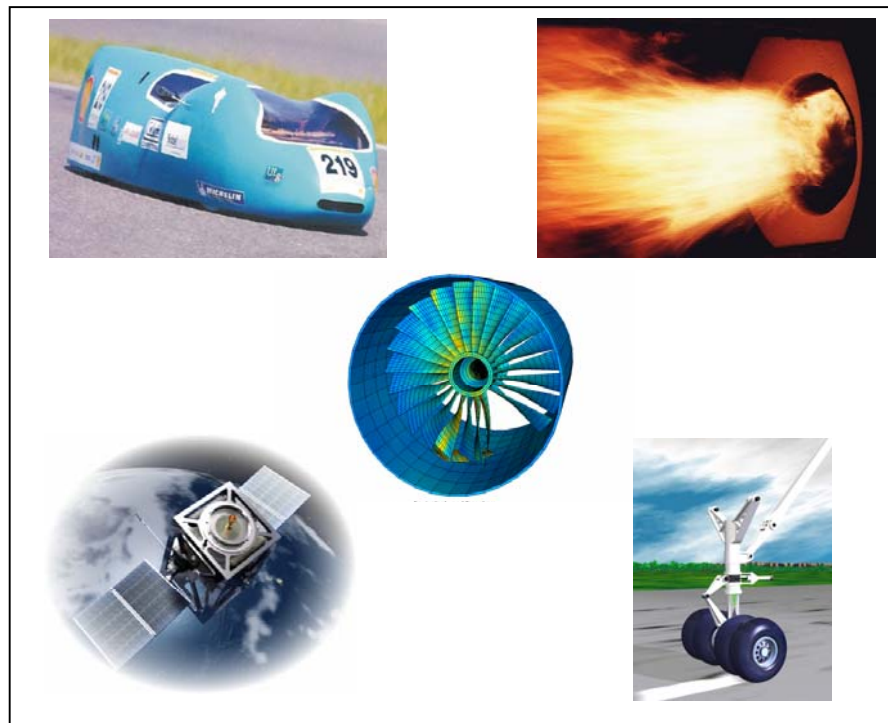




## Activity Report 2005



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## 2. Research Activities

### 2.1. Aerodynamics (AER) – J.A. ESSERS

#### 2.1.1. NUMERICAL MODELLING OF THREE-DIMENSIONAL VISCOUS FLOWS AT MODERATE REYNOLDS NUMBERS. APPLICATION TO FLOW IN MICRO-DUCT AND MICRO-CAVITIES

The 3D finite-volume code developed in the aerodynamic group has been modified to introduce viscous effects and to solve the full Navier-Stokes equations. A particular attention has been paid to ensuring a sufficient accuracy in the discretization of viscous derivatives on severely distorted grids. Micro-flows with relatively low Reynolds number and rarefaction effects near the wall have been simulated. The wall boundary condition accounts for a slip velocity depending on the velocity gradient and on the Knudsen number. The code will be used to study fluid-structure interaction in MEMS.

*Publications* : AER001, AER002, AER004

*Research staff involved* : J.M. Vaassen, D. Vigneron, J.A. Essers

*Related project* : ARC project mentioned in 3.2.

#### 2.1.2. CALCULATION OF HIGHLY UNSTEADY FLOWS OF COMPRESSIBLE LIQUIDS IN POSITIVE DISPLACEMENT PUMPS

The finite volume code for 3D viscous flows developed in the aerodynamic group has been modified to accommodate compressible liquids. A dual time stepping approach with a local preconditioning applicable to these very low Mach number flows has been developed. In positive displacement pumps, such as e.g. in G-rotors, the shape of the computational domain and the mesh are strongly modified in time and computed automatically at each time step. A special accurate time integration algorithm has been developed to satisfy the discrete geometric conservation law when computing the highly unsteady flow on deforming meshes.

*Publications* : AER003

*Research staff involved* : D. Vigneron, J.A. Essers

*Related projects* : doctoral thesis of Didier Vigneron

*Partners* : LTAS Turbomachinery and Propulsion Group

#### 2.1.3 CONSERVATIVE INTERPOLATIONS AT THE INTERFACE BETWEEN MESHES IN RELATIVE MOTION

In various fluid flow problems, the mesh used to solve Euler and Navier-Stokes equations is made of different parts moving with respect to each other. The aim of this research was to develop a very general interpolation algorithm to ensure strict conservativity at the

interface between these parts. It is developed in the frame of cell centered finite volume techniques using three-dimensional unstructured meshes with arbitrary polyhedral cells limited by triangular and quadrilateral faces. It will namely be applied to the simulation of flows in G-rotor pumps and to the study of rotor-stator interactions in turbomachinery.

*Research staff involved* : M. Basile, D. Vigneron

*Related project* : doctoral thesis of D. Vigneron

## **2.2. Applied Thermodynamics – J. LEBRUN**

### **2.3. Automotive Engineering (VEH) – P. DUYSINX**

#### 2.3.1. GENERALIZED SHAPE OPTIMIZATION USING EXTENDED FINITE ELEMENT METHOD (X-FEM) AND LEVEL SET DESCRIPTION

*Description* : The objective of our research is to study and develop a new shape optimization approach which takes its place between the two classical methods of shape and topology optimization. It is based on using the recent Level Set description of the geometry and the novel eXtended Finite Element Method (X-FEM). The method benefits from the fixed mesh work using X-FEM and from the curves smoothness of the Level Set description. Design variables are shape parameters of basic geometric features or NURBS control points. The number of design variables of this formulation remains small whereas various global and local constraints can be considered. A key problem which is investigated is the sensitivity analysis and the way it can be carried out precisely and efficiently. Sensitivity analysis related to the displacements, the stresses or the compliance have been introduced. Several numerical applications (in two dimensions) which illustrate the great interest of using X-FEM and Level Set description together have been realised.

*Keyword*: X-FEM, structural optimisation, Level set

*Publications*: VEH-05-04, VEH-05-08, VEH-05-09

*Research staff involved*: L. Van Miegroet, T. Jacobs, P. Duysinx, C. Fleury

*Partners*: Open engineering.

*Related project*: ARC 03/08-298 (see point 3.2)

#### 2.3.2. TOPOLOGY OPTIMIZATION OF MICRO ELECTROMECHANICAL SYSTEMS

*Description*: The electrostatic actuation devices used in MEMS are generally based on capacitive systems in which one electrode is mobile and the other one is fixed. Applying voltage between the electrodes generates an electrostatic force which tends to reduce the

gap between the electrodes. Due to the non-linearity of the electrostatic force in function of the distance between electrodes, there exists a limit voltage from which there is no equilibrium between electrostatic and mechanical forces leading to the pull-in phenomenon. In some applications, the pull-in instability is undesirable and maximizing pull-in voltage is searched.

In consequence, the research has been focused on the application of the topology optimization method to the problem of maximizing the pull-in tension of microbeams. Microbeam is the simplest example of electrostatically actuated MEMS exhibiting pull-in and consequently it is suited to serve as test to develop topology optimization of similar devices. To avoid direct modification of the electric field by the optimization process, this first study considers a non design electrode and uses topology optimization to design an optimal suspension structure. In this way, the structural optimization domain is separated from the electrical domain. The solution procedure of the optimization problem is based on CONLIN optimizer using a sequential convex linear programming. On each step of the optimization process, the sensitivity analysis requires the knowledge of the current structure pull-in conditions. These last parameters are computed using a multiphysics finite elements method which is combined with a Riks-Crisfield algorithm.

*Research staff involved:* E. Lemaire, V. Rochus, P. Duysinx, J.-C. Golinval

*Partners:* Open engineering.

*Related project:* ARC 03/08-298 (see point 3.2)

### 2.3.3. SIMULATION OF ENGINE DYNAMICS USING A FLEXIBLE MULTIBODY SYSTEM APPROACH

*Description:* The work realized in collaboration with the GDTech enterprise aims at simulating the engine dynamics using the flexible multibody simulation tool SAMCEF-MECANO. The computing procedure has a particular interest in calculating high loaded engine components such as connecting rods and crankshafts. The preliminary study has been carried out with MECANO in the SAMCEF-FIELD environment. The connecting rod and piston have been modelled in the CATIA V5 system. Different finite element models of the connecting rods have been compared and validated. The simulation of the system is realized using flexible multibody system time-domain simulations as well as statico-dynamic finite element simulation of the components. The study has shown that a complete calculation file can be carried out using MECANO. Future work in 2006 will be devoted to develop a new computing procedure in the framework of the FIRST Entreprise GMPDYN project with SAMTECH in order to establish a frequency domain analysis procedure using a multibody system approach.

*Keywords:* Multibody system dynamics, finite element method, engine dynamics

*Research staff involved:* Julien Francart, Pierre Duysinx

*Partners:* GDTech, Samtech S.A., Excilis S.A.

*Related project:* Convention RW n° 4940 RW-Samtech SA. FIRST Enterprise GMPDYN

#### 2.3.4. OPTIMIZATION OF MECHATRONIC SYSTEMS: APPLICATION TO A MODERN CAR EQUIPPED WITH A SEMI-ACTIVE SUSPENSION

*Description:* The work takes place in the framework of an Inter University Attractive Programme (IUAP5/06, *Advanced Mechatronic Systems*) sponsored by the Belgian Federal Government, in which Belgium universities active in the mechatronic field collaborate and develop common researches. In this research PRM (UCL), PMA (KUL) and LTAS(ULG) develop and exchange methods and software tools for modelling, control and optimization of mechatronics systems. The main goal is to emphasize a global mechatronic approach to solve and optimise complex industrial applications. One of the demonstrators that have been selected to illustrate the application of numerical optimisation to a complex multibody system (MBS) and its controller: the optimisation of a modern car equipped with a semi-active suspension.

Two different approaches are used and compared to realize the modelling and the optimization. At first, based on the collaboration work with J.-F. Collard and P. Fiset (UCL), a MBS modelling approach based on a symbolic tool is used. The behaviour models of the MBS, the hydraulic actuators, the sensors and the controller are integrated in the MATLAB-SIMULINK environment. Optimization is also carried out in the same environment using a genetic algorithm (GA). On another hand, the second approach conducted at ULg relies on a general multibody simulation tool based on the Finite Element (FE) approach (SAMCEF-MECANO) whereas the optimisation is realized with SAMCEF-BOSS QUATTRO, an open optimisation tool.

*Keywords:* Multidisciplinary optimisation, Mechatronics, Multibody systems, Control, Vehicle, Industrial applications.

*Publications:* VEH-05-03

*Research staff involved:* Olivier Brûls, Pierre Duysinx, Jean-Claude Golinval

*Partners:* PRM-UCL, PMA-KUL

*Related project:* Inter University Attractive Programme (IUAP5/06, *Advanced Mechatronic Systems*), Ph D Thesis of Olivier Brûls.

#### 2.3.5. CREATIVE INTERFACE AND CONCEPTION: APPLICATION TO DESIGN IN MECHANICAL ENGINEERING

*Description:* The IC&C project proposes to finalise a third generation of human computer interface based on an original association of electronic art pen technologies

and voice recognition, able to understand, in real time, how the designer spontaneously works (drawing, hand moving and talking).

This new kind of interface allows to answer to the problematic of the "freehand sketching" which characterise creative (sketching) and correction (plans modification) levels in design engineering. With a practical vision, this freedom of expression is completed with a freedom of thought which allows the designer, using embedded technologies (TabletPC), telecommunications (WI-FI, wireless Internet) and basic distributed databases systems, to dispose of a working tool in each professional conditions: intention sketch for a client, technical sketches on workplace with the other intervenants, finalised plans back to his office with collaborators (anywhere, anytime).

*Keywords:* Preliminary design, free hand sketch, virtual concept, ergonomics.

*Research staff involved:* Geneviève Martin, Pierre Duysinx

*Partners:* Lucid group (University of Liège), Prof. J. Verly and J. Piater (Department Montefiore- ULg), Prof. V. DEKEYSER (Department of work psychology, ULg), Prof. J. Hancq (Facultés Polytechniques de Mons).

*Related project:* Convention RW-ULg 03/1/5438, (WIST), IC&C "*Interface Créative et Conception*."

### 2.3.6. FEASIBILITY STUDY OF A NEW HYDRAULIC MOTOR PUMP AND ITS APPLICATION TO HYBRID HYDRAULIC VEHICLES

*Description:* The work has to assess the technical feasibility of a new reversible motor / pump patented by a Walloon inventor. We have also estimated the performance curves by similarity with existing products. The work has also carried out the potential energy savings resulting from the application of the new motor pump in different applications, including hydraulic elevators and hybrid hydraulic vehicles. Hybrid hydraulic vehicles have been identified as the major potential application field and we have carried out an in-depth assessment study of the feasibility and of the potential applications of Hydraulic Hybrid Vehicle (HHV) technology. HHV vehicles are compared with Hybrid Electric Vehicles (HEV). Three categories of vehicles are studied: a C-segment passenger car, a Sport & Utility Vehicle (SUV) and an urban bus. In this study, the hydraulic pump/motor is used to provide power assist during vehicle acceleration and to recover energy during vehicle braking. The study concludes that HHV significantly benefit from regenerative braking possible with heavy vehicles during frequent starts/stops driving cycles thus making the HHV technology a valid alternative in niche markets such as urban buses, bin lorries or heavy urban delivery vehicles.

*Keywords:* Hydraulic motor pump, Hybrid hydraulic vehicles, modelling and design, fuel saving, CO<sub>2</sub> emissions.

*Publications:* VEH-05-10

*Research staff involved:* Frédéric Van Loo, Jonathan Nzisabira, Sébastien Christiaens, Pierre Duysinx, Philippe Mathieu.

*Partners:* RW DGTRE énergie, Mr Claude Waudoit, Flone Engineering

*Related project:* RW contract (DGTRE Energy) *Projet ENERCARE : étude technico-économique (Appel CAIMAN II).*

### 2.3.7. PRELIMINARY STUDY OF A TWO STROKE TURBO DIESEL ENGINE IN THE PERSPECTIVE OF HYBRID ELECTRIC VEHICLE APPLICATIONS

*Description:* This work consists in a pre-study aimed at evaluating the feasibility of an alternative engine concept, a two stroke opposed piston turbo Diesel engine, specially designed for use in a hybrid electric vehicle. The overall performances of the engine concept were evaluated through the development of a computer model of the engine, set up in the *Matlab* environment. The model showed promising performances in terms of specific power with an efficiency similar to that achievable with modern conventional four stroke engines. The model also helped to identify the most influencing parameters of the engine that have to be taken into account more closely in a further detailed study.

The second part of this work consists in a comparison between the two-stroke-opposed-piston-turbo-Diesel engine and a more conventional four stroke turbo Diesel engine of the same power rating. The criteria taken into account in the study are fuel consumption and emissions, weight, packaging, reliability, serviceability, noise vibration and harshness and manufacturing cost. This study shows that the two stroke opposed piston turbo Diesel engine offers many advantages over the four stroke engine, mainly in terms of weight, size, cost and simplicity and that its identified disadvantages are reduced when used in a hybrid electric vehicle.

*Keywords:* Two-stroke-piston-engine, Hybrid electric vehicle.

*Research staff involved:* Sébastien Christiaens, Pierre Duysinx, Philippe Ngendakumana, André Jamoule.

*Partners:* Green Propulsion

*Related project:* Master thesis (DEA) of Sébastien Christiaens

### 2.3.8. DEVELOPMENT OF ECO EFFICIENCY INDICES TO ASSESS AUTOMOTIVE PROPULSION SYSTEMS

*Description:* One generally assesses vehicles impact on environment based on a purely ecological index as LCA or ecoscore. However, daily experiments proved that this index is not sufficient to reflect the customers acceptance of the transportation systems and thus to serve as a good support for decision makers. In order to establish a more relevant ranking of propulsion systems a recent study ordered by the Walloon Region has shown that an eco efficiency index, which takes into account the trade off between the

operational performance of the vehicle (cost, safety, availability, reliability, range, design, serviceability, etc.) and its ecoscore is a superior index to rank different alternative solutions. Evaluating the operational performance and the users satisfaction is supported by a Value Analysis methodology and a multi criteria approach (AHP method). This preliminary study has to be completed further with development in order to be more robust and suited for a wider range of applications.

*Keywords:* Hydraulic motor pump, Hybrid hydraulic vehicles, modelling and design, fuel saving, CO<sub>2</sub> emissions.

*Research staff involved:* Jonathan Nzisabira, Pierre Duysinx, Philippe Mathieu.

*Partners:* Prof. J.L. Lilien (Department Montefiore – Ulg), Prof. A. Germain (Department of Applied Chemistry), Green Propulsion S.A.

*Related project:* Subvention RW n°02/16207 « *Développement et transfert de technologies éco-efficaces.* »

### 2.3.9. FROM CONCEPTUAL DESIGN TO PROTOTYPING OF FUEL CELL POWERED VEHICLES: APPLICATION TO THE SHELL ECO MARATHON RACE

*Description:* Since 2003, the automotive engineering sector is involved in the design and prototyping of fuel cell powered vehicles. The members of the department are active in many aspects of the development of hybrid fuel cell powered vehicles from simulation, design, experimental validation of components (batteries, fuel cell, power electronics, thermal and energy management). The expertise that has been accumulated is illustrated by the development of a shell eco marathon prototype, which has been presented in 2004 and 2005 in Nogaro race organized by Shell France. The lightweight vehicle has achieved rather good performances with an equivalent fuel economy of 2136 km with the energy of one litter of gasoline. The vehicle finished in an 8<sup>th</sup> position in the general classification of the Shell eco marathon and 2<sup>nd</sup> in the category of hydrogen and fuel cells. Moreover, the work of University of Liège has been distinguished by the eco design award, the second one in a row since the same vehicle has won it also in 2003.

*Keywords:* Fuel cell, hydrogen, hybrid electric vehicles, lightweight structures, eco design

*Research staff involved:* Sébastien Christiaens, Frédéric Van Loo, Laurent Van Miegroet, Geneviève Martin, Pierre Duysinx.

*Partners:* Prof. A. Germain (Department of Applied Chemistry), Green Propulsion S.A. Samtech S.A. MES-DEA (Switzerland).

*Related project:* Shell eco marathon project

## **2.4. Computer Graphics and CAD – P. BECKERS**

## **2.5 Continuum Mechanics and Thermomechanics (MCT) – M. HOGGE**

GENERAL OVERVIEW: NUMERICAL SIMULATION OF PROCESSES INCLUDING LARGE STRAINS

- Virtual manufacturing and numerical simulation of forming processes.
- Crashworthiness and impact modeling and simulation.
- Advanced constitutive modeling (plasticity, viscoplasticity, viscoelasticity, damage, rubber-like materials).
- Frictional contact.
- Tire mechanics
- Computational Biomechanics
- Finite element techniques for nonlinear mechanics.

All these developments are integrated an in-house FE code, named METAFOR, for nonlinear solid mechanics, based on an object-oriented development platform (cumulated manpower  $\cong$  150 men-year).

### 2.5.1. NUMERICAL SIMULATION OF COLD ROLL-FORMING/FUNDAMENTAL ASPECTS

*Description:* This project aims to implement numerical methods to achieve precise simulation of the cold roll forming process. By the ability to perform complete simulation of the forming process, the work will allow the manufacturer to understand their process and the mechanical causes of defects such as springback, camber, twist, oil caning, ... Computing sensitivities on the process and using optimizations methods, the work will allow the tracking of the source of defects and gives solutions to reduce and remove defects.

*Our tasks:* Our contribution to this project is to provide numerical tools (FE technology) for an efficient simulation of cold roll forming. In particular, this includes:

- Implementation of complex Elasto-Plastic Material Behavior using isotropic and kinematic hardening.
- Development of enhanced finite element giving a better springback simulation for a lower cost
- Development of specific roll contact tools
- Development of reverses methods for parametrical identification and shape optimization
- Development tuning and validation of a roll forming test for numerical parameters analysis and defect analysis

**Publications:** MCT-TA-162 - MCT-TA-167

**Research staff involved :** L.Papeleux and R. Boman

**Industry partners:** ARCELOR (Belgium - France), GDTech (Belgium)

**Related project:** R.W. project PROMETA

## 2.5.2. SIMULATION SOFTWARE FOR COLD-ROLL FORMING PROCESSES

*Description:* This project aims to validate advances of the finite element technique in the simulation of forming processes, in particular the cold-roll forming technology. To this end, a series of experiments has been carefully designed and carried out on a real forming line. A numerical modeling of this experimental line has been performed with the help of the Metafor code – a finite element software dedicated to large strain computations. Simulations were then launched, and a comparison between numerical results and experimental data allows examining the validity of the numerical simulation. Once it is fully tested and validated, the numerical simulation can be further exploited in order to master the influence of different parameters to the forming process. It can also be employed to investigate the occurrence of defects on the final products. In this way, numerical simulations reduce error-and-trial effort in order to obtain a correct design of cold-roll forming products. This clearly increases the productivity of cold-roll forming technology.

*Our tasks:* Our contribution to this project is to provide a reliable validation of numerical tools (FE modeling) for an efficient simulation of cold-rolling processes. In particular, this includes:

- Correct modeling of an experimental line of cold-roll forming
- Following experiments and handling experimental data
- Parametric study of different factors (like material models, friction between sheet and rolls ...) susceptible to have a strong impact to the cold-forming process
- Investigation of different setting (like meshes, element types, penalty coefficients in contact treatment) toward an efficient strategy of computations
- Examination of different possibilities to enhance the performance of the simulation

**Publications:** MCT-TA-162 - MCT-TA-167 - MCT-TA-171

**Research staff involved:** Q.V. BUI

**Industry partners:** Arcelor I R & D, Steel Solutions and Designs for Construction (Liège, Belgium)

Arcelor I R & D, Automotive Research Center (Montataire, France)

**Related project:** R.W. Project PROINDU

## 2.5.3. CONSTITUTIVE LAWS FOR THIXOMOULDING PROCESS

*Description:* Semi-solid metals exhibit time and strain rate dependent behavior known as thixotropy: they behave like solids in the undisturbed state and like liquids during shearing provided the shear rate is high enough. The solid-like behavior is due to the

presence of a solid skeleton consisting of interconnected grains. Shearing breaks the bonds between grains leading to a release of entrapped liquid and decreasing the viscosity of the semi-solid alloy. Semi-solid metal forming called thixoforming exploits this thixotropic and shear-thinning behavior since the semi-solid slug may be handable but also may flow easily in the die. The use of FE simulations to obtain the filling of the dies and to optimize the thixoforming process is clearly of a great interest.

*Our tasks:* Our contribution to this project is to provide numerical tools (FE technology and constitutive equation) for the simulation of the semi-solid behavior. This will be performed along two main axes: The first one is to implement a new material law in a FE code; the second one is to plan a set of experiments on different steel alloys in order to determine the material parameters of this law.

*Research staff involved:* R. Koeune

*Industry partners:* CRIF, Pôle matériaux de Wallonie, Ascometal, ELAP (W. Legros, A.Rassili-University of Liège), MMS (J. Lecomte-Beckers-University of Liège)

*Related project :* Thixomoulding

#### 2.5.4. NUMERICAL SIMULATION OF BRAIN DEFORMATIONS DURING SURGERY

*Description:* As an image-guided surgery procedure progresses, preoperative images become increasingly irrelevant. This is due to the organ of interest (e.g., the brain) being subjected to various sources of deformations, such as brain shift, cuts, retractions, and resections. Even if intraoperative images are taken during surgery, preoperative images cannot be discarded, since they are of better quality and some modalities are not available intraoperatively. It is thus critical to continue using all preoperative images and to update them as the organ deforms.

*Our tasks:* Our approach to updating preoperative images is based on (1) estimating the displacements of a number of key landmarks that can be extracted and tracked from successive intraoperative interventional-MRI images, (2) estimating the displacement field throughout the organ volume using a biomechanical model, which consists of a 3D volume mesh and a mechanical behavior law, and is deformed in accordance with the displacement of key landmarks, and (3) warping preoperative images according to this displacement field.

This technique gives to the biomechanical model a crucial and very central position. This means that a strong modeling effort has to be carried out during the design of the brain biomechanical model as well as its validation through clinical data.

*Research staff involved:* R. Boman

*Related project:* BrainNav

### 2.5.5. MULTISCALE MODELING AND NUMERICAL SIMULATION OF THE MECHANICAL BEHAVIOR OF POLYCRYSTALLINE MATERIALS BY CRYSTAL PLASTICITY : FORMATION OF SUBGRAIN MICROSTRUCTURES AND DETAILED STUDY OF GRAIN BOUNDARIES

*Publications:* MCT-TA-165 - MCT-TA-174 - MCT-TA-176 - MCT-TF-74 - MCT-TF-75

*Research staff involved :* L. STAINIER

*Related project :* F.N.R.S.

### 2.5.6. IMPROVEMENT OF TIME INTEGRATION ALGORITHMS FOR NUMERICAL SIMULATION OF IMPACT ON AERONAUTICAL STRUCTURES

*Publications related to this project:* MCT-TA-146 - MCT-TA-172

*Research staff involved :* L. NOELS

*Related project :* F.N.R.S. – Doctoral Fellowship

### 2.5.7. NUMERICAL SIMULATION OF MIXED LUBRICATION IN COLD ROLLING

*Description:* Rolling is one of the forming processes most widespread in the steel industry. The demand for steel keep increasing what justifies an increase in the production capacity. In order to accelerate the rate of the existing manufacturing units in activity, it is necessary to improve the knowledge in the field of lubricated contact. Indeed, friction in rolling is the key parameter in order to allow an acceleration of the rate of production. The numerical simulation of the lubricated contact is the main objective of this project.

*Our tasks:* To develop a semi-analytical numerical model. This model must allow a qualitative analysis of the industrial points of their rolling mill. In order to increase its predictive behavior at the quantitative level, technical improvements are brought to the model compared to previously published ones.

The principal problem is the model of friction used for asperities tops where solid-solid contact is supposed. A user parameter is indeed needed. In order to improve our knowledge of the conditions of lubrication for these zones, some finite elements simulations are planned to highlight the capacity of our code METAFOR to simulate micro fluidic flows. It is thus necessary to introduce a fluid material and to carry out simulations with Arbitrary Lagrangian Eulerian formulation taking into account fluid-solid contacts.

*Publications:* MCT-TA-170 - MCT-TA-179

*Research staff involved:* A. Stephany

*Industry partners :* Cockerill-Sambre, groupe Arcelor (Luxembourg)

*Related project:* R.W. 215052. FIRST Europe Objectif 3: project METALUB:

#### 2.5.8. MODELING AND CRASHWORTHINESS OF AERONAUTICAL STRUCTURES SUBMITTED TO IMPACT.

*Description:* Advanced high-strength steels or titanium alloys are gaining popularity in automotive and aeronautics applications because they exhibit a large ductility for a high strength level. As a result, these newly developed alloys are ideal for crash energy management, fatigue and durability of sensitive parts. With proper design strategy, these materials offer a great opportunity for weight reduction and crash performance. Therefore, the characterization of the mechanical properties of these materials has to be performed in the context of rate dependent plasticity at large strains and for both low and high strain rates. Moreover, finite element simulation of fast phenomena requires adequate solution algorithms. In a finite element simulation of high strain rates phenomena, three parameters have to be taken into account. At first, adequate constitutive equations including strain rate and temperature effects must be used to measure the increasing of hardening due to the high strain rate and the thermal softening of the material. Secondly, the study of fast phenomena must be coupled with large strain formulation for which every modes of strain must be considered (in other words one has to avoid locking of the finite elements). Therefore, it is important to use finite element providing a good answer to different sollicitation modes, especially bending. Thirdly, numerical solution algorithms have to evaluate accurately the evolution of temperature during the process. Moreover, due to the fastness of the studied phenomena, the mechanical inertial effect can not be neglected and the resolution algorithms have to be able to quantify these dynamic effects.

*Our tasks:* Our contribution to this project is to provide numerical tools (FE technology and time integration algorithms) for an efficient simulation of fast thermo-mechanical phenomena. In particular, this includes:

- Development of constitutive laws depending simultaneously on plastic strain, plastic strain rate and temperature in a thermomechanically coupled formulation.
- Development of an implicit thermomechanical staggered scheme coupling Newmark family scheme for the resolution of mechanic problem and mid-point generalized for the resolution of thermal problem
- Application of the EAS finite element formulation to dynamics thermomechanical problems.

*Publications:* MCT-TF-72 - MCT-TF-73

*Research staff involved:* P.P. Jeunechamps.

*Industry partners:* Techspace Aero (Belgium)

*Related project:* RW n° 215275. Project FIRST-EUROPE Objectif 3: IMPAMETA.

#### 2.5.9. NUMERICAL MODELING OF BOLTED JOINTS LINES FAILURE FOR THE AERONAUTICAL STRUCTURES UNDER IMPACT.

*Description:* The final goal of the project is to provide the industrial partner involved in the project, as well as any interested enterprise, a finite element software that allows

simulating structures under shock or impacts. In particular, the problem is to consider jointed bolts under dynamic stress. To do this, an intermediate, but still very important step is to enlarge the capacities of the software METAFOR in order to be able to correctly simulate the evolution of damage and rupture of bolted joints. The failure of the first joint in a line can provoke, such as a domino effect, the rupture of all the lines of bolted joints. In order to capture the singularity of the stress field in the crack tip, current techniques propose to enormously decrease the mesh in the neighborhood of the crack tip. Furthermore the study of crack propagation implies multiple and expensive remeshing operations which in their turn can bring rather big numerical difficulties, especially in 3D. In order to bypass these difficulties, the X-FEM (eXtended Finite Element) can be used. This method proposes to enrich the form functions in those finite elements where the crack occurs, and not to or almost not to remesh. The use of this method near crack tips can reduce significantly the number of elements necessary for a realistic model of the phenomenon, thus reducing the calculation costs, always rather big in this kind of simulations.

*Research staff involved:* O. Karaseva

*Industry partner:* SONACA s.a.

*Academic partners:* University of Reading (UK), Ecole Centrale de Nante (France), ONERA (France)

*Related project:* R.W. N° 415778. FIRST Europe « Objectif 1 » Project METARIV

#### 2.5.10. OPTIMIZATION OF CONSTRAINED FORMING PROCESSES. NUMERICAL PROCEDURES FOR DEFECT CONTROL AND COMPENSATION

*Description:* The main objective of the project is to provide a user-friendly software, and its associated methodology, that enables interested users to optimize, in a virtual way, deep drawing processes. In order to produce realistic studies and simulations, this software will guarantee the formed metal component to be exempt from manufacturing defects (tearing, wrinkling). Hence the software will be able to perform springback compensation by adapting tools shape. As a consequence, the number of needed experimental tests to adjust a real metal forming process, will be reduced to a minimum, thus decreasing significantly manufacturing costs and developing time associated to the fine tuning of a new deep drawing manufactured product.

*Our tasks:* Our contribution to this project is to provide optimization algorithms that consider realistic manufacturing constraints, such as wrinkling or tearing. In particular, this includes:

- Acquisition of knowledge about optimization techniques based on response surface methods,
- Implementation of equivalent drawbead line models,
- Development of appropriate optimization algorithms (SQP, genetic algorithm...) working under different constraints such as LFC (Limit Forming Curve),
- Validating this optimization toolbox using real industrial cases with the cooperation of RDCS/ Cockerill-Sambre.

*Publications:* Rapport LTAS n° TR-40.

*Research staff involved:* S. Trichon

*Industry partners:* RDCS S.A. (ARCELOR RESEARCH– Belgium)

*Related project:* R.W. N°415823 Project METAOPT FIRST-EUROPE Objectif 3:

#### 2.5.11 DEVELOPMENT OF A FINITE-ELEMENT CODE HIGHLY PARALLELIZABLE ACCOUNTING FOR FLUID/STRUCTURE INTERACTION, BASED ON THE "GHOST-CELLS" METHOD

*Description:* The ghost-cell method is a means of coupling a Lagrangian mesh, representing the solid structure, with an Eulerian mesh, representing the fluid domain. The fluid method is solved on the entire fluid domain and on the space overlapped by the solid mesh. On the moving boundary of the solid mesh, impermeability conditions are applied (R.P. Fedkiw et al. 1999). The collaboration consisted in coupling the fluid code AMROC (Dietering, 2005) developed at Caltech with the solid code Adlib (Radovitzky) developed at MIT. The moving boundary is computed using the « closest point transform » (Maunch, 2003) algorithm, which is based on sign distance functions, and which is developed at Caltech. The participation of the Laboratory was to take care of the communication between the different solvers and was realized during a visitor exchange of Ludovic Noels at MIT.

*Publications:* Rapport LTAS n° TR-40.

*Research staff involved:* L. Noels

*Partners:* MIT and Caltech

*Related project:* FNRS grant

#### 2.5.12 DEVELOPMENT OF A DISCONTINUOUS GALERKIN METHOD FOR NON-LINEAR SOLID MECHANICS

*Description:* Discontinuous Galerkin methods constitute a generalization of weak formulations allowing for discontinuities of the problem unknowns in the interior of the problem domain. This is generally accomplished by restricting the integration by parts to subdomains, which naturally leads to boundary integral terms on the subdomain interfaces involving jump discontinuities. The main appeal of discontinuous Galerkin methods lies in their ability to represent physical discontinuities present in the problem solution in a natural way. The primary purpose of the research in collaboration with MIT was to establish a discontinuous Galerkin framework for large deformations of solids in the context of non-linear static mechanics. The method is based on a general Hu–Washizu–de Veubeke functional allowing for displacement and stress discontinuities in the domain interior. The consistency and linearized stability of the method in the non-linear range as well as its convergence rate were proven. An implementation in three dimensions was developed, showing that the proposed method can be integrated into

conventional finite element codes in a straightforward manner. In order to demonstrate the versatility, accuracy and robustness of the method examples of application and convergence studies in three dimensions were studied.

*Research staff involved:* L. Noels  
*Partner:* MIT

### 2.5.13 NUMERICAL SIMULATION OF VISCOELASTIC BEHAVIORS

*Description:* Many materials can be classified as having viscoelastic behaviour: rubbers, thermoplastics, biological tissues, among many others. While viscoelastic constitutive equations for small strain regimes are quite well developed, no unified formulations are usual for the case finite strains. The inclusion of viscoelasticity in an unified context of variational models for hyperelastic-inelastic materials is the goal of this project.

*Specific tasks:*

- To develop a formulation of variational constitutive equations capable of representing viscoelastic behaviour in a finite strain regime. This model must allow the representation of different viscoelastic materials depending on the choice of appropriate potentials without changing the main approach.
- Parameter identification for a set of practical materials, ranging from rubbers, thermoplastics and soft tissues.

*Publications:* MCT-TA-164 - MCT-TA-169 - MCT-TA-177

*Research staff involved:* E . Fancello

*Academic Partners:* Universidade Federal de Santa Catarina (Brasil)

*Related Project:* Project VISCOX

## **2.6 Fracture Mechanics (FRM) — NGUYEN-DANG HUNG**

### 2.6.1 DELAMINATION AND DAMAGE OF LAMINATED COMPOSITES UNDER DYNAMIC LOADING

*Description:* The main objectives are the following :

Modelling the extension of the delamination of laminated composites under complex loadings. Criterion of mixed modes are implemented. Realisation of the connection themetis finite element with enriched with singularity fields in SAMCEF software. Implementation of the low speed impact modelling under non linear conditions. Adapting the existing high speed impact software to the present problems.

*Publications:* FMR155, FMR158, Several internal reports.

*Research staff involved:* SCOOT COONCE

*Partners:* SAMTECH, SONACA

*Related project:* COMDY (R.W.)

## 2.6.2 DIRECT LIMIT ANALYSIS OF PLANE STRUCTURES BY OPTIMISATION OF GLIDING LINE FIELD GENERATED BY RIGID FINITE ELEMENTS

Description: The research project envisages an application of the kinematical upper bounds theorem in limit analysis. Plastic flows in plane structures are supposed to be concentrated in some discontinuity lines at limit state. Simple rigid elements are performed to generate the gliding lines field and optimisation algorithm is implemented to find out the good form of the ultimate mechanism. That means the lengths and the orientations of each discontinuity line are considered as conception variables. Various numerical examples will illustrate the performance of the present method.

*Publications:* FMR173

*Research staff involved:* PHAN HONG QUANG

*Partners:* EMMC Centre, Ho Chi Minh City University of Technology, Vietnam.

*Related project:* EMMC (supported by CUD, Belgium's French Community) and EU-EMMC (supported by European commission).

## 2.6.3 MODELISATION OF THE INTERACTIONS BETWEEN INTERLOCKING BLOCKS (TAC178), SOIL AND WATER OF PITCHED DIKE REVETMENT USING SAMCEF SOFTWARE

Description: This study presents a three-dimensional finite element model of interlocking blocks within the context of the software Samcef. The geometry and material properties of the model are provided by the inventor Dr. Phan Duc Tac. The technique of super-element allows reducing the number of degree of freedoms of the block model. This also permits to focus into the main problem of the interaction between the structure, the soil and water and their efficiency for the slope protection. Several numerical simulations are carried out in order to investigate the distribution of the contact forces inside a block and between the components of blocks during wave attack. The numerical results indicate that for Tac178-blocks, the resistance of the structure under wave attack is augmented because the distribution of force between Tac178-blocks dissipates concentrated wave energy on the faces in the better way.

*Publications:* FMR153, FMR179, FMR180

*Research staff involved:* NGUYEN VAN HIEU

*Partners:* EMMC Centre, Ho Chi Minh City University of Technology, Vietnam.

*Related project:* EMMC (supported by CUD, Belgium's French Community) and EU-EMMC (supported by European commission).

#### 2.6.4 ADVANCED LIMIT AND SHAKEDOWN ANALYSIS OF STRUCTURES WITH SEMI RIGID CONNECTIONS

*Description:* The problem of limit and shakedown optimisation and analysis of structures particularly frame structures constitutes one of the research domain devoted by Prof, Nguyen Dang Hung since 1974. A software (CEPAO) was realized to perform automatically the computation of this topics via linear programming techniques. A new doctorate engineer HOANG VAN Long is now in charge to reactivate the CEPAO programme and perform new subroutines to take account of the possibilities of semi rigid connections and other up-to-date situations useful for practice civil engineering domains.

Research staff involved: HOANG VAN LONG

Partners: University of Le Qui Don, Vietnam.

Related project: MCMC (supported by CHRI, Belgium's French Community).

### **2.7 Manufacturing Laboratory (LMF) – J.F. DEBONGNIE**

#### 2.7.1 PREDICTION OF THE FORM ERRORS ARISING IN THE CUTTING PROCESS

*Description:* Form errors generally do arise in the cutting process, due to the clamping conditions for one part, and to the deformations under the cutting forces for a second part. From a quality point of view, it is essential for the manufacturer to be able to predict these errors and to verify that they comply with the indicated tolerances. The objective of the present research is precisely this prediction. It implies an analysis of the fixture devices, an evaluation of the cutting forces, a description of the actual trajectory of the tool in the part, and a finite element analysis of the deformation of the part under these circumstances. Although it is a relatively classical use of finite elements, the difficulty is to obtain an effective algorithm due to the facts that huge finite element models are used and that a very great number of load cases have to be treated. It is therefore necessary to develop special procedures taking account of the specificity of the problem.

*Publications:* LMF102

*Research staff involved:* L. MASSET

*Partners:* RENAULT S.A.

*Related project:* Doctoral thesis

#### 2.7.2 CONTROLLING FORM ERRORS FROM A SET OF MEASURED OR COMPUTED POINTS

*Description:* This research is a corollary of the preceding one. Having computed the actual shape of the part, it is necessary to assess the value of its form error in order to compare it to the given tolerances. Contrarily to most approaches in which a least square

method is used, the aim of this research is a correct assessment, following ISO standards. This leads to a Tchebicheff-type approximation, with a funnel-shaped minimum and in some cases, local minima. Two types of methods are used. The first one, based on direct geometrical considerations, is restricted to some cases. The second one, based on an iterative process making use of some properties of the p-norms, is completely general.

*Research staff involved:* L. MASSET, J.F. DEBONGNIE

*Partners:* RENAULT S.A.

*Related project:* Doctoral thesis

### 2.7.3 CHATTER PREDICTION IN MACHINING

*Description:* Chatter is a very harmful vibratory phenomenon which can arise in machining. Very noisy, it may be detrimental to the tools and to the surface finish. It may be due to the vibration of the tool or to the vibration of flexible elements of the part. The present research is devoted to chatter prediction when it comes from the part geometry. The approach is based on a stiffness analysis, in the spirit of Tlusty's theory.

*Publications :* LMF104

*Research staff involved:* L. MASSET

*Partners:* RENAULT S.A.

*Related project :* Doctoral thesis

### 2.7.4 DUAL ANALYSIS AND EQUILIBRIUM FINITE ELEMENTS

*Description:* The dual analysis is an effective tool for the error assessment of finite element analyses. It requires two finite element solutions, the first one with displacement elements and the second one with equilibrium elements. The possibility to develop 3-D equilibrium elements was only recognized recently. These elements had to be developed, and their theory, to be investigated.

Ladevèze-type dual analysis has also been developed for plates.

*Publications:* LMF101, LMF102

*Research staff involved:* J.F. DEBONGNIE

*Partners:* ASMA-Infographie, University of Ho Chi Minh City

### 2.7.5 GUIDING SYSTEM USED IN MICROMECHANICS

Miniaturization and integration of functions (mechanical, sensing, control, computing) within confined spaces are becoming increasingly important in modern systems. Examples are mobile phones, wearable sound and video systems, digital organizers, robot endoscopes, micro-pumps for medical applications, aerospace equipment, etc. In a micro-system, many functions need to be fundamentally reconsidered. Scale laws make some

physical principles useless for microsystems, while other principles, although without interest in macrosystems, may be extremely useful for miniaturized systems.

This is the case of the hinge function. Classical bearings such as ball bearings, sliding bearings and other pivots may be difficult to manufacture at the micro scale. As it is very difficult to manufacture small parts with good tolerances, the guiding precision may be insufficient for a particular application. In micromachines, friction may become very important compared to other forces and torques. In some applications, e.g. in medical devices, cleanliness exigencies practically prohibit the use of greasy lubricants. Consequently, there is an important need to develop frictionless micro bearings. Finally, the assembly of small components may become very difficult, and a device composed of a minimal number of components becomes paramount.

Among all possible solutions, notch hinges and spiders seems to be very attractive : no friction, no lubricant required, minimum space required, only one part to manufacture, no assembly, etc.

This last advantage is decisive. Indeed, the best way to simplify the assembly is to avoid, or better, to eliminate any assembly.

*Research staff involved:* P. MERKEN

## 2.7.6 SHIP OPTIMIZATION

*Description :* The project relates to an extension of the capacities of the LBR-5 software which was developed at the University of Liege in order to optimize metal structures of orthotropic type on the basis of their cost. The optimality criterion is a minimum cost, under technological, geometrical and resistance restrictions, and this at the preliminary draft stage. The structures considered come from the hydraulics, naval and offshore fields. The software allows a significant gain of time in the preconception of the structures, which is of primary interest for the industrialists. It is easy of use because a minimum of data is required and is complete in its results. This is why an improvement of a software such as LBR-5 is pertinent. The task of the Manufacturing Methods sector consists in the introduction of topological and form optimization. The form optimization will make it possible to find the shape of the cross-section which will correspond to the required restrictions. Topological optimization will give the optimum number of stiffeners to be used, their location and their form.

*Research staff involved:* J.F. DEBONGNIE, L. MASSET, P. MERKEN,

*Partners:* ULB-ANAST

*Related project:* OPTICOUT

## **2.8. Mechanical Production Systems and Dimensional Metrology – L.MASALAR**

### 2.8.1 USE OF ARTIFICIAL VISION IN 3D MEASUREMENT

*Description* : Dimensional Metrology has been revolutionized through the intervention of two recent technologies : artificial vision and three-dimensional metrology. The aim of this research is to develop algorithms and measurement techniques that take advantage of these two technologies together. The main advantages of artificial vision are non-contact measurement, possibility of intelligent and automatic displacement, collisions prevention, multiple-points measurement. Those of three-dimensional measurement are a high positioning resolution and a 3D displacement.

*Research staff involved* : F.Gauder

### 2.8.2 INFLUENCE OF MODERNIZATION ON MEASUREMENT UNCERTAINTIES

*Description* : Some old measuring machines are still mechanically high-performance but become obsolete because of their signal acquisition and treatment system. The aim of this research is to examine the influence of modernization on measurement uncertainties through a practical example (a circularity measuring machine). Modernization brings some advantages (modern signal treatment is more reliable, better reduces noise,...) but also brings additional uncertainties sources (mainly because of conversion of an analogical signal to a numerical one).

*Research staff involved* : F.Gauder

## **2.9 Metallurgy and Materials Science — J.P. COHEUR, J. LECOMTE –BECKERS, A. MAGNEE**

### 2.9.1 Specialty Metallic Materials Unit (MMS) — J. LECOMTE-BECKERS

#### 2.9.1.1 CHARACTERISATION OF MECHANICAL AND THERMAL HOT PROPERTIES

*Description*: The thermophysical properties of pure metals or alloys have been widely studied by the metallurgy industries, giving them the data needed for the simulation, but also for a better scientific understanding of different physical process. Today, the simulations of material forming process are powerful and irreplaceable tools for the design and the modelling of new pieces, for the automotive industry, for example. So, there is a constant need of thermophysical data more and more accurate on known

material as well as data on new alloys. The laboratory of the sector MMS is specially equipped to study phase transformation and measuring thermophysical properties ( $\alpha$ ,  $\lambda$ , Cp...) and studying microstructure of materials. ATD – DSC – TG (1500°C) – dilatometry (1500°C) – laser flash (2000°C) - optical microscopes - metallographic preparation - thermal treatment furnace and quench devices.

Non-oriented electrical steel grades are developed for application in magnetic core of rotating machines, low and medium powered transformers and various electrical equipments. During operation, energy and consequently heat is dissipated in the stack of electrical steel laminations. Especially in large rotating machines, efficient extraction of the heat is a major design constraint. In this framework, an in-depth research to characterize and understand the influence of microstructure and alloying on the substrate thermal conductivity is required. The determination of the substrate influence is investigated measuring their thermophysical properties.

Resistance spot welding is one of the oldest welding electric processes in use by industry today. The weld is made by a combination of heat, pressure and time. As the name implies, it is the resistance of the material to be welded to current flow that causes a localized heating in the part. The current project aims to characterise the weldability of a number of material resistance spot welded and to establish a statistical model to be integrated in simulation tools. Therefore a thermophysical properties study is realised through the determination of the density, specific heat and thermal diffusivity, which are required for the statistical model achievement.

*Publications:* MMS167, MMS168, MMS169, MMS178, MMS176, MMS181, MMS182, MMS184, MMS185, MMS238, MMS239, MMS240

*Research staff involved:* M. CARTON

*Partners:* Aleurope, Hydroaluminium-Raeren, Sonaca, UCA, TAC, Forcast, Fafer, CFR, CMI, MSM (A.M. Habraken, S.Cescotto) (University of Liège)

*Related project:* RW Convention 9813793 caract. à chaud; *Contracts:* UCA, Gontermann Peipers, Arselor Sollac méditerranée, OCAS, IRSID, Akers

### 2.9.1.2 EFFECT OF CARBIDES AND INCLUSIONS IN HIGH ALLOYED IRONS AND STEELS

*Description:* The aim of this research is to establish in a quantitative and statistically justifiable way the relationship between on the one hand, the cleanliness of the steel, the amount of carbides and the microstructure of materials, and then on the other hand their mechanical properties in service.

Raw materials are high alloyed steels and cast irons which were obtained from different casting processes prior to thermomechanical treatments.

Behaviour of raw materials depends to a large extent on the type, the size and the overall distribution of carbides in the matrix, while inclusions have a direct influence on mechanical properties in service. Therefore, quantification of such particles appears to be of great interest, before determining correlations inference between microstructure and mechanical properties.

The final inclusions and carbides assessment was done by means of Image Analysis, whereas mechanical tests included tensile, compression, fatigue and impact toughness trials, on a large batch of samples with a defined microstructure.

Prior to assessment of inclusions and carbides is the identification of these particles, which was done towards specific methods involving, optical microscopy, colouring etching, scanning electron microscopy and Energy Dispersive Spectroscopy with X-Rays.

*Publications:* MMS171, MMS173, MMS174, MMS180, MMS186

*Research staff involved:* J. TCHOUFANG TCHUINDJANG

*Partners:* Forcast, Marichal Ketin, MSM (AM Habraken, S.Cescotto) (University of Liège), MICA ( E.Pirard) (University of Liège)

*Related project:* “Study of carbides forming elements in alloys type HSS and semi-HSS”, “Effect of carbides and inclusions in high alloyed irons and steels”, Convention RW 114877 INCA

### 2.9.1.3 DEVELOPMENT OF NEW ALLOYS FOR HOT ROLLS

*Description:* .The hot rolling mill is a massive piece that endures high service solicitation like thermal and mechanical constraints as well as fatigue or usury. The rolled product quality and the productivity of the process are directly related to the quality of the working mills.

The goal of this project is to enhance the knowledge in this sector and particularly to study the kinetic of the precipitation and the formation of the carbides required for a good quality of the product. Additional studies on surface corrosion will be done at the Complutense University in Madrid.

This approach is essential to define the optimal structure leading to the highest life span of the mills.

*Publications:* MMS170, MMS174, MMS187, MMS226, MMS227, MMS228, MMS229, MMS230, MMS231, MMS232

*Research staff involved:* M. HERMAN, J. TCHOUFANG TCHUINDJANG

*Partners:* Marichal Ketin

*Related project:* “Study of carbides forming elements in alloys type HSS and semi-HSS”, Convention RW-MARICHAL KETIN 3967, 4524, 6060, convention RW-DGRE - DRI - Project N0 01-10898 “Study of precipitation in foundry alloys type HSS” AND “Kinetic of phase transformations in foundry alloys for rolls type ICDP”

### 2.9.1.4 THIXOMOULDING

*Description:* Semi-solid metals exhibit time and strain rate dependent behavior known as thixotropy: they behave like solids in the undisturbed state and like liquids during shearing provided the shear rate is high enough. The solid-like behavior is due to the presence of a solid skeleton consisting of interconnected grains. Shearing breaks the bonds between grains leading to a release of entrapped liquid and decreasing the viscosity

of the semi-solid alloy. Semi-solid metal forming called thixoforming exploits this thixotropic and shear-thinning behavior since the semi-solid slug may be handeable but also may flow easily in the die. The use of FE simulations to obtain the filling of the dies and to optimize the thixoforming process is clearly of a great interest.

The aim of this project is to write a new micro-macro constitutive equation that describes the semi-solid behavior. This will be made in two fronts: The first one is to plan a set of experiments in order to determine the parameters of this law for steels; the second one is to implement the new material law in the METAFOR FE code.

*Publications:* MMS166, MMS172, MMS175, MMS177, MMS183, MMS188, MMS189, MMS233, MMS2434, MMS235, MMS236, MMS237, MMS241

*Research staff involved:* R. KOEUNE and C. Fraipont

*Partners:* CRIF, ULG, Pôle métal de Wallonie, ELAP (W. Legros, A. Rassili) (University of Liège), MC et thermomécanique (JP. Ponthot) (University of Liège)

*Related project:* Subvention objectif 2- URBAIN Meuse-Vesdre Moyens, Contract Ascométal

#### 2.9.1.5 DEVELOPMENT OF TI-LBC FOR TURBOREACTORS TITAERO

*Description:* The main goal of this project is to develop a new material based on an existing alloy: Ti-LCB, but with better fatigue damaging properties and sufficient ductility.

First, the characterisation and the understanding of the relationships between the thermo mechanical history and the fatigue structural properties will be established. So, on one side, the construction of the microstructure along the thermo mechanical path, implying allotropic transformation or phenomena like rehabilitation, recrystallisation and grain growth, will be studied. On the other side, the microscopic mechanisms leading to the structural properties of this alloy, like tenacity, fatigue resistance and cyclic plasticity will be examined.

Another objective is to implement this knowledge into micro mechanical models. The project will focus on a physical based model able to predict the fatigue resistance of biphasic-Ti-alloys with thin grains.

The third goal is the validation of the model based on real loading studies.

*Publications:* MMS259, MMS260

*Research staff involved:* M. CARTON

*Partners:* Tech Space Aero, MSM ( AM Habraken, S.Cescotto) (University of Liège)– University Catholic of Louvain ( PCIM Pascal jacques)

*Related project:* Convention RW 415659

#### 2.9.1.6 FABRICATION OF METALLIC FOILS BY VACUUM DEPOSITION – FIRST SPIN OFF

*Description:* Metallic foils have proved to be useful in many fields like packaging or magnetic products. So far, the foils have been mainly produced by rolling in the case of soft materials like aluminium, or by electrolysis in the case of metals like copper. Those process do not give the surface quality required, so the foils must be treated by PVD (Physical Vapour Deposition) afterwards.

In this project, a technique of SIP (Self-induced Ion Plating) is proposed. This technique would be able to realise foils with good surface quality in one step. The SIP process is a combination of cathodic pulverisation process and evaporation. Its main advantage is the high deposition rate and the good quality of the deposit.

In the actual state of the research, the goal is not yet to realise composite materials, but to look at the possibilities to achieve thin coatings of the materials that the composite will be made of.

*Publications:* MMS243 to MMS257

*Research staff involved:* S. PACE

*Partners:* RdCs

*Related project:* Convention RW – EVAFOIL – 415810

#### 2.9.1.7 MICRO-MACRO STUDY OF HIGH TEMPERATURE DAMAGE IN STEELS

*Description:* This project attempts to set a micro-macro model of the hot damaging behaviour. Most of damaging models established so far are ductile cold rupture, fragile rupture, fatigue or creep. All are valid at low temperatures.

For monotone solicitations at very high temperatures, the damage process is fast creep or diffusion creep. The present project is focused on this particular phenomenon.

The industrial application is the simulation of the continuous casting and particularly the areas where cracking can start.

The final goal of this research is the definition of rupture criteria coupled with a macroscopic damaging model. Those criteria should be able to predict the cracking for any kind of solicitation and the origins of the cracking will be analysable.

*Publications:* MMS167

*Research staff involved:* J. TCHOUFANG TCHUINDJANG

*Partners:* CDAM de Cockerill-Sambre-Usinor, MSM (A.M. Habraken, S. Cescotto, S. Castagne) (University of Liège)

*Related project:* ULg grants, “Micro-macro study of high temperature damage in steels”, “Study of carbides forming elements in alloys type HSS and semi-HSS”

### 2.9.1.8 MACROFOAMS, A NEW MATERIAL FOR SECURITY IN CIVIL ENGINEERING

*Description:* Study and development of macro cellular foams obtained from cheap metallic components, in particular from recycled material (chips from machining, metallic wires, expanded metal sheets, ...): study of possible topologies, analysis of fabrication possibilities, determination and modelling of mechanical, thermal and acoustic properties. Applications in the domain of safety and robustness of buildings (resistance to explosives, anti-intrusion walls, seismic resistance, ...) or others (new types of safety barriers along the roads, light armour plating for money transporting cars, shock absorbers for parachuted material or for nuclear waste transportation boxes, ...).

*Research staff involved:* J. TCHOUFANG TCHUINDJANG

*Partners:* University of Liège : Division of Mécanique des Solides et des Matériaux - MSM- (CESCOTTO Serge), Division of l'Ingénierie Sismique –SE- (PLUMIER André), Division of l'Ingénierie du Feu –FE- (FRANSSEN Jean-Marc), Division of Cellule d'Etudes et de Développement en Ingénierie Acoustique –CEDIA- (NEMERLIN Jean)

*Related project:* CF – concerted action, “Macrofoams, a new material for security in civil engineering”

### 2.9.1.9 VIRTUAL INTELLIGENT FORGING - COORDINATED ACTION

*Description:* Forging and related metal forming processes are key industrial technologies since they are required to produce economically many highly reliable parts. Over the last decades, these industrial processes have been improved through many RTD projects in materials science, mechanical engineering and more recently in numerical simulation. The goal of ViF-CA is to gather and analyse this scattered knowledge in order to solve some of today's industrial problems and to incorporate into industrial practices the recent advances in virtual production, supply chain and life-cycle management. The strategy is to create a forging knowledge community through several scientific, technological, training and educational activities.

The consortium gathers educational and research organisations, experts in the various scientific areas, and a large number of forging, software and IT industries from 17 European countries. The Deliverables include a Book of forging, projects for an e-Database and an e-learning platform, benchmarks for process simulations and materials testing, and a structure for a virtual supply chain.

*Research staff involved:* R. KOEUNE

*Partners:* MSM (A.M. Habraken) (University of Liège)

*Related project:* Convention NMP2-CT-2004-507331

#### 2.9.1.10 NON- CONTACT ULTRASONIC SYTEM FOR RAIL TRACK INSPECTION (U-RAIL)

*Description:* Periodic in-track rail inspections are performed to detect critical defects before they grow enough to cause structural failure. Nondestructive inspection (NDI) technologies currently used worldwide rely mainly on conventional ultrasonic technologies. These use water filled rubber wheels, containing transmitter-receiver piezoelectric transducers that are kept in continuous contact to the rail running surface. These methods have limitations, as they require contact conditions between the inspection probes and the surface of the rail track. Although such contact ultrasonic methodologies have been extensively and successfully used in detecting many surface-breaking and internal cracks, and are proved to be reliable, they are not perfect. In fact, train derailments caused by broken rails that pass inspection still occur.

In an effort to improve rail track inspections, this project proposes a non-contact ultrasonic system for periodic in-field inspections of rail tracks that has recognized advantages over conventional technologies currently available to the railroad industry. The feasibility study, the development and the manufacture of a prototype will prove the capability of the proposed inspection technique for in-track rail flaw detection..

*Research staff involved:* J. TCHOUFANG TCHUINDJANG

*Partners:* MSM (S. Cescotto) (University of Liège)

*Related project:* Convention COOP-CT\_2004-507622

#### 2.9.1.11 OPEN ACCESS TO THE BELGIAN NUCLEAR HIGHER EDUCATION NETWORK FP6-ACTIONS TO PROMOTE AND DEVELOP HUMAN RESOURCES AND MOBILITY

*Description:* As the Consortium BNEN, five Belgian universities (KULv, UCL, UG, ULg, VUB) have established in collaboration with the federal Belgian Nuclear Research Center, a common Belgian Interuniversity Programme of the 3rd cycle, a "Master of Science in Nuclear Engineering". The aim of this project is to use the experience of the Consortium BNEN for the realization of a common "European Programme in Nuclear Engineering".

The objective of the BNEN project is to provide commonly accepted evaluation methodologies especially adapted for the assessment of education programmes; also the conclusions of an external evaluation of the BNEN scheme by EU-25 stakeholders in combination with a self assessment of the scheme, both based on the afore-mentioned evaluation methodologies. Another goal is to obtain recommendations and suggestions how the BNEN scheme and experience can be used for the creation of the common "European Nuclear Education Programme", and in extension how the scheme can be useful for the set-up of European education programmes in general. Finally, it should get points of particular interest that are of importance to stakeholders of the new member countries and to women, and that therefore need to be integrated into the common "European Nuclear Education Programme".

At the end the BNEN project will have contributed to the mobility of the European scientists and the creation of the European Area of Higher Education, to the integration of the candidate countries into the European Research Area and thus to the enlargement of Europe and also to the reinforcement of the place and role of women in science.

*Publications:* MMS242

*Research staff involved:* M. HERMAN

*Partners:* ULg, UCL, RUG, VUB, KUL, SCK-CEN

*Related project:* Convention FP6-012564-BNEN

#### 2.9.1.12. POWDER METALLURGY

*Description:* Process of powder metallurgy is able to perform many kinds of pieces and technical components in a large diversity of alloys. The technique consists in compacting a blend of metallic powders which leads to a green. This last one is heated up to a temperature at which the sintering process occurs. This process, based on atomic diffusion mechanisms, creates bounds between particles and reduces the porosity. The powder metallurgy technique offers two main advantages. First, the production of final products is achieved in a very few steps, since the number of manufacturing stages is low. Then, it produces pieces with unique material properties that can not be obtained by any other process.

So far, the present researches have been performed along two main axes. First, the influence of the composition, the parameters of the process leading to the green and of the sintering step, on the magnetic properties as well as on the Curie's temperature, has to be analyzed. The second axis is focused on the relationship between, on one side, the parameters of the powder processing of titanium and Ti-Ni alloy and, on the other side, the porosity ratio and the mechanical properties. This last study involves the project EVOYOUNG which aims to develop a new biomaterial for prosthesis.

*Publications:* MMS179, MMS258

*Research staff involved:* Ch. BRASSINE

*Partners:* Applied thermodynamics – University of Liège (J. LEBRUN); Thermo technical engineering – University of Liège (Ph. NGENDAKUMANA); ELAP – University of Liège (P. DULAR, A. RASSILI); MSM – University of Liège (A.-M. HABRAKEN)

*Related project:* Convention RW-550086 GEMMAG P.1; Convention RW-550088 GEMMAG P.2; EVOYOUNG to submit

#### 2.9.1.13. DEFINITION OF A THUMB IMPLANT MADE OF AN INTELLIGENT BIOMATERIAL WITH GRADUAL YOUNG'S MODULUS

*Description:* Most bones prostheses are made of titanium based alloys with an elastic modulus still way higher than human bones. This difference in elastic behaviour may be the reason of an early degradation of the bone material in contact with the edges of the

implant. Several studies simulate the behaviour of the complex assembly bone-thumb prosthesis and show that prosthesis with a decreasing elastic modulus from head to tail could significantly enhance the lifetime of the assembly.

So, this research involves the analysis, the conception and the fabrication of a thumb prosthesis made of a gradual Young modulus and titanium based material and performed using the powder metallurgy technique. This gradient modulus will be obtained thanks to a varying and controlled porosity. Nevertheless, a high porosity ratio will act upon the fatigue resistance and the yield stress of the pure Ti-based alloy. This need of a material with a larger elastic domain justifies the use of a Ti-Ni alloy which may exhibit a superplastic behaviour.

*Research staff involved:* Ch. BRASSINE

*Partners:* MSM – University of Liège (A.-M. HABRAKEN); CEIB – University of Liège (C. GRANDFILS)

*Related project:* EVOYOUNG to submit

#### 2.9.1.14. STUDY OF THE INFLUENCE OF THE PHYSICAL CHEMISTRY IN FE-CR-CX ALLOYS ON THE SOLIDIFICATION KINETICS AND NANO PROPERTIES OBTAINED BY THERMO-MECHANICAL TREATMENTS

*Description:* The aim of this research is to establish a metallurgical predicting tool capable of optimising the microstructure and the subsequent mechanical behaviour of a HSS alloy towards a primary chemical composition setting. Optimisation procedure will focus on solidification kinetics during casting process as well as subsequent heat treatments performed in the solid state. The novelty in this research lies on the study of phase transformations in dynamic conditions that are reactions kinetics far from equilibrium state. In fact, state of the art dealing with non equilibrium kinetics issues remains quite restricted.

*Research staff involved:* J. TCHOUFANG TCHUINDJANG

*Partners:* MSM – University of Liège (S. CESCOTTO); MICA – University of Liège (E. PIRARD)

*Related project:* CINA to submit

### 2.9.2 Physical Metallurgy (MMS) — A. MAGNEE

#### 2.9.2.1. DEVELOPMENT OF NEW COATING MATERIALS USING LASER TECHNOLOGY DIODE FOR ADVANCED SYSTEMS OF COOLING IN COLLABORATION WITH RMI (RMI-ULG-RW CONTRACT)

*Description:* The study relates to the development of composite materials (metal and ceramics) for advanced systems of cooling. The properties of damage in erosion and abrasion were analysed using ULg tribometers. The characterisation of materials in being able of cooling was undertaken, in particular the variation of the thermal diffusivity

by a laser device flash ULg. An approach of the complex thermal fields was carried out by finite elements (code ABAQUS) in order to specify the operational limits of the coatings considered.

#### 2.9.2.2. STUDY OF THE DEGRADATION MECHANISMS BY EROSION-CORROSION OF MATERIALS IN HYPER-AGGRESSIVE PHOSPHORIC MEDIUM IN COLLABORATION WITH PRAYON S.A. (PRAYON-CRM-ULG-RW CONTRACT)

*Description:* In the chemical industry, the materials are subjected to serious constraints by generalised corrosion and pitting of acid H<sub>3</sub>PO<sub>4</sub>. Phenomena are amplified in the presence of abrasive and erosive solid particles. A study of the coupled phenomena is undertaken in ULg in collaboration with the CRM, so as to specify the mechanisms of in situ degradation.

#### 2.9.2.3. STUDY OF SAFETY JOINTS FOR THE AIRCRAFT INDUSTRY- NEW AIRBUS GENERATION IN COLLABORATION WITH THE SONACA S.A. (ULG-ULB-SONACA CONTRACT)

*Description:* The aircraft industry is confronted with specific problems of damage by erosion of aeronautical safety joints. A device of controlled erosion was developed in ULg. The procedures implemented allow qualified in a reliable way the new joints under consideration for the development of the fleet AIRBUS of last generation.

#### 2.7.9.4. STUDY OF THE NEW SURFACE TREATMENTS DLC AND COLD PLASMA FOR MEDICAL PROSTHESES (IN COLLABORATION WITH THE ECOLE SUPÉRIEURE DES MINES DE ST ETIENNE AND NITRUID)

*Description:* The prostheses of hip and those of the knee in the long run in vivo require a thorough study of the mechanisms of deterioration. The tribological studies realized and the new surface treatments suggested open a prospect for future applications to increased reliability.

## **2.10 Modeling and Mathematical Methods (MMM) — E. DELHEZ**

### 2.10.1 DIAGNOSTIC TOOLS

Description: Development of diagnostic tools. Constituent oriented Age and Residence time Theory.

*Publications:* MMM100, MMM101

*Research staff involved:* E. DELHEZ, G. MARTIN, Ch. MERCIER

*Partners:* University of Louvain-la-Neuve, Delft University of Technology, University of Vigo, Proudman Oceanographic Center

*Related project:* RACE – Concerted Action (Belgium’s French Community)

### 2.10.2 NUMERICAL MODELLING

Description: Mathematical modelling of the hydrodynamic and biogeochemical processes of the ocean. Numerical modelling of ocean hydrodynamics on unstructured grids : development of a multipurpose finite element model. Sediment dynamics.

*Publications:* MMM200

*Research staff involved:* E. DELHEZ, Ch. MERCIER

*Partners:* University of Louvain-la-Neuve

*Related project:* SLIM – Concerted Action (Belgium’s French Community)

### 2.10.3 OPTIMIZATION

Description: Development and application of optimisation algorithms for unconstrained and constrained problems.

*Publications:* MMM300 — MMM301

*Research staff involved:* P. TOSSINGS, J. WALMAG, E. DELHEZ

*Partners:* ASTRON Buildings

*Related project:* OPFA (Impulse Project – Ulg), OPTIF (Industrial project)

### 2.10.4 CYBERNETICS

*Description:* Theory and modelling of anticipatory systems.

*Research staff involved:* D. DUBOIS

## **2.11. Multidisciplinary optimization (OPT) – C. FLEURY**

### 2.11.1. NUMERICAL OPTIMIZATION METHODS FOR VERY LARGE SCALE PROBLEMS

*Description:* Numerical optimization methods are now facing enormous challenges with regard to the drastically increasing size of the problems to be solved. In Europe, for its new A340M, A350 and A380 airplanes the AIRBUS consortium has provided us with problems involving thousands of design variables and hundreds of thousands of design functions (objective functions and/or constraints). In the US, for its topology optimization capabilities, ALTAIR Engineering has requested to be capable of solving problems with millions of variables (but less than 100 functions). MSC software has also expressed a similar interest. With its new algorithms the optimization system CONLIN Version 4 is now able to deal with such very large problems.

### 2.11.2. MAXIMIZATION OF PULL-IN VOLTAGE OF MICRO-ELECTROMECHANICAL STRUCTURES USING TOPOLOGY OPTIMIZATION

*Description:* The electrostatic actuation devices used in MEMS are generally based on capacitive systems with one mobile and one fixed electrodes. Applying voltage between the electrodes generates an electrostatic force, which tends to reduce the gap between the electrodes. Due to the non-linearity of the electrostatic force with respect to the distance between electrodes, there exists a limit voltage from which there is no equilibrium between the electrostatic and mechanical forces. This leads to the pull-in phenomenon. In some applications, the pull-in instability is undesirable and maximizing the pull-in voltage is desired. The design problem consists in maximizing the pull-in voltage using a topology optimization approach. Sensitivity analysis is one of the key issues of the optimization process and is performed with the formulation of eigenvalue topology optimization problems. The research investigates topology optimization of strongly coupled electromechanical systems. To avoid important modifications of the electric field by the optimization process, this first study considers a non design electrode and use topology optimization to design an optimal suspension structure. Solution procedure of the optimization problem is based on the CONLIN optimizer using a sequential convex programming. This method that has proved its efficiency in many structural problems (sizing, shape) is here tailored to strongly coupled multiphysics design problems. The choice of appropriate explicit convex approximations schemes for multiphysics problems is investigated.

### 2.11.3. GENERALIZED SHAPE OPTIMIZATION WITH X-FEM AND LEVEL SET DESCRIPTION APPLIED TO STRESS CONSTRAINED STRUCTURES

*Description:* Recently the extended finite element method (X-FEM) has been proposed as an alternative to remeshing methods. The X-FEM method is naturally associated with the Level Set description of the geometry to provide an efficient treatment of problems

involving discontinuities and propagations. Up to now the X-FEM method has been mostly developed for crack propagation problems, but the potential interest of the X-FEM method and the level set description for other problems like topology optimization was identified recently. In this research an intermediate approach between parametric shape and topology optimization is developed by using the X-FEM and Level Set description. The method takes benefit of the fixed mesh work using X-FEM and of the smooth curves representation of the Level Set description. One major characteristic of the approach is to be able to model exactly void and solid in the structure. The statement of the optimization problem is similar to classical shape optimization: Design variables are the parameters of basic level set features (circles, rectangles, etc.) or NURBS control points, while various global (compliance) and local responses can be considered in the formulation. Conversely to shape optimization, structural topology can be modified since basic Level Sets can merge or separate from each other. A central issue is the sensitivity analysis and the way it can be carried out efficiently. This research also treats carefully the problem of the numerical integration of FE stiffness matrices in order to get sufficient accuracy of the X-FEM results. A special attention is paid to stress constrained problems. Numerical applications revisit some classical 2D benchmarks from shape and topology optimization and illustrate the great interest of using X-FEM and level set description.

## **2.12. Nuclear Engineering – P. MATHIEU**

## **2.13 Polymers Materials and Composites (PMC) — J.M. LIEGEOIS**

### 2.13.1 COMPARISON BETWEEN UV-EB ACTIVATION IN MANUFACTURE OF POLYESTER COMPOSITES ; EMPHASIS ON DOSIMETRY

*Description* : The project aims at comparing two processes of polymerization of unsaturated polyester resins. In the UV process, the polymerization is activated through the irradiation of a photoinitiator whose absorption spectra matches the emission spectra of a mercury lamp. This process has demonstrated its efficiency at the industrial scale by the partner Sitotech (Jumet). The electron beam process uses the energy of accelerated electrons to initiate the polymerization of unsaturated polyester or epoxyacrylate resins. Mechanical and physicochemical composite characterization in the context of economic aspects is studied in order to optimize both processes. European partners involved are National Physical Laboratory (Teddington, United Kingdom) and DSM Composite Resins (Ludwigshafen, Germany).

*Research staff involved*: B. SERVAIS

*Partners*: National Physical Laboratory (London), Sitotech SA (Jumet)

*Related project*: First Europe Objectif 1 – Convention n°114984 (Wallon region)

### 2.13.2 KNOWLEDGE BASE DEVELOPMENT OF THE EFFECTS OF IONIZING RADIATIONS ON MATERIALS

Most of the processes involving plastic engineering will face at some stage some kind of thermal involvement. Thermal processing has direct or indirect impact on the processing, the product and impacts the environment. This applied research addresses the Walloon plastic community at large with an alternate processing technology of accelerated electron. This ionizing electron beam technology is believed to be amenable to newer higher plastic productivity associated with decreased environment stress than classical heat and solvents schemes. This technology also has the potential to retain manufacture in our country because of the alleviation of the pollution problematic and adding value to our good production. The main technological innovation resides in the blend of unprecedented flexibility of the process control with high energetic yield as compared to the classical heat processing. This technology is here today for seemingly trivial applications as medical sterilization and more sophisticated military endeavors. The commercial success will reward the application of this technology to selected high money yield application.

*Research staff involved:* M. LINNE

*Partners:* IBA SA and Interface Ulg

*Related project:* First Spin-off – Convention n°0114802 (Walloon region)

### 2.13.3 RADIATIONS AND ELECTRONS CURING OF NOVEL MATERIALS FOR STRUCTURAL APPLICATIONS.

*Description:* The objective of the project is the development of a new process to cure thermoset resins, which could lead to a significant and economical widening of the fabrication of composites materials.

The standard curing process, which is intrinsically slow because it is characterized primarily by a thermal activation, would be replaced by a new fast process calling upon new monomers or reagents specially adapted to the effect of X radiations or high energy electrons.

*Research staff involved:* J. HARRAY, C. MOMMER, C. DA ROCHA, J. MAAS, E. MUNOZ DE CELIS

*Partners:* HEMES - Centre de recherché de l'Institut Gramme (Liège)

*Related project:* Convention n° 0114868 (Walloon region)

### 2.13.4 HIGH PERFORMANCE DAMPING TECHNOLOGY FOR AIRCRAFT VIBRATION ATTENUATION AND THERMO-PHONIC INSULATION

*Description :* A.T.P.I. project aims at setting up a Shared Cost Project the goal of which is to find a new technology of damping treatment providing high vibration and thermo-phonic performances in association with present blanket used for aeronautic applications.

It will lead to better insulate the cabin from both vibrations, acoustic and thermal exterior annoyances. Furthermore, as it will be placed below the glass wool, it will prevent from capturing humidity. The purpose of the project is to research and find a new light damping technology adapted to thin shell structure (fuselage skin) including noticeable thermo-phonic insulation performances. The technology will be based on ARTEC patented damping surfacic technology, which reduces significantly noise and vibration levels of thin shell structures, providing unexpected performances. The latter developed for general vibration issues of thin shell structures, is not suitable for aerospace use and therefore a research must be done towards new materials along with new assembling technology to meet the specific requirements: light weight, high damping performances, thermal and phonic insulation, and stringent environmental conditions. Combined with standard acoustic material (glass wool, ...), the global solution will therefore drastically increase the thermo-acoustic performance. Community as well as passenger acceptance is essential for the commercial success of a new aircraft. Hence, environmental cabin comfort issues are important for any turbofan or turbo-propeller aircraft - from business jet to large civil transport - and are becoming more and more important as a market factor. These small range and small capacity aircraft's are more and more necessary, but their main drawback is the passenger comfort, which must be improved.

*Research staff involved:* D. CELLO

*Partners:* EC – AIRBUS – AMORIM – CATHERINEAU – EURO INTER – HPK – LRMA – OPTRION – ARTEC

*Related project:* Convention n° R-ATPI-05834-PV (FP6 – European Project)

## **2.14 Structural Dynamics and Identification (VIS) — J.C. GOLINVAL**

### 2.1 NONLINEARITY IN STRUCTURAL DYNAMICS: CHALLENGES AND OPPORTUNITIES

*Description:* Although it is often overlooked by designers, nonlinearity is a frequent visitor to engineering structures and can drastically alter their behavior — sometimes catastrophically. Nonlinearity may give rise to complex dynamic phenomena, including jumps, bifurcations, limit cycles, and chaos. Any attempt to apply traditional linear analysis to capture the dynamics of a structural system possessing such phenomena is certain to fail. The objective of the research is to develop new methodologies to take nonlinearities in engineering structures into account. The first aspect concerns the inverse problem of the development of reliable and accurate nonlinear structural models from experimental measurements. This is referred to as nonlinear system identification in the technical literature. The second part of the research goes one step further. We propose not only to model nonlinearities but to take advantage of the richness and complexity of nonlinear dynamics for the design of engineering structures. In particular, passive nonlinear energy transfers in coupled vibrating systems are studied, which may find applications in vibration absorption and aeroelastic instability suppression.

*Publications:* VIS101, VIS107, VIS110-112, VIS137-138, VIS140, VIS144-146, VIS148-155

*Research staff involved:* G. KERSCHEN

*Partners:* University of Sheffield, University of Illinois at Urbana-Champaign, National Technical University of Athens

*Related project:* F.N.R.S. Postdoctoral Fellowship

## 2.2 MODEL RELIABILITY ANALYSIS AND EXPERIMENTAL VALIDATION

*Description:* This research project represents the second phase of a study initiated with the convention described in section 2.11.2 and related to the fatigue testing of mechanical components. The object of the present research is to develop a probabilistic finite element approach in order to better understand and predict the dynamic behaviour of mechanical components. The geometric uncertainties, due to production margins and assembly processes, as well as the statistic distribution of material properties are taken into account. The material is a common aluminium casting alloy used in the manufacturing of street lighting devices.

*Publications :* VIS136

*Research staff involved:* A. PHILIPPART, F. MARIN

*Partners:* R-Tech (Schröder Group GIE)

*Related project:* ANFIMOCE

## 2.3 MODELING OF ELECTRO-MECHANICAL COUPLING PROBLEM APPEARING IN MEMS USING THE FINITE ELEMENT FORMULATION

*Description:* MEMS are very small devices in which electrical as well as mechanical dynamics phenomena appear. Because of the microscopic scale, some strong coupling effects between the different physical fields appear, and some forces, which are negligible at macroscopic scales, have to be taken into account. In order to make a good design of these micro-systems, it is important to analyse the coupling between the electrical and mechanical fields. The work performed in this research is based on the finite element method (FEM) and includes modal analysis around non-linear equilibrium positions, taking into account large mesh displacements. Classical methods used to simulate the coupling between electric and mechanical fields are usually based on staggered procedures, which consist in computing quasi-static configurations using two separate models: a structural model loaded by electrostatic forces predicted at the current iteration step and an electrostatic model defined on the current deformed structure. Staggered iterations then lead to the static equilibrium position. In this research, a fully coupled electro-mechanical FE formulation is proposed, which allows to compute static equilibrium positions in a non-staggered way, and which provides fully consistent tangent stiffness matrices that can be used for transient analyses.

*Publications:* VIS137-138, VIS143, VIS152, VIS162

*Research staff involved:* V. ROCHUS  
*Partners:* Delft University, Open Engineering  
*Related project:* F.N.R.S. Doctoral Fellowship

## 2.4 STUDY OF THERMAL STRESS IN THE FABRICATION PROCESS OF RF-MEMS

*Description:* The project consists in the use of the Oofelie software in order to simulate the fabrication process of RF-MEMS (PolyMUMPS process). The simulation uses the finite element method in order to estimate the strains and stresses generated by the difference in thermal expansion coefficient between the several material layers during fabrication. The values of these stresses strongly influence the behaviour and properties of the RF-MEMS. The pull-in voltage and the natural frequencies are particularly affected. The simulation will help with the prediction of the fabrication conditions leading to the MEMS desired properties.

*Research staff involved :* F. CLEMENT  
*Partners :* University of Mons  
*Related project :* RW MOMIOP

## 2.5 THERMOELASTIC COUPLING IN MICRO-STRUCTURES

*Description:* In the design of MEMS devices such as micro-resonators or micro-gyrometers, dissipation mechanisms may have detrimental effects on the quality factor. One of the major dissipation phenomena to consider in such micro-systems is the thermoelastic damping. The objective of this research is to study the influence of thermoelastic coupling on the behaviour of vibrating micro-structures. For this purpose, the finite element method (FEM) is used to perform modal analyses considering the coupling between the mechanical and thermal fields. The thermoelastic finite element formulation is derived from the variational principle in which both mechanical and thermal degrees of freedom are considered simultaneously. The developed F.E. formulation is validated on simple examples for which analytical models exist.

*Publications :* VIS161  
*Research staff involved:* S. LEPAGE  
*Partners:* ONERA, Open Engineering, Institut d'Electronique Fondamentale  
*Related project:* F.N.R.S. Doctoral Fellowship

## 2.6 FLEXIBLE MULTIBODY DYNAMICS - MECHATRONICS

*Description:* The purpose of a mechatronic system is to generate a controlled motion. For instance, robots, machine-tools and vehicles are mechatronic systems, composed of mechanisms, sensors, actuators and control units. Recently, a number of researchers and

industrial manufacturers have highlighted the potential advantages of lightweight parallel mechanisms with respect to the accuracy and dynamic performances issues. The design of such a mechatronic system requires a multidisciplinary approach where the mechanical deformations have to be considered. In this project, two research orientations are considered. The former concerns the development of modeling techniques for flexible mechanisms, which are suitable for the design of a control system. Since existing formalisms in flexible multibody dynamics lead to complex and strongly nonlinear models, model reduction techniques are specifically addressed for this purpose. The second orientation concerns the integrated simulation of mechatronic systems, accounting for the coupled dynamics of the mechanism, the sensors, the actuators and the control units. This simulation tool is valuable for the pre-prototyping and the optimization of the whole mechatronic system.

*Publications:* VIS156-160

*Research staff involved:* O. BRULS

*Partners:* Georgia Institute of Technology, Katholieke Universiteit Leuven, Université Catholique de Louvain, Open Engineering

*Related project:* F.N.R.S. Doctoral Fellowship

## 2.7 STRUCTURAL DAMAGE DETECTION AND HEALTH MONITORING

*Description:* This research is concerned with on-line structural health monitoring (SHM) of aerospace, mechanical as well as civil engineering structures. Our effort is mainly concentrated on the development of damage detection and localization methods based on the statistical analysis of output-only measurements. The developed methods were applied to simple laboratory structures (e.g. aircraft mockup), to vibration fatigue testing of mechanical equipments (e.g. lighting devices) on electrodynamic shaker and to very large constructions, typical of Civil Infrastructure, proposed as benchmarks in the framework of the European COST F3 Action (e.g. the *Steelquake* structure constructed and tested at the Joint Research Centre (JRC) at Ispra, Italy; the Z24 bridge in Switzerland tested as part of the SIMCES project funded by Brite Euram). In this last case, special effort has been paid to eliminating the effect of varying environmental conditions (e.g. temperature variations) during the long-term monitoring period.

*Publications:* VIS099, VIS100, VIS101, VIS114, VIS135

*Research staff involved:* A.M. YAN

## 2.8 MODEL VALIDATION IN THE PRESENCE OF NONLINEAR DYNAMIC PHENOMENA

With the advent of powerful computers, it has become less expensive both in terms of cost and time to perform numerical simulations, than to run a sophisticated experiment. The consequence has been a considerable shift toward computer-aided design and numerical experiments, where structural models are employed to simulate experiments,

and to perform accurate and reliable predictions of the structure's future behaviour. Even if we are entering the age of virtual prototyping, experimental testing and system identification still play a key role because they help the structural dynamicist to reconcile numerical predictions with experimental investigations. The project is concerned with the development of accurate, robust, reliable and predictive models of bladed disks assemblies in the presence of nonlinear dynamic phenomena (e.g., nonlinear material behavior).

*Research staff involved:* F. PONCELET

*Related project:* FIRST D.E.I. Grant VAMOSNL

*Partners:* Techspace Aero

## 2.9 OPTIMAL EARTH-MOON ORBIT TRANSFER

*Description:* To reach the moon using as little fuel as possible is a celebrated problem in celestial mechanics. The traditional approach to performing such a space mission is by impulsive Hohmann transfer. Due to the advent of new propulsion systems and the improvement of nonlinear dynamics theory, innovative and more efficient transfer trajectories have been developed. For instance, spacecrafts propelled by low-thrust engines are capable of delivering a greater payload fraction compared to those using conventional chemical systems. By combining low-thrust propulsion systems to the invariant manifold theory, a novel way to construct a minimum-fuel spacecraft transfer trajectory is proposed.

*Research staff involved:* P. IBANEZ TARRAGO, G. KERSCHEN

*Partners:* University of Illinois at Urbana-Champaign

## 2.10 MODELLING OF COUPLED PROBLEMS IN MEMS

*Description:* The development of Micro-Electro-Mechanical Systems (MEMS) is of growing importance in the field of engineering. The maturity of the production processes inherited from the electronics industry has allowed for ever more complicated structures to be created. However, due to their reduced size, such devices are often subjects to strong coupling between different physical fields. Those interactions are now well known but their effects on the behaviour of the mechanical structures still need investigating. The aim of this research is to develop both analytical and numerical tools to quantify these phenomena and isolate the main parameters contributing to them. A first topic of interest focuses on allowing different codes developed to study different physical fields separately (i.e. mechanical, electrical, fluid...) to be used together. This leads to the study of coupled systems by the staggered method. A second topic is concerned with the modelling of the dynamical behaviour of multi degree of freedom resonators with an emphasis on non-linear phenomena such as parametric resonance (arising due to the electrostatic actuation) and non-linear energy transfer between the different degrees of freedom characterizing the system.

*Research staff involved:* G. SERANDOUR

*Related project:* Action de recherche concertée, convention n° 03/08-298

## 2.11 STUDY AND IDENTIFICATION OF NONLINEAR VIBRATIONS IN DUAL-ROTORS

The aim of the research is to study the nonlinear behaviour of rotors, especially dual-rotors, for the identification of unwanted phenomena occurring on specific industrial machines. The first part of the project is dedicated to mono-rotors. The idea is to simulate machinery faults with mathematical models and compare response spectra with those obtained on an experimental test rig. The models are then extended to the case of dual-rotors for the study of rotor coupling effects on time and frequency responses. Different methods of signal processing are used to compare model results with measures from the structure of practical interest.

*Research staff involved:* C. LOFFET

*Related Project:* Convention RW 5145

*Partner:* Euro-Diesel

## 2.12 FINITE ELEMENT FOR NONLINEAR FERROELECTRIC MATERIALS

Ferroelectric materials are presently being used in a large range of MEMS applications such as sonar, rotors blades, actuators for active control... These materials are often subjected to high mechanical and electrical loads. Thus, nonlinear working domains are rapidly reached and the classical linear modelling approach is no longer sufficient to capture nonlinear effects. Unmodeled nonlinear phenomena, such as hysteresis, can lead to adverse effects including instability, inaccuracy in open-loop control ...It is therefore of interest to build a finite element code for the analysis of nonlinear piezoelectric materials.

*Research staff involved:* A. NEBIE

*Related project:* Action de recherche concertée, convention n° 03/08-298

## **2.15. Thermotechnics (THE) – Ph. NGENDAKUMANA**

### 2.15.1. COMBUSTION CONTROL IN FUEL OIL BOILERS

*Description :* The influence of the nozzle capacity on the performance of a domestic fuel oil boiler has been investigated. In short, for the same output power, the thermal efficiency and the pollutants emission are not affected in steady-state regime. But, in the start-up regime, the CO emissions increase drastically when the nozzle capacity is increased. That behaviour is mainly explained by the droplets size. Indeed, this latter increases when the nozzle capacity is increased.

*Publications* : THE001, THE002

*Research staff involved* : C. Masy and Ph. Ngendakumana

*Related projects* :

*Partners* : UCL and FPMs

### 2.15.2. IN-FLIGHT LOX COLLECTION FOR FUTURE LAUNCHERS

*Description* : For future launchers, the objective is to increase the payload by decreasing the mass of the launcher at take-off. The horizontal take-off and horizontal landing (HTHL) launcher is one of the candidates. That kind of launcher is supposed to take-off with empty LO<sub>x</sub> tank and the filling of this latter is supposed to be achieved during the atmospheric phase of the flight. One of the critical device for that kind of launcher being the in-flight oxygen collection plant, a test bench for a rotary air separator has been designed and built. That test bench is able to feed the air separator with saturated vapour air and saturated liquid air. With the help of two adsorption air chillers (whose dew point temperature goes down up to  $-70^{\circ}\text{C}$ ), the test bench is able to handle up to 120 g/s of air. On the other hand, a pre-design of the air pre-cooler heat exchanger (Air-H<sub>2</sub>) has been achieved.

*Publications* : THE003, THE004, THE005, THE006

*Research staff involved* : Laurent Dardenne, and Ph. Ngendakumana

*Related projects* :

*Partners* : RMA (Royal Military Academy through the ASBL Renaissance), TechspaceAero, VKI (Von Karman Institute), LASSC (Laboratoire d'Analyse et Synthèse des Systèmes Chimiques - ULg), IBERESPACIO (Spain) and ULB

### 2.15.3. USE OF BIODIESELS IN INTERNAL COMBUSTION ENGINES

*Description* : In order to reduce CO<sub>2</sub> emissions and thus to fulfil the Kyoto requirements, rapeseed oil is one of the candidates to replace fuel in diesel internal combustion engines. Tests have been performed in the laboratory in order to assess the energetic and environmental performance of a diesel engine (1.9 l VW TDI) when fuelled with a rapeseed oil, the opacity of the flue gas and the break output power being aimed at.

*Publications* : THE007

*Research staff involved* : S. Christiaens, and Ph. Ngendakumana

*Related projects* :

*Partners* :

#### 2.15.4. THERMO-HYDRAULIC PERFORMANCE OF HEAT EXCHANGERS ALREADY OR TO BE USED IN THE AUTOMOTIVE INDUSTRY

*Description* : The automotive industry is looking for new heat exchangers for engine cooling (radiators), exhaust gas cooling before recirculation (to reduce NO<sub>x</sub> emissions) and fuel cells cooling systems. Tests have been carried out for Renault and PSA (Peugeot – Citroën) car manufacturers to investigate the thermo-hydraulic performance of existing or prototypes heat exchangers. In the case of tube-and-fins heat exchangers, flow maldistribution has been investigated by means of the infrared thermography technique.

*Publications* : Confidential reports

*Research staff involved* : C. Cuevas and Ph. Ngendakumana

*Related projects* :

*Partners* : RENAULT and PSA (Peugeot-Citroën)

### **2.16 Tribology – J.L. BOZET**

#### 2.16.1 TRIBOLOGY OF MATERIALS IN SEVERE ENVIRONMENT

*Description*: This research aims with the characterization of material combinations for bearing applications in LOX. First, compatibility tests have been performed to assume the safety and feasibility of further research operations. Then tribology tests were made on a pin-on-disc apparatus using LOX as working environment. The measurement of friction and wear allowed a comparison between different kinds of metallic and ceramic materials.

*Research staff involved*: J.L. BOZET, M. NELIS

*Partners*: ULg CIOR, SNECMA

*Related project*: Sub-contracting “SNECMA – Moteurs” Vernon, 15.000€

#### 2.16.2 DESIGN OF FLUID BEARINGS IN CRYOGENICS

*Description*: Ceramic matrix composites (CMC) are a new type of ceramic material, which - due to their reinforcement with high strength fibres - lack the brittle failure behaviour of conventional industrial ceramics. The materials, based on carbon and silicon carbide fibres embedded in silicon carbide matrix, have been developed mainly for use in high temperature applications, where metals are beyond their limits and high reliability of the components under severe mechanical and thermo-mechanical conditions is required. The developments have lead to successful qualification of carbon fibre reinforced silicon carbide (C/SiC) components for heat shields in reusable space vehicles, where temperatures of about 1900 K are present for several minutes each re-entry. Under cold conditions the CMC-material SiC/SiC has been applied successfully as shaft sleeve material in journal bearings for big pumps of power plants and in tubular casing pumps. With water of up to 160°C as the lubricant and conventional SSiC ceramic being the

tribological partner, the bearing system can sustain about three times higher loads than any other tested couple of materials. This result has been the incentive to consider the same ceramic journal bearing system for pumps in cryogenic rocket engines for future reusable launch vehicles (RLVs), where the lifetime of mechanical components is a critical issue. Improved stiffness and damping properties, reduced wear, increased reliability and no limitations in the result speed times diameter are some of the expected advantages of using journal bearing instead of the presently used ball bearings.

*Research staff involved:* J.L. BOZET, M. NELIS

*Partners:* ULg CIOR, MAN Technology, SNECMA, FIAT AVIO

*Related project:* “Journal Bearing Technology”, ESA Contract, 2005-2006

### 2.16.3 MECHANICAL BEHAVIOUR OF PLASTIC GEARING

*Description:* This research focus on two types of tests which characterize plastic gear wear: the loss of torque and the loss of mass. In the two cases, the materials used by combinations for the tests are nylon 6/6 (N), acetal (A), Ultra High Molecular Weight Polyethylene UHMWPE (U) and carbon steel G10100 (S). To measure the loss of torque, a gear pair is performed at 2000 RPM and 2.5 kW, for 8 continuous hours without lubrication. In tribological loss of mass tests, the specimens are disks which have 60 mm in diameter and 16 mm in face width; each pair is gathered on a shaft turning at different speeds with a normal strength of 287 N. Through these two tests results, the various combinations analysis prove that the percentages of loss of torque  $\Delta F_{rac}$  and loss of mass  $\Delta_m$  keep the same tendencies globally except the case of the combination (N/A) where  $\Delta_m$  is 8 times less than (A/N) and 6 times for  $\Delta F_{rac}$ .

*Research staff involved:* J.L. BOZET, M. NELIS

*Partners:* UQTR, VALEO (Creteil)

*Related project:* Convention CGRI / Coopération Wallonie – Québec, 10.000€

## **2.17 Turbomachines and Propulsion (TUR) — O. LEONARD**

### 2.17.1 HEALTH MONITORING OF GAS TURBINE ENGINES

*Description:* This project is based on the development of parametric models used to determine the performances of the studied process. The identification of the health parameters of the gas turbine engines is based on measurements taken on the process and includes the validation of these last. It makes it possible to collect the evolution with respect to time (a possible degradation) of the condition of the process. The adaptation of the model and the estimation of the health of the engine are based on the use of Kalman filters, modified to take into account the nonlinear character of the operation of the gas turbine engines and to allow the detection of erroneous measurements.

*Publications:* TUR034

*Research staff involved:* S. BORGUET, P. DEWALLEF  
*Partners:* Techspace Aero, National Technical University of Athens  
*Related project:* Convention Région Wallonne FIRST-Europe PARIS

### 2.17.2 OPTIMIZATION USING METAHEURISTIC METHODS

*Description:* The purpose of this project is to solve optimization problems, design or industrial process control which utilizes simultaneously parameters which can take only some precise values (binary, whole or discrete parameters), and others which vary continuously. It results from it a very great number of configurations to be considered, which must moreover satisfy a great number of constraints. This project brings a response to this type of problem, by combining the advantages of two approaches: on the one hand the genetic algorithms, which allow a broad and systematic sweeping space of design, the various possible solutions being subjected to a Darwinien natural selection process, and on the other hand some nonlinear mathematical programming. Up to now these optimization tools were applied to the problem of optimal sizing of lubrication pumps for turbojets, to the optimization of the operation of blowers and to the optimization of heat pipes geometry.

*Publications:* TUR033, TUR036, TUR037, TUR038

*Research staff involved:* V. KELNER

*Partners:* Group of Stochastic Methods (University of Liège), Free University of Brussels

*Related project:* Convention Région Wallonne No 215187 PIGAL

### 2.17.3 THROUGHFLOW SIMULATIONS IN TURBOMACHINES

*Description:* The objective of this project is to introduce certain non stationary effects due to the rotor-stator interactions into a throughflow model for compressors and turbines. These effects are introduced by the deterministic stresses, similar to the Reynolds stresses but translating non stationary but non stochastic effects correlated to the rotor rotational speed. The inclusion of these deterministic stresses in a stationary model in particular makes it possible to predict the radial mixing process observed in experiments and in non stationary simulations, but which are not reproducible in stationary simulations using a mixing plane.

*Publications:* TUR032

*Research staff involved:* J.-F. SIMON

*Partners:* Techspace Aero, Ecole Centrale de Lyon

*Related project:* Convention Région Wallonne No 991-4384 LEGO

#### 2.17.4 QUASI-ONE-DIMENSIONAL SIMULATIONS IN TURBOMACHINES

*Description:* The performances of a gas turbine engine must be analyzed well before the engine is tested on the bench or in flight. This study provides the designer with guidelines for the choice of the many design parameters and for optimizing the final configuration of the jet engine. It also allows to test (in a virtual way) the correct operation of the engine during critical manoeuvres. This study is based on the numerical modelling of the operation of the turbojet. Thanks to the progress of the simulation methods and computing power, it is now possible to develop and to use models of jet engines based on the application of the laws of the fluid mechanics to a great number of cells. This approach makes it possible to describe with a high degree of accuracy the exchanges of mass, energy and momentum within the machine, while reducing to the bare minimum the quantity of information of empirical nature. This tool, once developed, will be applied to the aerodynamic analysis of low pressure compressors (boosters) and of whole turbojets, in order to evaluate the impact of the design parameters of a booster to the performances, the operability, the reliability, the weight and the cost of a turbojet.

*Publications:* TUR035

*Research staff involved:* O. ADAM

*Partners:* Snecma Moteurs and Techspace Aero

### **2.18 Wind Tunnel Laboratory (CAT-SOUFFLERIE) — P. DE BOE**

#### 2.18.1 WIND INTERACTION WITH BRIDGE STRUCTURES

*Description:* Wind loads are induced on a structure as a result of a complex interaction between wind and structure. These loads are able to produce large-amplitude motions of the flexible structure that might be catastrophic.

Analytical and numerical simulations of the aerodynamic forces on oscillating bodies are computationally challenging due to the complexity of the fluid-structure interactions and of the turbulence effects.

On the other hand, there are three main types of wind tunnel tests that are commonly used in a wind tunnel setup: on full structure models, on taut-strip models and on section models. Full models are expensive to build, require large wind tunnels and demand similarity of mass distribution, reduced frequency and mode shapes, while taut-strip are intended to model the prototype mode shapes of the deck alone. For section model, the Strouhal similarity is used, which will respect the aerodynamic and geometrical characteristics of the model. By evaluating the modal integrals involving the prototype mode shapes, the behavior can be extrapolated to full scale.

*Research staff involved:* P. De Boe

*Partners:* ASMA-Aerodynamics group, ASMA-VIS, Greisch Ingénierie

*Related project:* F.N.R.S. – F.R.F.C.

## 2.18.2 EXPERIMENTAL CHARACTERIZATION OF A NON STATIONARY AERODYNAMIC FIELD BY PARTICLE IMAGE VELOCIMETRY (PIV)

*Description:* The technical of proper orthogonal decomposition (POD) has become potentially useful in specifying the fluctuating pressure field around structure. On the other end, this also method is capable of identifying the deterministic or systematic structure hidden in the random fluctuations of a flow and thus helps in better understanding of the flow phenomena.

*Research staff involved:* M. Godard  
*Related project:* F.N.R.S. – F.R.F.C.

## 3. Projects

### 3.1 ULg Grants

- Shell eco marathon project. Funding : 15.000 EUR
- Research grant, « Project BrainNav » (chercheurs défiscalisés - R. Boman)

### 3.2 Belgium's French Community

- Action de recherche concertée RACE “Rapid Assessment of the marine Coastal Environment”.
- Action de recherche concertée SLIM “Design of a second generation ocean model”.
- Action de Recherche Concertée – convention n° 03/08-298 “Modelling, Multiphysics Simulation and Optimization of Coupled Problems – Application to Micro Electro-Mechanical Systems (MEMS)” – 1 083 765 EUR
- CUD Doctoral Fellowship " Limit analysis of plates and shells" (NGUYEN VAN Hieu)
- CUD Doctoral Fellowship "Rigid finite elements and limit analysis" (PHAN HONG Quang)
- DGRE - DRI - Project N0 01-10898 “Kinetic of phase transformations in foundry alloys for rolls type ICDP (2004-2006)” 5.500 EUR
- F.N.R.S. Research Associate Fellowship (L. STAINIER)
- F.N.R.S. Postdoctoral Fellowship "Identification, recalage et validation de modèles structuraux en dynamique non-linéaire" (G. KERSCHEN)
- F.N.R.S. Doctoral Fellowship " Contribution à la modélisation et à la conception de structures mécaniques et de leur système de contrôle: méthodes de simulation intégrée et d'optimisation, réduction de modèles, architecture de logiciels et confrontation expérimentale" (O. BRULS)
- F.N.R.S. Doctoral Fellowship "Contribution à la modélisation de structures piézoélectriques: méthodes de discrétisation par éléments finis stochastiques, analyse de la fiabilité et de la robustesse de modèles, architecture logiciel et confrontation expérimentale." (S. LEPAGE)
- F.N.R.S. Doctoral Fellowship "Modélisation du couplage électro-mécanique dans les systèmes micro-électro-mécaniques (MEMS) par des méthodes numériques telles la méthode des éléments finis ou celle des éléments frontières" (V. ROCHUS)
- F.N.R.S. Doctoral Fellowship (L. NOELS)
- F.N.R.S.-F.R.F.C. : « Etude de l'interaction du vent avec des structures de pont. Analyse des effets de gradients de vitesse moyenne et de niveau de turbulence sur les instabilités aéroélastiques » – Grant for equipment : 100 000 € over 4 years. Supervisor : J.A. Essers
- F.N.R.S.-F.R.F.C. « Caractérisation expérimentale d'un champ aérodynamique instationnaire par vélocimétrie d'images de particules (PIV). Analyse du champ des vitesses par décomposition en modes orthogonaux (POD) ».

- “Comportement mécanique des engrenages en plastiques”, biennium 2004-2005, CGRI/Coopération Wallonie - Québec (ULg – tribologie / Université du Québec à Trois-Rivières)
- “Macrofoams, a new material for security in civil engineering (2004-2009)” 1.204.885 EUR – concerted action

### 3.3 Walloon Region

- Convention RW- R-TECH S.A. n° 4898 ANFIMOCE “Analyse de la fiabilité des modèles et confrontations expérimentales” 436 000 EUR
- Convention RW n° 114696 COMDY “Modelling of delamination of laminated composites under dynamic loadings“, with the participation of SONACA and SAMTECH (221 820 EUR).
- Convention Région Wallonne Programme "Recherche d'initiative" n° 0114868 – CREDIMUS “Radiation and electrons curing of novel materials for structural applications”, Budget total 986.235,00 EUR
- Convention RW ENERCARE : étude technico-économique (Appel CAIMAN II). Duration 6 months (24 750 EUR)
- Convention RW 415810- EVAFOIL “Fabrication of metallic foils by vacuum deposition (2004-2006)” 136.250 EUR
- Convention RW-550086-GEMMAG « Etude et faisabilité d’un générateur magnétothermique, avec dispositif expérimental. Phase 1 : Etude de faisabilité » (2005), 90.000 EUR
- Convention RW-550088-GEMMAG « Etude et faisabilité d’un générateur magnétothermique, avec dispositif expérimental. Phase 2 : Expérimentation » (2005-2006), 180.000 EUR
- Convention RW No 991-4384 LEGO « Développement d'un logiciel de conception aérodynamique et mécanique de turbomachines » (346.307 EUR).
- Convention RW n° 021/5183 MOMIOP “Modélisation de micro-systèmes électro-thermo-mécaniques. Optimisation avec lois de fabrication.” 437 040 EUR
- Convention RW n°02 1 5176 OPTI COUT “Logiciel d’Optimisation du Coût de Fabrication des Structures Métalliques” (87.668,75 EUR)
- Convention RW 41822- PHAKIR “Kinetic of phase transformation in high chromium alloys – First Europe (2004-2006)” 125.000 EUR
- Convention RW No 215187 PIGAL « Résolution de problèmes d'optimisation discrets et continus par algorithmes génétiques et programmation mathématique » (657.200 EUR)
- Convention RW N° 01/1/4710 project PROMETA: Numerical prediction of the over forming angle to cold roll forming (2001-2006)
- Convention RW ST4543a -Project PROINDU: Simulation Software for Cold-Roll Forming Processes (2003-2006)

- Convention RW 415659 “Development of Ti-LBC for turboreactors TITAERO (2004-2008)” 531.765 EUR
- Convention RW 03/1/5438, (WIST), IC&C « Interface Créative et Conception ». (1404 212 EUR).
- Convention RW n°04/45785/STEP dans le cadre de l'Accord AIE "Energy Conservation and Emissions Reduction in Combustion". 120.000,00 EUR
- Convention RW n°02/16207 « *Développement et transfert de technologies éco-efficaces.* » Duration: 6 months. (4000 EUR).
- Convention RW-Euro-Diesel n° 5145 “Identification et étude de phénomènes vibratoires non-linéaires apparaissant dans les grandes machines à double rotor” 115 200 EUR
- Convention RW-MARICHAL KETIN 4524 “Study of degradation phenomenon’s of hot rolls (2002-2005)” 3.750 EUR
- Convention RW-MARICHAL KETIN 6060 “Kinetic of phase transformations in foundry alloys for rolls (2004-2006)” 24.177 EUR
- Convention RW First DEI VAMOSNL n°516108 “Validation de modèles structuraux en présence de phénomènes dynamiques non-linéaires ” 243 000 EUR
- Convention RW FIRST Entreprise n° 4940 RW-Samtech SA. GMPDYN « Logiciel Métier de test virtuel de la dynamique d’un groupe motopropulseur ». Rémunération partenaire universitaire : 20.000EUR
- Convention RW FIRST-Europe No 114920 PARIS «Identification paramétrique de l’état de fonctionnement de turboréacteurs » (226.594,00 EUR).
- Convention RW FIRST-Europe 215052. Objectif 3: project METALUB: Lubrication study for mixed regime in cold rolling (2002-2006).
- Convention RW FIRST-Europe n° 215275. Objectif 3: IMPAMETA: Modeling and crashworthiness of aeronautic structures submitted to impact. (2003-2007).
- Convention RW FIRST-Europe N° 415778. Objectif 1 Project METARIV: Numerical modeling of bolted joints lines failure for the aeronautical structures under impact. (2005-2007). O. Karaseva.
- Convention RW FIRST-Europe N°415823 Projet METAOPT, Objectif 3: Optimization des processus d’emboutissage sous contraintes de fabrication : Compensation et contrôle des défauts (2005-2007)
- Convention RW FIRST EUROPE OBJECTIF 1 Convention n°114984 RAY-CURE "Comparison between UV-EB Activation in Manufacture of Polyester Composites; Emphasis on Dosimetry", 210.988,46 EUR
- Convention RW FIRST SPIN-OFF Convention n°0114802 E.-B.CONSULT “Knowledge base development of the effects of ionising radiations on materials”, 316.288,12 EUR.
- Projects ANTIERO I and II : "Coastal protection in the province of Binh Thuan, Vietnam", with the participation of Water resource university in Hanoi, Vietnam (100 000 EUR)

- Subvention objectif 2- URBAIN Meuse-Vesdre Moyens pôle d'excellence Pôle métal de Wallonie « thixomoulding » Total Budget: 3.313.706 EUROS/ ULG Budget 1.080.000 EUROS
- Development of new coating materials using laser technology diode for advanced systems of cooling in collaboration with RMI (RMI-ULg-RW Contract)
- Study of the degradation mechanisms by erosion– corrosion of materials in hyper-aggressive phosphoric medium in collaboration with Prayon S.A. (Prayon-CRM-ULg-RW contract)

### 3.4 Interuniversity Projects

- Interuniversity Attraction Poles Advanced Mechatronic Systems IUAP5/06
- "Ph. D. training programme for Vietnamese students" with the participation of University of Liège, 10 European Universities, University of Civil Engineering of Hanoi and 10 Vietnamese universities (supported by Vietnamese Government, 1000000 EURO).
- Study of safety joints for the aircraft industry– new airbus generation in collaboration with the sonaca s.a. (ULg-ULB-Sonaca contract)

### 3.5 European Projects

- COST 526 - APOMAT: Automatic Process Optimization in MATerials Technology. URL: <http://www.cost526.de>
- FP6 – Convention n°R-ATPI-05834-PV – ATPI "High performance damping technology for Aircraft vibration attenuation and Thermo-Phonic Insulation", 58.080,00 EUR
- Convention NMP2-CT-2004-507331 “Virtual Intelligent Forging - Coordinated Action” Total Budget: 1.499.999 EUROS / ULG Budget: 27.450 EUROS
- Convention COOP-CT\_2004-507622 “Non- contact Ultrasonic system for rail track inspection (U-RAIL)- (2004-2006)” Total Budget: 1.044.428 EUROS / ULG Budget: 119.680 EUROS
- Convention FP6-012564-BNEN “Open Access to the Belgian Nuclear higher Education Network FP6-Actions to promote and develop human resources and mobility” Total Budget: 150.000 EUROS/ ULG Budget: 25.000 EUROS
- EURO-CEANS : EUROpean network of excellence for OCEan Ecosystems ANalysis.
- "European Master in Modelisation of Continuum, EU-EMMC". with the participation of Delf (Holland) and Montpellier II (France), and Ho Chi minh University of Technology, 200000 EURO.
- "European Master in Modelisation and Design of Engineering Sciences, EU-EMMD”, with the participation of Lulea (Sweden) and Marseille II (France), and Hanoi University of Technology, 200000 EURO.
- “Euomotor e-learning”, EC Leonardo, 2003-2005
- “Campus automobile”, Interreg IIIA EMR 3.0304, 2004-2007

- “Journal Bearing Technology”, ESTEC/Contract n°18768/04/NL/CP, 2005-2006, 120 kEURO
- ESTEC (ESA) Contract Number 19200/05/NL/GM. Advanced Heat Exchangers for In-Flight LOx Collection for Future Launchers. 19.950,00 EURO
- New diamond cladding technique using one automated HPLD equipment (in collaboration with Technogenia, Diarotech, NEMITSAS, DDS, CERITEC, HEA, ASIST, INSA, IREPA) (contract R350 EURO)

### 3.6 Contracts with Industry

- OPTIF Optimization of design and cost of steel buildings (ASTRON Building S.A. - Diekirch, Grand-Duché de Luxembourg).
- Various research topics are carried out in collaboration with RENAULT, all related to machining problem. Among those, form error prediction of complex automotive parts, form error analysis (computer aided metrology) and chatter prediction.
- “Simulation numérique de l’écoulement d’un jet d’air sur une bande d’acier”, contract with the SEGAL Company (Yvoz-Ramet).
- Consulting expertise for various companies: Green Propulsion S.A., Mazda Belgium, Bureau d’Expertise Léonard-Collignon.
- “Caractérisation tribologique de matériaux pour solutions d’étanchéités cryogéniques”, SNECMA - Moteurs Vernon, 2005-2007
- Numerical simulation of the 3D flow in an hydraulic turbine, study carried out for RUTTEN s.a., montant : 9490 EUR
- Research topics dealing with thermo-hydraulic performance of heat exchangers were carried out in collaboration with RENAULT and PSA (Peugeot-Citroën). 58.097,00 EURO.
- RTECH (Schröder group): Qualification of luminaries
- ENERGIE 2030: Anemometer calibration
- Belgian Royal Military Academy: Wind tunnel testing of the EMATADOR drone
- VRTECH: Wind tunnel testing of a wind turbine
- OCAS Belgium “Characterisation of thermophysical properties of laminated steels for electrical applications (2005)” 15.000 EUROS
- Akers “Characterisation of thermophysical properties of steels for rolls (2004)” 5.000 EUROS
- IRSID “Characterisation of the weldability of material resistance spot welded” 15000 EUROS (2005-2006)
- Group AKERS : study of the alloyed steels for hot rolling
- Group SALUC : Metallurgical characterisation of ball bearings for food crushers
- The STIB : strategy of steels selection for the Brussels subway of Brussels : Study of the coupled mechanisms of wear-tyre

## 4. Publications and Reports

### 4.1 Refereed Journal Publications

AER001 — D. Vigneron, J.-M. Vaasen, J.A. Essers, An implicit high order cell-centered finite volume scheme for the solution of three-dimensional Navier-Stokes equations on unstructured grids, *Computational Fluid and Solid Mechanics* 2005 (pp923-927), Elsevier Science Ltd. K.J. Bathe (Editor).

MCT-TA-106 — P. Chabrand, F. Dubois, R. Boman, D. Graillet & J.P. Ponthot (2005), Numerical simulation of tribological devices used as a set of benchmarks for comparing contact algorithms. *Finite Element Analysis and Design* 41 (2005) 637-665.

MCT-TA-140 — J.P. Ponthot & J.P. Kleinermann (2005), Optimization methods for initial/tool shape optimization in metal forming Processes. *International Journal of Vehicle design*, Vol. 39, Nos 1/2, pp. 14-24.

MCT-TA-149 — L. Adam & J.P. Ponthot (2005), Thermomechanical modeling of metals at finite strains: first and mixed order finite elements. *International Journal of Solids and Structures*, Vol. 42/21-22 pp 5615-5655.

MCT-TA-146 — L.Noels, L. Stainier & J.P. Ponthot (2005), Simulation of complex impact problems with implicit time algorithms. Application to a turbo-engine blade loss problem. *International Journal of Impact Engineering*, Vol. 32, pp. 358-386.

MCT-TA-179 — A. Stephany, H.R. Le, M.P.F. Sutcliffe, An efficient finite element model of surface pit reduction on stainless steel in metal forming processes. *Journal of Materials Processing Technology*, 170 (2005), 310-316.

MMM100 — E.J.M. Delhez, E. Deleersnijder, M. Rixen, Tracer Methods in Geophysical Fluid Dynamics, *JMS special issues*, Elsevier, Amsterdam, 193 pp.

MMM101 — E.J.M. Delhez, Transient residence and exposure times. *Ocean Science Discussion*. 2/3, 247-265. SRef-ID: 1812-0822/osd/2005-2-247

MMM200 — C. Raick, E.J.M. Delhez, K. Soetaert, M. Grégoire, Study of the seasonal cycle of the biogeochemical processes in the Ligurian Sea using an 1D interdisciplinary model, *Journal of Marine Systems* 55/3-4, 177-203.

MMM300 — J.M.B. Walmag, E.J.M. Delhez, A trust-region method applied to parameter identification of a simple prey predator model. *Applied Mathematical Modelling*, 29/3, 289-307.

MMM301 — J.M.B. Walmag, E.J.M. Delhez, A note on Trust-Region Radius Update., *SIAM Journal on Optimization*, 16/2, 548-562.

MMS178 — S. Gerard, J. Gyselinck, J. Lecomte-Beckers, Finite element modelling of an asynchronous motor with one broken motor bar, comparison with the data recorded on a prototype and material aspects, *Bulletin scientifique de l'AIM*, p 13-22, n° 1/2005

MMS184 — A. Simar, J. Lecomte-Beckers, T. Pardoën, B. De Meester, Effect on the boundary conditions and heat source distribution on the temperature distribution in Friction Stir Welding, *Science and Technology of Welding and Joining*, 2006, Vol 11, N°2, p170

VEH-05-01 — M. Bruyneel, P. Duysinx : "Note on topology optimization of continuum structure including self-weight". *Structural and Multidisciplinary Optimization*. Vol 29, No 4, pp 245-256.

VEH-05-02 — J.-F. Collard, P. Fissette, P. Duysinx, (2005). "Contribution to the optimization of closed-loop multibody systems: application to parallel manipulators" *Multibody System Dynamics*, special issue, Vol. 13, pp 69-84.

VIS099 — A.M. Yan, G. Kerschen, P. De Boe, J.C. Golinval, Structural damage diagnosis under changing environmental conditions, Part I: A linear analysis, *Mechanical Systems and Signal Processing* 19, 847-864.

VIS100 — A.M. Yan, G. Kerschen, P. De Boe, J.C. Golinval, Structural damage diagnosis under changing environmental conditions, Part II: local PCA for nonlinear cases, *Mechanical Systems and Signal Processing* 19, 865-880.

VIS101 — G. Kerschen, A.M. Yan, J.C. Golinval, Distortion function and clustering for local linear models, *Journal of Sound and Vibration* 280, 443-448.

VIS107 — G. Kerschen, J.C. Golinval, Generation of accurate FE models of nonlinear systems - Application to an aeroplane structure, *Nonlinear Dynamics* 39, 129-142.

VIS110 — A.F. Vakakis, L.I. Manevitch, A.I. Musienko, G. Kerschen, L.A. Bergman, Transient dynamics of a dispersive elastic wave guide with an essentially nonlinear end attachment, *Wave Motion* 41, 109-132.

VIS111 — G. Kerschen, J.C. Golinval, A.F. Vakakis, L.A. Bergman, The method of proper orthogonal decomposition for dynamical characterization and order reduction of mechanical systems: an overview, *Nonlinear Dynamics* 41, 147-170.

VIS112 — G. Kerschen, P. De Boe, J.C. Golinval, K. Worden, Sensor validation using principal component analysis, *Smart Materials and Structures* 14, 36-42.

VIS114 — A.M. Yan, J.C. Golinval, Structural damage detection by combining flexibility and stiffness methods, *Engineering Structures* 27, 1752-1761.

VIS137 — S. Tsakirtzis, G. Kerschen, P. Panagopoulos, A.F. Vakakis, Multi-frequency nonlinear energy transfer from linear oscillators to MDOF essentially nonlinear attachments, *Journal of Sound and Vibration* 285, 483-490.

VIS138 — G. Kerschen, A.F. Vakakis, Y.S. Lee, D.M. McFarland, J.J. Kowtko, L.A. Bergman, Energy transfers in a system of two coupled oscillators with essential nonlinearity: 1:1 resonance manifold and transient bridging orbits, *Nonlinear Dynamics* 42, 283-303.

VIS140 — Y.S. Lee, G. Kerschen, A.F. Vakakis, P. Panagopoulos, L.A. Bergman, D.M. McFarland, Complicated dynamics of a linear oscillator with an essentially nonlinear local attachment, *Physica D* 204, 41-69.

VIS143 — V. Rochus, D. Rixen, J.C. Golinval, Electrostatic coupling of MEMS structures: transient simulations and dynamic pull-in, *Nonlinear Analysis* 63, 1619-1633.

VIS144 — D.M. McFarland, G. Kerschen, J.J. Kowtko, Y.S. Lee, L.A. Bergman, A.F. Vakakis, Experimental investigation of targeted energy transfers in strongly and nonlinearly coupled oscillators, *Journal of the Acoustical Society of America* 118, 791-799.

VIS145 — Y.S. Lee, A.F. Vakakis, L.A. Bergman, D.M. McFarland, G. Kerschen, Triggering mechanisms of limit cycle oscillations due to aeroelastic instability, *Journal of Fluids and Structures* 21, 485-529.

## 4.2 International Conference Proceedings

AER002 — J.-M. Vaassen, D. Vigneron, J.A. Essers : An implicit high order finite volume scheme for the solution of 3D Navier-Stokes equations with new discretization of diffusive terms, *Acomen 2005 Conference*, Ghent, Belgium, May 30 - June 2, 2005.

AER003 — D. Vigneron, J.-M. Vaassen, J.A. Essers : An implicit finite volume method for the solution of 3D low Mach number viscous flows using a local preconditioning technique, *Acomen 2005 Conference*, Ghent, Belgium, May 30 - June 2, 2005.

AER004 — D. Vigneron, J.-M. Vaassen, J.A. Essers : A finite volume method with conservative and consistent viscous terms discretization for three-dimensional flows, *35th AIAA Fluid Dynamics Conference and Exhibit*, Toronto, Canada, June 6-9, 2005.

INF001 — P. Beckers, Le graphique de communication, Journée  $\Phi^2$ AS sur "Interprétation des Résultats", Paris, November 15.

INF002 — B. Beckers, L. Masset, P. Beckers, Descriptive geometry mutating to design tool, *International Conference on Computational & Experimental Engineering and Sciences*, India, December 1-6, 2005.

INF003 — M. Kempeneers, P. Beckers, A tetrahedral equilibrium finite element for dual analysis in three-dimensional elastoplasticity, *International Conference on Adaptive Modeling and Simulation*, Barcelona, Spain, 2005.

LMF107 — J.F. Debonnie, L. Masset, Prédiction numérique des défauts de forme engendrés par l'usinage, *7e Congrès de Mécanique*, Casablanca, Marocco, April 18-21 2005.

MCT-TA-162 — Q.V. Bui, L. Papeleux, R. Boman, J.P. Ponthot, P. Wouters, R. Kergen, G. Daolio, Numerical simulation of cold roll forming process. *Proc. of 8<sup>th</sup> Int. ESAFORM, Conference on Material Forming*, Cluj-Napoca, Romania, D.Banabic ed., April 27-29, pp. 141-144.

MCT-TA-163 — L. Adam, J.P. Ponthot, Heat generation due to friction and plastic dissipation – A coupled thermomechanical approach for impact and metal forming simulation. *Proc. of Int. Conf. on Computational Methods for Coupled problems in Science and Engng. – COUPLED PROBLEMS 2005*, Papadrakakis, Onate & Schrefler Eds; Santorini Island, Greece, May 25-27.

MCT-TA-164 — E. Fancello, L. Stainier, J.P. Ponthot, A variational formulation of constitutive models and updates in nonlinear a finite viscoelasticity. *Proc. 7<sup>o</sup> Colloque National en Calcul des Structures*, Giens, France, 17-20 May.

MCT-TA-165 — F. Perales, Y. Monerie, F. Dubois, L. Stainier, Computational non-smooth fracture dynamics in nonlinear and heterogeneous materials. Application to fracture of hydridred zircaloy. *Proc. "18<sup>th</sup> Int. Conf. on Structural Mechanics in Reactor Technology" (SMIRT 18)*, August 7-12, Beijing, China.

MCT-TA-167 — R. Boman, L. Papeleux, B.Q. Viet, J.P. Ponthot, P. Wouters, R. Kergen, An ALE Model for Numerical Simulation of Cold Roll Forming Process. *Proc. of NUMISHEET 2005, 6<sup>th</sup> Int. Conf. on Numerical Simulation of 3D Sheet Forming Processes*, CP778, Vol. A, Edited by L.M. Smith et al., August 15-19, Detroit Michigan, USA, pp. 768-773.

MCT-TA-169 — E. Fancello, L. Stainier, J.P. Ponthot, A variational framework of nonlinear viscoelastic models in finite deformation regime. *Proc. of ACOMEN 2005*, 20 May-2 June, Ghent, Belgium.

MCT-TA-170 — A. Stephany, J.P. Ponthot, Numerical simulation of mixed lubrication in cold rolling using an object-oriented philosophy. *Proc. of ACOMEN 2005*, 20 May-2 June, Ghent, Belgium.

MCT-TA-171 — Q.V. Bui, J.P. Ponthot, Finite element simulation of cold roll-forming processes. *Proc. of ACOMEN 2005*, 20 May-2 June, Ghent, Belgium.

MCT-TA-172 — L. Noels, L. Stainier, J.P. Ponthot, Simulation of complex crashworthiness problems by using a combined implicit/explicit time integration. *Proc. of COMPLAS 2005, Int. Conf. on Computational Plasticity*, Barcelona, 5-8 September.

MCT-TA-174 — L. Stainier, Q. Yang, M. Ortiz, On the variational formulation of nonlinear coupled thermomechanical constitutive equations and updates. *Proc. of COMPLAS 2005, Int. Conf. on Computational Plasticity*, Barcelona, 5-8 September.

MCT-TA-177 — L. Stainier, E. Fancello, J.P. Ponthot, A variational framework for nonlinear viscoelastic and viscoplastic models in finite deformation regime. *Proc. of VIII Argentinian Congress on Computational Mechanics*, Nov. 16-18, Buenos Aires, Argentina.

MCT-TA-178 — J.P. Ponthot, C. Garcia-Garino, A. Mirasso, Large strain elasto/viscoplastic constitutive model. Theory and numerical scheme. *Proc. of MECOM 2005*, Nov. 16-18, Buenos Aires, Argentina.

MCT-TF-72— P.P. Jeunechamps, J.P. Ponthot, S. Bouvier, Analyse numérique des tests expérimentaux à grande vitesse de déformation sur des aciers dual phase. *Colloque National MECAMAT 2005*, Aussois, France, 23-28 janvier.

MCT-TF-73 — P.P. Jeunechamps, J.P. Ponthot, S. Bouvier, A. Uenishi, Analyse numérique de tests expérimentaux à grande vitesses de déformation. *Actes du 7<sup>o</sup> Colloque National en Calcul des Structures*, 17-20 mai, Giens, France.

MCT-TF-74 — F. Perales, Y. Monerie, F. Dubois, L. Stainier, Simulation numérique de la rupture dynamique des matériaux hétérogènes. *Actes du 7<sup>o</sup> Colloque National en Calcul des Structures*, 17-20 mai, Giens, France.

MCT-TF-75 — F. Perales, Y. Monerie, F. Dubois, L. Stainier, Fissuration dynamique des composites à matrice métallique. Application au zircaloy hydruré. *Actes du 17<sup>ème</sup> Congrès Français de Mécanique*, Troyes, France, 29 août-2 septembre.

MMS173 — J. Lecomte-Beckers, J. Tchoufang Tchoundjang, Use of Microscopy for identification of complex carbides MC, M2C, M6C, M7C3 and M23C6 in high speed-steels, in *G.I.T. Imaging and Microscopy, 2/2005*, P2-3, GIT Verlag

MMS175 — M. Carton, J. Lecomte-Beckers, Study of liquid fraction of semi-solid steels for thixoforming, *Proceedings of the conference Numiform – Romania - ascometal* april 2005

MMS176 — C. Bouffieux, M. Carton, J. Lecomte-Beckers, A.M. Habraken, Determination of the optimal forging conditions of a Cr-Mo-V high alloy steel through a microstructural, thermophysical and mechanical study, in the proceedings of the conference *ESAFORM 2005* Cluj-Napoca, Ro. pp 45-48; Ed the Publishing House of the Romanian Academy – ISBN 073-27-1175-2 ISBN 073-27-1173-6

MMS177 — J. Lecomte-Beckers, A. Rassili, M. Carton, M. Robelet, Study of liquid fraction evolution of semi-solid steels for thixoforming, in the proceedings of the conference *ESAFORM 2005* Cluj-Napoca, Ro. pp 1087-1090; Ed the Publishing House of the Romanian Academy – ISBN 073-27-1175-2 ISBN 073-27-1173-6

MMS001-1 — A. Magnée, Strategies for the selection of alloyed steels for cold rolling in multicylinder stands. *26th International Iron and steel Days– Re-examined Metallurgy–* December 2005– France

MMS002-1 — A. Magnée, Contribution of new surface treatment techniques cold plasma for orthopaedic prostheses. Orthopaedic biomaterials and prostheses - *Euroforum–* June 2005– France

MMS003-1 — A. Magnée, Tribology of orthopaedic titanium alloy prostheses. *50th International Congress EUROCOR -* Keynote lectures – September 2005– Lisbon

MMS004-1 — A. Magnée, Surface treatments by diffusion and coatings applied to titanium alloys *STIF–* October 2005– Besancon

MMS005-1 — A. Magnée, New techniques of laser cladding with tungsten carbide and diamond powders. *Int. Conf. Spray. –* May 2005 – Basel.

SPMM001 — H.-C.W. Hoang, L. Masalar, Study of a vision camera implemented on a 3D Measuring Machine; *International scientific conference “INTER-ING”,* UPM Targu Mures, Romania ; November 10-11, 2005.

THE001 — C. Masy and Ph. Ngendakumana : Influence of the Nozzle Capacity on the Performance of a Domestic Fuel Oil Boiler. *Proceedings of the 2<sup>nd</sup> Edition of European Combustion Meeting (ECM 2005).* Louvain-la-Neuve, April 4-6 , 2005

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TUR033 — V. Kelner, F. Capitanescu, O. Léonard, and L. Wehenkel, An Hybrid Optimization Technique Coupling Evolutionary and Local Search Algorithms, *Proceedings of the 3rd International Conference on Advanced Computational Methods in Engineering - ACOMEN'05*, Ghent, 2005

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VEH-05-04 — L. Van Miegroet, N. Moës, C. Fleury, P. Duysinx “Generalized Shape Optimization based on the Level Set Method”. Proceedings of 6<sup>th</sup> World Congress of Structural and Multidisciplinary Optimization (WCSMO6) (J. Herskowitz, ed.), Rio de Janeiro, Brasil, May 30 – June 3, 2005.

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VIS136 — F. Poncelet, F. Marin, C. Fleury, J.-C. Golinval, Optimal design of Fixtures for vibration testing of structures on electro-dynamica shaker, *Twelfth International Congress on Sound and Vibration*, Lisbon, July 2005

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MCT-TR-36 — J.P. Ponthot, A. Stephany, Projet METALUB. Lubrification en laminage à froid. Convention n° EPH3310300R0172/215052. Prolongation. Rapport d'activité et rapport scientifique et technique. Premier semestre (01.10.2004-31.03.2005)

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MCT-TR-38 — J.P. Ponthot, P.P. Jeunechamps, Projet IMPAMETA. Modélisation des structures soumises à choc ou impact. Convention n° EPH3310300R0252/215275. 4° semestre (01.04.2005-31.09.2005).

MCT-TR-39 — J.P. Ponthot, P.P. Jeunechamps, Projet IMPAMETA. Modélisation des structures soumises à choc ou impact. Convention n° EPH3310300R0252/215275. Rapport final (01.10.2005-30.09.2005).

MCT-TR-40 — J.P. Ponthot, S. Trichon, Projet METAOPT. Optimization des processus d'emboutissage sous contraintes de fabrication : Compensation et contrôle des défauts. Convention n° EPH3310300R075F/415823 – 1° semestre (01.05.2005-31.10.2005).

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MCT-TR-43 — R. Boman, L. Papeleux, J.P. Ponthot, Projet PROMETA. Convention R.W. n° 01/1/4710 « Recherche d'initiative ». Prédiction numérique de l'angle de surformage en profilage à froid. Rapport annuel d'avancement (période du 01.10.2004 au 30.09.2005).

MMS226 — J. LECOMTE-BECKERS, M. HERMAN, FIRST EUROPE objectif 3, ACTIVITY REPORT N°1: « Cinétique des changements de phase – Application à l'étude de la cinétique de précipitation dans des alliages fortement alliés au chrome », 13/04/2005, Marichal Ketin - Convention n°EPH3310300R074F / 415822, Projet «PHAKIR»

MMS227 — J. LECOMTE-BECKERS, M. HERMAN, FIRST EUROPE objectif 3, TECHNICAL AND SCIENTIFIC REPORT N°1: « Cinétique des changements de phase – Application à l'étude de la cinétique de précipitation dans des alliages fortement alliés au chrome », 13/04/2005, Marichal Ketin - Convention n°EPH3310300R074F / 415822, Projet «PHAKIR»

MMS228 — J. LECOMTE-BECKERS, M. HERMAN, FIRST EUROPE objectif 3, « Rapport de stage du séjour du chercheur Mirielle Herman, à la Faculté de Chimie à l'Université de Sofia du 02/02/05 au 03/04/05 », 13/04/2005, Marichal Ketin - Convention n°EPH3310300R074F / 415822, Projet «PHAKIR»

MMS229 — J. LECOMTE-BECKERS, M. HERMAN, « Etude bibliographique du brevet japonais 2003-342669 relatif à la fonte à trempe indéfinie faiblement alliée au vanadium et au niobium pour cylindres de laminoir » december 2005, Marichal Ketin - Convention Région Wallonne/MK-CRM RETECH 4844

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MMS231 — J. LECOMTE-BECKERS, M. HERMAN, FIRST EUROPE objectif 3, TECHNICAL AND SCIENTIFIC REPORT N°2, « Cinétique des changements de phase – Application à l'étude de la cinétique de précipitation dans des alliages fortement alliés au chrome », 13/10/2005, Marichal Ketin - Convention n°EPH3310300R074F / 415822, Projet «PHAKIR»

MMS232 — J. LECOMTE-BECKERS, M. HERMAN, ACTIVITY REPORT 2005, Commission mixte Communauté française de Belgique- RW – Bulgarie : « Cinétique des changements de phase – Application à l'étude de la cinétique de changement de phases par traitement thermique dans les alliages de fonderie pour cylindres de laminoirs type ICDP », 2004-2005, Marichal Ketin – Convention RW-DGRE-DRI

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MMS238 — M. CARTON, J. LECOMTE, « Caractérisation des tôles M00, M21 et M31 par détermination de la chaleur spécifique et de la diffusivité thermique », January 2005, Arcelor, convention OCAS

MMS239 — M. CARTON, J. LECOMTE, « Caractérisation thermique de deux nuances de l'IRSID par analyse dilatométrique, DSC et laser flash », April 2005 IRSID, convention OCAS

MMS240 — M. CARTON, J. LECOMTE, « Mesures de diffusivité thermique sur 7 tôles de chez OCAS », August 2005, arcelor, convention OCAS

MMS241 — C. FRAIPONT, J. LECOMTE, « Compte-rendu de la réunion du 14 novembre 2005 et programme de travail 2006 » 2005, Magotteaux, convention THIXO

MMS242 — Deliverable No 3– Self Assessment Report (BNEN) « Studiecentrum voor Kernenergie • Centre d'Etude de l'Energie Nucléaire » Due date of deliverable: 31/10/2005

MMS243 — S. PACE, « Rapport de réunion comité de pilotage EVAFOIL », PV03, 26/01/2005, convention 415810, 2p. Arcelor

MMS244 — S. PACE, « Rapport rencontre CircuitFoil », PV04, 23/02/2005, convention 415810, 2p. Arcelor

MMS245 — S. PACE, « Fabrication de feuilles minces métalliques par dépôt sous vide. Rapport scientifique et technique semestriel First spin-off », report 02, 01/04/2005, convention 415810, 41 p. Arcelor

MMS246 — S. PACE, « Rapport de réunion comité de pilotage EVAFOIL », PV05, 30/06/2005, convention 415810, 2p. Arcelor

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MMS248 — S. PACE, « Fabrication de feuilles minces métalliques par dépôt sous vide. Rapport scientifique et technique semestriel First spin-off », report 03, 01/10/2005, convention 415810, 63 p. Arcelor

MMS249 — S. PACE, « Rapport de réunion comité de pilotage EVAFOIL », PV07, 12/10/2005, convention 415810, 2p. Arcelor

MMS250 — S. PACE, « Rapport rencontre Centre CRIF », PV08, 21/10/2005, convention 415810, 2p. Arcelor

MMS251 — S. PACE, « Rapport rencontre Metal Forming », PV09, 08/11/2005, convention 415810, 2p. Arcelor

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MMS253 — S. PACE, « Rapport rencontre Interface ULg, brevetabilité du procédé », PV11, 14/12/2005, convention 415810, 2p. Arcelor

MMS254 — S. PACE, « Rapport de réunion comité de pilotage EVAFOIL », PV12, 21/12/2005, convention 415810, 4p. Arcelor

MMS255 — S. PACE, « Rapport rencontre CircuitFoil, caractérisation des foils », PV13, 22/12/2005, convention 415810, 4p. Arcelor

MMS258 — J. LECOMTE, C. BRASSINE, J. LEBRUN, P. NGENDAKUMANA, P. DULAR, A. RASSILI, P. MATHIEU, « Etude et Faisabilité d'un générateur magnétothermique, avec dispositif expérimental. Phase 1 : Etude de faisabilité », Rapport final, 30/11/2005, Convention N°550086 – GEMMAG, 62 p.

MMS259 — M.CARTON, J.LECOMTE-BECKERS, « Analyses DSC et métallographiques sur les états « brut » et « trempé » du TI-LCB », October 2005, Convention N° 415944 TITAERO

THE007 — C. Masy et Ph. Ngendakumana. Principe de la régulation automatique de la combustion - Essais effectués avec deux photodiodes avec un brûleur - Information concernant le dépôt de brevet. Rapport technique pour la RW dans le cadre des activités de l'AIE - Combustion, Mars 2005

THE008 — C. Cuevas et Ph. Ngendakumana. Etude expérimentale et modélisation des performances thermo-hydrauliques de radiateurs prototypes - Influence de la position des piquages sur les collecteurs pour l'alimentation du circuit EGR. Rapport technique pour PSA Peugeot-Citroën, Septembre 2005

THE009 — C. Brassine, J. Delvaux, P. Dular, J. Lebrun, J. Lecomte-Beckers, Ph. Ngendakumana, A. Rassili et P. Wathieu. Etude de faisabilité d'un générateur magnétothermique. Rapport technique pour la RW dans le cadre du projet de recherche GEMMAG1, Octobre 2005

THE010 — C. Cuevas et Ph. Ngendakumana. Etude expérimentale et modélisation des performances thermo-hydrauliques de radiateurs d'air de suralimentation (RAS) et de condenseurs d'air pour applications pile à combustible dans les véhicules. Rapport technique pour Renault, Décembre 2005

TUR052 — Résolution de problèmes d'optimisation discrets et continus par algorithmes génétiques et programmation mathématique, convention Région Wallonne No 215187, intermediate report No 4

TUR053 — Résolution de problèmes d'optimisation discrets et continus par algorithmes génétiques et programmation mathématique, convention Région Wallonne No 215187, intermediate report No 5

TUR054 — Développement d'un logiciel de conception aérodynamique et mécanique de turbomachines, convention Région Wallonne No 991-4384, intermediate report No 7

TUR055 — Développement d'un logiciel de conception aérodynamique et mécanique de turbomachines, convention Région Wallonne No 991-4384, intermediate report No 8

TUR056 — Identification paramétrique de l'état de fonctionnement de turboréacteurs, convention FIRST-Europe No 114920, intermediate report No 6

TUR057 — Identification paramétrique de l'état de fonctionnement de turboréacteurs, convention FIRST-Europe No 114920, intermediate report No 7

VEH05-10 — F. Van Loo, J. Nzisabira, S. Christiaens, P. Mathieu, P. Duysinx. « Etude de l'efficacité énergétique et de la faisabilité technique d'un nouveau moteur pompe

hydraulique et de ses applications ». Rapport final. Projet ENERCARE Partim : Etude Technique. Appel CAIMAN 2. Région Wallonne, DGTRE, division Energie. (115 pages)

Nélis M, Adaptation of FKFS Automotive Aerodynamic courses to Autotrain e-learning platform. “Euromotor e-learning”, EC Leonardo, 2003-2005

Nélis M, Development of training programs for “Campus Automobile” project, Interreg IIIA EMR 3.0304

Nélis M, Choice and description of dedicated equipment for supporting trainings in the automotive field, Interreg IIIA EMR 3.0304

Nélis M, Measurement of wear observed on plastic gear teeth using a 3D roughness apparatus, CGRI / Coopération Wallonie - Québec

#### 4.5 Books or chapters in books

MECA 2451 – Fabrication mécanique – Notes de cours partie Debongnie, SICI, LLN, Réf. Giaco : G21, 2003.

MECA 2455 - Fabrication assistée par ordinateur – Notes de cours, SICI, LLN, Réf. Giaco : G21, 2004.

Liviu MASALAR, Quality Insurance and Consumer Protection, University “Petru Maior” edition, Targu-Mures, Romania, 2005.

Liviu MASALAR, Total Quality Management, University “Petru Maior” edition, Targu-Mures, Romania, 2005.

## 5. Theses

### 5.1 Ph.D. theses

O. BRULS, Integrated simulation and reduced-order modeling of controlled flexible multibody systems, Supervisor : Prof. J.C. GOLINVAL.

P: DEWALLEF; Application of the Kalman Filter to Health Monitoring of Gas Turbine Engines. A Sequential Approach to Robust Diagnosis; Supervisor : Prof. O. LEONARD

NGUYEN TIEN DUONG, Modélisation du délaminage des composites sous chargement complexe par éléments métis, Supervisor: NGUYEN DANG Hung

### 5.2 M.S. theses

BUI Quoc Tinh, Application of the Element Free Galerkin Method for Dual Analyssi, Supervisor : NGUYEN DANG Hung

S. CHRISTIAENS. Preliminary study of a two stroke turbo Diesel engine in the perspective of hybrid electric vehicle applications. September 2005. (PGD). Prof. P. DUYSINX et P. NGENDAKUMANA

LE Duy Binh, Calculation of propagation of elliptic crack under the action of fatigue tensile loading, Supervisor : NGUYEN DANG Hung

LE Hoai Long, Modification of a Quarter-Point Element in Calculating Fracture Mechanics, Supervisor : NGUYEN DANG Hung

LE Van Canh, Dual limit analysis of bending plates, Supervisor : NGUYEN DANG Hung

LE Van Hoai, Determination of stress singularity orders at the free-edge in composite laminates, Supervisor : NGUYEN DANG Hung

P. MERKEN : Systèmes de guidage en micromécanique, Supervisor : J.F. DEBONGNIE

NGUYEN Ngoc Dung, Conforming Model and Error Estimation FEM for Plate Bending and Thin Shell Structures, Supervisor : NGUYEN DANG Hung

NGUYEN Xuan Nguyen, Finite Element Limit Analysis of Soils, Supervisor : NGUYEN DANG Hung

NGUYEN Vinh Phu. An Object Oriented Approach to the Extended Finite Element Method with Applications to Fracture Mechanics, Supervisor : NGUYEN DANG Hung

NGUYEN Ngoc Giang, Calculation the crack in concrete and reinforced concrete structure for a three-point bend beam, Supervisor : NGUYEN DANG Hung

P.P. JEUNECHAMPS, Identification de lois constitutives par méthode inverse et méthode expérimentale, Supervisor : J.P. PONTHOT

TRAN The Truyen, Etudes du modèle de rupture par propagation des fissures dans les poutres en béton armé, Supervisor : NGUYEN DANG Hung

TRAN Thi Kim Hue, Effect of breathing crack on the natural frequencies, Supervisor : NGUYEN DANG Hung

## **6. Professional Activities, Awards, Memberships**

### 6.1 Organization of symposia, conferences and workshops

G. KERSCHEN, Symposium on Nonlinear Dynamics Experimentation, Characterization and System Identification, 20th Biennial Conference on Mechanical Vibration and Noise (ASME), Long Beach, USA, September 2005. (together with Prof. B. FEENY).

Ph. NGENDAKUMANA, "EES-TRNSYS" days (in collaboration with Ph. ANDRE). Liège, July 11-13.

J.P. PONTHOT, Thermomechanical simulation of Forming and Impact Problems. (with C. Agelet de Saracibar) lors de COUPLED PROBLEMS 2005 – Computational Methods for Coupled Problems in Science and Engineering. Santorini island, Greece, May 25-28.

J.P. PONTHOT, Computational Modeling of Forming and Impact Problems. (with C. Agelet de Saracibar) lors de COMPLAS 2005 – VIII International Conference on Computational Plasticity, Barcelona, Spain, September 5-8.

### 6.2 Member of organizing or programme committee

J.L. BOZET, UPEX Congress (Automotive Experts), Liège, April 2005

J.L. BOZET, CVA summer session (Community of Ariane Cities), Barcelona, August

J.L. BOZET, "European Space Mechanisms and Tribology Symposium" (ESMAT), ESA/ESTEC, Luzern, September

E. DELHEZ, International Liege Colloquium on Ocean Dynamics

J.LECOMTE-BECKERS, Coordination for the Groupe Fonderie of the European project

O. LEONARD, Review organizer for the 6th European Conference on Turbomachinery Fluid Dynamics and Thermodynamics, Lille, March

J.M. LIEGEOIS, Society of Plastics Engineers 4th Additives & Colors Conference, Aachen Germany March 16-17.

L.MASALAR, Member of International Scientific Committee of "International Conference "INTER-ING" 10-11 nov. Upm Targu-Mures Romania

L.MASALAR, Member of Organizing Committee of 10 "Quality club's 2005" seminars of CQLL (Centre de Qualité Liège-Luxembourg)

Ph. NGENDAKUMANA, "EES-TRNSYS" days (in collaboration with Ph. ANDRE). Liège, July 11-13,

J.P. PONTHOT, 7<sup>ème</sup> Colloque National en Calcul des Structures, May, Giens, France

J.P. PONTHOT, ACOMEN 2005 – Third International Conference on Advanced Computational Methods in Engineering, Gent, Belgium, May.

### 6.3 Invited lectures and seminars

P. BECKERS, Adaptive meshing methods, Intensive Seminar 2005, Optimal Design of Materials and Structures, Xi'an, China, 1-3 November 2005

J.L. BOZET, Presentation of Interreg IIIA EMR project Campus Auto, Heysel "Salon de l'auto", February.

J.L. BOZET, "Fluid bearings in cryogenics", technology transfer workshop, CVA, April

J.L. BOZET, Place of apprenticeship by automotive project in a mechanical engineering curriculum, EAEC 2005 Congress, BELGRADE, 30th May - 1st June.

O. BRULS, A Mechatronic Formalism for Controlled Flexible Mechanisms: Multidisciplinary Simulation and Model Reduction, ITM Seminar – University of Stuttgart, Germany, May 2005.

J. LECOMTE-BECKERS, Belgian Society of microscopie's yearly day of studies

J. LECOMTE-BECKERS, S2P 2004 - 9<sup>th</sup> International Conference on Semi-Solid Processing - 8-10 September (Corée)

J.M. LIEGEOIS, C. MOMMER, The Potential Growing Applications for Radiation Processing in the European Polymer Industry. SPE Thermoset Division, Philadelphia PA, Nov. 11.

L.MASALAR, The way of Excellence by Quality Tools and Methods, University "Petru Maior" Targu-Mures, Romania, April & November.

L.MASALAR, Risk analysis, security and health of dangerous manufacturing machines, University "Petru Maior" Targu-Mures, Romania, April.

L.MASALAR, What the new Master Scanner method brings in comparison of traditional thread calibration methods, Presentation in the "Education in Metrology" section at NCSLI conference, Washington, USA, August.

L.MASALAR, Measurement Uncertainties following the GUM method, Two conferences in the IFC Training Day, University of Liege, Belgium, 3d of march (Formation IFC n° 340610/322).

L.MASALAR, F.GAUDER, Quality tools: Brain storming, Ishikawa & Pareto diagrams, Club Qualité CQLL, Centre de Qualité Liège – Luxembourg, Belgium, 19 April 2005.

E. MUNOZ de CELIS, Linear Parabolic Solar Reflector, SAMPE Student Chapter, Eindhoven NL Nov. 14.

Ph. NGENDAKUMANA, Energy Conservation and Emissions Reduction in Combustion. University of Concepcion (Chili), October.

J.P. PONTHOT, Simulation of crashworthiness problems. A review of recent improvements in implicit and explicit/implicit time integration algorithms, Seminar given at Doctoral school of the UPC (Universitat Polytechnica de Catalunya), Barcelona, Spain, March.

### 6.4 Scientific distinctions, awards and nominations

J.L. BOZET, Guidance of EM-GM students who obtained 2 awards at Challenge SIA in Le Mans, June.

J.L. BOZET, Member of the board of "Campus Automobile" and chairman of the "Comité d'Orientation Pédagogique"

J.L. BOZET, Member of the “Conseil General” of the CRIF / WTCM research centre  
P. DE BOE, Member of the steering committee for the elaboration of the Belgian, appendix NBN EN 1991-1-4 ANB 2005 (F) of the Eurocode : “Wind effect on structures”.

E. DELHEZ, Member of the editorial board of Ocean Science (EGU)

E. DELHEZ, Guest Editor of Estuarine Coastal and Shelf Science (Elsevier)

J.C. GOLINVAL, Associate Editor of the Journal of Vibration and Acoustics

G. KERSCHEN, Prix des Amis de l'Université de Liège 2005

J.LECOMTE-BECKERS, member of Scientific Committee of SCK-CEN(Belgium)

J.LECOMTE-BECKERS, member of CDC Sûreté des réacteurs, combustibles et matériaux de réacteurs SCK-CEN

J.LECOMTE-BECKERS, member of conseil scientifique des rayonnements ionisants de l'agence fédérale de contrôle nucléaire - FANC

L.MASALAR, nominate as ARA Branch Director for Western Europe (ARA = American Romanian Academy of Arts & Sciences)

L.MASALAR, nominate as NCSL International Region Coordinator 2005 for Central Europe

## 6.5 Member of professional societies

P. DE BOE , Association de l'Ingénierie du Vent (AIV), Belgique, France, Suisse

J.F. DEBONGNIE, American Society of Mechanical Engineers

J.F. DEBONGNIE, Society of Manufacturing Engineers

J.F. DEBONGNIE, FTA / SME

E. DELHEZ, European Geophysical Union

P. DUYSINX, ISSMO (Int. Society for Structural and Multidisciplinary Optimization).

P. DUYSINX, PRIMECA (Utilisation des Ressources Informatiques en Mécanique).

J.A. ESSERS, Assoc. Fellow of the American Institute of Aeronautics and Astronautics

J.A. ESSERS, American Society of Mechanical Engineers

J.A. ESSERS, Chairman of the F.N.R.S. Commission for Mechanics and Electricity

J.A. ESSERS, National Committee for Theoretical and Applied Mechanics of the Belgian Academy of Science

J.A. ESSERS, Member of the FRIA selection committee for doctoral fellowships.

J.C. GOLINVAL, American Society of Mechanical Engineers

J.C. GOLINVAL, Society of Experimental Mechanics

G. KERSCHEN, American Society of Mechanical Engineers

G. KERSCHEN, Society of Experimental Mechanics

J.LECOMTE-BECKERS, Société Belge de Microscopie

J.LECOMTE-BECKERS, American Society for Metals

J.LECOMTE-BECKERS, Iron and Steel Society

J.LECOMTE-BECKERS, Société Française de Matériaux

O. LEONARD, American Society of Mechanical Engineers

O. LEONARD, American Institute of Aeronautics and Astronautics

O.LEONARD, Association pour la Promotion des Energies Renouvelables

O. LEONARD, Consortium Industrie Recherche en Turbomachines

J.M. LIEGEOIS, Society of Plastics Engineers Inc.  
 A. MAGNEE, Member of Société Française de Métallurgie et de Matériaux  
 A. MAGNEE, Member of Cercle d'Etudes des Métaux (correspondant member)  
 A. MAGNEE, Membre de l'Assoc. Technique de Traitement Thermique et de Surface  
 A. MAGNEE, Membre de Benelux Metallurgie  
 A. MAGNEE, Member of Iron and Steel society of AIME  
 A. MAGNEE, Member of Société Tribologique de France  
 A. MAGNEE, Member of Club Ecrin, Paris – Recherches – Entreprises.  
 L.MASALAR: Membership of the NCSLI International  
 L.MASALAR, Full Member of ARA (American Romanian Acad. of Arts and Sciences).  
 L.MASALAR, Member of the Board of Directors and Vice-president of the CQLL  
 Ph. NGENDAKUMANA, New York Academy of Sciences  
 Ph. NGENDAKUMANA, Combustion Institute  
 Ph. NGENDAKUMANA, Commission d'Agrégation Optimaz  
 Ph; NGENDAKUMANA, Combustion Institute (Belgian Section)  
 Ph; NGENDAKUMANA, Society of Automotive Engineers  
 J.P. PONTHOT, IACM, International Association for Computational Mechanics  
 J.P. PONTHOT, EUROMECH, European Mechanics Society  
 J.P. PONTHOT, SAE, Society of Automotive Engineers  
 J.P. PONTHOT, MECAMAT, Groupe Français de Mécanique des Matériaux.  
 J.P. PONTHOT, ESAFORM, European Scientific Association for Material Forming.  
 J.P. PONTHOT, DYMAT, Dynamic Behavior of materials  
 L. STAINIER, CSMA, Computational Structural Mechanics Association.  
 L. STAINIER, AIAA, American Institute of Aeronautics and Astronautics  
 L. STAINIER, MECAMAT, Groupe Français de Mécanique des Matériaux.

## 6.6 New spin-offs

S. PACE, (Fabrication of metallic foils by vacuum deposition) (to be created)

## 6.7 Invited speakers at ULg

C.BOLOS, Professor at UPM University, Romania, Modern methods in drawing assembly of mechanical parts, November 2005.  
 J-M.COMPERE, Managing Director of" QUASYS" company, Belgium, Human Resources and Changing Management, December, 2005.  
 L.MARIAN, Rector of UPM University, Romania, Projects Management, April 2005.

## 6.8 Guests for Extended Period

Eduardo FANCELLO, Universidade Federal de Santa Catarina, Brazil  
 Joanna RIZOU, National Technical University of Athens

## 6.9 Miscellaneous Items

The prototype PAC2FUTURE from University of Liège participated for the second in the Shell Eco Marathon Race in Nogaro (France) May 21-22, 2005:

- N°8 in the general classification
- N°2 in hydrogen category
- Eco design award price