylov Subspace Iteration method, (4) Householder Matrix Decomposition, (5) the Fortran Compiler, (6) the QR algorithm, (7) the Quicksort algorithm, (8) Fast Fourier Transform (FFT), (9) the Integer Relation Detection algorithm, and (10) the Fast Multipole algorithm.

Researchers and practitioners of *Computational Mechanics* (CM) will surely observe that not all of these algorithms are close to their hearts. On the other hand, undoubtly one can think of algorithms which are extremely important to CM and do not appear in the Dongarra-Sullivan list. Also, the appearance of the Fortran Compiler as an item in the list is puzzling, since as important to scientific computing it may be, Fortran cannot really be regarded as an algorithm. In this light, I thought it would be appropriate to compile a new list, which consists of 20th-century numerical algorithms and methods that have influenced CM the most.

Four of the ten algorithms of the original list are retained in the new list. These greatly influenced CM as well as many other fields of science and engineering. The rest are replaced because their particular impact on CM is felt to be smaller.

> *" It is often claimed that FEM is the single most important invention in computational engineering. "*

Before presenting the new list, four remarks have to be made. First, the items on the list are numerical "methods",' not just "algorithms". The difference between the two notions is not clear-cut - both are mathematical procedures to solve a given type of problem by performing a finite number of steps. However, generally the steps of an algorithm are very basic, whereas the steps of a method are more involved; each step of a method may be a known algorithm in itself. Second, we broaden the list even more, such that each item represents a *family* of related methods. The reason is that in most cases it is the combined effect of the whole family that has an impact on CM, not just a single method devised in this family.

Third, the list consists of methods that are believed to have influenced CM greatly; the influence of a method is judged only by how much it is used in current CM work. This influence measure is rather objective, in contrast to the "importance" of a method which is subjective and very hard to judge. Finally, the proposed list is unavoidably biased due to the author's specific background, knowledge, interpretation and taste. For example, the reader will notice the author's emphasis on techniques that are particularly useful in solid FE analysis...

So here is the proposed top-10 list in chronological order.

1. The Finite Element Method (FEM)


R Courant


J Argyris


O.C. Zienkiewicz

How could FEM be forgotten in the original list? No need to tell the readers of IACM Expressions how central in CM FEM is.

It is often claimed that FEM is the single most important invention in computational engineering. FEM can be described as a general method for the approximate solution of partial differential equations based on a variational (or a weak) formulation.

The method was originally devised by the famous applied mathematician R. Courant in 1943 [1], but was totally ignored (mainly because of lack of computers back then) until it was reinvented by engineers in 1956. One of the pioneers was R.W. Clough, who also coined the term `finite elements' [2]. Other recognized early developers include O.C. Zienkiewicz and J. Argyris. See, e.g., the historical accounts by Oden [3] and Zienkiewicz [4].

Closely related to FEM is the *Boundary Element Method (BEM)* which was developed much later, and combined known integral equation techniques and FEM ideas. The first work using BEM in its modern form can be traced back to a seminal paper by T.A. Cruse and F.J. Rizzo in 1968 [5]. See also the historical account by Rizzo [6].

2. Iterative Linear Algebraic Solvers

Almost every single numerical method in CM involves the solution of a linear algebraic system, $Ax = b$. It is well known that direct solution methods like Gaussian Elimination are effective only for small and moderately-large systems, whereas very large systems (say, of dimension larger than 10,000) must be solved iteractively. Since CM very often leads to very large algebraic systems of equations, iterative linear solvers are extremely important in this domain.

Effective iterative schemes exploit the special structure of the matrix A, such as symmetry and sparseness.

Iterative methods for the solution of $Ax = b$ started to appear in 1950, with the invention of the method of *Krylov spaces* and the method of *Conjugate Gradients* by Hestenes and Stiefel [7] for symmetric matrices. Since then these methods have been improved significantly, and many new iterative methods have been invented, such as *GMRES* by Saad and Shultz (1986) [8] for non-symmetric matrices, which is widely used today in CM applications.

3. Algebraic Eigenvalue Solvers

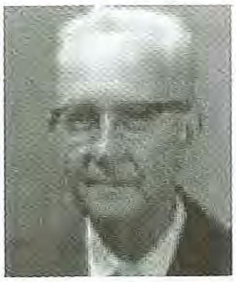
C. Lanczos

Both the standard eigenvalue problem $Kd = \lambda d$ and the generalized eigenvalue problem $Kd = \lambda Md$ occur often in CM, e.g., in free vibration or buckling analyses. Often the matrices K and M are large and sparse.

A powerful method that solves both types of problems had been devised in 1950 by *Lanczos* [9]. About ten years later, J.G.F. Francis developed the now well-known *QR algorithm* for computing eigenvalues [10]. During the 60's and 70's the QR method dominated the field, because in contrast to the Lanczos method which was invented to compute a few extreme eigenpairs, the QR method finds all the eigenvalues of a reasonably small matrix almost as fast as a few.

However, since the 80's, when large eigenvalue problems started to attract attention in CM, the Lanczos algorithm had a glorious "come-back" because it was particularly appropriate for such problems, and enabled the efficient computation of a small portion of the eigenmodes.

4. Matrix Decomposition Methods



A. Householder

Many algebraic solution techniques (for both linear-system solvers and linear-eigenvalue solvers) in use today are heavily based on matrix decomposition (or factorization), namely on the ability to express a matrix as a product of simpler matrices.

The simpler matrices may be diagonal, triangular, symmetric, skew-symmetric, orthogonal, etc.

In the context of CM, the decomposition often has a physical meaning as well. Examples include spectral decomposition and polar decomposition.

The pioneer in this area is *Householder* that has shown, in a sequence of papers starting in 1951, why matrix decomposition is very useful and has developed factorization algorithms. The most accessible reference on this work is Householder's book from 1964 [11].

5. Finite Difference Methods for Wave Problems

In the early days of CM, systems of ordinary differential equations emanating from (hyperbolic) wave problems were solved by the classical Euler time-integration techniques. However, in the late 50's the CM community realized that special methods developed directly for wave problems were in need.

Two early time-integration methods that are still commonly used today are the family of schemes developed by *Newmark* in 1959 [12] for structural dynamics, and the *Lax-Wendroff* scheme devised in 1960 [13] for the solution of 1st-order hyperbolic systems. Later many other schemes were proposed, with some improved properties. We mention for example the *Hilber-Hughes-Taylor* scheme from 1978 with improved numerical dissipation.

One important issue that arises in the computational solution of hyperbolic and parabolic-hyperbolic problems is that of discontinuity capturing, and especially capturing of shock waves. The classical finite difference methods could not resolve discontinuities properly. S.K. Godunov was the first to recognize the difficulty and in 1959 proposed, for problems in fluid dynamics, the now well-known *Godunov* scheme [14]. This opened the way to various *upwinding* and *flux-splitting* schemes proposed by van Leer (1974, 1982), Steger and Warming (1979), Roe (1980) and others, which can be found today in many of the modern production codes.

Related methods have been developed in the context of the Finite Volume Method and FEM as well.

> *"... early time-integration methods that are still commonly used today are the family of schemed developed by Newmark in 1959 for structural dynamics, ..."*

6. Nonlinear Algebraic Solvers

Most problems in CM are nonlinear. Discretization in space and time leads to a nonlinear system of algebraic equations. When large-scale problems started to be considered when it was realized that classical nonlinear solvers, like Bisection, Secant or even Newton were either not powerful enough or were inefficient.

One important family of improved solvers is that of *Quasi Newton (QN)* schemes. The first QN method was suggested by Davidon in 1959 [15], and was later publicized and improved by Fletcher and Powell. A QN method which became famous was the *BFGS* scheme which was developed in 1970 independently by Broyden, Fletcher, Goldfarb and Shanno.

A totally different approach to nonlinear problems with nonlinearity of a non-monotone nature is represented by *Arclength* methods (called `continuation methods' by mathematicians). The first Arclength methods in the context of CM were proposed by G.A. Wempner (1971) [16] and E. Riks (1972) [17].

7. Fast Fourier Transform (FFT)

Spectral methods in CM often rely on the discrete Fourier transform. The most important step in this context is the calculation of the first N Fourier coefficients of a function when its values at N points are given.

A straight forward calculation of the Fourier coefficients requires $O(N^2)$ floating-point operations. The FFT is an algorithm for doing this calculation with only $O(N \log N)$ operations.

The FFT method was invented in 1965 [18] by J.W. Cooley from IBM and J.W. Tukey from Princeton University and AT&T Bell Labs. The method had an immediate enormous impact on signal processing, but its contribution to CM and other branches of computational science were very important as well.

J. Tukey

8. Nonlinear Programming

The Simplex method appearing in the Dongarra-Sullivan list is a very well-known algorithm, invented by G. Dantzig, for linear programming, namely for optimization problems with linear objective function and linear inequality constraints. However, most optimization problems encountered in CM are associated with *nonlinear* objective functionals.

On the discrete level, the simplest problems of this type are *Quadratic Programming (QP)* problems, with quadratic objective function and linear constraints. Such problems arise in various fields of CM, including elastic contact and plasticity. This class of problems is also very important because the solution of more complicated problems can be approached by considering a sequence of QP problems.

Early work on Nonlinear Programming is due to Goldfarb (1969) [19], Murtagh and Sargent (1969) [20], McCormick (1970), Fletcher (1971) and Murray (1971). Methods for large scale optimization (variations of which are used today in some optimization packages) are due to Griffith and Stewart (1961) and Murtagh and Saunders (1978).

9. Soft Computing Methods

Buddha

Traditionally, CM has been based on `rigorous' classical mathematical procedures that draw on PDE theory, theoretical mechanics, numerical analysis, functional analysis, etc. However, since the early 80's new families of computational methods, which are sometimes collectively termed "soft computing" methods, have been applied. These types of schemes are based on a heuristic approach rather than on rigorous mathematics and draw on concepts of Artificial Intelligence (AI). Despite the fact that these methods were initially received with suspicion, they have turned out in many cases to be surprisingly powerful, and their use in various areas of CM keeps increasing.

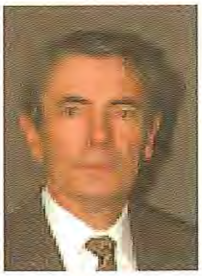
The three main techniques that had an important impact on CM are *Neural Networks, Genetic Algorithms* and *Fuzzy Logic.* All three types of methods can be thought of as general optimization techniques, but they are based on totally different methodologies.

Traces of soft computing ideas can be found already in the 40's. Pioneers include McCulloch and Pitts in Neural Networks, Holland in Genetic Algorithms and Zadeh in Fuzzy Logic - although some claim that Fuzzy Logic was invented by Buddha! In the 60's and 70's the area was advanced by computer scientists, but only since the early 80's application of soft computing methods in CM have started to appear. See, e.g., the books [21,22] and the review paper [23].

10. Multiscale Methods

T.R.J Hughes

I Babuška



T.J. Oden

Many problems in CM involve more than one length scale. Moreover, in some cases the different length scales interact with each other in a complicated way. This may occur in two levels: the physical level, where the phenomenon under consideration involves both a micro scale and a macro scale (two examples are aeroacoustics and fracture mechanics), and the numerical level, where poor resolution in one scale causes the deterioration of accuracy in another scale. Methods that address these issues are collectively called Multiscale Methods.

One famous multiscale technique is the *Multigrid* method which can be thought of as an iterative linear algebraic solver requiring only $O(N)$ operations. The chief inventor is A. Brandt, in 1977 [24].

Another approach is that of *Wavelets,* which, like simple sines and cosines, constitute building blocks of general functions, but are local and have special translation and dilation properties which allow them to resolve different scales. Wavelets have origins already in 1909 (in the thesis of A. Haar) but were formulated in the way familiar today in 1985 and later, by each of S. Mallat [25], Y. Meyer and I. Daubechies.

Research in Multiscale Methods is still very dynamic. To end with a futuristic note, let us mention, in the context of FEM, the very recent Variational Multiscale method proposed by T.J.R. Hughes [26], the Partition of Unity Method of J.M. Melenk and I. Babuška [27], and the Hierarchical Modeling approach of J.T. Oden's group [28]. All these methods are very promising but are still evolving and only time will tell what impression they will leave on CM.

Acknowledgment

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> *"Research in Mulitscale Methods is still very dynamic .... these methods are very promising but are still evolving and only time will tell what impression they will leave on CM."*

Integrated Multiscale Science-Engineering Framework: An Advanced Approach to Materials R & D and Engineering

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Abstract

New challenges characterize materials technology innovation. Relationships between materials science and engineering are changing. Costs and times to develop innovative systems are not decreasing. On the contrary, they are positively going up. Evolutionary improvements over classical R&D and engineering methodologies are not up to the challenge, and we envisage a new Integrated Science-Engineering Framework, based on the Multiscale concept. This vision allows us to go beyond the classical "Virtual Prototyping" concept. Multiscale represents a new "Unifying Paradigm" i.e. a common theoretical context and language to enable a real integration of science and engineering. Multiscale has a "strategic" value still not explored. It represents the basis to define new strategies for university-research-industry cooperation and a new structure for the R&D and engineering world.

Introduction

Notwithstanding an ever more intensive and extensive resort to advanced Computing, Information, and Communication technologies and methodologies, costs, times and risks to develop really innovative material and materials processing technologies and routinely insert them into production hardware, are not decreasing. Instead, in several cases, they are positively going up. The US Department of Defence recognized this critical situation and launched the Accelerated Insertion of Materials (AIM) program1 just to deal with these issues. In this scenario some key questions arise:

- Are evolving/incremental improvements to classic computational research and engineering methodologies up to development challenges, or is a new conceptual and methodological framework, overcoming traditional divisions between science and engineering models, methods, and views, really needed ?
- Are current methodologies for modelling and simulation adequately suited to take full advantage of the continuous advances in computing technologies (teraFLOPs computers, high speed networks, etc.) or is progress in technology still to be matched by advances in methodology?
- What relationships are there between modelling and simulation in the teraFLOPs and petaFLOPs era and the traditional experimental/testing approach?

The fundamental thesis of this article is that we need a cultural revolution for R&D and engineering methodologies to realize a revolution in the technology innovation process both in the materials and other fields. Several large-scale programs have been already launched in US to develop and apply new concepts and methods such as multiscale and science-based engineering, with particular reference to the materials field: the National Science Foundation (NSF) Knowledge and Distributed Intelligence (KDI) initiative2, the Department of Energy (DoE) Accelerated Strategic Computing Initiative (ASCI) and Academic Strategic Alliance Program (ASAP)3, the National Partnership for Advanced Computing Initiative (NPACI)4 and National Computational Strategic Alliance (NCSA)5. Multiscale is the cornerstone of this ongoing revolution but its "revolutionary potential" has not been fully analysed and understood.

"Multiscale represents a new "Unifying Paradigm" i.e. a common theoretical context and language to enable a real integration of science and engineering."

PRESENT SCENARIO ANALYSIS

R&D and Engineering Process Fragmentation

Science is increasingly at the root of technology development for materials and materials processing, but we still do not have a real "Unifying Paradigm" that allows us to rigorously correlate different science and engineering models, views, drivers, goals, metrics, languages and representations. In the R&D and engineering process we have a plethora of different not communicating models. Furthermore, experimental, testing, and computational models at different levels of detail and resolution are developed without a well defined overall strategy and without taking into account the need of exchanging data and information.

Predictive Physics-based Modelling

The development of predictive physics-based materials (and not only materials) computational models is widely considered as a key target to streamline R&D and engineering processes by reducing the resort to highly costly and lengthly experimental and testing activities. Accordingly, one of the the most critical issues for computational materials research and engineering is the rigorous definition of the models range of validity, predictive capabilities, and the related degree of uncertainty.

Unfortunately, this kind of evaluation is problematic in the present R&D and engineering framework. It is extremely difficult, if not impossible at all, to extrapolate models outside the range of availability of experimental and testing data. That is a major critical stumbling block. Achieving a real high level of predictability and the ability of reliably describing complex scientific and engineering phenomena and systems (physics-based modelling) means that two basic conditions must be satisfied:

- Researchers and engineers understand what physical length scales and phenomena and interscale relationships are important for specific R&D and design tasks and purposes. Accordingly, how "good" the models are to be.
- Researchers and engineers are able to define the range of validity of the models and, inside this range, the degree of reliability of models. In other terms, we should be able to determine what spectrum of physical phenomena can be accounted for and the related uncertainty level . A key requirement for the predictive use of modelling and simulation is the ability to define the "information space" associated with the computational models. Validation is the ability to define both characteristics and boundaries of that space.

These conditions can not be met by using classic single-scale approaches, independent science and engineering models and representations, and isolated experimental and simulation strategies and visions. The limited science/engineering integration in the computational environment severely impacts the role of modelling and simulation for R&D and technology innovation. It really hampers the possibilities opened by terascale and multi-terascale computing.

Multiscale science-engineering information analysis strategy and the integrated multiscale science-engineering framework, defined under the following heading, can represent a first answer to this critical issue.

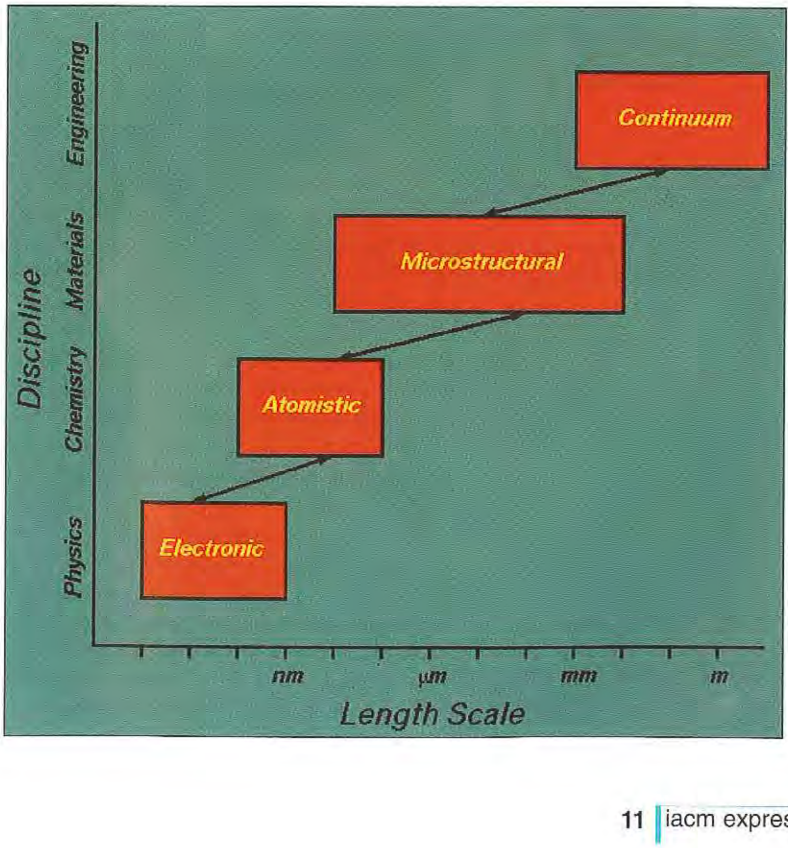
Experimentation/Testing vs. Modelling & Simulation :

When we develop innovative technological solutions, often theories are not well developed and reliable. The availability of experimental/testing data is fragmented or lacking altogether. We face a fundamental contradiction: modelling & simulation is the reference strategy for limiting risks, costs, and development times by resorting to less complex and expensive experimental and testing activities. However, contrary to what happens in the evolving technology environment, we cannot adopt this strategy because we still need very significant experimental and testing activities to develop and validate the needed computational models.

How to overcome this stumbling block ? Certainly not simply relying on more powerful computers and bigger models. I think that a new conceptual and methodological environment that goes far beyond the classical "Virtual Prototyping" approach is really needed. Virtual prototyping can be well suited for the evolutionary technology development field but not for the innovative one. The complex dynamics of technology innovation can not be fully embodied in this classical approach. In several cases, advanced modelling and simulation and experimental and testing programs are conceived and managed, if not as antithetic entities, surely as independent activities. This situation can lead to cost increases and hamper the effectiveness of both programs.

> *"It represents the basis to define new strategies for university-research-industry cooperation and a new structure for the R&D and engineering world."*

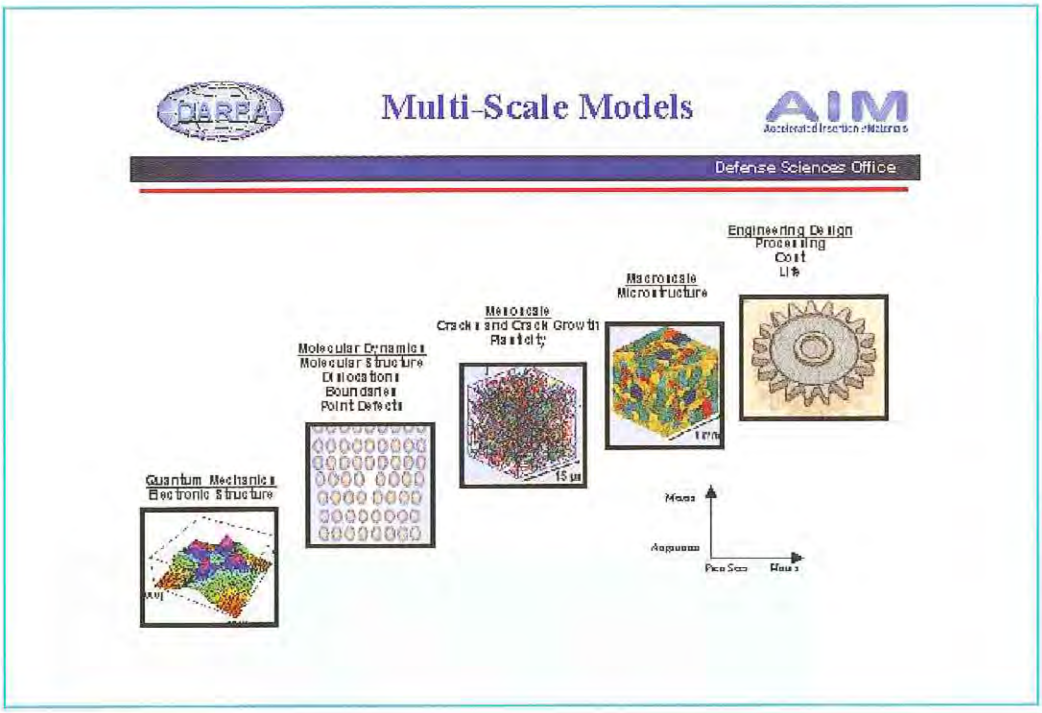
Figure 1:
University of Oxford Multiscale Materials Modeling approach



THE FUTURE SCENARIO: MULTISCALE SCIENCE-ENGINEERING INTEGRATION

New Integrated Multiscale Science-Engineering Framework

The proposed "Integrated Multiscale Science-Engineering Framework" is based on a new theoretical paradigm (multiscale) to integrate (correlate) science and engineering visions, languages, methods, cultures and strategies and dealing with systems of increasingly complexity. This new theoretical and methodological context enable us to also conceive innovative cooperative environments and strategies to be implemented through Virtual Distributed Science-Engineering Environments (VDSEEs)



Multi-Scale Models

Defense Sciences Office

Engineering Design
Processing
Cost
Life

Macroscale
Microstructure

Mesoscale
Cracks and Crack Growth
Plasticity

Molecular Dynamics
Molecular Structure
Dislocations
Boundaries
Point Defects

Quantum Mechanics
Electronic Structure

Figure 2:
DARPA Accelerated Insertion of Materials (AIM) Program Multiscale strategy

The proposed science-engineering methodological environment develops around three fundamental concepts and methods :

- ☐ A new unifying paradigm and language (multiscale)
- ☐ A new implementation strategy : "Multiscale scientific and engineering information analysis" which guides and shapes the new approach
- ☐ A New Integrated R&D and Engineering Framework

Multiscale : A new unifying paradigm and language

Multiscale is the theoretical foundation of the new integrated science-engineering framework. Multiscale entails the integrated and synergistic use of different computational, analytical, and experimental techniques with different degrees of space and time resolution which, until now, have been developed and applied in different stages of the R&D and engineering process following a fragmented vision and strategy.

Multiscale, as interpreted in this article, goes beyond the classical reductionist approach. It enables the development of systemic models that consider the global behaviour of complex systems as a whole integrating representations and information across multiple scales and disciplines.

Multiscale is not only a new method to improve reliability and predictive capabilities of computational models, as interpreted by most of US and European programs, but it can represent, as already pointed out, a new powerful "Unifying Paradigm" i.e a common theoretical context and language to enable a real integration of Science and Engineering visions and models.

Computational methodologies represent the true expression of the multiscale knowledge and they play the role of "Knowledge Integrators and Multipliers" (KIM) synthetizing classical analytical and experimental models, methods, and knowledge. Multiscale deals with both length and time scales.(spectrum of characteristic relaxation times).

A rigorous connection of quantum-based descriptions (electronic and atomic levels) with continuum level representations calls for the identification of the degrees of freedom and internal variables at the microstructural scale that determine the macroscopic material response. It is important to highlight that the behaviour of structures is determined by structural and material response. Often these two levels of response are highly coupled in particular when off-nominal, extreme operational conditions, and safety issues are concerned. A key goal for multiscale in the materials field is a new approach where we can design and control structures and materials as an integrated system. Another very important objective for innovation technology is to define engineering models which can be extrapolated with confidence outside the validation range. This result can be achieved by rigorously connecting macro parameters with underlying meso and microstructures and physical variables. Even if multiscale can not be considered as a completely mature field, it is widely recognized as a key methodology for materials research and engineering. [6,7,8,9,10,11,12,13,14]

Implementation Strategy : Multiscale scientific and engineering information analysis

The proposed R&D and engineering framework requires a general methodology to shape, guide and orchestrate the integration among the different methods at different scales and resolution levels, and assess when, to what extent, and if, multiscale and integration are really needed. It is absolutely obvious that not for all the cases and tasks, a multiscale methodology is a real need.

For that reason, we define the "multiscale scientific and engineering information analysis" methodology which foresees the following fundamental steps:

- Analysis of what kind of information, at what level of detail and reliability is needed to achieve specific technological, engineering, and operational requirements.
- Identification of the hierarchy of variables and physical phenomena occurring at different space and time scales which govern the dynamics of the system under consideration.
- Identification, for each scale, of what kind of information at what level of precision and reliability (uncertainty definition) is needed to achieve the previously identified technological, engineering and operational requirements (Information-driven Analysis).
- Analysis of interscale relationships and definition of the schemes to transfer information across the different scales and computational/experimental procedures.
- Selection of a set of multiscale and multidisciplinary computational, experimental, analytical procedures and definition of the sequence through which such procedures are to be used.

Together with a top-down approach, we can consider a bottom-up approach which is best suited to evaluate the impact of advances in the scientific domains on engineering developments.

In some cases can be useful to combine both approaches. Multiscale Science-Engineering Information analysis could ease the evaluation of how progress at fundamental scales (atomic, molecular, micro, and meso) can affect the development of new technological solutions. Multiscale Science-Engineering Information analysis can also represent the basis we can build upon new university-research-industry cooperation frameworks because it rigorously correlate not only scales but also teams and disciplines.

Integrated R&D and Engineering Frameworks

Multiscale, Multiscale Scientific And Engineering Information Analysis, and the KIM concept are the foundations of a new Integrated R&D and Engineering framework. The multiscale concept and method also extends to experimentation and testing, allowing the development of true integrated multiscale and multidisciplinary R&D and engineering design methods. However, we highlight that, presently, multiscale is essentially bound to computational methodologies.

Multiscale experimental/testing strategies are only at a very preliminary development stage. This is an important research line for materials science and engineering. The ultimate goal of the new R&D and engineering environment is a full integration of multiscale analytical theories, multiscale computational methods, and multiscale and multisensor experimentation and testing techniques. This integration will improve the ability of researchers and designers to resolve, identify, and understand new physics which represents the basis of technology innovation. Modelling & Simulations, viewed as "Knowledge Integrators and Multipliers", can serve as a powerful laboratory through which we "fuse" information and knowledge from different methodologies to make discoveries and reach a fundamental understanding of emerging elusive phenomena.

Advanced experimental methods and technologies are absolutely critical to resolve physics at greater resolution than presently embodied in the simulation codes and characterize unknown phenomena and processes which represent the needed knowledge basis to develop new theories and the related computational models across dramatically different scales (length and time). It is a two-way dependence. Data and information get with advanced experimental/testing techniques represent the needed prerequisite to the development of new analytical theories and predictive physics-based computational models and their validation. In turn, physics-based models will be more and more fundamental to design ever more detailed experiments, interpret the data, and enable integration of data from multiple experimental sources.

> *"It enables the development of systemic models that consider the global behaviour of complex systems as a whole, integrating representations and information across multiple scales and disciplines."*

"At the same time, the development and implementation of new multiscale computational methods running on very powerful computers opens the way to the definition of completely new experimental and testing techniques and strategies."

Simulation and experiments, jointly, provide critical tests of the updated theories which, in turn, represent the needed basis to develop new experimental/testing strategies, and so on.

It is an interactive interplay. The synthesis of different scientific and engineering methodologies is a fundamental way for innovating technology but this kind of synthetist is not embodied in the classical "Virtual Prototyping" concept.

It is worth noting that if computing technologies and methodologies make continuous significant progress, even experimental and testing technologies are continuously progressing. It is sufficient to think of the impact that the Scanning Tunnelling Microscopy (STM) and Atomic Force Microcopy (AFM) techniques have had on materials research. An effective R&D and design methodology should find the way of synergistically taking advantage of advances in both the fields. These relationships and interdependencies are automatically accounted for in the KIM concept in a better and more comprehensive way than inside the classical Virtual Prototyping approach.

From an operational point of view, even if attention to integration issues increases, there are still conceptual and methodological relationships not thoroughly examined between challenges and advances in modelling and simulation, and progress and challenges in experimental and testing techniques.

More complex and large-scale computations call for increasingly sophisticated and expensive experimental techniques, and viceversa. This implies that the effective use of teraFLOPs and petaFLOPs computers is dependent on developing methodologies and related environments that facilitate integration among (multiple scale) modelling and simulation, and (multiple scale) experimental and testing visions, models, and methods. At the same time, the development and implementation of new multiscale computational methods running on very powerful computers opens the way to the definition of completely new experimental and testing techniques and strategies.

Multiscale experimental/testing methods also open the way to new validation procedures for predictive science-based computational models.

Multiscale and System Design

New multiscale methods enable the design of hierarchical multilevel (from nano to macro), multifunction systems and structures which tightly integrate different technologies performing different functions at different scales. The interactions between different components and technologies (materials, fluidics, biological structures) involve an extremely wide range of time and geometrical scales and several different physico-chemical phenomena. The multiscale system design approach opens the way to new strategies for complex systems control. A combination of new sensors, meso, micro and nano systems, and distributed computing systems can lead not only to innovative control schemes, but a wealth of revolutionary engineering and manufacturing solutions provided that we will be able to integrate all the scales and disciplines involved. New sensors will be able to deliver not only "averaged" data and information, as in the past, about space and time variations of key physical and technological variables (pressure, temperature, chemical composition,....) but the detailed map of local values and rates at different levels of resolution and time and space scales. This kind of information can also be used to develop and validate off-line physical models no longer based on an empirical and semi-empirical (averaged) knowledge but on a first principles understanding of the physical reality. Highly detailed real-time models to control technological systems will grow out of this new level of understanding and will run on an array of distributed HPC systems. A "Revolution in Technology" can emerge from this scenario.

The "Strategic Value" of Multiscale

We point out that we can have two interpretation levels for multiscale :

- Operational and Algorithmic, which is being widely accepted and pursued in the Academic and Research world;
- Strategic which is still to be explored, defined, and implemented.

The "Unifying Paradigm" concept and the "Multiscale Scientific and Engineering Information Analysis" allow us to define the "Strategic" value of Multiscale for R&D and engineering. Multiscale, in this context, holds a "revolutionary potential" to reshape the whole structure and organization of the R&D and engineering world for materials and other key technological sectors.

In particular, multiscale can contribute to:

- Define new cooperation and partnering schemes among, academy, research, and industry;
- Define a new structure and organisation for the research and industrial world (Virtual Distributed Multicale Science-Engineering Environments) based, from a technological point of view, on classical Virtual Distributed Environments and, from a methodological point of view, on the multiscale framework.

MULTISCALE APPLICATION EXAMPLES

Applications of the new multiscale science-engineering methodologies include :

- performance prediction in extreme thermal, mechanical and chemical environments new processing and recycling technologies for advanced alloys, composites, ceramics, intermetallics;

- development of novel materials and processes emerging from basic science (e.g ultrapure materials, surface and interface science, nano-technology, etc.).

a) Materials Characterization

A key and reference program in the materials field is the Computational Materials Program15 carried out at Lawrence Livermore National Laboratory. Its fundamental objective is to simulate and accurately predict the performance of advanced materials and systems in extreme operational conditions.

b) Composite Mechanics

Two significant programs in this area are the NASA Langley Computational Materials16 and the ONERA Multiscale Mehanics of Composites17 programs

c) Processing: Films Growth

Several organisations and universities started programs in this areas (MIT18, DARPA19,..). A full hierarchy of variables and physico-chemical phenomena at the different scales governs the process:

- Macroscopic (growth rate, film uniformity, and film composition);

- Intermediate (point defects, dislocations, stacking faults, grain boundaries, voids, surface morphology and compositional uniformity);

- Microscopic (atom diffusion and reaction).

Time scales range from femtoseconds (i.e., the period of lattice vibrations) to hours (the duration of growth runs).

Space scales range from angstroms (fractions of the lattice spacing for strain calculations) to meters (dimensions of the deposition reactor) on the length scale.

Separated models are not up to the challenge: Thin film properties (thermal and electrical conductivity or intrinsic stress) are coupled with intermediate scale phenomena which are controlled by atomic scale surface phenomena operative during deposition processes that, in turn, are governed by the thermal fields and mass flows within the reactor.

Conclusions

To really streamline the R&D and engineering process for materials and processing we can not go on adapting existing methodologies and hoping that the availability of more and more powerful computers, more and more capable networking and software systems will automatically solve problems.

Figure 3:
Livermore hierarchical multiscale strategy for tantalum characterization

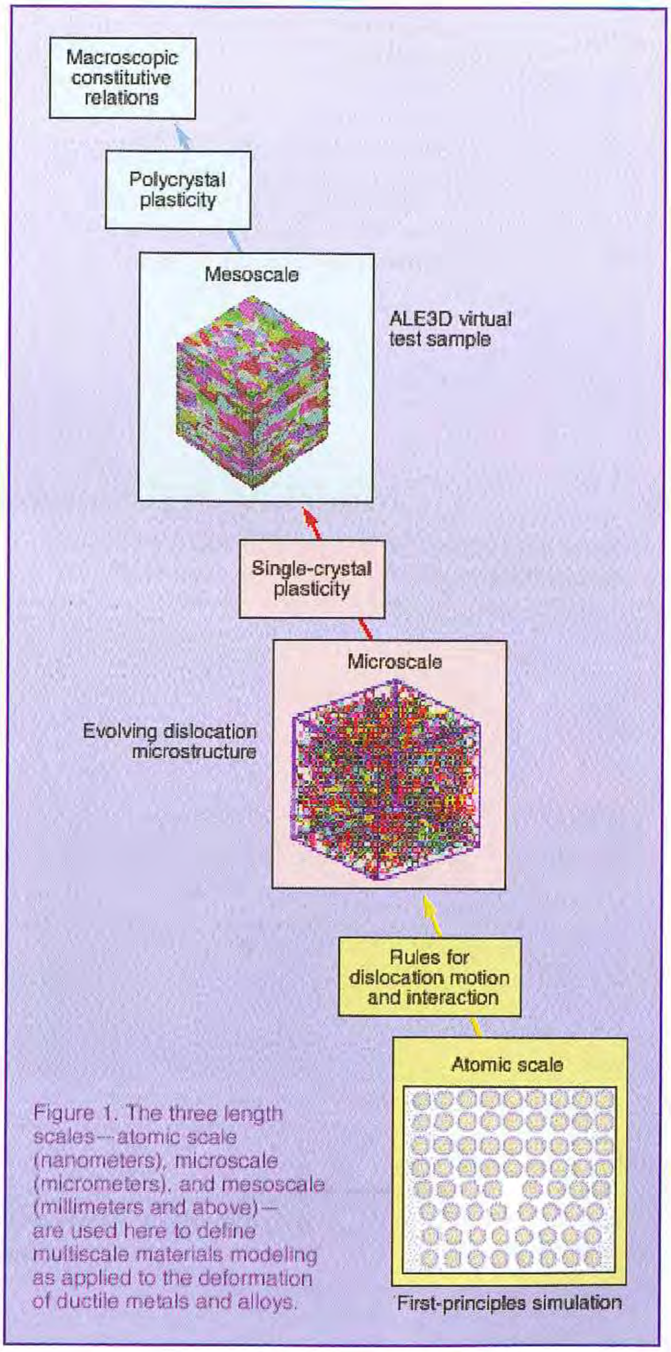


Figure 1. The three length scales—atomic scale (nanometers), microscale (micrometers), and mesoscale (millimeters and above)—are used here to define multiscale materials modeling as applied to the deformation of ductile metals and alloys.

> *"The ultimate objective of this article is to stimulate reflections about the limits of R&D today, engineering methodologies, and activate a wide and comprehensive debate about the definition of new solutions."*

Breaking computing speed, networking bandwidth, and computational model dimension records can be a necessary condition to improve R&D and engineering processes but it is still to be demonstrated that is also a sufficient condition. While an ever growing number of European and US universities and research centres start multiscale programs in the materials and other fields, its "revolutionary (strategic) potential" on R&D and engineering is still largely not explored.

We lack in-depth analyses of the impact of multiscale on technology innovation processes university-research-industry cooperation structures and strategies. We can postulate that the impact can be relevant, as done in this article, but we can not demonstrate that. The ultimate objective of this article is to stimulate reflections about the limits of R&D today, engineering methodologies, and activate a wide and comprehensive debate about the definition of new solutions.

Acknowledgments

I would like to thank Prof. I. St. Doltsinis, Faculty of Aerospace Engineering, University Of Stuttgart, for his fruitful suggestions, the continuous support, and several stimulating discussions. ●

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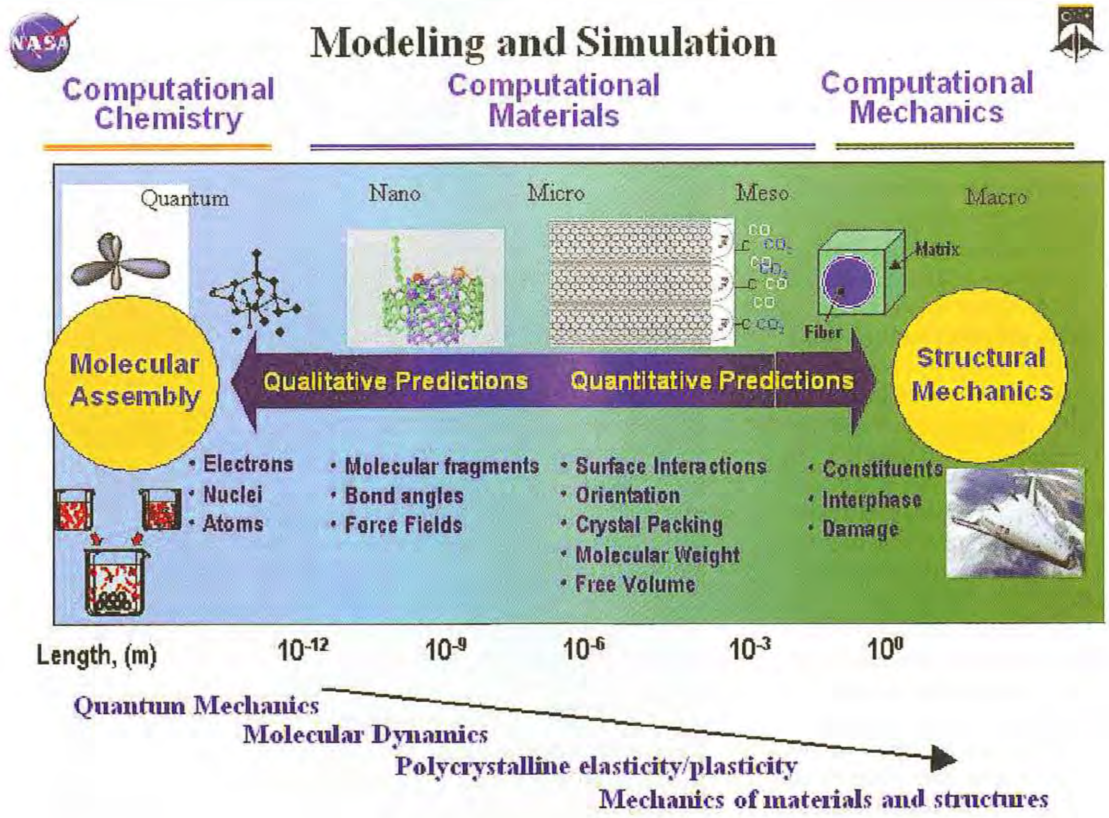
Figure 4: NASA Langley Computational Materials Program



Jacques-Louis Lions

Honouring the founder of the French Applied Mathematical School

Jacques Louis Lions, 73, a world recognized applied mathematician, passed away on May 17, 2001 after a long illness. Born in Grasse, France, on May 2, 1928, Professor, University of Nancy 1954-1962, Professor, University of Paris 6, 1962-1973; Professor, Ecole Polytechnique, 1966-1986, Professor at College de France, 1973-1998, he talentuously taught modern mathematics, supervized many doctoral students from France and other countries and anticipated the profond impact that parallel computers would have on applied mathematics to solve challenging applications of industry and society.

His research activities were focused on Partial Differential Equations, Analysis and Control of Systems, Scientific Computing with applications to Environment, Aerospace Engineering, Energy, Production, Telecommunications.

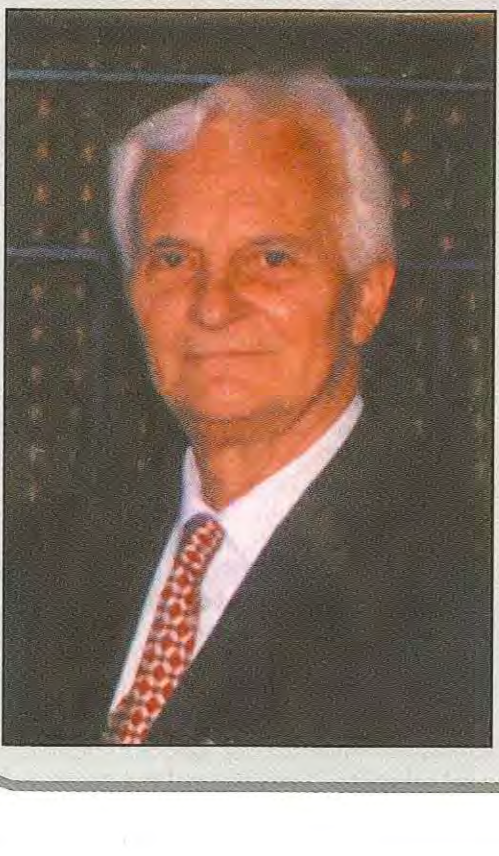
All along his outstanding career, J.L. Lions played a very important role in promoting mathematics with their applications to industry. He created and led a french school of mathematics famous in the world and inspired a new generation of applied mathematicians who in turn widened the influence of his school.

He was a member of the French Academy of Science at the early age of 45, then President elected of it from 1996 to 1998 and as chairman of the Comite 2000 coordinated a report of assessment of scientific issues facing the 21st century Society at the request from the President of the French Republic. J.L. Lions was also a member of many foreign academies, namely National Academy of the US, Royal Society, Russian Academy of Sciences, Academia Sinica and Academie Pontificale. He was also Doctor Honoris Causa of many universities and a founding member of Academia Europae and recently of Académie des Technologies.

Author of many books (the landmark work on control theory being his 1968 book on Contrôle Optimal des Systèmes Gouvernés par des Equations aux Dérivées Partielles), he received for his outstanding contribution to Applied Mathematics numerous prizes, including the John von Neuman Prize in 1986, the Japan Prize and the Harvey Prize in 1991 and the Lagrange Prize in 1999.

Among his numerous responsabilities he was from 1980 to 1984 the first President of INRIA promoting scientific computation through the French National Institute for Research in Computer Science and Automation and President of Centre National d'Etudes Spatiales from 1984 to 1992 during which critical decision were made with the european ARIANE 5 rocket, the HERMES Space Vehicle and the TOPEX POSEIDON satellite. In the last period of his life he held very active high level scientific advisory positions in industry with Dassault Aviation and Elf.

To illustrate his clear cut position in modern Sciences and Technologies, J.L. Lions chaired in 1999 the Strategic Board of a prospective European Network of Excellence on the interactive role of Applied Mathematics and Engeneering for solving new multidisciplinary challenges, MACSInet (MAthematics, Simulation and Computation for Industry), a kernel assembled from two existing european associations, European Community for Computational Methods in Applied Sciences (ECCOMAS) and European Consortium for Mathematics for Industry (ECMI); his last introductory lecture delivered at the kick-off meeting of MACSInet in Amsterdam on November 23, 2000 was entitled: "APPLIED MATHEMATICS WORKING AT INTERFACES"» and started as follows :



"Alan Turing is reported as saying that PDE's are made by God,
the Boundary Conditions by the Devil !
The situation has changed , Devil has changed places.....
We can say that the main challenges are in the INTERFACES
with Devil not far away from them..."

He is survived by his wife Andrée and his son Pierre- Louis who, as a distinguished mathematician, won a Fields Medal in 1994- a great happyness for him-.

Many colleagues and friends will remember J.L. Lions as an exceptional human being, modest, competent, warm and extraordinary human.

Jacques Periaux,
Dassault Aviation, Direction de la Prospective
IACM, Executive Council member
July 2001

CFD-Based Prediction of the Aerolastic Behaviour of High-Performance Aircraft: Towards a Change in Culture

by
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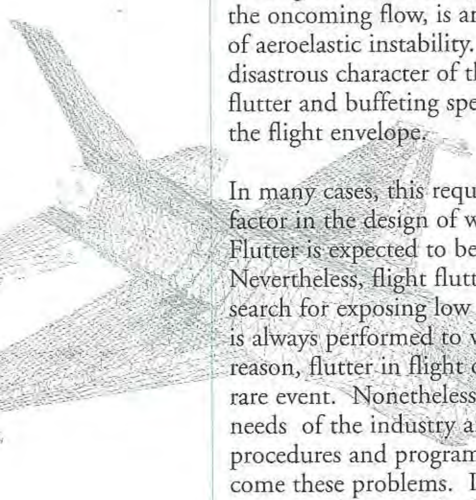
Aeroelasticity is the study of the behaviour of an elastic structure or vehicle immersed in an airstream wherein there is significant interaction between structural deformation and fluid flow. An aircraft immersed in a flow is subjected to surface pressures induced by that flow. If the incident flow is unsteady or the boundary conditions are time-dependent, these pressures become time-dependent. Moreover, if the aircraft undergoes dynamic motions, it changes the boundary conditions of the flow and the resulting fluid pressures, which in turn change the deflections of the aircraft.

If one notes that the external aerodynamic forces acting on a flexible aircraft increase rapidly with the flight speed, while the internal elastic and inertial forces remain essentially unchanged, one can easily imagine that there may exist a critical flight speed at which the flexible aircraft becomes unstable. Such instability may cause excessive structural deformations and may lead to the destruction of some components of the aircraft. Flutter, which is an unbounded oscillation in time of a structure caused by the high-speed passage of air along or around it, is an example of such instability problems. Limit cycle oscillations are a nonlinear phenomenon where the amplitude of the vibrations of the structure can be important but remains bounded in time. Hence, flutter is catastrophic and must be avoided at all costs, while LCO is essentially a fatigue problem. Buffeting, which is the unsteady loading of a structure by velocity fluctuations in the oncoming flow, is another important example of aeroelastic instability. Because of the potentially disastrous character of these phenomena, aircraft flutter and buffeting speeds must be well outside the flight envelope.

> *"...aerospace executive once stated... 'We can't afford these flutter guys'."*



In many cases, this requirement is the determining factor in the design of wings and tail surfaces. Flutter is expected to be eliminated by design. Nevertheless, flight flutter testing - which is the search for exposing low damping regions in flight - is always performed to verify a design. For this reason, flutter in flight of an approved aircraft is a rare event. Nonetheless, cases occur. The special needs of the industry are for reliable yet noncostly procedures and programs to anticipate and overcome these problems. Indeed, dealing with flutter issues can be so costly that an aerospace executive once stated with respect to the aeroelastic analysis costs in development of a small STOL (Short Take-Off and Landing) aircraft "We can't afford these flutter guys" [1].

Linear theory of dynamic aeroelasticity

In the linear theory of dynamic aeroelasticity, it is assumed that an elastic aircraft immersed in an unsteady flow with a free-stream velocity V_∞ undergoes a damped harmonic motion characterized by *small displacement amplitudes*, a *wet* (or aeroelastic) circular frequency ϖ, and a wet positive or negative damping coefficient $\overline{\alpha}$. It is also assumed that the airflow surrounding the aircraft can be accurately predicted by an *inviscid linearized theory*. Furthermore, the dynamic response of the aircraft is usually represented by the first m modes of its structure - say $20 \leq m \leq 40$. Consequently, aeroelastic stability problems such as flutter can be cast into an eigenvalue problem where the left hand-side matrix is a real function of the reduced aeroelastic circular frequency $\overline{k}=\overline{w}/V_\infty$, and the eigenvalue is a complex number whose imaginary part vanishes when and only when $\overline{\alpha}$ is zero. It follows that a critical value of $\overline{k}', \overline{k}^{cr}$, is that for which the flutter eigenvalue problem has a real eigenvalue.

Given a free-stream Mach number M_∞ and a free-stream density, the critical value of the reduced frequency, if it exists, can be found by sweeping on $\overline{k}$ and solving the flutter eigenvalue problem until a real eigenvalue is found. In that event, the flutter mode of the aircraft is the mode i for which $\overline{\alpha}_i^{cr}$, the flutter speed of the aircraft is $V_\infty^{cr}=\varpi_i^{cr}/\overline{k}^{cr}$, and the flutter dynamic pressure $\lambda^{cr}=\rho_\infty V_\infty^{cr^2}/2$. Such a procedure for extracting the flutter speed of an aircraft is known as the "k" method [3]. It is accurate when the assumptions stated above hold, and when the structure is less than 10% damped. When the structure has a higher percentage of damping, an improved version of this procedure known as the "p-k" method [4] is preferable for finding the flutter dynamic pressure. Assuming that the positive or negative $\overline{\alpha}_i$ coefficients are small, the variations of the aeroelastic frequencies and damping coefficients with the Mach number can also be predicted by sweeping on M_∞ and solving the flutter eigenvalue problem.

The "k", "p-k", and other computational procedures for flutter analysis that are based on the *linear* theory of aeroelasticity are fast and memory lean. For this reason, they are popular in the aerospace industry. In the subsonic regime, most if not all of these procedures rely today on the doublet-lattice method [5] for computing the linear aerodynamic operator that appears in the left hand-side of the flutter eigenvalue problem.

It is interesting to note that this method, which was developed over thirty years ago, remains today the most used method for predicting subsonic unsteady flows in production environments, for both load and flutter analyses. In the supersonic regime, various methods related to the piston theory [6] are used for these purposes.

Unfortunately, high-performance military aircraft are usually flutter critical in the transonic speed regime where LCO, aileron buzz, and shock-boundary layer oscillations may also be encountered. In that regime, the mixed subsonic-supersonic flow patterns and shock waves are such that the linear flow theory in general - and therefore the doublet-lattice method in particular - are not reliable for predicting the unsteady aerodynamic forces acting on an aircraft. As a result, flutter testing of a scaled model in a transonic wind tunnel is always used to generate corrections to flutter speeds computed by linear methods. However, the design, construction and testing of a wind tunnel flutter model, and the analysis of the resulting data, typically require over a year's time. For this reason, leading authorities in this field from *industry* have recently noted that *"Even at present, existing* CFD [Computational Fluid Dynamics] *codes should be able to obtain five flutter solutions in one year"* [7], and suggested that *"The results of a finite number of* [nonlinear] CFD *solutions could be used as a replacement for wind tunnel testing, assuming a validated code was available"* [7]. Such statements signal a timely change in culture in the aeronautics industry. However, it remains for the research community to investigate whether CFD-based nonlinear aeroelastic analysis capabilities can take on this challenge, and eventually contribute to the development of such a sought-after validated code.

Three-field formulation of nonlinear fluid-structure interaction problems

During the last decade, a research group led by the author has been developing, at the University of Colorado a high-fidelity, high-performance, CFD-based nonlinear aeroelastic simulation capability. The foundation of this effort is the three-field formulation in the time domain of coupled fluid-structure interaction problems that was first introduced in [8]. The formulation is quite general. It can address many aeroelastic problems besides flutter, including the prediction of steady and unsteady loads and control surface effects in level flight and maneuvering, aeroelastic tailoring, and performance analysis. In that formulation, the structure is no longer restricted to a harmonic motion with small displacement amplitudes, and its response is not necessarily represented by a truncated basis of its normal modes. In principle, there is also no reason to confine the constitutive modeling of the structure to that of an elastic material. However, while aircraft structures can undergo large displacements and rotations, they seldom experience large strains. Therefore in many applications, the nonlinear modeling of the structural behaviour can be limited to the proper accounting of nonlinear geometric and free play effects. More importantly, the aerodynamic forces acting on the structure are no longer predicted in that formulation by the use of a linear aerodynamic operator, because of the limitations associated with such an approach, particularly in the transonic regime. Rather, the unsteady forces are determined from the solution of the compressible Euler equations when viscous effects can be neglected, and the solution of the compressible Navier-Stokes equations augmented by a large eddy simulation or a turbulence model otherwise. Furthermore, no restriction is imposed on the nature of the fluid-structure coupling, which is numerically modeled by suitable fluid-structure interface boundary (or transmission) conditions.

The origin of the three-field rather than two-field formulation of fluid-structure interaction problems goes back to the following observation. One difficulty in handling numerically the fluid-structure coupling stems from the fact that the structural equations are usually formulated with material (Lagrangian) coordinates, while the fluid equations are typically written using spatial (Eulerian) coordinates. Therefore, a straightforward approach to the solution of the coupled fluid-structure dynamic equations requires moving at each time-step at least the portions of the fluid grid that are close to the moving and flexing aircraft. This can be appropriate for small displacements but may lead to severe grid distortions when the structure undergoes large motion. Different approaches have emerged as an alternative to partial regridding in transient aeroelastic computations, among which stand out the arbitrary Lagrangian-Eulerian (ALE) formulation [9] and the closely related method of dynamic meshes [10]. These approaches treat a computational aeroelasticity problem as a two-field coupled problem. However, a moving mesh *(Fig1)* can also be viewed as a pseudo-structural (or fictitious structural) system with its own behaviour [8], and therefore, the coupled transient aeroelastic problem can be formulated as a *three-* rather than two-field problem: the fluid, the structure, and the dynamic fluid mesh. This three-field formulation has shed new light on the mathematical understanding of the numerical behaviour of various algorithms applied to the solution of the coupled fluid-structure problem, and has enabled the development of faster solution algorithms [11-15].

> *“...it remains for the research community to investigate whether CFD based nonlinear aeroelastic analysis capabilities can take on this challenge, and eventually contribute to the development of such a sought-after validated code.”*

Figure 1:
Unstructured moving fluid grid

N proc	CPU Total	CPU Fliud	CPU Mesh	CPU Structure	Parallel Speed-up	Parrallel Efficiency
1	69.8 hrs	62,00%	37.4%	0.2%	1.0	100%
3	24.6 hrs	64.6%	34.8%	0.6%	2.8	95%
6	12.8 hrs	63.3%	35.4%	1.3%	5.4	91%
12	5.9 hrs	57.1%	40.1%	2.8%	11.9	99%
24	3.3 hrs	52.7%	42.7%	4.6%	20.9	87%

As can be expected, the simultaneous solution of the governing nonlinear fluid, fluid mesh, and structure equations of motion is computationally intensive, and raises some concerns about the feasibility and practicality of this approach in production environments. However, because of significant advances in computational methods and the advent of parallel processing, the three-field CFD-based solution of nonlinear aeroelastic problems is now sufficiently mature and fast to be considered as a reliable simulation environment for addressing some of the critical flight conditions of a high performance aircraft.

Some computational issues and advances

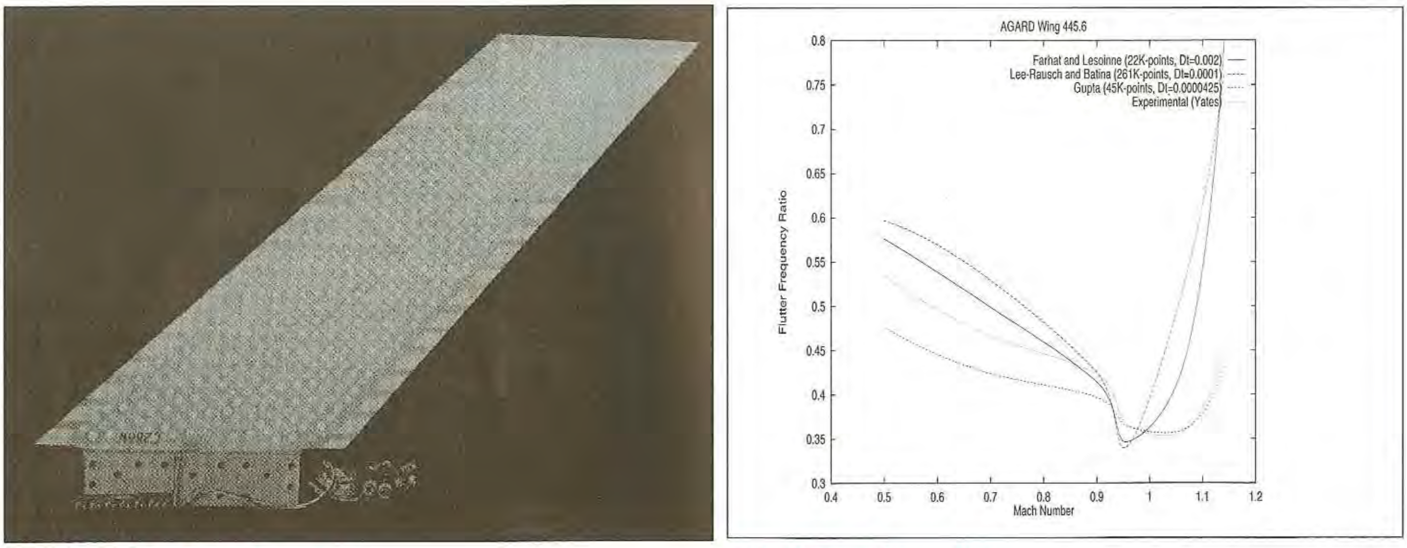
In the linear theory of aeroelasticity, the air surrounding a flying aircraft can be interpreted as an "algebraic" damper whose sign depends on the flight conditions. When positive, it attenuates any aircraft vibration excited by some initial disturbance. When zero, it only entertains it, and when negative, it amplifies that vibration. In other words, depending on the flight conditions, and particularly the Mach number, the air surrounding a vibrating aircraft can either extract energy from it, or act as a neutral agent towards it, or feed it energy and cause it to flutter. This energy interpretation of the flutter mechanism underscores the importance of *conserving* as much as possible the energy transferred between the fluid and structure subsystems when discretizing the transmission conditions on fluid and structure meshes with non-matching interfaces [16], and when solving the coupled system of fluid-fluid mesh-structure equations of motion [15]. Indeed, the extraction (transmission) from (to) the structure across the fluid-structure interface of any significant amount of spurious numerical energy can artificially stabilize (destabilize) an otherwise unstable (stable) aeroelastic system.

Since the three-field aeroelastic problem is formulated in the time domain, extracting the wet frequencies and damping coefficients of the underlying structure for flutter analysis requires post-processing of the numerical output - for example, the displacement field - by a parameter identification algorithm. Computational efficiency suggests using for that purpose an identification algorithm that requires as few cycles as possible of the predicted structural response. This in turn underscores the importance of producing a sufficiently accurate short window of the time-response, and therefore time-integrating the coupled fluid-structure [17] and not only the individual fluid and structure equations of motion [14] by a scheme that achieves second-order time-accuracy on moving grids. Usually, the aeroelastic response of the structure is dominated by its lowest modes. For this reason, computational speed - which is essential for production environments - favors implicit schemes and large computational steps, which underscores the importance of paying special attention to the numerical stability properties of the scheme designed for time-integrating the coupled fluid-fluid mesh-structure equations of motion.

The AERO simulation platform

The AERO-F, AERO-S, and MATCHER codes developed at the University of Colorado are a suite of software modules based on the three-field formulation outlined above for the solution on nonlinear transient aeroelastic problems. They are portable, and run on a large variety of computing platforms ranging from Unix workstations to shared as well as distributed memory massively parallel computers.

Figure 2:
Flutter analysis of the AGARD Wing 445.6



(a) The AGARD Wing 44.6

(b) Flutter boundary

The two- and three-dimensional AERO-F modules model a flow either by the Euler equations, or by the averaged Navier-Stokes equations equipped with the k-ε turbulence model and a wall function. They operate on static and dynamic unstructured meshes. More specifically, they combine a Galerkin centered approximation for the viscous terms, and a Roe upwind scheme for the convective fluxes. Higher-order spatial accuracy is achieved through the use of a multidimensional piecewise linear reconstruction that follows the principle of the Monotonic Upwind Scheme for Conservative Laws [18]. Time-integration on fixed grids can be performed either by a 3-step variant of the explicit Runge-Kutta algorithm, or by the implicit three-point backward difference scheme. Time-integration on moving grids is carried out by an implicit backward difference scheme that achieves second-order accuracy on dynamic meshes [14]. All linearized systems of equations are solved by the Restricted Additive Schwarz preconditioned GMRES iterative algorithm [19].

The AERO-F modules support two robust structure analogy methods for constructing dynamic meshes. The first one is based on time-dependent torsional springs [20-21]. The second method is based on the total Lagrangian approach for solving a fictitious nonlinear elasticity problem [22]. Both methods share in common the idea of constructing a fictitious stiffness of each fluid mesh element that increases to infinity when the area or volume of that element decreases to zero. This prevents all collapsing mechanisms (node-to-node, node-to-edge, and node-to-face) from occurring during the mesh motion. For applications where the structure undergoes large rotations - for example, aircraft maneuvering - the AERO-F modules invoke a corotational scheme to accelerate the update of the mesh motion [23].

The AERO-S suite of structural and thermal modules are capable of linear and geometrically nonlinear static, sensitivity, vibration (eigen), and transient FE analyses of restrained as well as unrestrained homogeneous and composite structures.

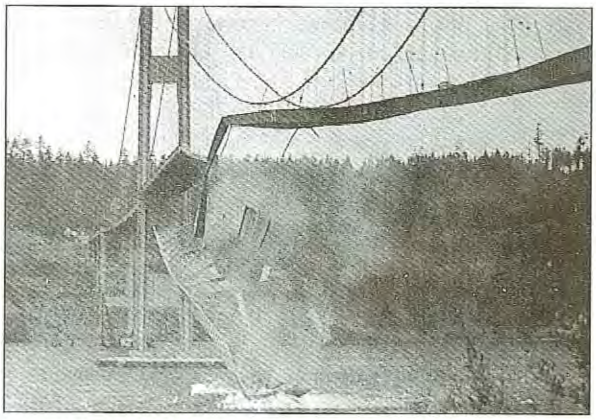
The AERO-F and AERO-S suite of codes communicate via run-time software channels. They exchange aerodynamic and elastodynamic data across non-matching fluid and structure mesh interfaces while conserving the energy transferred between the fluid and structure subsystems [16]. For that purpose, they are guided by information generated in a preprocessing phase by the MATCHER software [24].

Validation

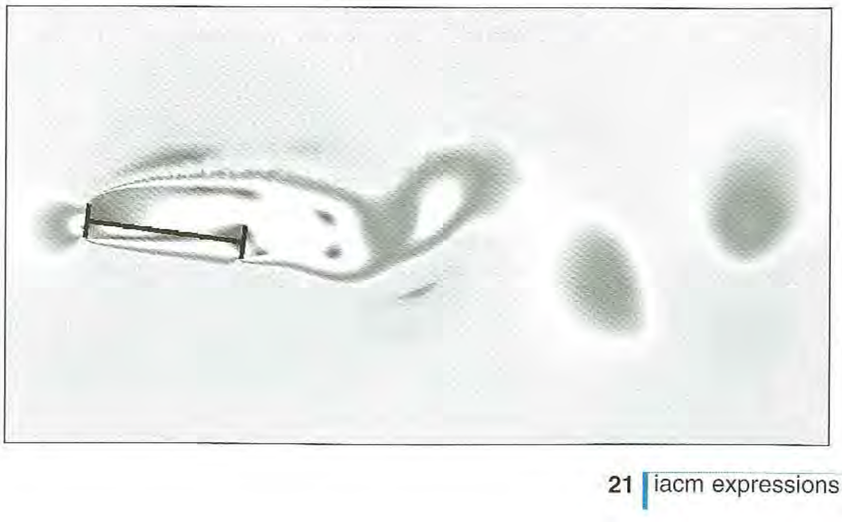
The AERO-F, AERO-S, and MATCHER codes have been validated with the three-dimensional flutter analysis of the AGARD Wing 445.6 [17] (inviscid calculations), and the two-dimensional aerodynamic stability analysis of the Tacoma Narrows Bridge (viscous computations) [21]. For the AGARD Wing 445.6 problem *(Fig.2)*, the suite of AERO codes have proved to be capable of capturing correctly the transonic dip. The have also demonstrated superior computational efficiency by operating accurately with a fluid time-step Δt_F that is 10 to 22 times larger, and a coupling time-step $\Delta t = \max\,(\Delta t_S, \Delta t_F)$ (where Δt_S denotes the structure time-step) that is 20 to 46 times larger than reported in the literature for other nonlinear aeroelastic codes [17, 26]. For the stability analysis of the Tacoma Narrows Bridge *(Fig. 3)*, the AERO simulation platform has predicted a critical wind speed of $V_\infty = 20.4$ m/s, whereas the critical wind speed observed for the torsional instability of this bridge was estimated at $V_\infty = 18.8$ m/s [25]. The 8.5% relative difference between these two numbers is small considering that the AERO analysis was performed in two dimensions, and that the assumed mechanical properties of the Tacoma bridge are tainted by uncertainties.

Figure 3:
Aerolastic Instability of the Tacoma Narrow Bridge

(a) Twisting Motion

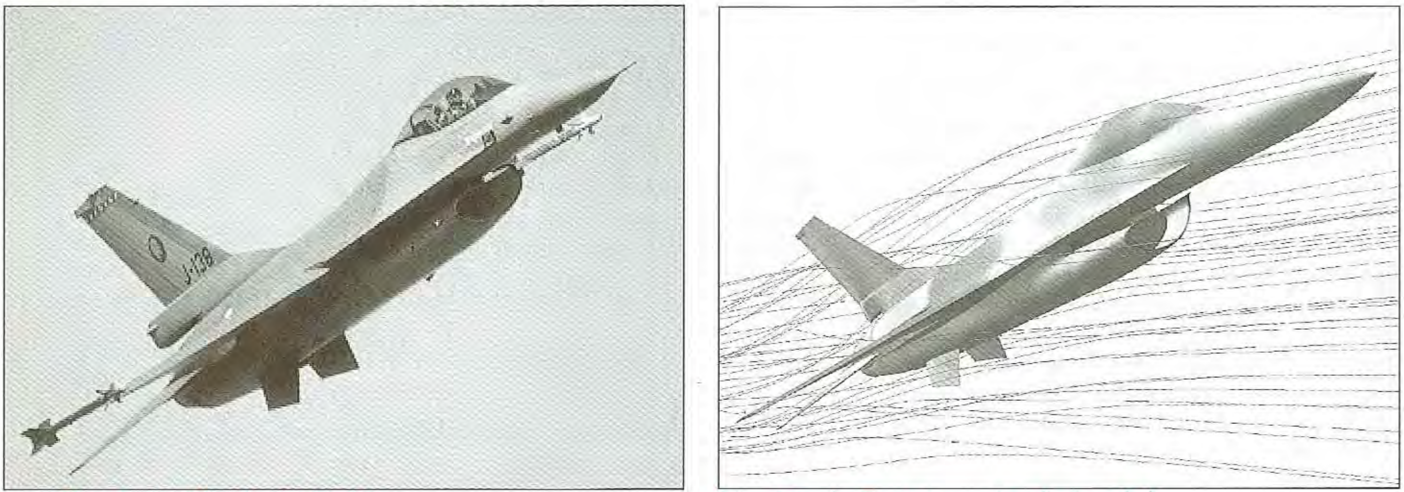


(b) Failure



(c) Simulated Vortex Shedding

Figure 4:
Aerodynamic Analysis of the F-16 Block 40 Fighter



(a) The F-16 Block 40 Fighter

(b) Mach Contours Analysis of the F-16 Block 40 Fighter

> *"...the doublet lattice method invented more than thirty years ago has stood the test of time."*

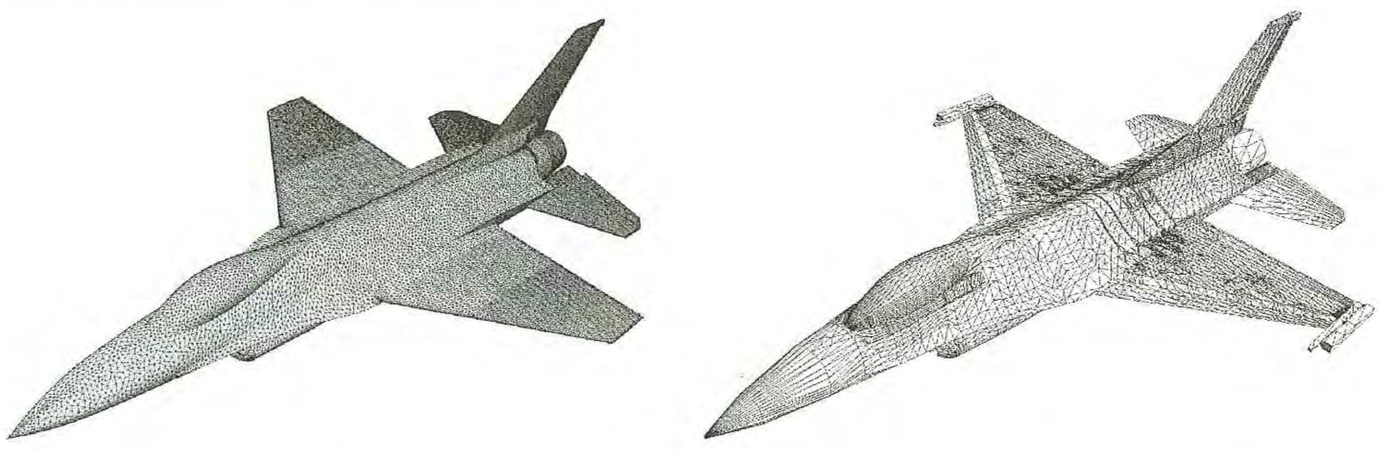
In view of assessing its potential for replacing flutter testing of scaled models in transonic wind tunnels, the AERO simulation platform was recently applied to the flutter clearance of an F-16 Block 40 in clean wing configuration but with tip missiles, for $0.7 \leq M_{\infty} \leq 1.4$ at the altitude of 3,000 m *(Fig. 4)*. Based on modeling information provided by Lockheed-Martin, a detailed three-dimensional FE structural dynamics model was constructed for the F-16 Block 40 in clean wing configuration but with a missile and launching system at each wing tip. This FE model features bar, beam, solid, plate, shell, metallic as well as composite elements, and a total of 168,799 dofs *(Fig. 5(a))*. It reproduces correctly the first ground bending and torsion frequencies which were measured as 4.76 Hz and 7.43 Hz, respectively. Using F-16 CAD data provided by the Air Force Research Laboratory at Wright Patterson and ignoring the wing tip missiles, a surface grid with 63,044 grid points was first designed *(Fig. 5(b))*, then a fluid volume mesh with 403,919 vertices was then generated.

Let $\overline{f}_{tor}$ denote respectively the frequency and damping coefficient of the first aeroelastic mode of the F-16 configuration described above that is dominated by torsion. To determine these aeroelastic parameters, a procedure replicating what occurs in flight testing was employed. The structure was excited in an appropriate manner and its response to the prescribed initial disturbance was simulated numerically. For each different Mach number, this generated 168,799 signals, one for each dof of the detailed FE structural model. However, only the vertical displacement dofs at two tip nodes and two root nodes of each wing were archived. This corresponds to positioning output sensors at these locations for flight testing. Once the signals were generated for two cycles, the Eigensystem Realization Algorithm (ERA) [27] was applied to extract from them the aeroelastic parameters $\overline{f}_{tor}$ and $\overline{\alpha}_{tor}$.

Figs. 6-7 show that the aeroelastic results produced by the AERO simulation platform correlate well with the aeroelastic torsional frequencies obtained from flight test data. More specifically, the relative errors in $\overline{f}_{tor}$ vary between 0.8% and 7%. The relative errors in $\overline{\alpha}_{tor}$ vary between 0.6% and 11%.

For the F-16 configuration described above, the AERO simulation platform sustains a coupling time-step on the order of 1 millisecond. This time-step corresponds to sampling the period of the first ground torsional mode of this fighter with 134 points. It also turns out that this time-step is such that 271 time-steps are needed to simulate the first two cycles of the structural response. The performance results for a typical F-16 aeroelastic simulation obtained on an Origin 2000 computer equipped with R10000 195 MHz chips are reported in Table 1 as a function of the allocated number of processors N_{proc}. These results correspond to a single Mach number point, two cycles of the response of the structure, and a sequential processing of the structure equations. For flutter simulations, assigning only one processor to AERO-S is justified by the fact that the linear structural solver is less computationally intensive than the flow and mesh motion solvers. The reader can observe that on average, 60% of the total CPU time is elapsed in the flow solver, 38% in the mesh motion solver, and only 2% in the structure solver. Note however that for maneuvering applications where nonlinear geometric effects must be accounted for, the percentage of the total CPU time elapsed in nonlinear structural computations is of the order of 15%.

Figure 5:
Structure and Fluid Models for an F-16 Block 40.



(a) Detailed FE Structural Model

(b) Structure and Fluid Models for an F-16 Block 40

The parallel speed-up and parallel efficiency results reported in Table 1 highlight the good parallel scalability of the AERO nonlinear aeroelastic simulation platform. One can reasonably argue that today, most aerospace engineers have access to a 6-processor computational platform. From the results reported in Table 1, it can be concluded that using such a computing system, the transonic aeroelastic parameters of a full fighter configuration can be extracted in 12.8 hours. For a given Mach number, finding the flutter speed usually requires a bracketing procedure. Such a bracketing procedure typically incurs 4 to 5 simulations that are similar to the one discussed herein. Hence, for a given Mach number, extracting the flutter speed requires between 51 and 64 hours CPU on a 6-processor computational platform. Therefore, using the AERO-F, AERO-S, and MATCHER suite of codes on a 6-processor configuration, five flutter point solutions for a fighter in the transonic regime can be obtained in less than 2 weeks. Using for this purpose 24 processors reduces the total simulation time to less than 4 days. These estimates, which do not include the time needed for building the FE structural model and generating the fluid grid, are confirmed by the author's experience with the F-16 Block 40 aircraft.

Figure 6:
F-16 Block 40: Aerolastic Torsional Frequency at an Altitude of 3.000m.

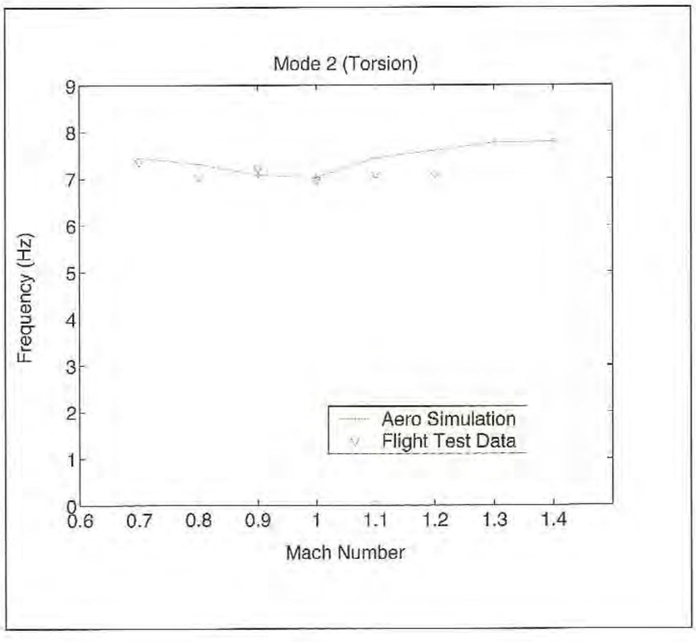
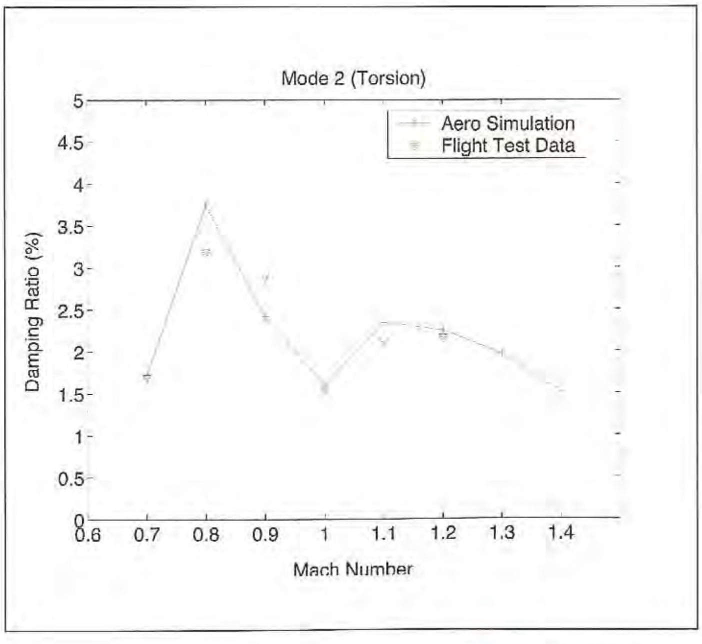


Figure 7:
F-16 Block 40: Aerolastic Torsional Damping Coefficient at an Altitude of 3.000m.



Conclusions

Because it is accurate enough for production load and flutter analyses - except in the transonic regime - and it is linear and therefore fast, the doublet-lattice method invented more than thirty years ago [5] has stood the test of time. It remains today the single most used method in the aeronautics industry for predicting unsteady aerodynamics. Unfortunately, high performance military aircraft are usually flutter critical in the transonic regime where the linear flow theory in general, and therefore the doublet-lattice method in particular, fail to predict correctly the unsteady aerodynamic forces acting on an aircraft.

Consequently, flutter testing of scaled models in transonic wind tunnels is always used to generate corrections to flutter speeds predicted by linear methods. However, the design of a wind tunnel flutter model and the analysis of the corresponding data require over a year's time. For this reason, a component of the aeronautics industry seems to be inclined to consider CFD-based nonlinear aeroelastic simulations as a replacement for wind tunnel testing, if they prove to be practical - that is, fast enough - and reliable [7]. One can reasonably expect this change in culture to continue in the near future, not only because of military aircraft, but also because of the next generation of civil transport aircraft such as the near sonic cruiser *(Fig. 8)* recently announced by Boeing [28] which will operate near $M_\infty = 1$, and because the linear theory of aeroelasticity cannot accurately predict phenomena such as LCO and buffeting, nor the transient loads and stresses developed during agressive maneuvering.

On the other hand, nonlinear aeroelastic analysis capabilities such as AERO and others developed at various research institutions are now sufficiently mature to attempt this challenge. The AERO simulation platform has been validated for a complete F-16 configuration. However, that was only one configuration. It needs to be further validated for many other configurations particularly those associated with LCO, and for civil transport aircraft which are usually characterized by thicker wings.

One can expect AERO and other similar simulation capabilities to face significant difficulties at high angles of attack, when vortex bursting in the vicinity of the aircraft can cause severe buffeting, because within such regions the flow is highly unsteady and accurate CFD computations require careful attention to turbulence modeling. These validations will require a significant amount of collaboration with the aeronautics industry. ●

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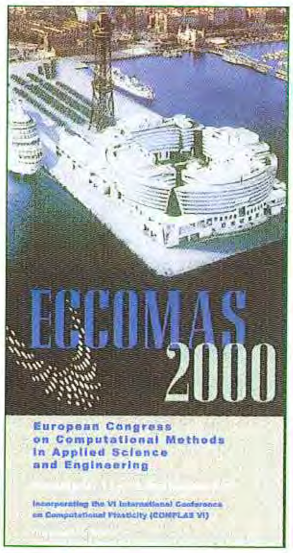
European Community for Computational Methods in Applied Sciences

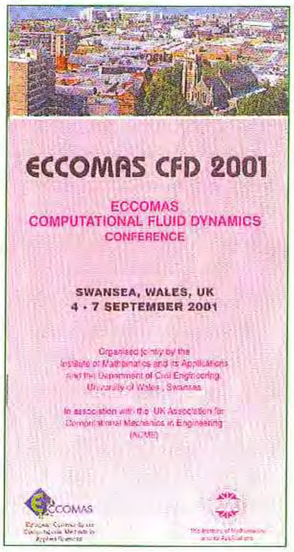


ECCOMAS is an organisation grouping European Associations with interests in the development and applications of computational methods in science and technology.

ECCOMAS incorporates all European Associations affiliated to the IACM and also represents the interests of the IACM in Europe. The cooperation between both organisations follows the agreements between IACM and ECCOMAS, signed in Göterborg on March 20th 1998 by Profs. Alf Sammuelsson and Oskar Marenholtz, then the Presidents of IACM and ECCOMAS, respectively. We expect that the continued interaction and cooperation of ECCOMAS and the IACM will result in a number of scientific initiatives which will benefit both organisations.

The core activity of ECCOMAS is the organisation of an European Congress on Computational Methods in Applied Science and Engineering. The congress is held at four year intervals. Previous editions of the ECCOMAS congress took place in Brussels (1992), Paris (1996) and Barcelona (2000). The ECCOMAS 2000 congress in Barcelona attracted some 1200 participants. A report of this congress was presented in the last issue of Expressions. The ECCOMAS 2004 Congress will be held in the city of Jyväskylä (Finland). Details are given in the box below.

ECCOMAS also organises large conferences devoted to structures and fluids. The second European Conference on Computational Mechanics: Solids, Structures and Coupled Problems (ECCM 2001) was held in Cracow (Poland) from 26 - 29 July 2001. The meeting was organised under the auspices of ECCOMAS and IACM and attracted over 500 participants.



The third ECCOMAS CFD Conference will take place in Swansea (UK) on 4 - 7 September 2001. These series of global meetings are complemented with more focused thematic conferences on state of the art topics in computational science and engineering organised with the support of ECCOMAS.

For more information on ECCOMAS and its activities, please visit www.cimne.upc.es/eccomas.

Eugenio Oñate
President of ECCOMAS

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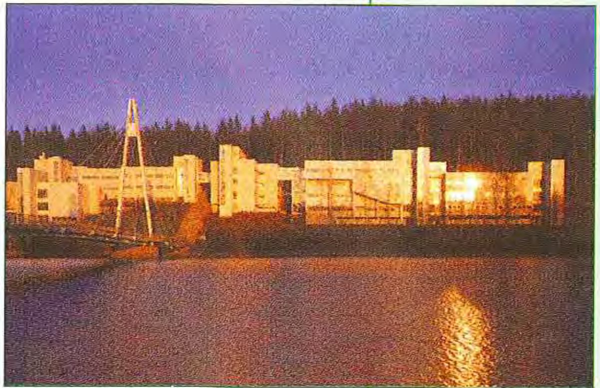

ECCOMAS is pleased to announce the fourth European Congress on Computational Methods in Applied Sciences and Engineering to take place in **Jyväskylä Finland on 24 – 28 July 2004.**

ECCOMAS 2004 will be organized in co-operation with ECCOMAS, the University of Jyväskylä, Department of Mathematical Information Technology, the City of Jyväskylä, and Jyväskylä Congresses.

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Some Aspects of the long history of three Italian Academic Institutions

by
Giulio Maier
Professor of Structural Engineering
Technical University of Milan
Italy

Only last year the IACM Past-President, Olgierd C. Zienkiewicz was elected a Foreign Member by the National Italian Academy called "dei Lincei" in Rome, and by the "Istituto Lombardo di Scienze e Lettere", Milan. Recently the Technical University (Politecnico) of Milan has announced the conferral on him of its "laurea honoris causa" in Civil Engineering in October.

Figure 1:
The "Accademia Reale dei Lincei" crest

Professor Zienkiewicz has deservedly received an exceptional, probably unprecedented, number of such honours from prestigious institutions all around the world.

The above three events, although they concern the same leading scientist, are otherwise not correlated. The concomitance of these honours gives an opportunity to once again express their congratulations and admiration to a founding father of the finite element method and pioneer of computational mechanics in general. However, as suggested by Prof. Zienkiewicz, we will mention here some unusual aspects of the long history of the three Italian academic institutions involved, rather than speaking of Professor Zienkiewicz' outstanding achievements universally known in the international community of computational mechanics.

In 1603 four young men, inspired by Galileo's work, founded an association in Rome called in Latin "Academia Lynceorum". Their purpose was to jointly look into and research nature, with the acute perception of the lynx. Two of the founders were particularly remarkable people: Federico Cesi, then eighteen, and the Dutchman Johannes Eck, then twenty-six.

When Galileo joined the Academy in 1610, it increased in number to 32 Italian and foreign scientists, but afterwards slowly decreased in member number and prestige, as a consequence of Galileo's condemnation in 1616 and Cesi's death in 1630.

In 1870, when Rome became the capital of Italy, and Quintino Sella was the Prime Minister (a scientist himself), the Academy was revived and given an official charter as "Accademia Reale dei Lincei". It was also assigned the present seat of the Palazzo Corsini (built in the 18th century and for a while residence of Queen Christine of Sweden) and the nearby Villa Farnesina (decorated by Raffaello's paintings). During the fascist period the Academy preserved its independence for years and refused to become submissive to the regime, especially during the presidency of prominent scientists like the mathematician Vito Volterra. As a reaction, the government founded the "Accademia d'Italia" (under the presidency of Guglielmo

Marconi) and abolished the "Lincei". In 1944, soon after the liberation of Rome, the "Accademia dei Lincei" was reinstated as the only national and highest cultural institution in the Italian Republic. The institution was then re-organised by a committee chaired by the philosopher Benedetto Croce, divided into two classes, that of "Physical Sciences" and "Moral Sciences".

The "Istituto Lombardo" was founded in 1797 by Napoleon, who became one of its 31 members, and by Alessandro Volta, who was the first president and whose manuscripts are all gathered in its building, Palazzo Brera, in the centre of Milan. Almost all prominent scientists who worked or were born in Lombardy were members of the institutes three "Sections" (Physical and Mathematical Sciences, Moral and Political Sciences, Literature and Arts). Besides Volta, these members included the astronomer Schiaparelli, the novelist Alessandro Manzoni, the biologist (and one of the first Nobel laureates) Camillo Golgi and the poet Eugenio Montale (Nobel prize for literature). Among the mechanicians were Beltrami, Betti, Cremona, Menabrea, Piola and Somigliana, but not, unfortunately, Carlo Alberto Castigliano, who died in Milan when he was 37 years old.

After Leonardo da Vinci's long and very productive stay in Milan (1482-1513) as chief civil and military engineer of the Dukes Sforza (and also as their most famous artist), engineering flourished in the dukedom. The many "ingeniarii" (this is the Latin name used then and later adapted to most modern languages) formed a kind of guild, the "Collegium", which for centuries had the task not only to charter professional engineers, but also to take care of engineering education. Only in 1863, the traditional university of Lombardy in Pavia added a technical university in Milan, the "Politecnico". This was followed six decades later by the University of Milan, a separate institution for sciences and humanities. According to the legacy of the main founder, the mathematician Francesco Brioschi, basic scientific researches (like the one on polymers which led to the Nobel prize in chemistry for Giulio Natta in the Sixties) have been and are being pursued at the Politecnico, as well as research in engineering and technologies. ●

Figure 2: Prof. O.C. Zienkiewicz

> *".... these honours gives an opportunity to once again express .... congratulations and admiration ...."*

Figure 3: Palazzo Corsini, the seat of the "Accademia"

The Leibniz Exhibition

Gottfried Wilhelm Leibniz (1646 - 1716)

as a Philosopher, Mathematician, Physicist and Engineer

by
Erwin Stein
University of Hannover,
Germany

In 1990, an Exhibition on Leibniz´s great achievements in mathematics, physics and engineering was produced in German language and presented at the University of Hannover on the occasion of the yearly GAMM-Conference (GAMM: Society of Applied Mathematics and Mechanics), initiated by Erwin Stein and organized by Erwin Stein and Albert Heinekamp†, the former director of the Leibniz-Archiv of the Niedersächsische Landesbibliothek Hannover, and by many other specialists and colleagues. The artistic design was made by Professor Herbert Lindinger, Universität Hanover.

In 2000 the exhibition was arranged completely new by Erwin Stein and Karl Popp with 29, both German and English figure and text panels, as well as original publications, in total 23 functional exhibits, and two accompanying books in German and English language, containing seven essays and 149 explaining figures from original pictures, machines, essays and articles as well as from functional models demonstrating Leibniz' main technical inventions. Also a five minutes video in German and English language is available.

Figure 1: Gottfried Wilhelm Leibniz

This new exhibition about the great universal scholar and inventor – now including also philisophy more pronounced – was produced on behalf of the World Exhibition in Hannover from June to October 2000 and presented at the University of Hannover in June and July 2000. After the following three-months exhibition in Kassel from August to October 2000, it will be shown in August and September 2001 at the Technical University of Berlin on the occasion of the VII International Leibniz Congress and in August/September 2002 at the Austrian Academy of Sciences on the occasion of the V WCCM of IACM in Vienna. Further exhibitions are scheduled abroad and in Germany, and we are interested to present the exhibition at other places if desired; it is equally the property of the Universität Hannover and the Niedersächsische Landesbibliothek. The authors of this report are the official representatives for its further use and development.

Motivation, Scope and Contents

G.W. Leibniz was born on 1st July 1646 in Leipzig, and he died on 14th November 1716 in Hannover where he lived for the last 40 years, interrupted by many journeys to nearly all countries of Europe. He was the first famous German philosopher of the age of Enlightenment and a great inventor and universal scholar as philosopher, mathematician natural scientist, engineer, lawyer and historian. Furthermore he tried all his life to promote and influence long–term peace contracts between the kingdoms and empires of Europe after the terribly 30 years war from 1618 – 1648 and to reunify the Christian religions after the reformation and separation in the 16th century. His overall work gives us a sense of his restless Promothean urge to achieve the virtually unachievable, namely improve the mental and physical conditions of human existence, and in the variety of his work we recognize his overarching philosophical and religious credo as a „Pacidius", a peacemaker , which is the way that he viewed himself.

Another important issue is the fact that Leibniz published only a very little part of his findings. His legacy contains about 60.000 pieces which still need the efforts of three archives in Germany for another 30 years in order to elaborate the complete edition of his written work. Therefore, many of his inventions and ideas are still only known to specialists. Such it is the purpose to communicate Leibniz´s fundamental results to the public in a conceivable and attractive manner.

The exhibits, plates and panels are designed to arouse not only scientific but also general interest into the ideas and important inventions of Leibniz in the context of his time and with references to former and later developments. This original approach to past ways of thinking and inventions is not distorted by later interpretations, and thus we emphasize the saying that the study of the masters is the true source of science. Moreover it should be pointed out that the 17th century – with the great scholars Galileo Galilei, Johannes Kepler, René Descartes, Blaise Pascal, Christiaan

The contributions of Professor Carl Popp, Universität Hannover, for the shaping and realization of the exhibition are gratefully acknowledged.

Huygens, Isaac Newton, Gottfried Wilhelm Leibniz and Johann and Jakob Bernoulli – is so to say the cradle of the following scientific and engineering age.

The goal of the exhibition is „to make Leibniz accessible" by functional models of his famous four-function decimal and the binary calculating machines, explained by large scale details of their crucial parts, as well as a converter from decimal to binary numbers, furthermore functional models of the Mariotte-Leibniz pendulum and the Brachistochrone problem (the normal cycloid as the curve of shortest time for a frictionless downgliding masspoint) and also impressive models of combined windmills and pumps for energy saving mining in the Harz mountains as well as a frequency controlled automatic brake system for windmills. Moreover, three energy saving winding engines for mining are presented and last but not least a new water supply with a pump house for the fountains of the large baroque gardens of Herrenhausen.

Leibniz's Inventions in Mathematics

Integration and Differentiation

The calculation of areas between curved lines and of volumes within curved surfaces, e.g. for determing the content of a barrel, was an important practical task already in the ancient cultures of the mediterranian countries and in Asia.

A genius approximation for integration was given by Archimedes from Syrakus, the greatest mathematician of his time, with the method of exhaustion. The area within a closed arbitrary plane curve is bounded by the areas of inscribed and circumscribed regular polygons with growing number of sides. By this method also the transcendental number À can be approximately the circle from above and from below. Several other geometrical approximations were developed by Cavalieri, Pascal and Huygens, e. g. by using suitable triangles. Various essentially algebraic methods were proposed by Descartes, Fermat, Gregory and Barrow until the middle of the 17th century.

One has to realize that the Greek mathematicians tried to solve analytical problems by geometrical methods – using circle and ruler only, and therefore they couldn't solve the three classical problems: the Delphi task (a cube with double volume), the triple division of an angle and the quadrature of the circle. Analytical methods didn't become predominant until the 17th century, then especially influenced by Descartes, but geometrical understanding and the finding of proportionality relations from figures was used furtheron by Newton, Leibniz, the Bernoullis´ and also by Euler in the 18th century – and as we still do it today with a mixture of abstract and geometrical thinking.

With respect to **differentiation**, the fundamental idea was given by **Blaise Pascal's** characteristic triangle of a curve in his **Traité des sinus du quart de circle** in 1658, *fig. 2.*

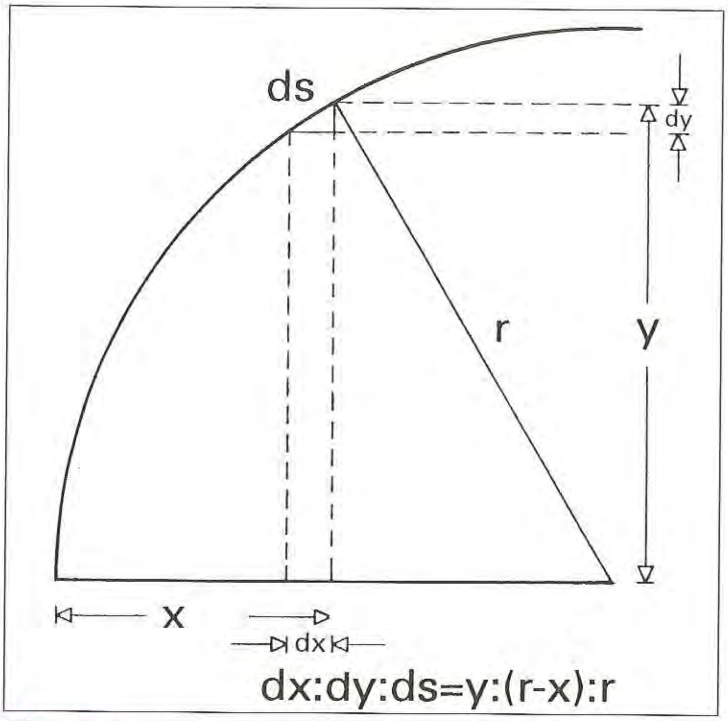


Figure 2:
Proportions of a characteristic triangle by Blaise Pascal

Isaac Newton wrote his first relevant work on the new infinitesimal calculus supposedly in 1669, entitled **De analysi per aequationes numero terminorum infinitas**, handed out to the Royal Academy not until 1695, using arithmetic power series, finding their roots, their inverse and also their term by term integration, based on earlier work of Barrow, Wallis and Mercator. He called the proportions of infinitely small quantities – so-called indivisibles – "moments" and placed them in relations to finite segments. Newton changed his concept of differentiation after 1671, using now the physical imagination of the continuous movement of a mass particle in time and space and finding its velocity at all time instants. He called these rates of movements „fluxions" with the notation $v(t) = \dot{s}(t)$. This explanation avoids differentials and allows the equal treatment of both variables time and way for describing the position of the particle, but getting also problems in case of parameter depending variables. Lateron he combined the "moments" and the "fluxious" in order to get an abstract calculus independent from mechanical interpretation. Newton claimed: I don't establish hypotheses (hypothesis non fingo), and instead used the induction principle in mathematical analysis.

As a self-taught mathematician, **Gottfried Wilhelm Leibniz** had a primarily geometrical access after reading and recognizing the importance of Pascal's characteristic triangle in 1673 during his stay in Paris from 1672 to 1676. Not knowing the unpublished work of Newton. Pascal's triangle lead Leibniz to a completely new understanding of the differential and integral calculus, including his important symbols and a systematic notation which we still use today.

> *".... calculation of areas between curved lines and of volumes within curved surfaces was an important practical task already in the ancient cultures of the mediterrianian countries and in Asia."*

Leibniz published his method in 1675 in a three-part treatise. The concept is characterized by the complementarity of differences and summations in the discrete range on one hand and the infinitesimal and integral calculus for continuous problems on the other. He got the first derivative of a differentiable function $y = f(x)$ as follows, e. g. for the quadratic parabola $y = x^2$. For the infinitesimal increments dx and dy we get $y + dy = x^2 + 2\,x\,dx + (dx)^2$. With $(dx)^2 << 2\,x\,dx$ it follows directly $\frac{dy}{dx} = 2x$. Using general polynomials he found the same rules as Newton and extended them to more general algebraic and transcendental functions. Leibniz invented the chain rule $D[f(g(x))] = \frac{df}{dg}\frac{dg}{dx}$, published in 1684, and the product rule $D^n[g(x)f(x)] = \sum_{\nu} \binom{n}{\nu} D^{\nu}[g(x)] D^{n-\nu}[f(x)]$, communicated in a letter from 1695 (published in 1710) as a "great example of the analogy between powers in algebra and differentials in infinitesimal calculus . In this context his famous alternating series $\frac{\pi}{4} = \sum_{n=1}^{\infty} (-1)^{n-1} \frac{1}{2n-1}$ should be mentioned.

"…. Leibniz introduced 'Reimannian sums´to derive the integrability of continuous functions."

He knew precisely that integration is the inverse of differentiation and introduced in 1686 the new sign · for the integral calculus with the words **"utile erit scribi · pro omnia"** (it is therefore useful to write · for all (the sum of infinitely many infinitesimally thin segments)).

In the dispute over the priority for the discovery of calculus between Newton and Leibniz people from behind heated it up. Today the independence of both inventions and methodologies is generally recognized.

It should be mentioned that in 1675, Leibniz elaborated his longest mathematical treatise he ever wrote *"On the arithmetic quadrature of the circle, the ellipse and the hyperbola. A corollary is a trigonometry without tables"*, published only 1993 for the first time. It represents a comprehensive discussion of infinitesimal geometry and contains a rigorous foundation of the theory of infinitely small and infinite quantities. In modern terms Leibniz introduced 'Riemannian sums' to derive the integrability of continuous functions.

Determinants and solving systems of equations

In ancient Chinese mathematics, a type of matrix and determinant theory appeared in the early Han period (202 B. C. to 9 A. D.) within the *Jinzhang suanshu* as part of the *"Nine chapters of the Mathematical Art"*. Different from this Takakazu Seki, founder of a Japanese school of mathematicians, published in 1683 his work *"Kaifuku-dai no Ho"* (Methods of solving fukudai problems) in which he used determinants (without giving them a name) for eliminating a common variable from higher-degree equations.

Independently Leibniz wrote a very nice paper on the solution of linear systems of inhomogeneous algebraic equations in 1684, using the determinant symbolism with double indices for the coefficients as well as deriving theorems and formulae for the direct calculation of determinants by the combinatoric rules invented by him. Furthermore he gave rules for practical calculations, which are equivalent to those of Gabriel Cramer, published in 1750.

The publication of a small part of Leibniz's results only followed in 1700 in Acta Eruditorium, and in 1710 in Miscellanea Berolinensia. He claimed to present "a new notation *(novum designationis genus)* which would prove to have great benefits in the analytical and combinatorial art".

Contributions to the Principles and Problems of Natural Science

Modern rational science was born in the 17th century. It started with Galilei and Kepler, then continued with Descartes, Pascal, Guericke, Hooke, Boyle, Mariotte and Huygens, reaching its pinnacle with Newton´s famous book *Principia Mathematica Philosophiae Rationalis* in 1687.

Figure 3:
Drawings from Leibniz´s paper **Brevis demonstration erroris memorabilis Cartesii** in Acta Eruditorum 1686. The force (energy) required for lifting the mass is measured by the product of weight and height

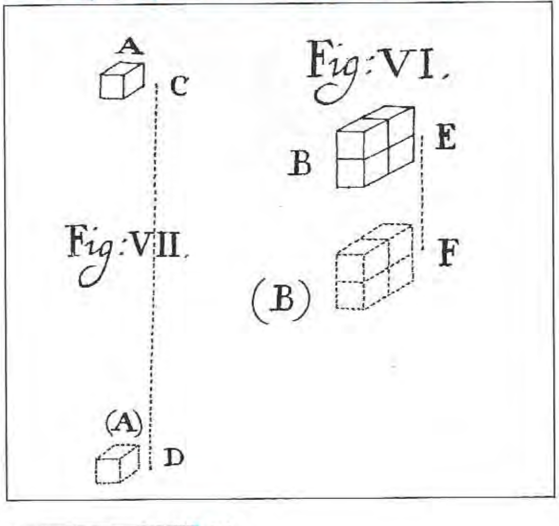
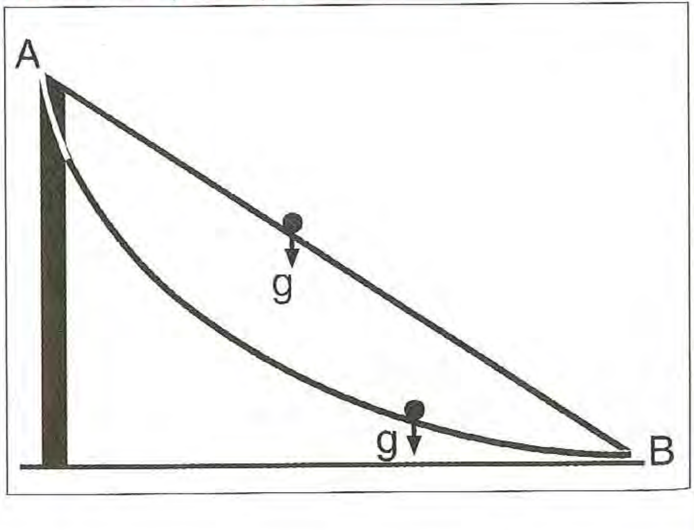


Figure 4:
The brachistochrone (normal cycloid) as the optimal curve for a frictionless downgliding mass particle in shortest time, posed by J. Bernoulli in 1695.



Leibniz had critical ideas about *"the true measure of force"*, where "force" also includes energy. In Newton's principia we find three notions of force: the *"vis insita"* (the inherent force acting on a body, e.g. due to gravity, $F^{(g)} = m\,g$, the *"vis motrix impressa"* (the impressed or physically given force which causes motion, e.g. due to wind power) and the "vis acceleratrix" (the inertia force $F^{(a)} = -m\,a$ against the acceleration of a body). The equivalence of gravity force and inertia force, already stated by Galilei, with the factor "1" was only finally clarified by the special relativity theory of Einstein.

Leibniz was especially interested in conservation quantities of moved bodies. One of his main discoveries is the kinetic energy $m\,v^2$ of a moved body – first without the factor ½ – and that this is a conservation quantity in mechanics next to the potential energy and such a "true measure of force". This result was expressed by proportionalities (not as a formula) in the critical essay *"Brevis demonstratio erroris memorabilis Cartesii"* (Short demonstration of a remarkable error by Descartes) publishes in Acta Eruditorum in 1686,. Descartes had stated that $m\,v$ (the momentum of mass) is a conservation quantit.

His interest in minimum principles of physics also originated from his teleological (purpose-oriented) philosophical ideas, see also the later chapter on the monad doctrine. Leibniz postulated: *"Dans les modifications de mouvement, l'action devient ordinairement un Maximum ou un Minimum"* (In all changes of motions the action usually reaches a maximum or a minimum) and furthermore: *"Causae plenae et effectus integri eadem potentia est"* (The entire cause and total effect have the same 'force', where "force" today has the meaning of energy, *fig. 3.*

From his thoughts on the optimality of the divine plan he concludes that God created the natural laws as simple and optimal as possible, enabling the highest complexity for all following dynamic processes.

Next to the **rationality principle** –nihil sine ratione–, the **continuity principle** was of fundamental importance for his work in mathematics and physics.

It has to be mentioned that the **first optimality principle** had been already formulated by **Pierre Fermat** (1605 – 1665) for the minimal time of the "lightway" (of a plane harmonic wave) in media of changing density, resulting in the Snellius refraction law for two media and the normal cycloid for the lightway in media with linearly changing density, discovered by **Johann Bernoulli** in 1696 in connection with the **Brachistochrone problem,** *fig. 4.*

This famous optimality problem was posed in 1695 by Johann Bernoulli, asking for the curve of shortest time (the Brachistochrone) which a friction free gliding mass particle takes in the gravity field from a point A to a lower point B in a certain horizontal distance; the solution is the normal cycloid (the rolling curve of a wheel on a straight line) which was discovered within one year by Johann and Jakob Bernoulli, Leibniz, Newton (anonymous without publishing the proof) and L'Hospital, published in the Acta Eruditorum of 1696. Note that the variational calculus was only invented by Leonhard Euler in 1744 such that the partly geometrical and analytical derivations of Johann and Jakob Bernoulli are very skillful, using special properties of the cycloid, e.g. that its evolute is again a cycloid and the curvature radius is equal to twice the normal. Leibniz submitted a genius purely geometrical solution, by constructing subsequently the cycloid in finite steps which can be transferred into a numerical algorithm and interpreted as a Finite-Element-Method for a parametrized one-dimensional variational problem, *fig. 5.*

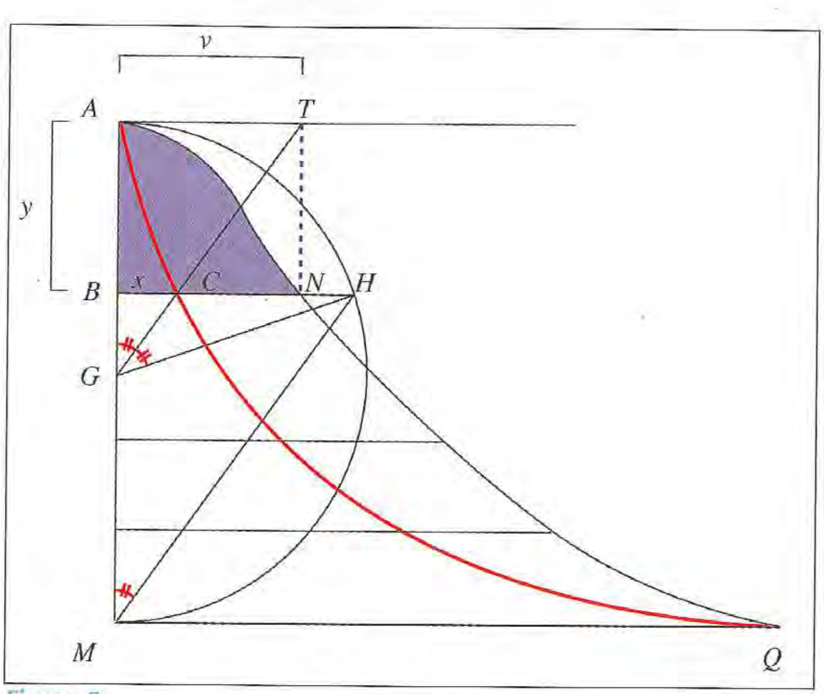


Figure 5:
Leibniz's geometrical solution of the brachistochrone problem in 1696

Long before that, Galilei had posed this optimization problem in his *discorsi* and assumed the quarter of a circle as the approximated solution. Interesting to know that Huygens had discovered the cycloid for his cycloid pendulum, providing constant frequency, independent of the amplitude, published in the *Horologium Oscillatorum* in 1673.

The Leibniz-exhibition includes a comparative model for the Brachistochrone problem with a straight line, the cylcoid and a deeper curved line.

A further remarkable contribution of Leibniz was the linear vibration analysis of the Mariotte-Leibniz Pendulum, *fig. 4*, in which a second pendulum is oscillating in a vertical plane which is orthogonal with respect to the first one, located at the end of its lever arm. Note that this pendulum shows chaotic behaviour at finite vibrations, *fig. 6*. Abbé Marriotte had made tests on this double pendulum and suggested to Leibniz to try analytical investigations.

There are also interesting contributions of Leibniz to geometrical optics, to acoustics and to the fracture stiffness of a beam, referring to Galilei´s work, which are not treated here.

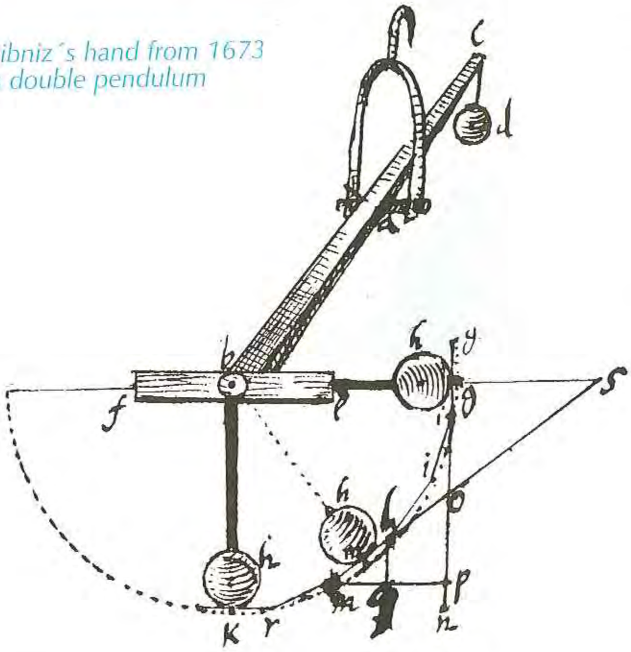


Figure 6:
Drawing in Leibniz´s hand from 1673 of Marriotte´s double pendulum

The Leibniz Four-Function Calculating Machine

His ambitious life-long work on constructing and building such a machine goes back to the beginning of his stay in Paris from 1672 to 1676. Before his attempts Napier´s so called bones or calculating sticks, Schickhard´s calculating device (burnt in the 30 years war and reconstructed) and especially Pascals two-function machine (the Pascaline) completed in 1644, *fig. 7*, became known in the 17th century (all needing some tricks), and of course, we have to regard the antique Greek and Roman *Abacus*, the Japanese *Soroban* and the Chinese *Suanpan*.

Leibniz´s credo *"it is unworthy to waste the time of excellent people with the slavery of calculating work because with the aid of a machine even the simplest person can reliably write down the result"* and even much more general: *"pars vitae quoties perditur hora perit (each hour one loses is a wasted part of one´s life)"* was the background for spending the enormous sum of about 23.000 Thaler in order to get built and repaired in total three machines in a period over about 40 years. Leibniz´s machine realises some completely new brilliant ideas which, however, needed a very complicated and accurate manufacturing process of a lot of different sophisticated cogwheels, shafts and spindles with sensitive adjustments, which could be done only by very few mechanicians at that time, accompanied by many failures, *fig. 8, fig. 9 a,b*.

Figure 7:
Pascal´s calculating machine for adding and subtraction from 1644

Figure 8:
The original four function Leibniz calculating machine that was constructed from 1693 in Hannover NLB (the "younger" of the two large machines).

The central idea of this machine is real mechanical multiplying and dividing by repeated fully automized addition and subtraction realised by the new mechanism of decimal carry, and pinwheels with a changing number of operational pins at the circumference. In contrast to what had been done before he separated the operations of setting numbers and doing the calculation, implementing a setting mechanism (input), a value transfer mechanism (but using lateron a stepped drum instead of the pinwheel) and – by transmission – the result mechanism.

There is only one known remaining original machine with 8 decimal digits, located at the Niedersächsische Landesbibliothek Hannover. Some rebuilt machines by the Brunswick company Brunsviga about 1935 have functional problems. N.J. Lehmann from the Technical University of Dresden rebuilt two machines in the 80th and 90th after careful research of the original Leibniz machine, and a third one was completed only recently in Dresden after the death of Professor Lehmann.

Leibniz's Interest in Binary Numbers and Binary Calculating Machines

His interest in binary numbers, which were already known at that time, originated not only from his ideas for constructing new calculating machines but also from basic philosophical reasons.

On the medal, minted on the occasion of the foundation of the Brandenburg Society of Sciences, in 1700 – due to his ambitions efforts and the patronage of the Prussian electoral princess Sophie Charlotte – , Leibniz shows on one side the binary and corresponding decimal numbers, as well as the rules for adding and multiplication binary numbers invented by him. Above this a symbolic picture of the creation of the universe is inserted. At the edge of the medal one reads "Omnibus ex nihilo ducendis sufficit unum" (to derive all from nothing one suffices).

Around 1680 he also designed a decimal-binary number converter, *fig. 10* and in 1679 he gave in *"De progressione dyadica"* (description of the binary calculator) a rough description of a binary working machine for adding and multiplication (by multiple adding), working with little balls and a box with holes (open for "one" and closed for "zero") and channels beneath in which the balls are rolling due to gravity and distributed

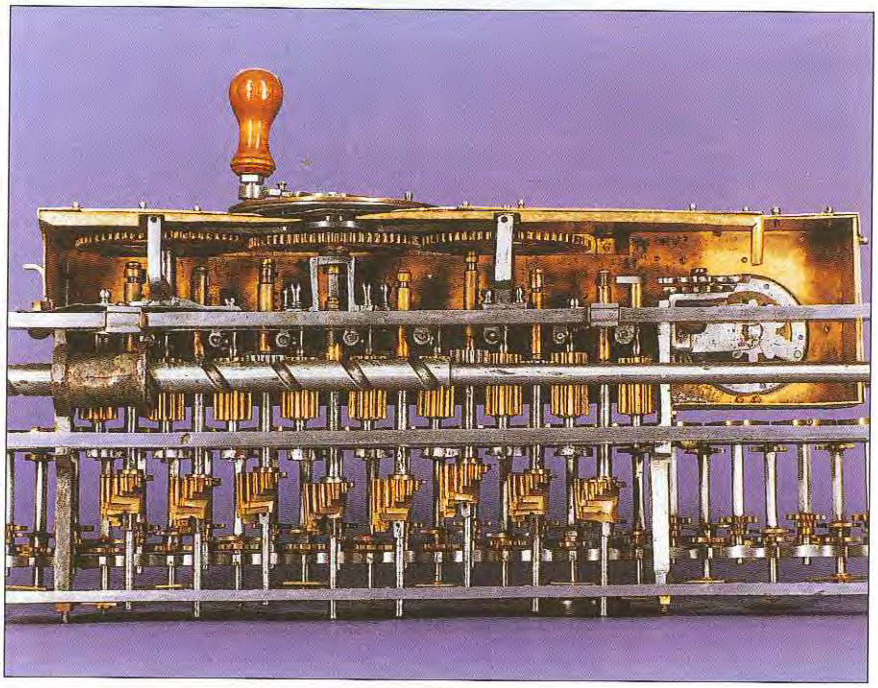


Figure 9 a:
Stepped drums and drawing spindle for moving the carriage in Leibniz´s four species calculating machine

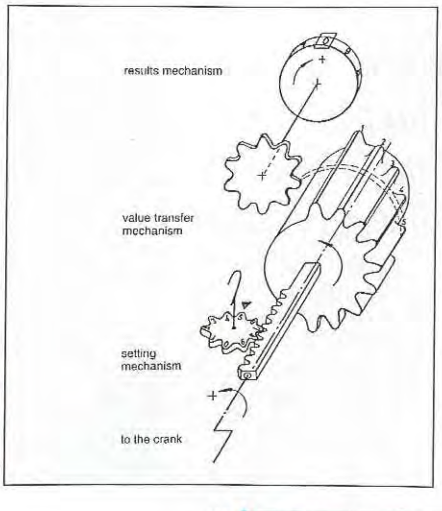


Figure 9 b:
Principle parts of a decimal place in Leibniz´s machine, using a stepped drum.

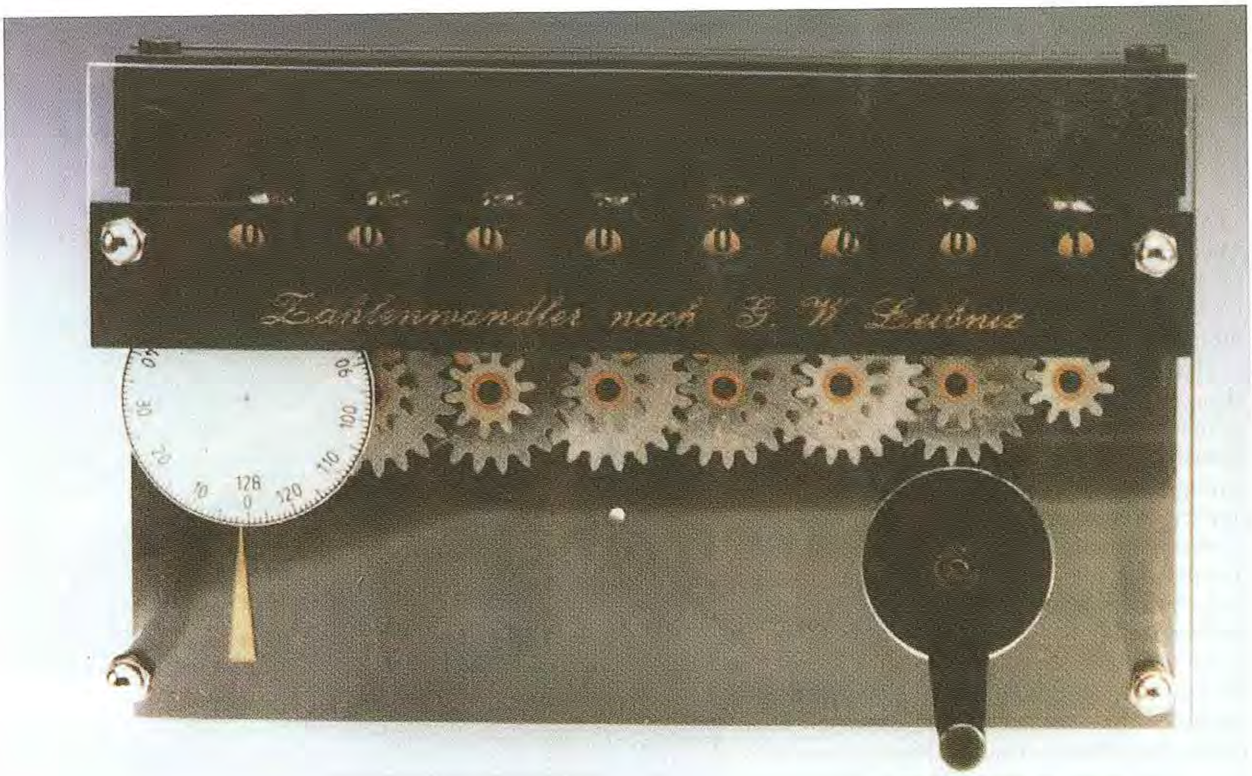


Figure 10:
Number Converter from decimal to binary numbers designed by R. Paland based on the sketch of G.W. Leibniz and further research of L. v. Mackensen.

according to the calculation rules. This machine was constructed in 1972 by L. von Mackensen, Kassel, and is part of the exhibition, *fig. 11*. Herein a sensitive spring–loaded flap controls the opening and closing of the holes. Of course, this is the same idea as for binary digital computers using magnetised or non-magnetised units combined by an electrical network for calculating – which is much simpler than the mechanical one. So at least in principal, a first idea for modern digital computing was given by Leibniz.

> *"…. his work in mathematics and natural sciences - is based on the predominant principle - nothing happens without sufficient reason and rationality."*

References to Leibniz's Monadology

The importance of the number "one" as "the unity" has relations to the "monad" (from the Greek word monas for unity) as the key to understanding of Leibniz's personality and philosophy. He recognises two areas of reality: the world of appearances (determined by causal laws and science) and the "spiritual" world of spiritual substances or monads as centres of mental force; they are simple and indivisible but nevertheless reflect in themselves the whole of reality and incessantly strive for new reflections. The monads are not in space and time and thus cannot be observed with the outer senses *(monads don't have windows)*, but through inner experience and contemplation do we have access to their world. The smallest part of matter is likewise based on an endless plenty of monads. As part of the world of experiences, man is subject to causal laws of cause and effect; as a monad however he acts for the sake of certain ends and purposes. He as freedom for acting with reason and choosing between several possibilities according to his own free will. Due to the omniscience of God – as the centre of monads – He could only create the best of all thinkable worlds in terms of physical and moral laws, even if often the impression exists that the morally-good person suffers while the bad thrives. Leibniz writes in his famous *Theodizee* (1710) *(Essais de Théodizée sur la Bonté de Dieu, la Liberté de l'Homme et l'Origin de Mal)* that according to the free will and the moral impetus of the individuals they can bear the deficiencies and injustices of the real world and should act relentlessly towards the recognition of God and the own Soul, to love God and to live virtuously regarding the common good, i.e. to live towards the purpose of the divine plan.

Leibniz's philosophy – and also his work in mathematics and natural sciences – is based on the predominant principle *"nihil sine ratione"* or *"nihil fit sine causa sufficiente"* (nothing happens without sufficient reasons and rationality). Especially by his monadology he tries to overcome the obvious contradictions of "ratio et religio" (of rationality and religion). Leibniz met with disapproval and his ideas even earned scorn and derision in the 18th century, e.g. by Voltaire in his Candide, but modern research is again very interested in Leibniz's philosophy, also in the context of his critical article *Nouveaux essais sur l'entendement humain* (1705), about John Locke's famous *Essai on human understanding*, a basic input to the Constitution of the United States of America.

Other Areas of Research and Conclusions

Since 1679 Leibniz was in charge of Duke Johann Friedrich of Hannover, to improve the mining facilities in the Harz mountains. He designed a whole system of windmills with attached water pumps and lakes on different altitudes in order to store energy from pumping the water out of the mines and using it lateron for energy saving transport of minerals. For this he improved existing windmills (with horizontal axis of the rotor) by connecting different types of waterpumps, and he constructed an automatic frequency controlled breaking device for stopping them in case of strong wind. Additionally he built a new type of windmills with a vertical axis of the rotor and radial blades which works for all wind directions without adjusting the mill, using several tangential sectors as openings, but having little effectiveness.

The idea of energy saving was also realised by conical winding drums (a big lever arm for the empty basket and a small one for the filled basket), drums of different width and endless ropes in case of skew mineral seams.

In all these attempts one recognises his motive *"Theoria cum Praxi"* (Theory together with practice) in order to improve the material conditions of man, to reduce the physical burdens of labor and such – by the progress of rational science and related technical inventions – finally to achieve *Commune bonum (the common good).*

Finally it should be mentioned that Leibniz designed a language for logic with definitions, notations and rules, e.g. the signs for *congruent* and *similar* mappings in geometry, and that he developed the *analysis* situs, a topic of current research.

In total this contribution should provide an overview of the main inventions of Gottfried Wilhelm Leibniz and other great researchers of the 17th century to science and technology which still highly influence our thinking and working of today. The crucial interaction problems between man, nature and technique have been focused already by Leibniz.

We believe that our exhibition provides a direct and lively access to the mental roots of our age. ●

> "…. Leibniz designed a language for logic and definitions, notations and rules …."

Preferences:

[1] Karl Popp, Erwin Stein (Editors):
Gottfried Wilhelm Leibniz: The work of the great universal scholar as Philosopher, Mathematician, Physicist, Engineer
(The accompanying book of the Leibniz-Exhibition)
Schlütersche, Universität Hannover, Hannover 2000 (available by the editors)

[2] Erwin Stein, Karl Popp:
Bilder und Texte der Ausstellung: G.W. Leibniz als Philosoph, Mathematiker, Physiker und Techniker in: GAMM-Mitteilungen, Band 24 2001, Heft 1, Wiley-VCH, Berlin

Figure 11: *Model of a binary calculating machine (for adding and multiplication) according to Leibniz´s ideas in his manuscript* ***De Progressione Dyadica****, 1679, reconstructed by L. v. Mackensen, Landesmuseum Kassel.*

USACM Chronicle

United States Association for Computational Mechanics

Message from the Incoming USACM President

As part of an update, and upgrade, of the USACM web pages, and electronic services provided by USACM to its members, the USACM web page **http://www.usacm.org** *has been professionally redesigned by JPMac Associates* **(http://www.jpmaconline.net/)**.

The content on the USACM web site has been updated to reflect current information. Also, the very popular "Positions Available" web page will again be updated regularly and maintained. Items to be posted to the USACM web site, including position announcements, calls for papers, and congress and meeting announcements should be emailed to **Postings@usacm.org**.

Recent issues of the USACM Digest, the email distribution to USACM members, are archived on the new USACM web site and are searchable via a keyword search engine. Items of interest to USACM members, to be included in the Digest, should be emailed to **Digest@usacm.org** *and will be included in the Digest as appropriate.*

Comments on, or problems with, the USACM web site should be directed to **USACM@usacm.org**.

Wing K. Liu

Awards & Honors

The 2001 USACM Awards and Honors recipients are:
Ted Belytschko, John von Neumann Medal; **Wing Kam Liu**, Computational Structural Mechanics Award; **David Gartling**, Computational Fluid Dynamics Award; **Charbel Farhat**, Computational and Applied Sciences Award; **Kenneth E. Jansen**, R.H. Gallagher Young Investigator Award

The new USACM Fellows are:
A. J. Baker, **Charbel Farhat**, **Jacob Fish**, **Stein Sture**, and **Leszek Demkowicz**.

The awards were presented at the 6th U.S. National Congress on Computational Mechanics. ●

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- Specialty Committee Reports -

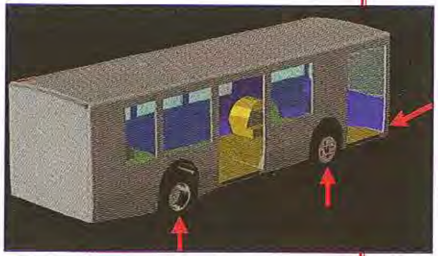
The Verification and Validation Committee met at the USACM Congress in Dearborn to discuss draft sections of the guidelines they are developing. The Committee expects to become an official ASME Standards Committee by the end of summer of 2001. The Committee is planning a Minisymposium at the World Congress in July 2002. Current information on the Committee's activities, and instructions on subscribing to its email distribution list, can be found on the Committee's web page http://www.schwer.net/VnV

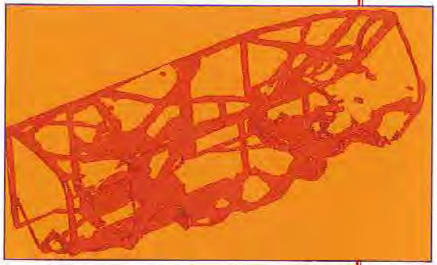
The Committee on Meshfree Methods (CMM) organized a 9-session USACM Minisymposium on Meshfree Methods. The Meshfree Minisymposium and the first CMM meeting will take place at the 6th US National Congress on Computational Mechanics. The CMM is also in the process of developing a web page to foster the research, development and application of meshfree methods.

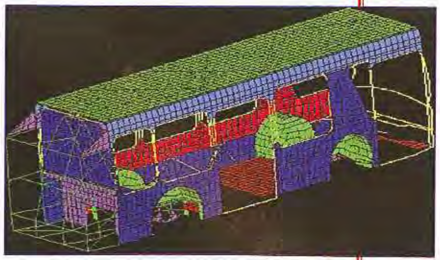
The Committee on Integration of Computational Mechanics and Manufacturing (ICMM) is co-sponsoring a workshop on composite sheet forming to be held from September 5-7, 2001 in Boston, Massachusetts http://www.mech.northwestern.edu/fac/cao/nsfworkshop.

The Committee on Material modeling (CoMm) sponsored three 3 specialized symposia at the 6th U.S. National Congress on Computational Mechanics. In addition, an Army Research Office sponsored workshop, entitled Integrated Modeling Of Structural And Material Systems: State of the Art and Future Directions will be held at the Ohio State University, Columbus in October 2001. Professors S. Ghosh and M.A. Zikry will be the co-chairs of this workshop, that will be co-sponsored by the CoMm

Several Northwestern University facultiey organized a 9 session Symposium on Virtual Tribology, and Micro- and Nano-Systems. To broaden the scope of USACM activities, USACM is currently looking for individuals who are willing to lead the new *Computational Nano-Technology Technical Committee.* ●







6th USACM Congress

The 6th U.S. National Congress on Computational Mechanics was held August 1-3, 2001 in Dearborn, Michigan. Fifty one Mini-Symposia were organized, comprising more than 780 papers in 152 technical sessions. The Congress was an international event, with participants from more than 30 countries. Two short courses were offered prior to the Congress:

"Verification and Validation in Computational Mechanics,"
by Dr. William Oberkampf (Sandia National Laboratories)

"A Hands-On Introduction to ADAMS,"
by Mechanical Dynamics, Inc.

The Post-Congress Short Course consisted of two topics:

"Meshless Methods,"
by Profs. Wing Kam Liu (Northwestern University),
Hirohisa Noguchi (Keio University),
and J.S. Chen (University of Iowa)

"Design Optimization,"
by Profs. Zafer Gurdal (VPI)
and Noboru Kikuchi (University of Michigan),
Dr. Ren-Jye Yang (Ford Motor Company),
and Uwe Schramm (Altair Engineering, Inc.)

7th USACM Congress

The next Congress, the 7th U.S. Natinal Congress on Computational Mechanics, is planned for the Summer of 2003 in Albuquerque, New Mexico. ●

International Conference on Trends in Computational Structural Mechanics

by
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& Manfred Bishoff
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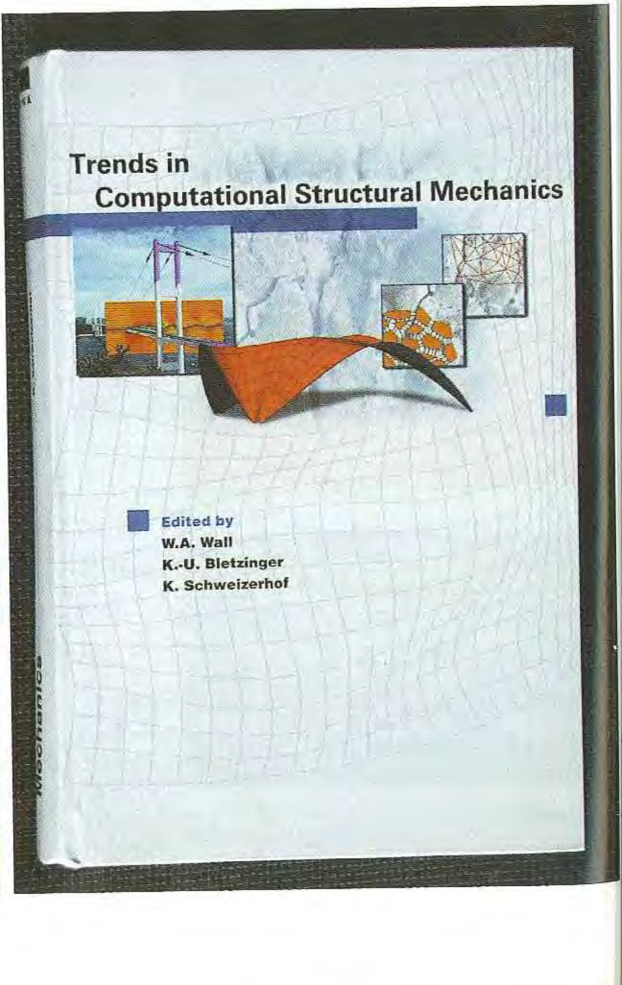
The International Conference on Trends in Computational Structural Mechanics was held from **May 20 to 23, 2001** in **Lochau**, near Bregenz, at the German-Austrian border. It took place in "Schloss Hofen", a renaissance castle built in the 17th century and picturesquely located near Lake Constance. It was organized under the auspices of the German Association of Computational Mechanics (GACM) and has been supported financially by the Deutsche Forschungsgemeinschaft (DFG) and the state of Baden-Württemberg.

About 130 participants from 20 different countries from all over the world followed the invitation of the organizing board (K.-U. Bletzinger, TU München, K. Schweizerhof, University of Karlsruhe and W.A. Wall, University of Stuttgart). The conference chairman and head of the organizing committee was Wolfgang A. Wall from the Institute of Structural Mechanics (Institut für Baustatik), University of Stuttgart. The inspiring and fruitful atmosphere of the whole conference was significantly characterized by the remarkable density of scientific excellence.

The main objective of the conference was to bring together leading scientists in the field of computational structural mechanics and to provide an international forum for presentation and discussion of recent developments and general trends in this fast moving field. A special dedication of the conference was due to Ekkehard Ramm, chair of the Institute of Structural Mechanics in Stuttgart, on occasion of his 60th birthday.

The scientific program covered topics in the fields of computational mechanics of materials, structural modeling and discretization, advanced solution techniques, structural optimization and multi-physics problems. The presented methods are of general interest in nearly all fields of engineering such as civil, mechanical, naval, aeronautical and bioengineering. The contents of most of the 82 lectures – presented in two parallel sessions and a total of four plenary lectures – are compiled as full-length papers in the conference proceedings ***"Trends in Computational Structural Mechanics"***, W.A. Wall et al. (eds.), CIMNE, Barcelona 2001 (see contact address at the end of this article). The plenary lectures by T.J.R. Hughes (Stanford), H.A. Mang (Vienna), E. Stein (Hannover) and R.L. Taylor (Berkeley) provided both an overview of substantial recent developments in computational mechanics and new ideas and perspectives.



Trends in
Computational Structural Mechanics

Edited by
W.A. Wall
K.-U. Bletzinger
K. Schweizerhof

Mechanics

Figure 1: Schloss Hofen Castle

The conference was accompanied by a varied social program, including pre- and post-conference tours as well as a conference banquet which took place at Burg Gebhardsberg, a medieval castle, located above the city of Bregenz with an overwhelming view of Lake Constance and the Rhine-valley. A musical soiree and a special buffet style dinner, denoted as „Bregenzerwälder Käsestraße" (which is only unsatisfactorily translated by "cheese road through the forest around Bregenz"), rounded the program on the remaining evenings. Special gratitude is expressed in this context to Kaspar Willam from Boulder, Colorado, who actually grew up in this region and who was an invaluable source for translations of a multitude of local dialect expressions. *Or did you already know what "Räskäs" means?*

The great success of the conference was not only ensured by the beautiful conference site and its scenic surroundings, but also by the perfect and smooth organization by Wolfgang Wall and his team from Stuttgart which covered virtually every need of the conference participants, starting from a shuttle service to and from the hotels and ending with a video projection of the champions league final on Wednesday evening.

Additional information about the conference and a variety of pictures taken during the meeting are available in the internet under http://www.uni-stuttgart.de/ibs/trends. The wording of the after-dinner speech at the banquet, delivered by Karl S. Pister, is also a feature article in this issue of Expressions.

The conference proceedings "Trends in Computational Structural Mechanics", (W.A. Wall, K.-U. Bletzinger and K. Schweizerhof, eds.) can be purchased via CIMNE, Barcelona http://www.cimne.upc.es. ●

Figure 2:
Ekkehard Ramm and Bob Taylor during a conference break

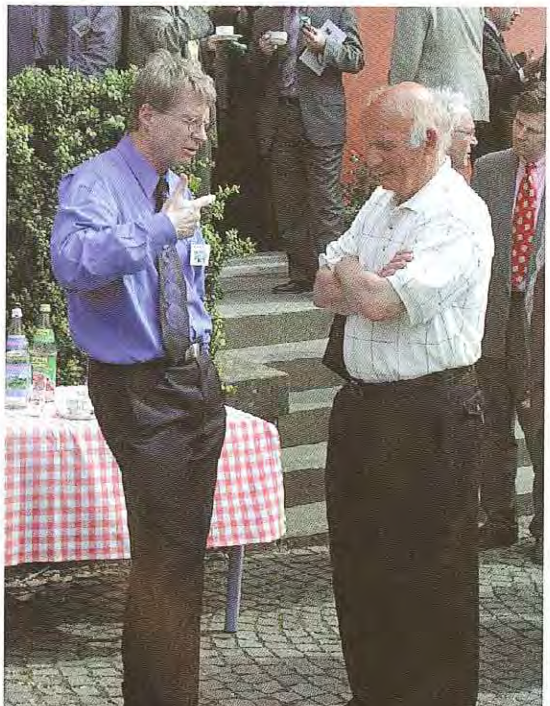


Figure 3:
Tom Hughes during his plenary talk in the former castle chapel

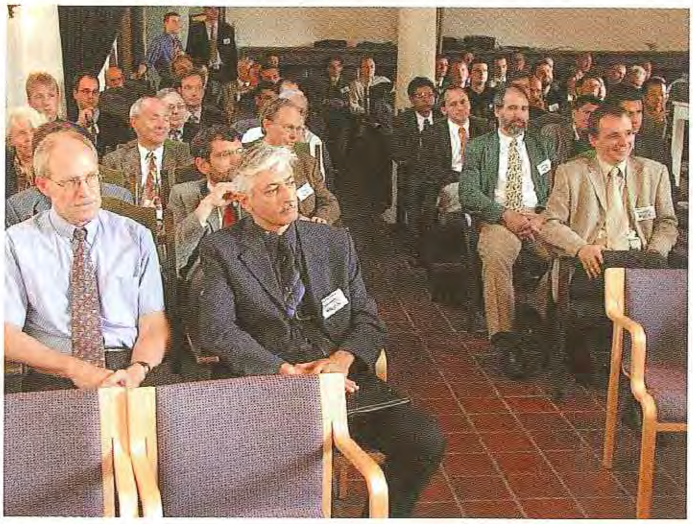


Figure 4:
Conference Theatre during the Monday evening concert

Figure 5:
Schloss Hofen team in Bregenzerwaelder costumes

Asociación Argentina de Mecánica Computacional

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Call for papers - ENIEF 2001

XII Congress on Numerical Methods and their Applications

Córdoba, Argentina, October 30th - November 2nd, 2001

AMCA announces ENIEF 2001, the XII Congress on Numerical Methods and their Applications. The congress is of interest for engineers, mathematicians, physicists, researchers and other professionals who develop numerical methods or use them as part of their professional practice. The ENIEF meetings started in 1983 as the only national meeting of users and researchers of the Finite Element Method. The success that the meeting had in the computational mechanics community in Argentina and neighbouring countries promoted a sequence of periodic ENIEF events, which alternate with the national MECOM congress.

TOPICS

Fluid mechanics; Heat transfer; Solid mechanics; Structural analysis; Discrete mathematics; Mesh generation; Visualization; Software development; Algorithms.

Figure 1: Bariloche, Argentina

ENIEF 2000

XI Congress on Numerical Methods and their Applications

20-24 November 2000, Bariloche, Argentina

The XI Congress on Numerical Methods and their Applications - ENIEF 2000 was held at Bariloche, Argentina, on November 20-24th, 2000. The argentinean community of computational mechanics meets regularly at this AMCA official congress held since 1983.

ENIEF 2000 took place at the beautiful city of Bariloche in the argentinean Patagonia, hosted by the Bariloche Atomic Centre (CAB). The main topics for this ENIEF were: Fluid mechanics; Heat transfer; Solid mechanics; Structural analysis; Discrete mathematics; Mesh generation; Visualization; Software development; Algorithms.

Some 90 delegates from several research centres of Argentina, as well as from Chile, Brazil, USA, Canada, Spain and France, participated at the conference. The ENIEF proceedings are edited as a book of the Series Mecánica Computacional . It contains 84 papers (in spanish and english), in 518 pages and was compiled by F. Quintana and S. Felicceli.

G. Bayada (CNRS-UMR, France); S. Elghobashi (Univ. of California Irvine USA); W. Habashi (Univ. Montreal, Quebec, Canada); J.C. Heinrich (Univ. of Arizona, Tucson, USA); E. Oñate (Univ. Politécnica de Cataluña, Spain) and B. Suárez (Univ. Politécnica de Cataluña, Spain) were invited lectures at ENIEF 2000.

The ordinary annual assembly of AMCA took place during the Congress. ●

Figure 2: *Invited lecturers and Organising Committee at ENIEF 2000*

CONGRESS LOCATION
Cordoba is an important tourist centre in Argentina, with lakes and mountains of great beauty. It also has a remarkable historical and architectural heritage reflecting a Spanish past, and some of this has been declared as a cultural patrimony of humanity.

INSTRUCTIONS AND DEADLINES
Participants should submit an extended abstract of at least 200 words as soon as possible. Printed copies, e-mail, or disc formats of the abstract will be acceptable. Notification and instructions will be mailed during July 2001. The complete papers must be received by August 26th, in order to be included in the conference proceedings.

INFORMATION
ENIEF 2001, Casilla de Correo 916, 5000, Córdoba, Argentina
email: enief@efn.uncor.edu, web: http://www.efn.uncor.edu/otros/enief
tel. 54 - 351 - 433 - 4144 / 3075, fax: 54 - 351 - 433 - 4139

First AMCA Awards

The Congress Banquet of ENIEF 2000, near one of the Bariloche's lakes, served as frame for the ceremony of the First AMCA Awards.

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

The first motivation for these awards was to help the work of outstanding young researchers. It was afterwards extended to the other categories. The award for Young Researchers was granted to Gustavo Buscaglia, from the Bariloche Atomic Center (CAB), Argentina.


Figure 3: *AMCA Award*

The award to the Scientific, Professional and Teaching Trajectory was granted to Alberto Cardona, from the International Center for Computer Methods in Engineering (CIMEC), Santa Fe, Argentina.

Finally, the award to the International Scientific Trajectory, intended to recognize not only the scientific trajectory in the field of computational mechanics but also the interaction with research centres of Argentina, was granted to Eugenio Oñate, from the Universidad Politécnica de Cataluña, Spain.

The AMCA awards consists in a statuette made by an Argentine artisan. In addition a cash prize is granted for the Young Research award. The jury for this First AMCA Awards was integrated by: Fernando Basombrio, Eduardo Dvorkin, Sergio Idelsohn and Carlos Prato.


Figure 4: *AMCA Awards*

A. Cardona

E. Oñate

G. Buscaglia

Call for Nominations for
IACM Awards

The International Association for Computational Mechanics announces four awards to recognize outstanding contributions in computational mechanics:

IACM Award is given in recognition of outstanding and sustained contributions to the broad field of computational mechanics. These contributions shall generally be in the form of important research results which significantly advance the understanding of theories and methods impacting computational mechanics, but special individual contributions in leadership and administration, industrial applications, and engineering analysis that advance computational mechanics shall also represent accomplishments worthy of recognition.

The IACM Award for Computational Mechanics will be given for contributions to traditional areas, such as computational structural mechanics and computational fluid dynamics, but may also be given to recognize contributions outside these specific areas. For example, the Award may be given in recognition of accomplishments in software development, scientific computing, research contributions in computational electromagnetics, semi-conductor device simulation, biomechanics or other areas not traditionally embraced by computational structural mechanics and fluid dynamics but which have general applicability to computational mechanics.

The IACM Award for Young Investigators in Computational Mechanics recognizes outstanding accomplishments, particularly outstanding published papers, by researchers 40 or younger. Eligibility requires that the nominee not turn 41 in the year the award is presented.

The Fellows Award recognizes individuals with a distinguished record of research, accomplishment and publication in areas of computational mechanics and demonstrated support of the IACM through membership and participation in the Association, its meetings and activities.

The IACM Congress Medal (Gauss-Newton Medal) is the highest award given by IACM. It honors individuals who have made outstanding, sustained contributions in the field of computational mechanics generally over periods representing substantial portions of their professional careers. The medal is bronze and carries the images of Newton and Gauss in recognition of the synergy between mathematics, numerical analysis, and mathematical modeling of physical events that underpin much of the broad field of computational mechanics. Past recipients include J.H. Argyris, O.C. Zienkiewicz, R.W. Clough, R.H. Gallagher, J.T. Oden, T.J.R. Hughes and E. Stein.

General guidelines and features of the awards are listed as follows:

Eligibility. All recipients shall be members in good standing of the International Association for Computational Mechanics.

Frequency. The awards shall not be given more frequently than once every four years. In Vienna, Austria, July 7-12, 2002 the awards will be given at the World Congress.

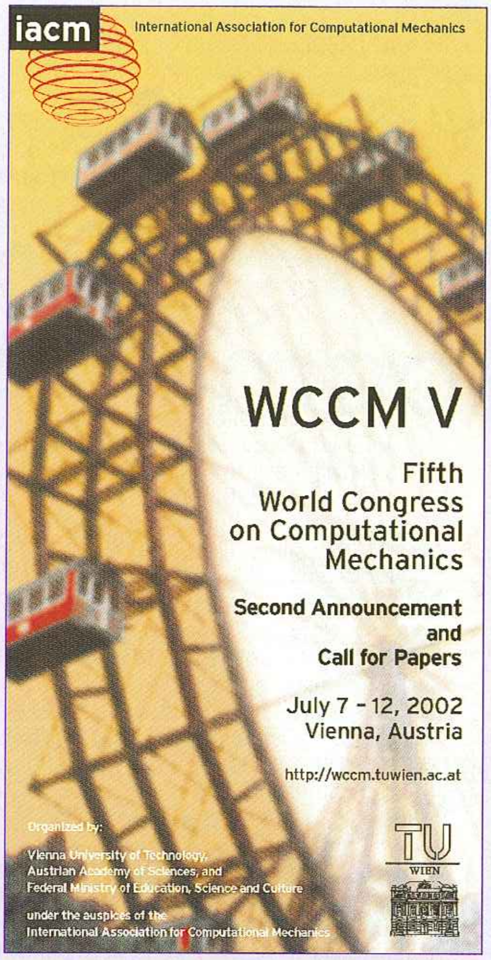
Nominations. The IACM Awards Committee, appointed by the Executive Council, solicits nominations from the IACM Membership. Nominators may nominate no more than one individual for each of the awards, with the exception of the Fellows Award in which case five individuals may be nominated, during the four-year interval between World Congresses. Self-nominations are not accepted. Nominators are invited to submit a one-page maximum combined nominating statement/vita in support of the nominee. The Awards Committee shall select candidate winners of each award and provide its recommendations of recipients to the IACM Executive Council, which shall select the awardees.

The Awards Committee consists of twenty appointees and the most recent winners of each award. The past awardees who are not among the twenty appointees are eligible to vote only for the awards which they received. It is the responsibility of the Awards Committee to make all preparations for the selection and presentation of the awards to awardees at the IACM Congress. If a member of the Awards Committee is nominated for an award that member is ineligible to vote for that award and is otherwise removed entirely from the selection of that award.

Call for Nominations. All members of IACM in good standing are invited to submit nominations to the Awards Committee Chairman: Professor Thomas J.R. Hughes, Division of Mechanics and Computation, Department of Mechanical Engineering, Stanford University, Stanford, CA 94305-4040.

The deadline for nominations is February 27th, 2002.

WCCM V
Fifth
World Congress on Computational Mechanics


iacm International Association for Computational Mechanics

WCCM V

Fifth
World Congress
on Computational
Mechanics

**Second Announcement
and
Call for Papers**

July 7 - 12, 2002
Vienna, Austria

http://wccm.tuwien.ac.at

Organized by:
Vienna University of Technology,
Austrian Academy of Sciences, and
Federal Ministry of Education, Science and Culture
under the auspices of the
International Association for Computational Mechanics

TU WIEN

Following the success of the four previous World Congresses on Computational Mechanics which took place in Austin (Texas, USA), in 1986, Stuttgart (Germany), in 1990, Chiba (Japan), in 1994, and Buenos Aires (Argentina), in 1998, the International Association for Computational Mechanics (IACM) is pleased to announce that the Fifth World Congress on Computational Mechanics (WCCM V) will be held from July 7 to 12, 2002, in Vienna, Austria.

At WCCM V, recent developments in the field of computational mechanics will be presented and discussed together with new trends and demands. Emphasis will be put on nonlinear finite element methods, boundary element methods, meshless methods and other discretization methods as well as on the coupling of different approaches. Novel developments in other computational methods having the potential of opening new avenues for promising applications will also be considered.

The congress is organized jointly by the Vienna University of Technology (TU Vienna), the Austrian Academy of Sciences (ÖAW), and the Austrian Federal Ministry of Education, Science and Culture under the auspices of the International Association for Computational Mechanics (IACM). Chairmen of WCCM V are Prof. Herbert A. Mang, Secretary General of ÖAW, and Prof. Franz G. Rammerstorfer, Vice Rector for Research of TU Vienna.

Figure 1: *Imperial palace 'Hofburg': St. Michael's Gate*

The venue of WCCM V is Vienna University of Technology. The opening ceremony and the first plenary lecture will take place in the 'Hofburg', the residence of the Emperors of Austria from 1804 to 1918.

The scientific programme consists of 2 plenary lectures, 16 semi-plenary lectures, minisymposia, industrial minisymposia, regular sessions, and poster sessions, organized in parallel. An up-to-date list of the topics and of the organizers of minisymposia and industrial minisymposia is available on the WCCM V website http://wccm.tuwien.ac.at.

An exhibition concerning life and work of the famous philosopher, mathematician, natural scientist, and engineer G. W. Leibniz (1646-1716) will be opened during the congress.

Authors who would like to contribute a paper to WCCM V are kindly requested to submit a one-page abstract related to the topics of the congress not later than August 31, 2001. Information about the acceptance of the contribution will be given until December 31, 2001, at which time instructions for preparing full-length papers will also be provided. The deadline for submission of the full-length paper is April 1, 2002.

A substantial reduction of the registration fee will be granted if this fee is received not later than February 1, 2002. ●

IACM WEB SITE

http://cimne.upc.es/iacm

The IACM web page is an electronic space to share information associated to Computational Mechanics and related topics. This web page contains among other things:

ABOUT IACM:
How IACM is organized with their affiliated organizations, Executive and General Councils.

NEWS:
Space where all members and organizations can publish relevant news that will be of interest for the IACM Community.

WORLD CONGRESES:
The latest information related to the Congresses organized by IACM.

CONFERENCES AND COURSES:
Related to events of interest to all members and associations.

IACM web page also has space for job offers and short courses, where members and organisations can announce their activities.

NEW!!!!

Now in the IACM web page, you can find IACM Expressions in its electronic version!

It is important that all members and organizations interact in the web site, by sending information of interest to the Computational Mechanics Community, publishing information about their associations, placing job offers or promoting Conferences or Short Courses… as well as any other issue of general interest.

Please send your comments and/or suggestions to:

iacm@cimne.upc.es . •

Book Report

Applied Plasticity

J. Chakrabarty (Ed.)
350 pp, 2000, US$ 98
Springer

This book begins with the fundamentals of the mathematical theory of plasticity. The discussion then turns to the theory of plastic stress and its applications to structural analysis.

It concludes with the wide range of topics in dynamic plasticity including wave propagation, armour penetration, and structural impact in the plastic range.

In view of the rapidly growing interest in computational methods, an appendix presents the fundamentals of a finite-element analysis of metal-forming problems. •

Symmetry is the key to Solving difApplied CFD Techniques: An Introduction Based on Finite Element Methods

Rainald Löhner (Ed.)
376 pp, 2000, August 2001,
Wiley.

Given the pervasive use of simulation techniques and virtual prototyping in engineering, physics and medicine, the Computational Fluid Dynamics (CFD) software business is growing and developing at an incredible pace.

Introducing the reader to the techniques required to achieve efficient CFD solvers, this text forms a bridge between basic theoretical and algorithmic aspects of the Finite Element Method and its use in an industrial context. Here, methods have to be both as simple, but also as robust as possible, to allow very large-scale computations, such as flow around a complete aircraft structure, to be performed safely and reliably.

In addition to the traditional use of CDF techniques by the aerospace and automotive industry, new applications are also discussed in this text, covering fields as diverse as engineering, medicine and physics.

- Covers the whole range of topics required for a thorough study and understanding of CFD
- Contains pieces of "pseudo-code", making it easier to code techniques for students •

Book Report

GID Times

Volume 1, Spring 2001
CIMNE, Barcelona

The new GID Times Magazine intends to present an entertaining overview of successful application and recent developments of the GID pre/post processor systems. GID was conceived at CIMNE in Barcelona to make life easier to engineers and scientists in the solutions of problems using numerical methods by providing state of the art pre and post processing facility in a user friendly, adaptive and personal environment.

GID allows students and engineers to link their own numerical tools with useful pre/postprocessing tools using PC's and larger computer systems operating in Windows, Linux and Unix. •

Computational Fluid and Solid Mechanics.

Proceedings of the first MIT Conference on Computational Fluid and Solid Mechanics, held in Cambridge, Massachusetts, USA, June 12-15 2001
K.J. Bathe (Ed.)
Elsevier.

Fundamentally, there are only molecules and particles for any material that interact on the microscopic and macroscopic scales. Therefore, to unify the analysis of physical systems and to reach a deeper understanding of the behaviour of nature in scientific investigations, and of the behaviour of designs in engineering endeavours, a new level of analysis is necessary.

This new level of mathematical modeling and numerical solution does not merely involve the analysis of a single medium but must encompass the solution of multi-physics problems involving fluids, solids, and their interactions, involving multi-scale phenomena from the molecular to the macroscopic scales, and must include uncertainties in the given data and the solution results. Nature does not distinguish between fluids and solids and does not ever repeat itself exactly.

This new level of analysis must also include, in engineering, the effective optimization of systems, and the modeling and analysis of complete life spans of engineering products, from design to fabrication, to possibly multiple repairs, to end of service. •

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In Memory of Prof J.L. Lions

Prof J.L. Lions died on 17 May 2001 after a long and valiant battle against illness which he fought with enormous courage and dignity. Prof. Lions was a leader in the international community of applied mathematicians, developers and practitioners of numerical methods. Expanding the many ties between the scientific community and companies is probably the best tribute we can offer to his memory.

80th Birthday Celebration for Prof O.C. Zienkiewicz

On the 18th May, **Prof. Olek Zienkiewicz** celebrated his 80 birthday. To mark this mile stone, a special presentation on Discontinuous Galerkin Methods was delivered by Olek together with Bob Taylor at the CIMNE offices in Barcelona which was attended by over 100 people. This was followed by a cocktail party on the terrace with friends, colleagues and some family.

Doctor Honoris Causa from Cracow University to Prof J.T. Oden

Prof J.T. Oden was awarded the degree of **Doctor Honoris Causa** from Cracow University (CTU). The Award Ceremony was held in Cracow on 25 June 2001.
The laudatum speech was presented by Prof J. Orkisz from CTU.

E. Stein and J. Argyris Awards

The **Erwin Stein Award** sponsored by the International Centre for Computational Engineering Science (ICCES) of the University of Hannover was granted to **Dr Peter W. Christensen** from Linköping University in Sweden. The Award was delivered in the Leibniz House of Hannover on June 14 2001 during a workshop on "Advances in Computational Mechanics" organised by the ECCES.

The John Argyris Award, sponsored by Elsevier, was granted to **Dr. Piotr Kowalczky** from the Institute of Fundamental Technological Research of the Polish Academy of Sciences. The Award was delivered at the Opening Session of the European Conference on Computational Mechanics held in Cracow and organised under the auspices of ECCOMAS and IACM.

The Warner T. Koiter Medal awarded to Prof G. Maier

Prof G. Maier from Politecnico de Milano received the 2000 **Warner T. Koiter Medal** awarded from the American Society of Mechanical Engineers.

Figure 1:
Eugenio Oñate and Bob Taylor with Olek Zienkiewicz during his 80th birthday presentation

IABEM 2000 International Sympsium on Boundary Element Methods

The IABEM 2000 Symposium of the International Association for Boundary Element Methods was held in **Brescia, Italy**, at the **University of Brescia, Faculty of Engineering**, from **July 4 to July 7, 2000**. It was organized by the Department of Civil Engineering, University of Brescia, on behalf of the International Association for Boundary Element Methods, with Profs. A. Carini and F. Genna as chairmen of the Organizing Committee.

The spectrum of the lectures was remarkably wide with 54 communications presented; the covered topics included symmetric Galerkin method, mathematical and computational aspects of Boundary Element Methods, their applications to solid mechanics, fracture mechanics, plates, dynamics, thermal effects and to a variety of engineering problems, fluid mechanics. The event gathered 68 participants representing institutions of 17 countries. Selected contributions will be published in the journal "Computational Mechanics".

In the Opening Session, after the words of welcome of the Dean of the Faculty of Engineering of the University of Brescia, Prof. Taroni, Prof. Bonnet, President of the IABEM had the opportunity to speak about the Association, its present and its future. Some words of welcome also from Mr. Luigi Nocivelli, President of the OCEAN Company, that was the main sponsor of the Symposium. He expressed his interest in the scientific research, particularly in Boundary Element Methods.

An opening speech was given by Giulio Maier, were he outlined the remote origin of the integral equation methods, focussing on Carlo Somigliana who was born and worked in Lombardy during most of his long and productive life. Somigliana was a descendent of Alessandro Volta, was a schoolmate of Vito Volterra in Pisa and a pupil of Betti and Beltrami. He was a pioneer and a leading researcher in mathematical theory of elasticity and, in particular, his boundary integral equations was achieved in his youth, before the end of the 19th century. Later, Somigliana devoted his research efforts to a variety of topics, primarily geophysics and earth sciences. As Professor in Pavia, Turin and Milan he was a fellow of the Italian National Academy of Lincei, Rome, the "Istituto Lombardo di Scienze e Lettere", Milan, the Accademia Pontificia and of other prestigious Academies. He died at 95 in Como.

One of the aims of Symposium was to foster the interaction between engineering and mathematics in the field of boundary element methods. Having good links between engineers and mathematicians will certainly be beneficial to the advancement of BEMs in general. With this in mind, a panel discussion on "Interaction of mathematicians and engineers in Boundary Element Methods", organized by Profs. Wendland and Morino, took place during the Symposium with six "panelist": Profs. Morino, Wendland, Maz'ya, Schwab, Bonnet and Guiggiani. A final discussion closed the topic with the hope that the conference would contribute to bridge the gap between engineers and mathematicians.

The Symposium was accompanied by an extensive social program including a visit to Franciacorta vineyards area, the conference dinner (held at Villa Baiana in Monticelli Brusati, still in Franciacorta area) and a trip to the Arena of Verona to attend the Opera "La forza del destino" by Giuseppe Verdi.

The Symposium was sponsored by the University of Brescia, the EULO (University Organization for East Lombardy), the IACM (International Association for Computational Mechanics), the Board of Engineers of the Province of Brescia and the OCEAN Company (that produce worldwide home and industrial appliances). Very special and warm thanks have to be given to the IACM, in particular to its President, Professor Hughes, who helped to make the Symposium be known to the international scientific community.

Finally, I would like to thank the IABEM Executive Committee, and in particular Profs. Cruse, Bonnet and Maier for choosing the Univ. of Brescia as the Symposium venue. They have given us the privilege of receiving outstanding personalities in the international scientific community and active researchers in the area of the Boundary Element Methods. ●

Angelo Carini

GIMC 2000
The XIII Italian Congress on Computational Mechanics

The annual Congress of the **Italian Group of Computational Mechanics (GIMC)**, operating inside the Italian Association for Theoretical and Applied Mechanics (AIMETA), a member of the IACM, took place in **Brescia** on **November 13 – 15, 2000**. The congress was sponsored, among others, by the IACM.

The site of the Congress was the Faculty of Engineering, the University of Brescia, which kindly gave hospitality to more than eighty participants. Brescia is a medium-size town in Northern Italy, of pre-Roman origins, located between Milano and Venice. It is a relatively young university (started in 1985) but, owing to the large basin of attraction, enrolls about 1000 student in Engineering every year. These subdivide into six different curricula (civil, electronic, environmental, management, materials and mechanical).

This congress is, by tradition, of an informal nature. Its main purpose is to bring together Italian researchers in the field of Computational Mechanics, trying to find a unifying link in the methods they use, rather than focusing on specific problems. Contributions are therefore welcomed from both the Mechanics of Fluids and the Mechanics of Solids. Every year participants importance is given to the presentations given by the younger members of the community, often still in their PhD programs, in an effort to try and diffuse information about common interests, used methods, encountered difficulties and possible lines of work.

With these premises, the Organising Committee, chaired by the National Coordinator of the Group, Prof. Bernhard Schrefler (Padova), and locally by Prof. Francesco Genna, has tried to make things as simple as possible, accepting contributions in all forms and in all stages of development. A rather difficult task for the organizers of this Congress has always been that of having a correct balance between the Fluid and the Solid Mechanics contributions. In the last few years the Congress had been almost a monopoly of Solid Mechanics environment, whereas this time it attracted a significant share of Fluid Mechanics researchers.

Another aim of the Congress has always been to collect contributions from industry as well, unfortunately with little success, so far. In this case only two papers out of about eighty were received from the extra-academic world. The reasons for this are complex – there is no time to attempt a rationalization here – but there is always the hope of improving the situation in the future.

Despite however the really short time available to organise the congress, there was no problems with the organisation, thanks both to the generous contributions from several organizations and to the personnel from the Faculty of Engineering.

Figure 1:
Prof. E. Tonti

Technically speaking, the Congress featured two 45 minute invited lectures, Prof. Enzo Tonti from Trieste Italy and Prof. Nikolaos Aravas from Volos, Greece. All the other presentations were 15 minutes plus 5 minutes for discussion – hence three hectic days. As expected, the young researchers outnumbered the experienced ones, and held their ground. The congress had a fair balance between 'extremes' such as applied mathematics (well represented by, among others Profs. Diligenti, Morandi Cecchi, Quarteroni and Tonti) and engineering applications, as well as including Finite Elements, Boundary Elements and other Methods.

At the end, the Group held its annual meeting where Prof. Umberto Perego of Milan was elected Group Coordinator. ●

Francesco Gemma

Figure 2:
Main congress room, Faculty of Engineering

conference notices

FWMF Friction and Wear in Metal Forming

FWMF will be held in **Valenciennes, France** from **18 - 21 June 2002**. The success of forging processes can be enhanced by the use of reliable finite element simulations, while the mastering of contact algorithms is required to improve the finite element code accuracy.

On the other hand, bulk behaviour laws of coatings and lubricants have to be identified in order to refine computations in the near contact zones. Therefore, specific methodologies using experimental and numerical approaches can be developed to quantify friction and wear, and to optimise the forging process.

The scope of Simulation of Friction and Wear in Metal Forming concerns specific simulations of forming processes with friction and contact conditions related to new experiments and testing apparatus.

Additional information can be received from:
Université de Valenciennes,
Le Mont Houy, 59313 Valenciennes
Cedex, FRANCE
E-mail : euromech435@univ-valenciennes.fr
http://www.univ-valenciennes.fr/euromech435 ●

II Congreso International Métodos Numéricos en Ingeniería y Ciencias Aplicadas

Guanajuato, Mexico
17 - 19 January 2002

The conference follows the success of the first meeting of this series held in November 1992 in the city of Concepción, Chile. The new editions of the conference aims to being a forum for Developers and Practitioners of numerical methods in Mexico and worldwide to discuss recent advances and identify future research directions for the numerical solutions of problems in science and engineering.

The following key note lecturers have confirmed their participation at the conference:
T.J.R. Hughes, J.T. Oden, T. Belytschko, R. Owen, B. Schrefler, B. Kröplin, M. Kleiber, R. L. Taylor, G. Ayala, J. Nocedal, I. Herrera.

For more information please see:
www.cimne.upc.es/congress/gto2002 ●

Numisheet 2002
The Fifth International Conference and Workshop on Numerical Simulation of 3D Sheet Forming Processes

The fifth international conference and workshop on numerical simulation of 3D sheet forming processes follows its four highly successful predecessors held in Switzerland, Japan, USA and France and will next be held on **Jeju Island, Korea** from **21 to 25 October 2002**.

As before, a selection of benchmarks will be proposed in order to compare state of the art simulations with carefully established experimental data. An important feature of the conference will be to emphasise the potential and practical industrial applications of current research of simulation, optimization and design of sheet forming processes. Numisheet will be held the week before and connected to the 7th International Conference on Technology of Plasticity.

For further information please contact the conference secretariat: CANESM Lab., ME 3254, KAIST, Science Town, Taejon, 305-702, Korea.
webmaster@numisheet2002.org ●

V Conference on Numerical Methods in Engineering
Madrid, Spain - 3 - 6 June 2002

This is the fifth conference promoted by the Spanish Association for Numerical Methods in Engineering (SEMNI).
The 2002 Conference is jointly organised by SEMNI and APMTAC (The Portugese Association for Theoretical, Applied and Computational Mechanics)

The Madrid conference aims to be a forum for those working in development and engineering applications of numerical methods in Spain, Portugal and Latin America to discuss the progress in the field and identify new research lines.

Keynote lectures include: J.C. Pereira, N. Kikuchi, M. Ortiz, E. Oñate, J. Bonet, S. Idelsohn, M. Géradin and J. Mosig. For information: www.cimne.upc.es/vcmni ●

PRESS RELEASE

the
UNIVERSITY
of
GREENWICH

Half a Million Grant to Develop Computer Experts for the Future

The School of Computing & Mathematical Sciences (CMS), at the University of Greenwich has won a £500,000 grant from the Engineering and Physical Sciences Research Council (EPSRC), to develop a masters training package in Computational Science and Engineering (CSE), in co-operation with industry.

Beginning in September, the new MSc course aims to develop industry-related skills and training for high calibre graduates in mathematics, science and engineering. Bursaries will be available to top candidates on a competitive basis. Professor Koulis Pericleous, Professor of Computational Fluid Dynamics says: "The growth in the number of organisations developing and accessing CSE technology has led to a dramatically increased requirement in industry for skilled people in this area. There is a glaring gap between what industry needs and what traditional undergraduate courses provide. This course will help to plug that gap enabling graduates to go on to solve real world problems."

Computational Science and Engineering is a rapidly growing discipline that brings together the power of computers and physical sciences. Computer based simulations of real life problems coupled to computer visualisation play a key role in scientific investigations and engineering design. The Centre for Numerical Modelling and Process Analysis - a research unit of CMS at the university - is one of the largest CSE research groups in the UK.

For over twenty years, its core activity has been the use of computers to solve complex industrial problems. The centre has attracted over £5 million in government grants and industrial sponsorship (many from overseas) since the last HEFCE Research Assessment Exercise in 1996. This success is due to the pioneering work of a multi-disciplinary team of researchers, who work at this boundary of computing, science and mathematics.

The centre's direct approach to problem solving has created a portfolio of industrial partners in the UK and internationally, including Europe, the US, Australia and South East Asia. Its efforts are having a significant impact across a number of industrial sectors from aerospace to mining and from medicine to process industries. Examples include the development of a computer model for a new iron production process for Rio Tinto in Australia, fluid-structure interaction computations to model flutter on aircraft wings for the US Airforce, the development of parallel compiler tools for use on NASA super computers and many others.

For information on the new course, contact Professor Pericleous,
e-mail k.p ericleous@gre.ac.uk or visit http://cse.gre.ac.uk.

Or call the University of Greenwich Enquiry Unit on:
email course info@greenwich.ac.uk or freephone 0800 005 006.
Further information about the university can also be found on the World Wide Web: http://www.gre.ac.uk

conference diary planner

19 - 21 September 2001	**EUROGEN 2001 -** **Evolutionary Methods for Design, Optimisation and Control with Applications to Industrial Problems** *Venue:* Athens, Greece Contact: Tel: (301) 77 21 636, Fax: (301) 77 23 789, WWWl: http://eurogen2001.ltt.mech.ntua.gr Email: kgianna@central.ntua.gr
20 - 22 November 2001	**APCOM'01 - First Asian-Pacific Congress on Computational Mechanics** *Venue:* Sydney, Australia Contact: Fax: (61) 2 - 93 85 61 39, Email: n.khalili@unsw.edu.au WWW: http://www.civeng.unsw.edu.au/conferences/apcom01/
24 - 28 September 2001	**XVII Congreso de Ecuaciones Diferenciales y Aplicaciones** **V11 Congreso de Matemática Aplicada** *Venue:* Salamanca, Spain. WWW: http://wwwmatapli.usal.es/cedya2001
17 - 19 January 2002	**II Congreso Internacional de Métodós Numéricos en Ingeniería y Ciencias Aplicadas** *Venue:* Guanajuato, Mexico Contact: Tel: (34) 93-401 74 41, Fax: (34) 93 - 401 65 17, Email: gto2002@cimne.upc.es WWW: http://www.cimne.upc.es/congress/gto2002
11 - 13 March 2002	**International Conference on High Performance Structures and Composites** *Venue:* Seville, Spain Contact: Wessex Inst. of Technology Tel: (44) 238 - 029 3223, Email: gcossutta@wessex.ac.uk WWW: http://www.wessex.ac.uk/conferences
22 - 26 April 2002	**WEHSFF 2002 - West East High Speed Flow Field Conference** *Venue:* Marceilles, France Contact: Tel: (33) 4 - 91 10 68 71, Fax: (33) 4 - 91 10 69 69, Email: leboisne@iusti.univ-mrs.fr WWW: http://iusti.univ-mrs.fr/wehsff
15 - 17 May 2002	**Fourth International Conference on Advances in Fluid Mechanics** *Venue:* Gwent, Belgium Contact: Wessex Inst. of Technology Tel: (44) 238 - 029 3223, Email: gcossutta@wessex.ac.uk WWW: http://www.wessex.ac.uk/conferences
3 - 6 June 2002	**V Congreso de Métodos Numéricos en Ingeniería** *Venue:* Madrid, Spain Contact: Tel: (34) 93-401 60 39, Fax: (34) 93-401 65 17, Email: semni@cimne.upc.es WWW: http://www.cimne.upc.es/congress/vcmni
17 - 19 June 2002	**24th World Conference on Boundary Element Methods incorporating Meshless Solutions Seminar** *Venue:* Sintra, Portugal Contact: Wessex Inst. of Technology Tel: (44) 238 - 029 3223, Email: gcossutta@wessex.ac.uk WWW: http://www.wessex.ac.uk/conferences
18 - 20 June 2002	**FWMF - Friction and Wear in Metal Forming** *Venue:* Valenciennes, France Contact: Email: euromech435@univ.valenciennes.fr WWW: http://www.univ-valenciennes.fr/euromech435
7 - 12 July 2002	**WCCM V - Fifth World Congress on Computational Mechanics** *Venue:* Vienna, Austria. Contact: Fax: (43) 1 586 - 91 85, Email: registration@wccm.tuwien.at WWW: http://wccm.tuwien.ac.at/
14 - 16 July 2002	**IABMAS'02 - First International Conference on Bridge Maintenance, Safety and Management** *Venue:* Barcelona, Spain Contact: Tel: (34) 93-401 74 41, Fax: (34) 93-401 65 17, Email: iabmas02@cimne.upc.es WWW: http://www.cimne.upc.es/iabmas
21 - 26 July 2002	**b'02 IFAC - 15th World Congress** *Venue:* Barcelona, Spain Contact: Tel: (34) 93-401 74 41, Fax: (34) 93-401 65 17, Email: secretariatnoc@b02.ifc2002.org WWW: http://www.ifac2002.org
21 - 25 October 2002	**NUMISHEET 2002** *Venue:* Jeju Island, Korea Contact: Tel: (82) 42-869 32 82, Fax: (82) 42-869 52 14, Email: webmaster@numisheet2002.org WWW: http://www.numisheet2002.org
31 March - 3 April 2003	**FEF 03 - 13th International Conference on Finite Elements in Flow Problems** *Venue:* Miejo University, Nagayo, Japan Contact: Email: fef03@cmlab.meijo-u.ac.jp WWW: http://cmlabtp.meijo-u.ac.jp/fef03/index.htlm
24 - 28 July 2004	**ECCOMAS 2004 - International Congress on Computational Methods in Applied Science and Engineering** *Venue:* Jyväskylä, Finland Contact: Email: pirjoleena.pitkanen@paviljonki-ikl.com WWW: http://www.mit.jyu.fi/ECCOMAS2004