

*Project-Team Macs**Modeling, Analysis and Control for
Computational Structural Dynamics**Rocquencourt*

THEME 4B

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2003

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1. Team

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2. Overall Objectives

Numerical simulation is undoubtedly a basic tool in engineering. Simulations are especially relevant in solid mechanics in general and in structural mechanics in particular. It is within this field that finite elements methods were initially developed and are still mostly influential.

In industrial design, experimentation and simulation methods go hand in hand. More and more simulations tend to replace experimentation resulting in significant cost cuts and reduced schedules.

In this general context, the MACS project goal is to address new research needs in particular:

- the need to develop robust and reliable numerical methods to solve large scale industrial problems;
- the emergence of active structure control, enabling the design of structures that are thinner, lighter and thus less costly or that are tightly controlled (vibration being a case in point).

The two involved disciplines (computational mechanics and control of structures) are more and more interlinked. The concept of a control law and its implementation are intrinsically based on the modeling and numerical simulation of the dynamical behavior of the structure. Moreover, active control, is a fundamental ingredient in modern structure design to the extent that the application includes a control device.

The novelty of our efforts come from the « coupling » we try to establish between this two scientific disciplines. We combine our expertise in numerical analysis and structural mechanics with state of the art control, automation and real time design.

5. Software

5.1. MODULEF

Participants: Dominique Chapelle, Amine Hassim, Marina Vidrascu [correspondant].

Most of the software modules developed in our Group are integrated in the Modulef library. From its inception, the Modulef library was designed to provide the building blocks for effective, reliable software development for finite element design and analysis. Rigorous data structures and the ease of integration of new modules, new methods or new algorithms are some of its key advantages.

Until 1998, the Simulog company distributed the Modulef Package to its paying members. To encourage widespread use, in 1999 it was decided to make it an open-source, free of charge, software. We coordinated all the efforts and arrangements necessary to support this new status.

Modulef can be downloaded from the INRIA-Rocquencourt web site at: (<http://www-rocq.inria.fr/modulef/>)

5.2. Design of Laminated Composites Against Impact Loading

Participant: Amine Hassim [correspondant].

The ADANIDEC software is a set of design/analysis tools for the selection and impact-induced damage evaluation of laminated composite materials for engineering design. Adanidec uses a multi-level (component, lamina, laminate) interactive database designed to store and retrieve information on composite materials. A Graphical User Interface has been developed and a pull-down menu leads the user to multi-level material selection from the database which - when combined with the use of finite element based numerical tools - enables the rapid identification of the optimal materials for a specific design.

ADANIDEC consists of :

- a **material database** which contains for a number of composite laminates : 1) at the component scale (whenever possible) : the moduli of the constituents (fiber, matrix) and the parameters describing the microscopic geometrical layout, 2) at the layer scale : effective properties, strengths, relevant damage parameters and experimental details, and 3) at the laminate scale : material description and typical experimental results and numerical predictions.
- a suite of software tools : 1) at the component scale : COMEP and VISUA for the evaluation of the behavior of composite layers in terms of the moduli of the components and of its microscopic geometry using a two-scale asymptotic homogenization method; 2) at the layer scale : EVODAM which implements a ply-level damage model; 3) IMPACT at the laminate scale for the numerical simulation of impact on laminated composites using 3D finite element method.
- a Graphical User Interface (GUI) to enable the user to interact with the database and the software tools at all levels. The user interface is designed to operate in a graphical format : data, relationships between data and navigation between different objects are presented in a graphical form and the user may interact via mouse clicks. At each of the three basic levels (laminate, lamina, component) the GUI provides: 1) direct access to the material database, 2) the construction of new material, 3) the numerical simulation using softwares designed at the level.

5.3. OpenFEM : a Finite Element Toolbox for Matlab and Scilab

Participants: Dominique Chapelle, Claire Delforge, Amine Hassim [correspondant], Marina Vidrascu.

OpenFEM (<http://www.openfem.net>) is an opensource toolbox for finite element computations (presently for structural mechanics only) built within a Matrix Computational Environment (MCE) such as Matlab (<http://www.mathworks.com>) or Scilab (<http://www.scilab.org>). This software is developed in a collaboration between MACS and the SDTools company (<http://www.sdtools.com>).

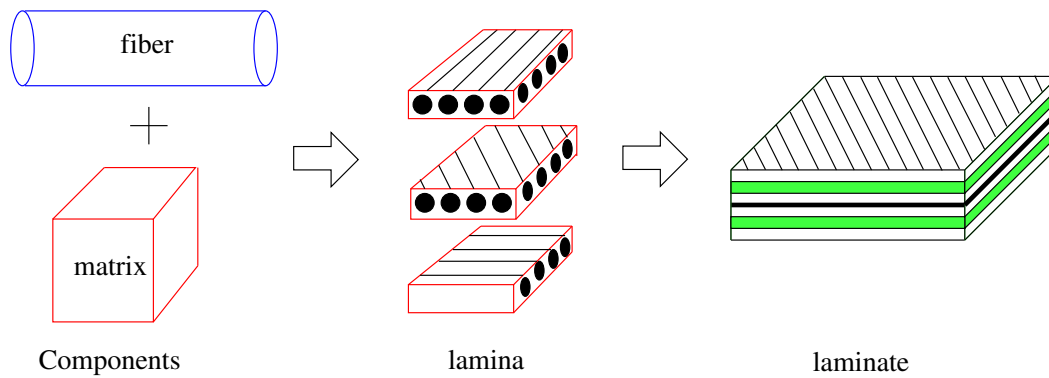


Figure 1.

Performing finite element computations within an MCE environment is of considerable interest. Chief benefits include ease of new developments, integration of new methods and software, greater portability of results and ease of postprocessing.

OpenFEM, (version 1.1) is available for download on the web site.

6. New Results

6.1. Design and analysis of effective numerical procedures for structural mechanics

Participants: Dominique Chapelle, Amine Hassim, Arnaud Münch, Marina Vidrascu.

Key words: *numerical reliability, MITC elements, 3D/shell coupling, composites, damage.*

6.1.1. 3D-shell finite elements for industrial applications

This research is stimulated by a collaboration with the Michelin company, see Section 7.1. With the objective of accurately simulating the behavior of thin, stiff and strongly anisotropic layers embedded in a 3D body (i.e. reinforcing sheets in tyres for this specific application), we formulate “3D-shell” (as we baptized them) models and finite element procedures.

Indeed, classical shell formulations are not well suited to modelling the coupling between a thin structure and the surrounding medium, because the shell degrees of freedom (dofs) lie on the mid-surface and frequently involve rotations, hence these dofs are not easily connected to the displacements of the outer medium on the interface. This drawback is not present in 3D-shell finite elements which feature standard 3D dofs (namely, with nodes on the top and bottom surfaces), which makes their coupling straightforward.

The corresponding 3D-shell models are in fact shell models, namely their unknowns are 2D fields defined over the midsurface of the shell. They are formulated by considering a quadratic kinematical assumption across the thickness (hence we can choose the unknowns as the coefficients of the quadratic polynomial), and by using this assumption in a 3D energy. In this respect, 3D-shell models belong to the “general shell element” family, see [4]. However, unlike classical general shell elements which require the use of a plane stress assumption and of an accordingly modified energy formulation, we have shown that the 3D energy can – and indeed *must* – be used “as is” for 3D-shell formulations and finite elements, which makes them even more general [9]. This advantage is particularly effective when using non-linear (large strain) stress-strain laws, which we demonstrated with the example of the Ogden-Ciarlet-Geymonat energy density [37].

Since 3D-shell formulations use a 3D energy without any prior modification, the singularity related to the incompressible limit is retained. By contrast, in classical shell formulations the plane stress assumption

removes the incompressible singularity. This raises the issue of the validity of shell models for use with incompressible materials, which is of course of utmost relevance in tyre applications. By performing an asymptotic analysis on both the incompressible and thickness parameters we have shown that classical shell models are “compatible” with incompressibility. On the other hand 3D-shell models do not feature the same desirable property, unless a slight modification is performed in the variational formulation in order to avoid a phenomenon that can be interpreted as incompressible locking.

6.1.2. *Damage Detection in Laminated Composites using Nonlinear Acoustical Spectroscopy*

Method

In a previous work instrumented impact tests have been performed on fiber-reinforced laminated specimens by using a height drop tower. The progressive non-visual damage induced during the impact and the consequent reduction in stiffness and strength have been investigated using in-situ observation and continuous monitoring of force and impactor tip deflection.

Software tools for design/analysis have been produced, namely finite element programs to detect the damage initiation and progression. A classical homogenization approach and continuum damage mechanics have been used to simulate the damage process. The direct integration method and also the modal superposition method have been used in the structural transient nonlinear dynamic analysis. A perturbation method has been developed to evaluate the influence of damage on the eigenproperties, treating the local damage as a small perturbation to the original structure. A version of the design/analysis software tools designed to be used within MATLAB and SCILAB is under development.

The present work concentrates on damage monitoring by means of vibro-acoustic spectroscopy. The sample is excited simultaneously by a low-frequency vibration (lowest bending mode generated by the first transducer) and high-frequency waves (resonant frequency of the second transducer). When damage is present, the related material non-linearity appears in the harmonics of the two waves and their sum and difference frequencies. The monitoring of the nonlinear wave mixing is the basis of the method. The nonlinear response amplitude is proportional to the local non linearity in the material behavior due to the presence of the micro-crack. Samples of a beam with a known damage excited by two force sources located at different points were used to demonstrate that the sensitivity of the cross-modulation spectrum observations can detect the appearance and the progression of a very small damage in structures.

We are currently developing the above acoustical nondestructive testing method not only to detect damage, but also to locate it and to experimentally investigate the damage signature for various composite specimens.

6.2. Structural dynamics and stability

Participants: Patrick Le Tallec, Marina Vidrascu.

Key words: *fluid-structure interaction, Newton algorithms.*

6.2.1. *Algorithms for fluid-structure interaction*

This work is done in collaboration with Jean-Frédéric Gerbeau¹. The objective is to simulate the mechanical interaction between the blood and the wall of large arteries. Due to the so-called “added mass effect”, this problem differs (algorithmically) from other classical fluid-structure problems (aero-elasticity), as its stability strongly depends on the accuracy of the resolution of the fluid-structure coupling at each time step.

Specifically, this means that an accurate energy balance must be achieved at each time step, hence it is mandatory to solve the coupling by implicit schemas. The resulting non-linear fluid-structure problem is difficult to solve. The first attempts were to solve this problem by a fixed point algorithm with several adaptive relaxation techniques. In order to decrease the computational cost we designed a quasi-Newton method where the tangent operator of the non-linear fluid-structure problem is replaced by a much simpler linear operator.

This algorithm was implemented and tested for several problems. Our test problems showed that for the structural dynamics problem the choice of the shell finite elements used is very important. The MITC4 general

¹project BANG

shell element proved to be most effective. On the other hand, for the fluid problem it is possible to use either tetrahedral or hexahedral finite elements. To this end, appropriate data structures capable of handling the coupling between quadrilateral shell elements and 3D finite elements were implemented.

The ultimate goal is to use 3D meshes automatically derived from data imaging. The existing algorithms in this field produce tetrahedral meshes. Work in progress implements an algorithm, designed by Pascal Frey², which starts with the triangular mesh obtained by the trace of the 3D mesh on the artery walls and subsequently derives a quadrilateral mesh.

The process of validation and evaluation of the reliability of the entire approach is in progress.

6.3. Active mechanics

Participants: Frédéric Bourquin, Robert Cimrman, Dominique Chapelle, Amine Hassim, Jacques Sainte-Marie, Michel Sorine [project SOSSO].

Key words: *controlled structures, biomechanics.*

6.3.1. Excitation-contraction coupling in the cardiac muscle: modeling, data assimilation and medical diagnosis

The approach we propose aims at using measurements of the cardiac activity in order to identify the parameters and state of a global electromechanical heart model, hence to give access to quantities of interest for diagnosing activation and contraction symptoms. This work is carried out within the framework of the multidisciplinary research project ICEMA³, see 8.1.1.

The model we use is based on a chemically-controlled constitutive law of cardiac myofibre mechanics introduced in [35] and consistent with the behavior of myosin molecular motors [44]. The resulting sarcomere dynamics is in agreement with the “sliding filament hypothesis” introduced in [40]. Denoting by σ_c the active stress and by ϵ_c the strain along the sarcomere, the relation between σ_c and ϵ_c is given by the following set of ordinary differential equations:

$$\begin{cases} \dot{\tau}_c = k_c \dot{\epsilon}_c - (\alpha |\dot{\epsilon}_c| + |u|) \tau_c + \sigma_0 |u|_+ & \tau_c(0) = 0 \\ \dot{k}_c = -(\alpha |\dot{\epsilon}_c| + |u|) k_c + k_0 |u|_+ & k_c(0) = 0 \\ \sigma_c = \tau_c + \mu \dot{\epsilon}_c + k_c \xi_0 \end{cases} \quad (1)$$

where u denotes the electrical input, with $u > 0$ during contraction and $u < 0$ during active relaxation. The parameters k_0 and σ_0 are the maximum value for the active stiffness k_c and for the stress τ_c , respectively, and μ is a viscosity parameter. The quantity u represents the electrical input and can be independently modeled (see ICEMA web) but at this stage we either consider it as given or as a parameter to be estimated.

The myofibre constitutive law described above is now incorporated in a rheological model of Hill-Maxwell type [36][38], as depicted in Figure 2. The element E_c accounts for the contractile electrically-activated behavior governed by (1) and each variable appearing with index c refers to this element. Elastic material laws are used for the series and parallel elements E_s and E_p . Based on experimental results, the corresponding stress-strain laws are generally assumed to be of exponential type for E_p [43], and linear for E_s [41]. The role of E_p is to prevent the heart from overstepping certain limits during filling or ejection, while E_s and E_c allow the contraction and the active relaxation. The corresponding complete governing 3D mechanical equations are presented in [36].

The successive phases of the cardiac cycle are distinguished in the coupling conditions between the ventricle and other parts of the cardiovascular system. The aortic valve opens when $P_{LV} = P_{aorta}$ whereas the mitral valve opens when $P_{LV} = P_{mitral}$, see Fig. 3-a. Thus the coupling conditions can be formulated as the following double contact problem:

²project GAMMA

³<http://www-rocq.inria.fr/sosso/icema2/icema2.html>

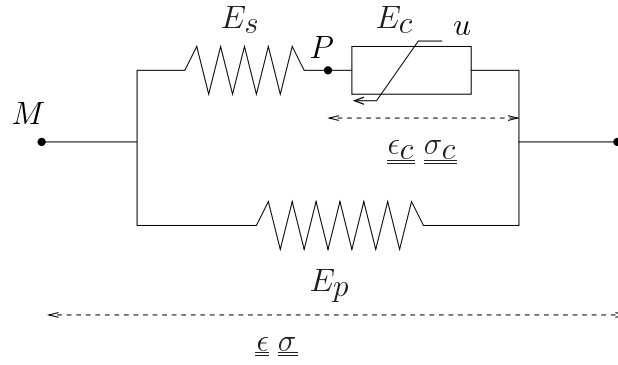


Figure 2. Hill-Maxwell rheological model.

$$\begin{cases} Q \geq 0 & \text{when } P_{LV} = P_{aorta} & \text{(ejection)} \\ Q = 0 & \text{when } P_{mitral} < P_{LV} < P_{aorta} & \text{(isovol. phases)} \\ Q \leq 0 & \text{when } P_{LV} = P_{mitral} & \text{(filling)} \end{cases} \quad (2)$$

Since relation (2) is not regular, its discretization leads to numerical problems and a regularized version of (2) is needed (Fig. 3-b), e.g. in the form:

$$Q = e^{l_1(P_{LV} - P_{aorta})} - e^{l_2(P_{mitral} - P_{LV})}. \quad (3)$$

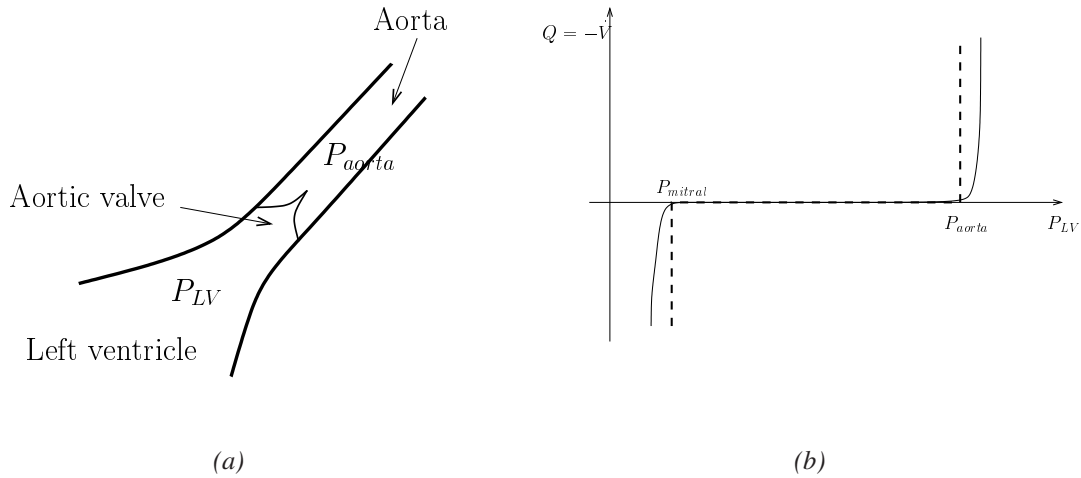


Figure 3. Aortic valve model, (a) mechanism and (b) formulation as a double contact problem, (- -) relation (2) and (-) relation (3).

A data assimilation technique is used to identify the parameters and state of the electromechanical model using the available measurements. Because some of the parameters appearing in (1) – in particular the contractility k_0 and σ_0 and the input u – are crucial for medical purposes we focus on their identification

in order to detect activation and contraction symptoms. Due to prohibitive computational costs, the data assimilation technique that we have previously formulated and demonstrated for a 1D simplified model must be adapted to the 3D problem. Thus we use filtering techniques based on the SEEK formulation [42] where the minimization of the covariance matrices is only achieved for a limited number of directions (Singular Value Decomposition). Often used in meteorology and oceanography [39], this data assimilation technique is innovative and promising for continuum mechanics problems.

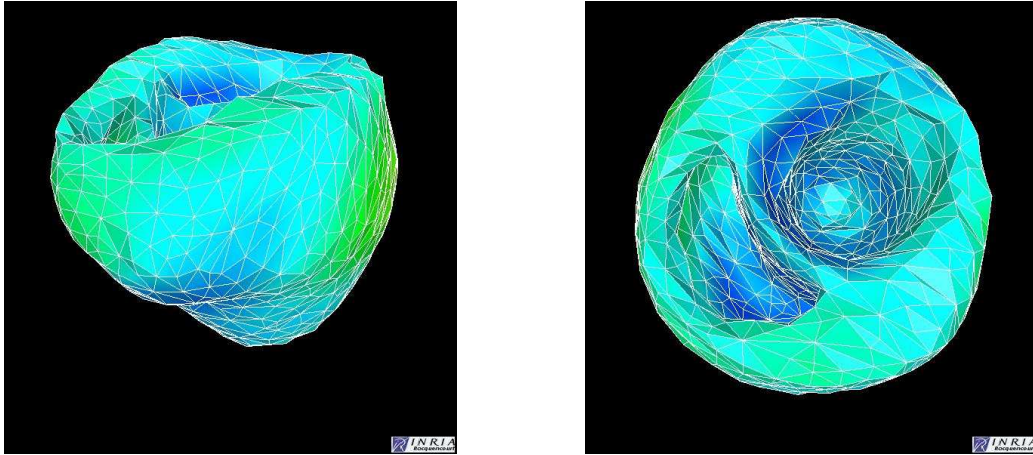


Figure 4. Mesh of the heart.

The geometric model used for the simulations (Fig. 4) comes from the Bio-Engineering Institute (Auckland university) and contains the cardiac fibre directions. Simulations of the above-described model have been carried out, and the results obtained – in particular stresses, strains and global indicators such as PV cycles – correspond reasonably well to cardiac physiology, see Fig. 5.

The complete validation of the 3D model is still in progress. In particular some important regulatory mechanisms such as the Starling effect ought to be included in our model. Another objective is to accurately reproduce some pathologies, e.g. non-obstructive cardiomyopathies. Regarding the data assimilation procedures, the first 3D results corresponding to synthetic (i.e. numerically simulated) data will be obtained soon.

7. Contracts and Grants with Industry

7.1. Michelin: simulation of the behavior of reinforcing sheets in tyres

Participants: Dominique Chapelle, Arnaud Münch, Marina Vidrascu.

The reinforcing sheets in tyres are thin, strongly anisotropic layers made of a stiff material embedded in the tyre rubber in order to increase the structural rigidity, see Figure 6. As explained in Section 6.1.1, classical shell models and finite elements are not well-suited to such cases, hence the purpose of the partnership is to develop efficient numerical methods to simulate the behavior of reinforcing sheets in an industrial software environment.

In the second step of this collaboration, corresponding to this year's work, we developed a new 27 nodes Q2 3D-shell element. This element uses the same mixed interpolation procedure as the MITC9 general shell element, and thus has the same desirable locking prevention properties. In addition, the 3D energy density is used unmodified, hence very general densities can be employed. In addition to the generalised Hooke energy for large displacements, we also implemented the Ogden-Ciarlet-Geymonat to handle large deformations.

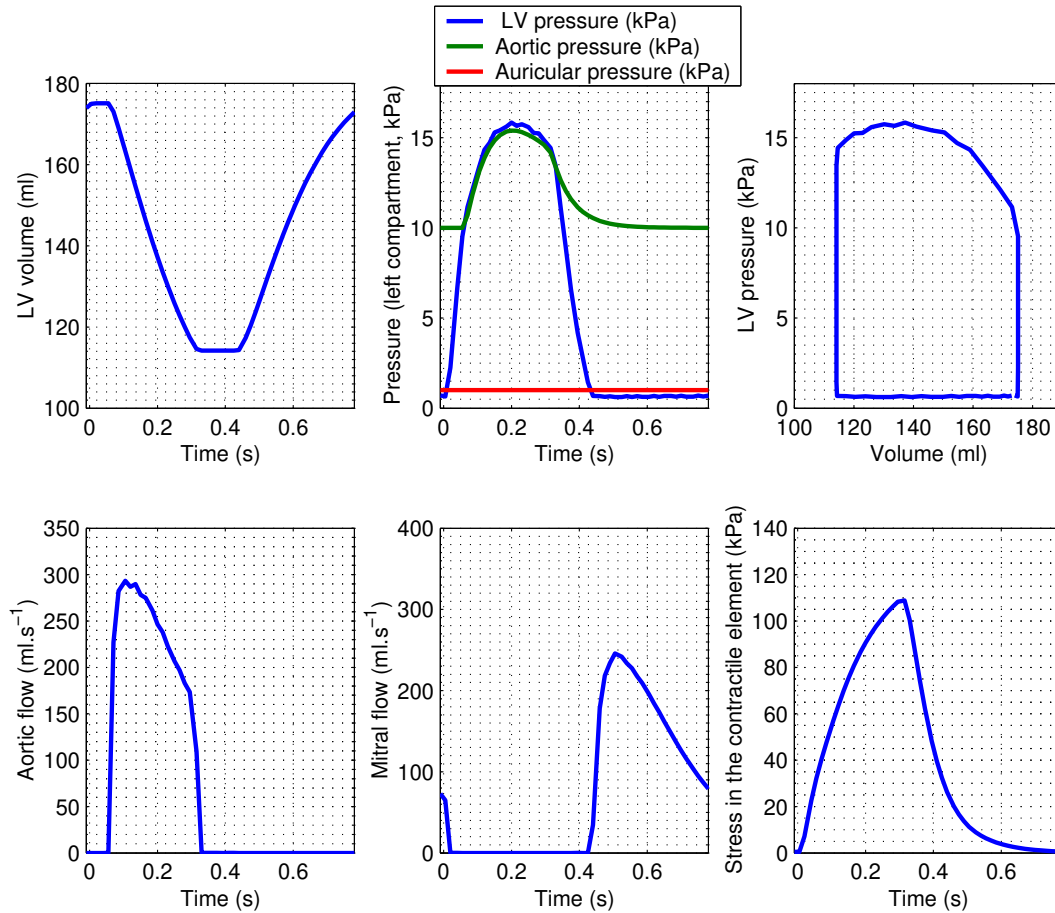


Figure 5. Classical indicators of the heart behaviour have been obtained from the simulation of a heart beat using the 3D model previously described.

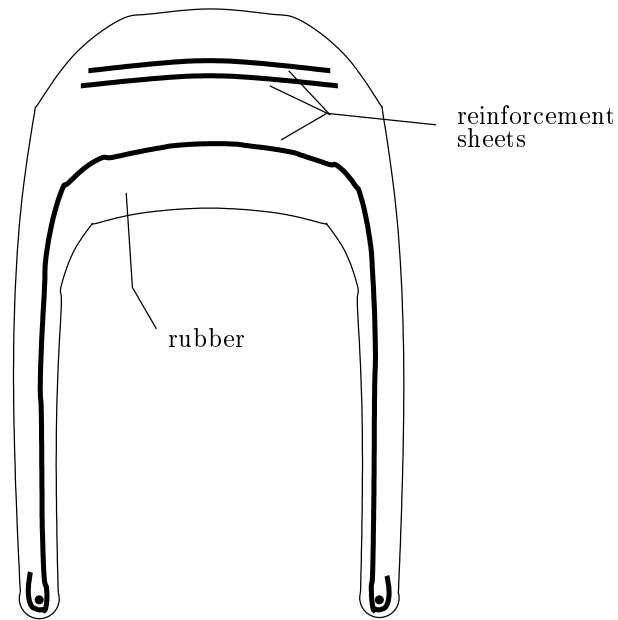


Figure 6. Cross-section of a tyre

Furthermore, we developed a specific energy density based on shell deformation tensors (as opposed to 3D strains) so as to fit material characteristics by means of actual structural experiments (bending, stretching, etc. of sheets) compared to simulation results.

We demonstrated the efficiency of our elements using a set of classical linear and non-linear test cases. Some “real-life” industrial test problems were also considered.

In addition, we analysed a specific numerical locking phenomenon that arises due to the strong anisotropy of the sheets, and the effect of incompressibility on 3D-shell models and finite elements (see Section 6.1.1).

8. Other Grants and Activities

8.1. National projects

8.1.1. ARC ICEMA2 (*Images of the Cardiac Electro-Mechanical Activity*)

Participants: Dominique Chapelle, Patrick Le Tallec, Robert Cimrman, Jacques Sainte-Marie, Marina Vidrascu.

This project⁴ is coordinated by Frédérique Clément (Projet SOSSO) and includes the Epidaure and Sinus teams from Sophia Antipolis as well as the SOSSO and MACS teams from Rocquencourt.

The aim is to combine data processing techniques (in particular as regards images) with biophysical modelling and numerical simulations of the electro-mechanical activity of the heart, so as to estimate the model parameters and state, hence use the predictive capabilities of the model. The main two physical phenomena occurring in the heart are the action potential propagation and the contraction of the muscle tissue. Both phenomena can be modelled by PDEs which are – of course – coupled. In this project, MACS is more specifically in charge of modelling and simulating the mechanical behavior. For more details and recent results, see Section 6.3.1.

⁴<http://www-rocq.inria.fr/sosso/icema2/icema2.html>

8.1.2. ACI CONSTRUCTIF (*COuplage de coNcepts pour la Surveillance de sTRUCTures mécaniques InFormatisées - Coupling of concepts for the surveillance of computerised mechanical structures*)

Participants: Frédéric Bourquin, Dominique Chapelle, Amine Hassim.

This project⁵ coordinated by the Sigma2 team (IRISA) is part of the “ACI Sécurité Informatique”⁶ and was launched in September 2003 (for 3 years). The objectives are:

- the coupling of statistical models of sensor data with models of the physical phenomena governing the instrumented structures for monitoring purposes;
- the investigation of the combined use of multidisciplinary approaches – namely, statistical inference, data assimilation, finite element model updating and optimization methods – with a view to diagnosing and localising damage.

One of the key issues of this project pertains to the analysis of the temperature effect, which has a dramatic impact on the vibration monitoring of civil engineering structures in particular, and is widely considered as a major scientific challenge.

8.2. International projects

8.2.1. RTN Project “SMART”

Participants: Michel Bernadou, John Cagnol, Dominique Chapelle, Arnaud Münch, Marina Vidrascu.

This project⁷ – an RTN project of the fifth European Framework Program – started in November 2002 (for 4 years). The aim is to foster research and to provide training for researchers in the field of new materials and adaptive systems. “New materials” is used here as a generic term for “functional” materials whose physical or chemical properties are used in the design of control elements yielding smart systems. The scientific objectives of the research are to develop efficient mathematical methods and numerical tools for modelling, control and numerical simulation.

This network project is coordinated by ESIEE⁸, MACS being the other French member out of a total of 11 members from 8 European countries.

8.2.2. NSF-INRIA Project “Control of interactive structures with dynamic shells”

Participants: Michel Bernadou, John Cagnol, Dominique Chapelle.

This project supports collaborative research between our group and the University of Virginia (principal investigator Irena Lasiecka), on problems related to stabilization and optimal control of dynamical shell models where control actions and sensing are implemented via smart materials technology.

This year’s work was concerned with deriving the free boundary conditions and associated strong form of a shallow Kirchhoff shell model based on intrinsic geometry methods. Manipulations of the model result in a cleaner form where the displacement of the shell and shell boundary is written explicitly in terms of standard tangential operators.

8.2.3. Other long-term collaborations

- Collaboration on numerical locking with MIT and ADINA R&D (Klaus-Jürgen Bathe).

⁵<http://www.irisa.fr/sigma2/constructif/constructif-welcome.htm>

⁶<http://acisi.loria.fr/>

⁷<http://www.esiee.fr/smart-systems/index.php>

⁸<http://www.esiee.fr/>

9. Dissemination

9.1. Various academic responsibilities

- Dominique Chapelle is a member of the editorial board of “Computers & Structures”.
- Dominique Chapelle is the scientific coordinator of the CEA-EDF-INRIA Schools organized by INRIA.

9.2. Teaching activities

- Dominique Chapelle :
 - DEA (Master’s) Course on Finite Element Procedures at Université Saint-Joseph (Beyrouth, Lebanon), 10-21 November 2003.
 - Lecture at “Ecole Doctorale de Mathématiques de Paris-Centre”, 24 September 2003.
- Arnaud Münch: Teaching assistant in *Structural Mechanics* at Université de Villetaneuse
- Jacques Sainte-Marie :
 - Supervision of graduate and postdoctoral students.
 - Scientific advisor for the PhD thesis of S. Glaser (Laboratoire Central des Ponts et Chaussées) *Modélisation et contrôle d’un véhicule en trajectoire limitée. Application au développement d’un système d’aide à la conduite (in french)*. Defense December 2003.
 - Courses on linear algebra and formal calculus, University of Versailles-Saint Quentin, spring 2002.
- Marina Vidrascu : Course *Mathematical fundamentals of the finite element method*, at école Supérieure d’Ingénierie Léonard de Vinci.

9.3. Participation in conferences, workshops and seminars

Dominique Chapelle

- Second M.I.T. Conference on Computational Fluid and Solid Mechanics, 17-20 June 2003, Cambridge (MA-USA). Special session organizer, speaker and co-author.
- PSMN Workshop “Modeling in Medicine”, 3-4 June 2003, Lyon. Invited speaker.
- SMART School, 15-19 September 2003, Pavia (Italy). Lecturer.
- GAMNI Workshop on open finite element software, 23 May 2003, Paris. Speaker.
- Invited seminars at CMAP (20 March), Nancy (21 May), USJ (Beyrouth, 14 November), CERMICS (10 December), Rennes (17 December).
- Talk for visit of Mrs B. Chirac, 25 June 2003.

Robert Cimrman

- Second M.I.T. Conference on Computational Fluid and Solid Mechanics, 17-20 June 2003, Cambridge (MA-USA).

Amine Hassim

- Logiciels pour la Modélisation et le Calcul Scientifique, 25 avril 2003, IFP 92500 Rueil-Malmaison, (with E. Balmès) : *Openfem : Toolbox d'Éléments Finis en Opensource*
- Colloque National en Calcul des Structures - Session logicielle 20-23 May 2003, Giens (var), France. (with E. Balmès, D. Chapelle, C. Delforge, F. Génot, A. Hassim, J.M. Leclerc, M. Vidrascu) : *OpenFEM : une toolbox d'éléments finis en opensource*
- Institut Henri Poincaré, 28 March 2003, Paris. *GDR Applications Nouvelles de l'Optimisation de Formes*.

Arnaud Münch

- Université de Besançon , 10 April 2003. *Mathematical analysis of a non-linear model of glued joint*.

Jacques Sainte-Marie

- Second M.I.T. Conference on Computational Fluid and Solid Mechanics, 17-20 June 2003, Cambridge (MA-USA). *Data assimilation for an electro-mechanical model of the myocardium*.
- SampTA03 conference (Sampling theory and applications 2003 conference) 26-30 May 2003, Strobl (Austria) *A sampling technique based on transforms associated with a group representation*.

Marina Vidrascu

- Second M.I.T. Conference on Computational Fluid and Solid Mechanics, 17-20 June 2003, Cambridge (MA-USA). *General shell elements adapted to coupling*.

10. Bibliography

Major publications by the team in recent years

- [1] M. BERNADOU. *Finite Element Methods for thin Shell Problems*. Wiley, Chichester, 1996.
- [2] D. CHAPELLE. *Some new results and current challenges in the finite element analysis of shells*. in « Acta Numerica », Cambridge University Press, Cambridge, 2001, pages 215–250.
- [3] P. LE TALLEC. *Domain Decomposition Methods in Computational Mechanics*. North-Holland, 1994, Volume 1.

Books and Monographs

- [4] D. CHAPELLE, K. J. BATHE. *The Finite Element Analysis of Shells – Fundamentals*. Springer-Verlag, 2003.

Articles in referred journals and book chapters

- [5] K. J. BATHE, D. CHAPELLE, P. S. LEE. *A shell problem 'highly sensitive' to thickness changes*. in « Internat. J. Numer. Methods Engrg. », volume 57, 2003, pages 1039–1052.
- [6] M. BERNADOU, C. HAENEL. *Modelization and numerical approximation of piezoelectric thin shells. Part 1 : The continuous problem*. in « Comput. Methods Appl. Mech. Engrg », volume 192, 2003, pages 4003-4043.
- [7] M. BERNADOU, C. HAENEL. *Modelization and numerical approximation of piezoelectric thin shells. Part 2 : Approximation by finite element methods and numerical experiments*. in « Comput. Methods Appl. Mech. Engrg », volume 192, 2003, pages 4045-4073.

- [8] M. BERNADOU, C. HAENEL. *Modelization and numerical approximation of piezoelectric thin shells. Part 3 : From the patches to the active structures.* in « *Comput. Methods Appl. Mech. Engrg.* », volume 192, 2003, pages 4075-4107.
- [9] D. CHAPELLE, A. FERENT, K. J. BATHE. *3D-shell finite elements and their underlying model.* in « *Math. Models Methods Appl. Sci.* », 2003, In press.
- [10] D. CHAPELLE, A. FERENT. *Modeling of the inclusion of a reinforcing sheet within a 3D medium.* in « *Math. Models Methods Appl. Sci.* », volume 13, 2003, pages 573–595.
- [11] D. CHAPELLE, A. FERENT, P. LE TALLEC. *The treatment of “pinching locking” in 3D-shell elements.* in « *M2AN Math. Model. Numer. Anal.* », volume 37, 2003, pages 143–158.
- [12] D. CHAPELLE, D. L. OLIVEIRA, M. L. BUCALEM. *MITC elements for a classical shell model.* in « *Comput. & Structures* », volume 81, 2003, pages 523–533.
- [13] M. A. FERNÁNDEZ, P. LE TALLEC. *Linear stability analysis in fluid-structure interaction with transpiration. Part II: numerical analysis and applications.* in « *Comput. Methods Appl. Mech. Engrg.* », volume 192, 2003, pages 4837–4873.
- [14] M. A. FERNÁNDEZ, P. LE TALLEC. *Linear stability analysis in fluid-structure interaction with transpiration. Part I: formulation and mathematical analysis.* in « *Comput. Methods Appl. Mech. Engrg.* », volume 192, 2003, pages 4805–4835.
- [15] J. F. GERBEAU, M. VIDRASCU. *A Quasi-Newton Algorithm Based on a Reduced Model for Fluid-Structure Interaction Problems in Blood Flow.* in « *Mathematical Modelling and Numerical Analysis* », number 4, volume 37, 2003, pages 631-647.
- [16] F. KRASUCKI, A. MÜNCH, Y. OUSSET. *Numerical simulation of debonding of adhesively bonded joints.* in « *Internat. J. Solids. Struct.* », number 26, volume 39, 2002, pages 6355–6383.
- [17] F. KRASUCKI, A. MÜNCH, Y. OUSSET. *Mathematical analysis of nonlinear bonded joint models.* in « *To appear in Math. Model. Meth. Applied. Sciences.* », 2003.
- [18] J. SAINTE-MARIE, S. MAMMAR, L. NOUVELIÈRE, V. ROUAULT. *Sub-optimal longitudinal control of road vehicles with capacity and safety considerations.* in « *To appear in ASME Journal of Dynamic Systems, Measurement and Control* », 2004.
- [19] J. SAINTE-MARIE. *Modelling, estimation and analysis of inter-vehicular spacing during congested situations.* in « *IEEE Trans. Intelligent Transportation systems* », Submitted.

Publications in Conferences and Workshops

- [20] D. CHAPELLE, A. FERENT. *Reliability considerations for 3D-shell elements.* in « *Second M.I.T. Conference on Computational Fluid and Solid Mechanics* », volume 1, Elsevier, K. J. BATHE, editor, pages 181–184, 2003.

- [21] D. CHAPELLE, A. MÜNCH. *Obtention de modeles de coque incompressible par analyse asymptotique*. in « Actes du 35eme congrès d'analyse numérique - La Grande Motte », 2003.
- [22] R. CIMRMAN, J. KROC, E. ROHAN, J. ROSENBERG, Z. TONAR. *On coupling cellular automata based activation and finite element muscle model applied to heart ventricle modelling*. in « Simulations in Biomedicine V », WIT press, Z. ARNEŽ, F. BREBBIA, V. STANKOVSKI, editors, pages 25–34, 2003.
- [23] R. CIMRMAN, E. ROHAN. *Modelling heart tissue using a composite muscle model with blood perfusion*. in « Computational Fluid and Solid Mechanics 2003 », Elsevier Science, K. J. BATHE, editor, pages 1642–1646, 2003, Proceedings of the second MIT conference.
- [24] R. CIMRMAN, J. SAINTE-MARIE. *Towards mathematical heart modelling*. in « 19th conference on computational mechanics », University of West Bohemia, 2003.
- [25] R. CIMRMAN, J. SAINTE-MARIE. *Towards Mathematical Heart Modelling: Simplified Model of Left Ventricle with Valve*. in « Proceedings of the 19th conference Computational Mechanics 2003 », pages to appear, Nečtiny, 2003.
- [26] A. HASSIM, E. BALMES. *Openfem : Toolbox d'Eléments Finis en Opensource*. in « Logiciels pour la Modélisation et le Calcul Scientifique », IFP 92500 Rueil-Malmaison, 2003.
- [27] A. MÜNCH, Y. OUSSET. *Multi-dé laminage dans les structures composites*. in « Actes du VIeme colloque français de calcul des structures, Giens », pages 459–466, 2003.
- [28] L. MEVEL, M. BASSEVILLE, M. GOURSAT, A. HASSIM. *A subspace detection approach to damage localization*. in « 21st International Modal Analysis Conference (IMAC-XXI) », Kissimmee, FL, USA, 2003.
- [29] J. SAINTE-MARIE, D. CHAPELLE, M. SORINE. *Data assimilation for an electro-mechanical model of the myocardium*.
- [30] J. SAINTE-MARIE. *A sampling technique based on transforms associated with a group representation..* in « SampTA'03 conference (Sampling Theory and Applications) », 2003.
- [31] G. VANDERBORCK, A. HASSIM. *Damage Monitoring By Means Of Acoustic Spectroscopy*. in « 74th Shock & Vibration Symposium », San Diego, CA, USA, 2003.

Internal Reports

- [32] J. F. GERBEAU, M. VIDRASCU. *A Quasi-Newton Algorithm Based on a Reduced Model for Fluid-Structure Interaction Problems in Blood Flows*. Technical report, number RR4691, INRIA, janvier, 2003, <http://www.inria.fr/rrrt/rr-4691.html>.

Miscellaneous

- [33] E. BALMÈS, D. CHAPELLE, C. DELFORGE, F. GÉNOT, A. HASSIM, J. M. LECLERC, M. VIDRASCU. *OpenFEM : une toolbox d'éléments finis en opensource*. Giens (var), France, 2003, Colloque National en Calcul des Structures - Session logicielle.

- [34] I. PARÉS. *Propagation d'ondes dans les structures minces - Modélisation et schémas numériques*. Mémoire de DEA, Université Paris 6 et INRIA-Rocquencourt, 2003, Resp. D. Chapelle.

Bibliography in notes

- [35] J. BESTEL, F. CLÉMENT, M. SORINE. *A biomechanical model of muscle contraction..* in « Lectures Notes in Computer Science », volume 2208, Eds W.J. Niessen and M.A. Viergever, Springer-Verlag, 2001.
- [36] D. CHAPPELLE, F. CLÉMENT, F. GÉNOT, P. LE TALLEC, M. SORINE, J. URQUIZA. *A Physiologically-Based Model for the Active Cardiac Muscle*. in « Lectures Notes in Computer Science », volume 2230, Springer-Verlag, T. KATILA, I. E. MAGNIN, P. CLARYSSE, J. MONTAGNAT, J. NENONEN, editors, 2001.
- [37] P. G. CIARLET. *Mathematical elasticity*. series Three-dimensional elasticity. Studies in Mathematics and its Applications, volume Vol. I, North-Holland Publishing Co, Amsterdam, 1988.
- [38] A. HILL. *The heat of shortening and the dynamic constants in muscle*. in « Proc. Roy. Soc. London (B) », volume 126, 1938, pages 136-195.
- [39] I. HOTEIT. *Filtrage de Kalman réduits et efficaces pour l'assimilation de données en océanographie*. Ph. D. Thesis, Université J. Fourier, Grenoble, 2001.
- [40] A. HUXLEY. *Muscle structure and theories of contraction*. in « Progress in biophysics and biological chemistry », volume 7, Pergamon press, 1987.
- [41] I. MIRSKY, W. PARMLEY. *Assessment of passive elastic stiffness for isolated heart muscle and the intact heart*. in « Circul. Research », volume 33, 1973, pages 233-243.
- [42] D. PHAM, J. VERRON, M. ROUBAUD. *Singular evolutive Kalman filter with EOF initialization for data assimilation in oceanography*. in « J. Mar. Syst. », volume 16, 1997, pages 323-340.
- [43] D. VERONDA, R. WESTMANN. *Mechanical characterization of skin - Finite deformation*. in « Journal of Biomechanics », volume 3, 1970, pages 114-124.
- [44] F. JÜLICHER, A. AJDARI, J. PROST. *Modeling molecular motors*. in « Reviews of Modern Physics », number 4, volume 69, October, 1997.