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INSTRUMENT	SPECIFIC TARGETED PROJECT
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Contents

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EXECUTIVE SUMMARY

I-1 CASSEM PROJECT OVERVIEW

The ambition of the CASSEM project is to define the 'best' models and techniques that will permit us to model, simulate and validate the development of a more efficient vibration control. The most common general classification of vibration control differentiates between passive, active and hybrid passive-active control. Passive control involves the use of reactive or resistive devices that either load the transmission path of the disturbing vibration or absorb vibratory energy. Active control also loads the transmission path but achieves this loading through the use of actuators that generally require external energy. In passive control, the material properties of structure such as damping and stiffness are modified so as to change the response of structure. In active control, the structural response is controlled by adding external effort to the structure. Combining these two approaches, hybrid control integrates the passive approach with an active control structure, and is intended to reduce the amount of external power necessary to achieve control. Depending on the relative positions of the viscoelastic layer and the piezoelectric actuator, the viscoelastic passive and piezoelectric active actions can operate either separate or simultaneous actions. Typically, these materials have a sandwich structure, in which a soft, thin viscoelastic layer is confined between identical stiff, elastic layers. These structures yield a superior energy absorption. In particular, they offer the advantage of high damping with low weight addition. The interlayer-damping concept is highly compatible with the laminated configuration of composite structures and with their fabrication techniques, and provides an effective way to reduce vibrations and noise in structures. The damping is introduced by an important transverse shear in the viscoelastic layer. This is due to the difference between in-plane displacements of the elastic layers and also to the low stiffness of the central layer.

The performance of passive and hybrid vibration control systems depends strongly on the viscoelastic material layer and piezoelectric material properties. In this project, numerical identification based on direct/inverse approaches will be developed. An advanced non-contact laser technique (ISI-SYS vibrograph system and Polytec scanning vibrometer) will be applied for the vibration measurements. These experimental data will be used to determine the natural frequencies and corresponding loss factors by the developed modal analysis program.

Another issue of this FP6 project is to develop a general analytical and numerical (Finite Element) framework to model: (i) composite structures with piezoelectric sensors and actuators, (ii) thermal and pyroelectric effects in piezoelectric composites, and (iii) piezoelectric shunted damping.

In the context of the FP6 STREP Project 'CASSEM' (Composites and Adaptive Structure: Simulation, Experimentation and Modelling), we will also design a robust controller, which is stable in the presence of uncertainties of modelling and parameters, and ensures optimal disturbance rejection capability. In the implementation of the controller, actuators and sensors are needed. The locations of actuators and sensors over a structure determine the effectiveness of the controller in damping vibrations.

A variety of problems must be clarified before active systems can be implemented within structures. One of these - an important and not fully recognized problem - is the proper positioning of sensors and actuators on structures in the case of active systems, and the location of dampers in the case of passive systems. In active vibration control, actuator and sensor placement is a very significant issue, since it has a direct effect on the control efficiency and cost. For example, large flexible structures require many actuators for active vibration control, and the problem of optimizing their location becomes extremely significant in maximizing system controllability. An arbitrary choice of actuator positions can seriously degrade the system performance. The controllability index, the genetic algorithms, the gradient-based optimization procedure and the heuristic procedures were used to determine the proper sensor or actuator locations. The problem of positioning and size of passive dampers is also important, for similar reasons.

CASSEM is a highly interdisciplinary project combining engineering and physical sciences, for example, experimental material science, numerical modelling methods, mathematics, automation systems and mechatronics. The consortium consists of nine scientific and industrial partners from seven EU countries. The application of the project results will lead to long-term innovations in composites and adaptive structures. The development of vibration control systems will allow the areas of application of multi-functional composite materials to be extended based on the advanced knowledge and understanding of vibration response.

I-2 Project Objectives

As previously stated, the principal aim the of the FP6 STREP is developing a vibration control technology to enable higher performance, less energy consuming and lighter weight structural systems. This project will not only have a scientific aim but also a direct industrial application. The specific S&T objectives of the project can be summarised as follows:

- **Obj. 1.** Improved characterisation of electro-mechanical properties of materials and structures (including direct and inverse identification techniques). Various experimental techniques, methodologies as well as numerical identification based on direct/inverse approaches will be developed and used for the material properties identification of the VEM and PEM and composites (carbon fibre, glass fibre, sandwich, …). The mixed numerical-experimental technique based on experiment design will be developed for identification of the elastic and damping material properties of sandwich and laminated composites.
- **Obj. 2**. Advanced multi-physics (mechanical, electric) modelling of multifunctional multilayered (elastic, viscoelastic, piezoelectric) composite structures. This includes modelling developments for frequency and temperature dependant VEM layer, of sandwich and laminated composites with VEM layers and of non-linear vibration of damped sandwich and laminated composites as well as numerical validations of the all developed concepts as well as the development of a general analytical and numerical (FE) framework to model: (i) Composite structures with piezoelectric sensors and actuators and (ii) advanced multi-physics (mechanical, electric, thermal) modelling of multifunctional multilayered composite structures.

- **Obj. 3**: Optimisation of the locations and sizes of the actuators and sensors. Formulation of the optimisation problems and development of experimental design and response surface techniques with the purposes to get structures with maximum damping, to control vibrations and to get optimum design of the structure or a part of it.
- **Obj. 4**: Non-linear controllers will be developed to improve the control performance on a system with a non-linear behaviour. In addition, we will develop control algorithms and methodologies well adapted for damped structures and, if possible, taking advantage of the passive damping mechanism.

  Obj. 5: Development of a validation tests for the all proposed new concepts on representative structures for relevant applications.

  Obj. 6: The final research action will be devoted to a full scale testing of the obtained numerical and laboratory results. This will involve testing on airplane structural components, with integrated sensing and control vibration technology.

I-3 Achieved results

The table below summarises the achieved results, the sections of this report where further details can be found, and the links to documents providing extensive descriptions.

Result	Short description	links to read	Lead. Contrs.
CASSEM web site	A Plone based virtual communication platform have been developed and used for the communication and co-ordination of activities among the partners. The following functionalities are accessible: access-control to the forum, structured work-space for exchange of electronic messages with management by topic-specific folders, shared electronic agenda, chat capabilities, structured work-space with management capabilities by topic-specific folders for sharing and forwarding electronic documents.	www.cassem.lu	CRP Henri Tudor,
Database on the mechanical properties of multilayered composite materials, on piezoelectric and viscoelastic materials parameters the mathematical and experimental used methods.	Covers the development, testing and verification of all methods of material testing by means of a large spectrum of sample materials. The results of these works are incorporated in D 1 and present the most important part of this Deliverable.	D1-Deliverable	WBI,
Database of the tested materials properties	The database is developed under Plone® management system which an open source content management built on the powerful object-oriented Zope application server.	D2-Deliverable	CRPHT,
Inverse and direct approach used for the determination of viscoelastic and piezoelectric material properties.	Different identification techniques are developed, tested and applied to characterize advanced composite material properties: elastic, plastic, hysteretic, viscoelastic, piezoelectric and dielectric. These techniques are based on indentation and vibration tests, and computation of effective properties on a so-called representative volume element. Future research needs are discussed in addition.	D3-Deliverable	IST, RTU and CRP HT

Theoretical and finite element models for damped composite structure, and on the analytical and numerical methods for non-linear vibration analysis and their validation	Modeling developments for frequency and temperature dependant VEM layer, of sandwich and laminated composites with VEM layers and of non linear vibration of damped sandwich and laminated composites as well as numerical validations of the all developed concepts will investigated in this work package	D4-Deliverable	UM-LPMM, RTU and CRP HT
Theoretical and numerical modeling of adaptive composite structures.	This covers most of the work made by the various teams in the framework of the modelling of adaptive composite structures.	D5-Deliverable	POLITO, ISMEP, UM-LPMM, IST
Implementation of Matlab routines for uncertainties and development of reduced dynamic models.	Methods have been developed for implementation of controllers in a Matlab based environment, starting from a finite element model of a structure. The finite element model is first reduced using a Craig-Bampton technique. The model is then further reduced and translated into a state-space model which can be integrated in the Simulink environment. The Matlab/Simulink environment is suitable for the implementation of control routines. Examples of applications on a cylindrical composite boom equipped with macro fiber composite (MFC) actuators are presented.	D6-Deliverable	ULB

Control strategies and new linear, robust and adaptive controller and validated concept for passive, active and hybrid vibration control	Two major contributions: the first one is related to the development of control strategies. Non-linear control strategies based on fuzzy logics have been investigated and tested on a simple system. Investigations have been made in the design of a collocated Positive Position Feedback (PPF) controller in order to damp the first mode shape of a composite plate equipped with piezoelectric patches, and a composite boom equipped with MFC patches. An approach based on pseudo-collocated pairs is studied, in order to improve the performance of the controller by careful design of the sensors and actuators placement and arrangement. The second task concerns concept validations. This is carried out through experimental implementation of the control strategies on the composite boom example.	D7-Deliverable	ULB , CRPHT and EADS
Parameters Sensitivities and Optimization	Development of suitable methods to investigate the parametric sensitivity of dynamically loaded structures with passive and/or active devices and optimization of the size, location and type of actuators and sensors.	D8-Deliverable	ULB and IST
Experimental Validations for Test/Model Correlation	Most important results have been collected, to validated them if possible with experimental data, and to associate them with materials that are actually used in the design of engineering structures. EADS role was among others to provide such materials to the consortium. As a result, many partners were able to apply their findings on a composite plate representative of a composite aircraft fuselage skin (unstiffened).	D9-Deliverable	EADS
Performance evaluation of new concepts	Validation of several methods/approaches developed in the project is proposed. It supports an updated state-of-the-art in the domain of structural dynamics.	D10-Deliverable	EADS

PROJECT EXECUTION

Summary of the objectives of the Project, work performed and the main achievements in the period.

OBJ-1: SAMPLE LEVEL MATERIALS CHARACTERISATION

Elementary tests in order to improve the characterisation of viscoelastic layers

A viscoanalyser is used to obtain stiffness and damping characteristics of those materials with varying temperature and frequency. This data is usually supplied by the material manufacturer, but unfortunately with insufficient precision.

Mainly reverse engineering methods were used to measure viscoelastic, piezoelectric and other parameters. For viscoelastic materials long-time and short-time material data were investigated as well as parameters like dynamic loss-factors. New measurement systems like scanning laser vibrometer and two-axial static and dynamic test facilities were used. One specific innovative point is the characterisation of piezoelectric ceramics working in shear. The reverse method is based on direct measurements of forces and responses in terms of displacements and accelerations. Basic piezoelectric material properties, such as the piezoelectric constant, Young's modulus, electro-mechanical coupling factor and dielectric constant etc., are often applied to describe the quality of piezoelectric materials. For piezoelectric actuators attached to structures in practical applications, more straightforward parameters such as actuating force, mechanical power output, conversion efficiency between electric and mechanical energy are also imperative to characterise the applicability and efficiency of the actuators.

Precise field characterisation of Macro Fibre Composite actuators

Again in this case, data provided by the suppliers is not sufficient to precisely simulate the interaction of those actuators with the host structure. The use of non contact techniques, such as image correlation, allows a global measurement of the induced strain.

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A non-destructive methods for elastic and piezoelectric parameter estimation in active plate structures with surface bonded piezoelectric patches. These methods rely on experimental undamped natural frequencies of free vibration has been developed Composite materials characterisation (elastic, damped, active, hybrid).

Improved characterization of electromechanical properties of materials and structures

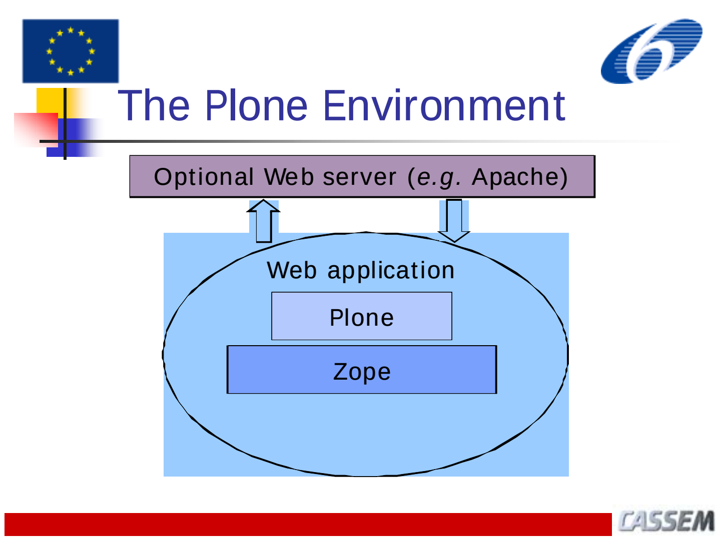
A complete 3D data set of Macro Fibre Composite (MFC) patches has been reached using three-dimensional (3D) Finite Element (FE) homogenization technique. For this purpose, the representative volume element approach has been used in conjunction with the commercial FE code ABAQUS. The obtained results were compared to analytical ones from the uniform fields approach available in the literature. It was shown that for this material, both techniques lead to the same set of homogenized piezoelectric properties. This provides a solution to the usual problem of the manufacture's incomplete datasheet.

Composite materials characterisation (elastic, damped, active, hybrid).

The main objective of this task is to investigate the mechanical properties of composite beams, plates and panels. EADS CCR participated in the identification of viscoelastic properties of ISD 112 material. It was important to test the identification methods (based on measures carried out on a viscoanalyser) on this particular material. Due to the nature of the very thin layer material (as opposed to a bulk rubber material), tests results were not as successful as expected. Active materials were tested too: a fiber piezoceramic actuator was characterised using image correlation during active elongation of the material.

Elaboration of a database of the tested materials properties

The design and the development of the Database system dedicated to CASSEM project were the main contribution to this task. The major efforts included: (1) Identification and synthesize the operational logic in the material testing processes so as to search for the best ways to organize and unify the forms, (2) Normalization of the relational database (SQL) and apply Internet techniques to secure data integrity and manage data flows within CASSEM project networks; (3) Integrate the existing data; (4) Protecting and archiving the data; (5) Improving the system flexibility such that new materials and new information can be inserted;



Identification of materials properties (direct/inverse).

An inverse technique, consisting of the experimental set-up, numerical model and material identification procedure, has been developed for characterisation of advanced composite material properties. POLYTEC laser vibrometer has been calibrated to obtain the natural frequencies and mode shapes for plane samples made from advanced composite materials. An additional program has been developed to extract modal loss factors, as engineering values, from the frequency response plots. In the developed inverse technique, the finite element method has been used for the modelling and dynamic analysis. The identification (inverse) methodology has been developed on the basis of experiment design and response surface technique. The basic idea of the proposed approach is that simple mathematical models (response surfaces) are determined only by the finite element solutions in the reference points of the experiment design. The error functional to be minimised describes the difference between the measured and numerically calculated parameters of the response of structure. By minimising the functional, the identification parameters are obtained. A significant reduction (about 50-100 times) in calculations of the identification functional is achieved in comparison with the conventional methods of minimisation. The technique developed has been successfully tested to characterise isotropic elastic material properties of homogeneous aluminium plates and successfully applied to characterise orthotropic elastic material properties of laminated plates and viscoelastic material properties of damping polymer ISD-112 used as a core material in the sandwich panels.

An inverse method for material parameter estimation of elastic, piezoelectric and viscoelastic laminated plate structures has been developed. The method uses gradient based optimization, with analytical and semi-analytical sensitivities, associated to FAIPA – Feasible Arc Interior Point Algorithm, in order to solve the inverse problem, through minimization of an error functional which expresses the difference between experimental natural frequencies and modal damping factors of free vibrations and the corresponding numerical data produced by the finite element model. Constraints on non-dimensional design parameters are established in order to keep the elasticity matrices positive definite. The finite element model is based on an equivalent single layer higher order shear deformation theory, where the complex modulus approach is used. The method developed has been successfully applied in the estimation of the properties that characterize layered composite specimens, with piezoelectric patches and/or damping properties. After estimation of material properties, the numerical model can be used with confidence along with the estimated parameters for the analysis and control of the particular structure tested, in the corresponding frequency range

The material parameter identification has also been investigated by using a gradient-based numerical optimisation procedure. The latter is assessed with respect to stability by using pseudo-experimental indentation curves, obtained from modelling with known material parameters, and superposed with artificial noise. The effect of the load history on parameter identification is investigated and the sensitivity analysis for the case of flexible-to-flexible contact, required in indentation testing, has been included.

Non-destructive methods for elastic and piezoelectric parameter estimation in active plate structures with surface bonded piezoelectric patches have been developed. These methods rely on experimental undamped natural frequencies of free vibration. The first solves the inverse problem through gradient-based optimisation techniques, while the second is based on a metamodel of the inverse problem, using artificial neural networks. A numerical higher order finite element laminated plate model is used in both methods and results are compared and discussed through a simulated and an experimental test case.

Material parameter identification has been investigated using a gradient-based numerical optimisation procedure. The latter is assessed with respect to stability by using pseudo-experimental indentation curves, obtained from modelling with known material parameters, and superposed with artificial noise. The effect of the load history on parameter identification is investigated and the sensitivity analysis for the case of flexible-to-flexible contact, required in indentation testing, has been included.

OBJ. 2. ADVANCED MULTI-PHYSICS (MECHANICAL, ELECTRIC) MODELLING

Review and assessments of various kinematic models for sandwich structures

Qualitative and quantitative assessments have been performed to address the applicability and the efficiency of the major classes of representative theories. The results have been presented and discussed for several geometrical and mechanical sandwich beams configurations as well as a clear picture on suitable applications of each analysed model. An attempt has been made to analyse and assess the various kinematics and theories used for the modelling of sandwich composites. Major classes of representative theories such as classical laminate theory (CLT), first-order shear deformation theory (FSDT) and high-order theories (HOT) as well as Zig-Zag based theory models have been considered and a unified kinematic formulation is then proposed. Comparative studies with a finite element solution free of any kinematics assumptions have been conducted to address the applicability and the efficiency of previously considered models and theories. Qualitative and quantitative assessments of displacement, stress fields and modal parameters (natural frequency and loss factor) have been presented and discussed for several geometrical and mechanical sandwich beams configurations as well as a clear picture on suitable applications of each analysed model.

Multi-scale of sandwich structures modelling.

In order to study local effects in Sandwich Structures, a meshless multi-scale method based on the Arlequin approach. The Arlequin method hence offers a framework to mix and glue different models with others. In this work, the gluing is realized not only between finite elements, but also between finite elements and numerical data. This permits to use the known numerical/analytical solutions to establish the gluing system and to obtain more information in the local fields. By proposing a new coupling operator for sandwich structures, the capabilities of the Arlequin method and the effectiveness of the implemented numerical tools are exemplified by both linear and non-linear problems, in which the non-linear finite element equations are solved by using Asymptotic Numerical Method (ANM).

New Shell Element for Hybrid Vibration Control of Sandwich Structures

A shell finite element is proposed for piezoelectric and viscoelastic sandwich structures. The new sandwich finite element is obtained by assembling five elements throughout the thickness. Using specific assumptions, displacement continuity at the interfaces and considering control laws, one reduces to eight the number of degrees of freedom (DOF) per node. Direct proportional feedback and velocity feedback controls have been considered and the obtained results are compared to analytical model and numerical developments using a commercial code.

Forced harmonic response of viscoelastic sandwich plates by an asymptotic numerical method

An asymptotic numerical method for forced harmonic vibration analysis of viscoelastic sandwich structures has been proposed. Symmetric plates with a viscoelastic layer inserted between two elastic ones are considered. Power series expansions and Padé approximants of the displacement and frequency are developed and the finite element method is used for numerical solution. Iterations of the process lead to a powerful continuation method. Resonance curves for sandwich plates are obtained for various frequency ranges, excitation amplitudes and viscoelastic models. Only some matrix inversions and a few iterations are needed for large frequency range.

Non linear vibrations of damped multilayered composites

In this section we describe methods and algorithms that have been developed for vibration analysis of viscoelastic composite structures using the same hypothesis - complex modulus module for the frequency and time domains, and preserving the frequency-dependence for the material storage and loss moduli. Two methods have been developed in order to calculate the dynamic characteristics of viscoelastic structures: the method of complex eigenvalues and energy method. Damped eigenfrequencies and corresponding loss factors in the method of complex eigenvalues are determined from the free vibration analysis solving the non-linear generalised eigenvalue problem with large complex symmetric matrices. Solution starts with a constant frequency. Then at each step the linear generalised eigenvalue problem is solved by the Lanczos method, which is programmed in a truncated version, where the generalised eigenvalue problem is transformed into a standard eigenvalue problem with a reduced order symmetric tridiagonal matrix. Orthogonal projection operations are employed with greater economy and elegance using elementary reflection matrices. When the desired eigenfrequency precision is obtained, the iteration process terminates. The modal loss factors of viscoelastic structures for each vibration mode are determined using the values of corresponding complex eigenvalues. This approach gives the possibility to preserve the frequency-dependence of viscoelastic materials and to calculate structures with high damping. In the energy method it is assumed, that for structures with slight damping, the dynamic characteristics can be calculated by the equation of natural vibrations of the corresponding un-damped structure. In this case the eigenvalues and corresponding eigenvectors are determined from the non-linear generalised eigenvalue problem with large real symmetric matrices using the subspace iteration algorithm at each step. It should be noted that this method gives the possibility to preserve the frequency-dependence only for the storage moduli and can be used only in the case of structures with slight damping.

Numerical tools for computing the non-linear forced response of sandwich beams subjected to harmonic excitations have been developed.

It is now well known that large vibration amplitudes of beam-like structures may induce a dynamic behaviour significantly different from the behaviour predicted by the linear theories. Nevertheless, there are only few works in which damping effects are taken into account. Moreover, most of these studies are based on a one mode Galerkin approach. So, results of these studies are likely to be accurate only near a resonance. Moreover, effects of geometrical non-linearities on the mode shape are neglected..

Non linear vibrations of damped sandwich and laminated composites

Several aspects concerning the formulation of and solution to amplitude equations for non-linear vibration will be discussed in detail. The use of several possible constraint equations to achieve the non-trivial solution to the amplitude equation will be investigated. The well-known concept of the Rayleigh quotient is extended to the non-linear case of interest. Some general remarks on the formulation of the non-linear amplitude equation and the non-linear Rayleigh quotient are also be investigated. Moreover, the introduced Rayleigh quotient will be used to develop a new and suitably efficient method to solve amplitude equations. The accuracy of solutions obtained by means of some widely used methods of analysis of vibration problems is also treated in this subtask.

Non linear vibrations of sandwich structures: Non linear geometrical effects/ Analytical and numerical studies

In this part, the non linear vibration of viscoelastic shell structures is investigated by an approximated method. Coupling an approximated harmonic balance method with one mode Galerkin's procedure, one obtains an amplitude equation depending on two complex coefficients. The latter are determined by solving a classical eigenvalue problem and two linear ones. To show the applicability and the validity of our approach, the amplitude-frequency and the amplitude loss factor relationships are illustrated for a sandwich plate with viscoelastic central layer and a viscoelastic circular ring.

Non linear vibrations of sandwich structures: numerical studies using a commercial code

This investigation deals with the development of a numerical tool for computing the non-linear response of sandwich beams with viscoelastic parts subjected to harmonic excitations. The proposed procedure is based on the harmonic balance method coupled with finite element approximations in space. For validation purposes, results of this approach are compared to results of fully non-linear dynamic analyses using direct time integration. A good agreement is observed.

Nonlinear vibration of sandwich piezoelectric beams: A Simplified approach

Nonlinear vibrations of piezoelectric/elastic/piezoelectric sandwich beams submitted to active control are studied in this paper. The proportional and derivative potential feedback controls via sensor and actuator layers are used. Harmonic balance method and the Galerkin procedure are adopted. A complex amplitude equation governed by two complex parameters is derived accounting for the geometric non-linearty and piezoelectric effects. The nonlinear frequency and loss factor amplitude relationships with respect to the gain parameters are obtained. The feedback effects are analyzed for small and large vibration amplitudes of sandwich beams. The frequency response curves are presented and discussed for various gain parameters.

Nonlinear vibration analysis of sandwich piezoelectric beams with geometric imperfections: non linear geometric effect,

Modal analysis is developed for linear and nonlinear vibrations of deformed sandwich piezoelectric beams with initial imperfections. The beam is subjected to axial displacement and active voltage generated by the top and the bottom piezoelectric layers. The mathematical formulation is developed for the multi-modal analysis. Using, the one mode assumption, simplified relationships accounting for the active voltage, the imposed axial displacement and the amplitudes of imperfections are presented for the load amplitude, the load-frequency and the nonlinear frequency-amplitude. The stability control of deformed beams is analyzed for various load and voltage levels. For statically deformed beams, a nonlinear frequency-amplitude relationship is presented with respect to positive and negative amplitudes. This formulation accounts for the piezoelectric, the imperfection and the load effects. Numerical tests are investigated for various voltage, load and amplitude levels. The under critical frequency behaviors related to deformed beams, showing the transition from softening to hardening effects, are presented for various levels of active voltage, static response and imperfection amplitudes of simply supported sandwich piezoelectric beams.

Non linear vibrations of damped sandwich and laminated composites: Non linear material effects

Finite element analysis of viscoelastic composite structures is performed. The present implementation gives the possibility to preserve the frequency dependence for the storage and loss moduli of viscoelastic materials and to use the same hypothesis-complex modulus model in the free vibration, frequency and transient response analyses. Dynamic characteristics of viscoelastic composite structures are evaluated by the energy method, the method of complex eigenvalues, from the resonant peaks of the frequency response function and using the steady state vibrations. To verify the approaches developed, the dynamic characteristics of different sandwich panels have been determined and analysed.

Models validation

The model validation is a key point of the undertaken research activities. To estimate the correctness of the approaches developed in Task 2.1, numerical and experimental vibration analyses of different sandwich samples with high damping properties have been performed. EADS CCR provided test articles to the interested partners in order to correlate modelling results to experimental data. It proposed also improved exchange between partners involved in this work package (definition of a work plan).

A-Validations on sandwich panels with a frequency dependent viscoelastic core

All the developed analytical and numerical models will be validated on a beam in first stage and on plate in the latter. A laser vibrometer will be used to measure accurate vibration at any point of the used structure. Important parameters such as resonance frequencies and damping ratio will be obtained from experimental apparatus and will be used to correct and validate the model. An aluminium bar suspended from the ceiling to simulate a free-free beam will be used. The goal with the boundary condition is minimize the amount of damping introduced to the structure by the fixturing. Two treated configurations will be tested. To verify the approaches developed, the dynamic characteristics of different sandwich panels with a frequency dependent viscoelastic core have been determined and analysed. Approaches developed present universal tools and give the possibility to model and analyse viscoelastic composite structures by the finite element method using the same viscoelastic damping model in the free vibration, frequency and time domain analyses. This is very important to obtain the dynamic characteristics by different methods and to compare them, since very often it is difficult to realise exactly the conditions of experiment in the numerical model. This technique gives the possibility to preserve an exact mathematical formulation for the viscoelastic frequency dependent damping model and to calculate structures with high damping. Material data in this case are taken from the frequency domain that is why the data from experiments are used directly in the finite element analysis after curve fitting procedure. Dynamic characteristics of viscoelastic composite structures are evaluated by the energy method, the method of complex eigenvalues and using the resonant peaks of the frequency response function, and the steady state vibrations. It is necessary to note that dynamic characteristics obtained by the complex eigenvalues method are located always between the corresponding dynamic characteristics obtained by the energy method and frequency response analysis. The method of complex eigenvalues, frequency and transient response analyses give the possibility to preserve the frequency dependence of viscoelastic materials and to calculate structures with high damping. In the same time the energy method gives the possibility to preserve the frequency dependence only for the storage moduli and can be used only in the case of structures with slight damping. The frequency response analysis takes a considerable computing time to determine dynamic characteristics, since the dynamic stiffness matrix must be recalculated, decomposed and stored at each frequency step. On this reason for structures modelled by a great number of degrees of freedom and in the case of a great number of desired dynamic characteristics to be calculated, it is more efficient to use the results of the free vibration analysis. The frequency response analysis may be successfully applied in the case, when it is necessary to determine a small number of desired dynamic characteristics, or when the eigenfrequency of the undamped structure is already known and only it recalculation and determination of the corresponding loss factor for the damped structure is necessary. Numerical and experimental results demonstrate a validity of the present implementation.

B: Validation on a non-symmetrical sandwich panels with a frequency and temperature dependent viscoelastic core

The damping properties are generally characterized, by two modal quantities, the loss factor (amortization) and the absorbed frequency. In the case of sandwich constructions, the numerical determination of these quantities induces two kinds of problems: the first one is linked to the model itself, which must be able to take into account shear stress in the central layer and the second problem is connected to the stiffness matrix that is complex and dependent of the frequency and the temperature. This implies the resolution of a non-linear eigenvalue problem. Numerical simulation of these structures requires, firstly an adequate kinematic model to obtain reasonable computational cost, and secondly a proper account of the shear stress in the core. To verify the approaches developed, the dynamic characteristics of different sandwich panels with a frequency dependent viscoelastic core have been determined and analysed. Non-symmetrical three layers sandwich beam manufactured by EADS is considered for the validation purposes. For this purpose, we developed and implemented a three-node shell finite element with 8 dofs able to model non-linear material non-linearities and we used a generalized Maxwell model to characterize the viscoelastic core (ISD112). The numerical results have been compared, considering various confirmations for the core, to those experimentally obtained by EADS.

OBJ. 3: ADAPTIVE COMPOSITE MODELLING

This work package attempts to develop a general analytical and numerical (FE) framework to model: (i) Composite structures with piezoelectric sensors and actuators. (ii) Thermal and pyroelectric effects in piezoelectric composites. (iii) Piezoelectric shunted damping. All the developed concepts and founding will be validated analytically and numerically as well as experimentally. A quite comprehensive coupled piezoelectric models for beam, plate and shell geometries have been developed. The modelling has hierarchic capabilities in the sense that its accuracy can be increased by augmenting computational efforts. In particular the following cases have been considered: classical model based on known theories for laminates, such as CLT (Classical Laminated Theories) and FSDT (First order Shear Deformation Theory); Layer-wise (LW) models that have independent variables in each layer and that describe zig-zag (ZZ) fields for the displacement; classical methods with only displacement variables (which are based on Principle of Virtual Displacements, PVD) and advanced methods based on Reissner Mixed Variational Theorem (RMVT) fulfilling interlaminar continuity of transverse (shear and normal) stresses as well as thermal and electrical fields.

Modelling composites with piezoelectric sensors/actuators

The Unified Formulation (UF) by Carrera (POLITO) has been considered for electrical voltage and the coupled electro-mechanical problem has been formulated in both PVD and RMVT framework. Particular care has been taken in this last case to get 'variationally consistent' constitutive equations of the layers to be used in the mixed environments. Solution and assessment have been provided for both plates and shells geometries. Finite elements have been developed for flat geometries. Numerical solution has been considered for various problems in both dynamic and static cases. Some benchmarks have been proposed for shells. As main conclusion it has been found that the use of layer-wise models could be mandatory to correctly predict mechanical and electrical field in piezoelectric 'smart structures. A comprehensive coupled piezoelectric models for plate and shell geometries has also been developed. The model has hierarchic capabilities in the sense that accuracy can be increased by augmenting computational efforts.

Mixed layer-wise finite element model for adaptive plates

A mixed layer-wise finite element model for static and free-vibration analysis of piezoelectric laminated plate structures was developed. A modified Reissner mixed variational principle was used to formulate the finite element model. The mixed functional was formulated using transverse stresses, displacement components and electrical potential as primary variables. This model, in contrast with the standard layerwise displacement finite element model, fulfils the continuity of all primary variables across the interface between adjacent layers. The in-plane stress components and the electric displacements were evaluated in the post-computation through the piezolaminate constitutive equations. The predictions of the primary variables and the efficiency of the model, mainly with reference to the interlaminar stresses have been compared with alternative three-dimensional solutions. The present solutions have been found to be in good agreement with the benchmark solutions for static and modal analysis problems.

Mixed plate finite element model based on Least-Squares formulation for the static analysis of laminated composite plates

A mixed finite element formulation for the static and free vibration analysis analysis of laminated composite plate has been developed. The formulation is based on least-squares variational principles, which is an alternate approach to the mixed weak form finite element models. The least-squares-based finite element model is developed using laminated first-order shear deformation theory, with the generalized displacements and the stress resultants as independent variables. The plate equilibrium equations are used in their first-order form to allow the use of C0 Lagrange interpolation functions in the finite element model. Moreover, high-order interpolation and full integration are used to construct the discrete least-squares-based finite element model, which results in a symmetric positive-definite system of algebraic equations. The predictive capability of the proposed mixed plate finite elements is demonstrated by numerical examples of the static and free vibration analysis of rectangular laminated composite plates, with various boundary conditions and side-to-thickness ratios. The quadratic eigen value problem for free vibrations was successfully solved. Particularly, the high-order mixed plate elements based on this formulation are shown to be insensitive to shear-locking.

Finite element models based on high order displacement fields for the analysis of laminated composite plate/shell type structures with integrated piezoelectric sensors and actuators

Quadrangular nine-node Lagrangian and flat three-node triangular finite element models based on higher order displacement fields have been developed, for the static, dynamic and buckling analysis of plate/shell type composite laminated structures with integrated piezoelectric sensors and actuators. The higher order displacement fields allow taking into account transverse shear stresses, and are suitable for the analysis of highly anisotropic structures ranging from high to low length-to-thickness ratios, leading to better results in stresses and vibration analysis when compared to classical Kirchhoff and first order shear deformation based models.

Conical and Cylindrical shell finite elements models based on high order displacement field and 3D solids for adaptive laminated structures with piezoelectric actuator/sensors

A conical shell finite element model, which has the possibility of having embedded piezoelectric actuators and/or sensors patches, has been developed. A mixed laminated theory was used, which combines an equivalent single layer higher order shear deformation approach for the mechanical behavior with a layer-wise representation in the thickness direction to describe the distribution of the electric potential in each one of the piezoelectric layers. The electrical potential function is represented through a linear variation across the thickness with two electric potential nodes for each piezoelectric layer. An axisymmetric semi-analytical laminated shell cylindrical model based on 3D formulation was also developed where the displacement field , electrical potential and loading was expanded by Fourier series considering symmetric and anti-symmetric terms.

Modelling thermo-piezoelectric composites with piezoelectric sensors-actuators

Development and implementation of computationally efficient finite elements (FE) of thermo-piezo-elastic new models for the analysis of smart structures has been addressed in that task. Accurate hierarchical formulations based on classical variational statements (Principle of Virtual Displacements, PVD) and advanced partial-mixed variational principles

(Reissner Mixed Variational Theorem, RMVT) have been proposed. The method has been successfully extended to thermal problems. The following main cases have been investigated:

- Layer-wise models that have independent variables in each layer have been used to describe zig-zag fields for the displacement, electric potential, normal stresses, normal potential and temperature Temperature has been considered as an external variables. The coupling temperature-mechanic field is neglected in this case.
- Temperature has been considered as an additional unknown and the coupling temperature-mechanic field is fully described.

Piezoceramic shunted damping concepts

The problem of increasing the damping capabilities of shunted piezoelectric elements by using negative-capacitance (semi-active) concepts has been considered. The study has shown that using a negative capacitance was equivalent to raising the coupling factor of the piezoelectric material, which in turns, increases the damping when the piezo is shunted. Numerical as well as experimental investigations are underway in order to show the efficiency of the proposed technique. The piezoceramic shunted damping (PSD) concepts that use resistive (R) and resonant (RL) extension (transverse) and shear mode piezoelectric responses has been explored. It is worthy to mention that, in contrary to the extension shunted damping (ESD), the shear shunted damping (SSD) is explored here for the first time. This made the exploration of the concept very difficult. For this reason, the ESD has been studied both theoretically and experimentally. Both ESD and SSD were modelled using the impedance approach that provides single mode evaluation of the expected performance from a relative quasi static position transfer function (PTF). The latter is used to get the amplitude reduction or added damping (via root locus analysis) of the electronic shunt.

A comparison of different shunted damping concepts on a laboratory truss structure

Resistive, inductive, negative capacitance has been achieved. The performance of the different techniques has been assessed both numerically and experimentally and compared to fully active solutions (Integral Force Feedback). A large effort has been made in the implementation of negative capacitance due to the possible unstable behaviour of this semi-active system and different solutions have been proposed in order to stabilize the system.

Advanced partial mixed variational formulations that enhance modelling thermo-piezoelectric multilayer composites have been derived.

The proposed statements are theoretically able to fulfil the flux field continuities at the layered composite interfaces in a natural way, provided that the right approximations are used. For this, a thermo-piezoelectric mixed variational theorem has been presented and discussed with regard to its usefulness in practice and in the light of the implementation trials of its uncoupled version, and the learned lessons from experimental analyses of the target smart composite structures

Piezoceramic shunted damping (PSD) concepts that use resistive and resonant extension (transverse) and shear mode piezoelectric responses were explored numerically, experimentally and analytically. It is worthy to mention that, in contrary to the extension shunted damping (ESD), the shear shunted damping (SSD) is explored here for the first time. Both ESD and SSD were modelled using the impedance approach that provides single mode evaluation of the expected performance from a relative quasi-static position transfer function. The latter is used to get the amplitude reduction or added damping (via root locus analysis) of the electronic shunt. It was shown that, for both concepts, the most important performance parameter is the so-called effective electromechanical coupling coefficient (EMCC). The latter is found to depend on the material EMCC and the modal strain energy (MSE) fraction in the piezoceramic patches bonded on (ESD) or embedded in (SSD) the host structure.

Critical evaluation and optimization of effective electromechanical coupling coefficients (EMCC) of piezoelectric adaptive structures. For this purpose, first, the piezoelectric beam FE used previously with the impedance approach for the analysis of the proposed extension and shear PSD concepts was upgraded so that the effective EMCC can now be post-processed from modal analyses under short-circuited (SC) and open-circuit (OC) piezoelectric patches with equipotential (EP) condition constraints on electrodes surfaces. Then, parametric analyses were conducted on the tested cantilever long/thin beam with small extension patches in order to assess the EP condition and charge cancellation effects. Finally, genetic algorithm optimisation has been conducted for the effective shear EMCC assessment.

Simulation of the proposed validating experiments for long/thin cantilever beams with small piezoceramic patches using 3D FE analysis by ABAQUS and ANSYS commercial softwares. Experimental serial and parallel electrical connections were simulated, respectively, by considering opposite and same poled patches, while the poling directions were modelled by introducing local coordinate systems or changing the sign of the piezoelectric coupling matrix. Besides, the clamp was updated from measured SC frequencies using springs with adjustable stiffness and the transverse blocked dielectric constant was updated using the measured individual electric capacities. The EP constraint was found to have a decoupling effect and electromechanical updating was necessary to get good model/test correlation.

2D FE analyses were also made for the same experiments using ANSYS under plane strains and stresses conditions. They showed that plane stresses 2D results are closer to the 3D FE ones, while the plane strains 2D ones were found to be sensitive to the width patch direction. Correcting the latter approach EMCC results with the patch-to-beam thickness ratio led to acceptable ones.

A piezoelectric discrete-layer beam FE was implemented and validated analytically and with the proposed validating experiments for long/thin cantilever beams with small piezoceramic patches. It enhances the electrical behaviour model by introducing a quadratic bubble function in the electric potential through-the-thickness approximation. The introduced Higher-Order Potential (HOP) degree of freedom, condensed at the ply level, lead to a passive stiffening effect similar to the higher-order induced potential concept introduced in above FE; the physical EP electrode effect, often neglected in the piezoelectric FE literature, was implemented after the electrodes FE assembly. Conducted parametric analyses have shown that the EP influence on the modal effective EMCC is more important than that of HOP one.

The new PSD concept performance evaluation and assessment experiment was simulated using ANSYS 3D FE according to the same realistic procedure used for the previous experimentation/simulation campaign. Besides the reference method, that uses SC and OC smart structure frequencies, the modal effective EMCC was evaluated in two additional ways; i.e., using either SC smart and baseline structures frequencies or using natural frequencies of the equipped beam modelled with purely elastic FE even for the patches, but with SC and OC properties for the latter. This approach is proposed here for the first time; compared to the reference approach, it led to acceptable results, while the former classical one led to unacceptable ones.

2D FE analyses were also made for the second campaign experiments using ANSYS under plane strains and stresses conditions. They confirmed that plane stresses 2D results are closer to the 3D FE ones than plane strains 2D ones which results need to be corrected with the patch-to-beam thickness ratio.

A piezoelectric discrete-layer plate FE was implemented and validated numerically with ANSYS 3D FE analyses and with the second and last campaign experiments. It extends the previous beam discrete layer beam FE. Both FEs are especially devoted to the EMCC evaluation, which is a capital parameter for the PSD design and performance predictive evaluation.

Models & Concepts Validation

Application and validation of the above advanced models and associated FE for various problems, and plates/shells due to mechanical or/and thermal loads by means of piezoelectric sensors and actuators.

OBJ. 4: DEVELOPMENT OF NON-LINEAR CONTROLLERS

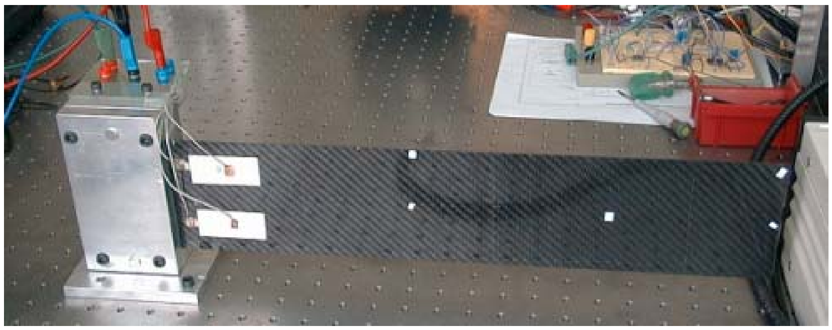
Non-linear control strategies based on fuzzy logics have been investigated and tested on a simple system. Investigations have been made in the design of a collocated Positive Position Feedback (PPF) controller in order to damp the first mode shape of a composite plate equipped with piezoelectric patches. Modeling tools developed in (MFC actuators, sensors) have proved very useful for the design of such a controller. Parametric and sensitivity studies have been performed in the past (Deliverable D8), showing which actuator-sensor pair should be used for a robust control strategy. Here, an approach based on *pseudo-collocated* pairs is studied, in order to improve the performance of the controller by careful design of the sensors and actuators placement and arrangement.In addition, experiments have been performed by EADS-IW in order to characterize the in-plane piezoelectric properties of the piezocomposite (MFC) actuators used in the boom example. Full field measurements have been carried out using an image correlation technique.The second contribution is related to task 4.4 (concept validations). An experimental implementation of *pseudo-collocated* control strategies has been carried out on a composite boom equipped with piezocomposite (MFC) actuators and sensors. A good correlation is found between the models and the experiments.

PPF controller for the damping of the first mode of a composite plate (ULB)

Staring from the developed methods for the implementation of controllers in a Matlab based environment and from a finite element model of a structure, the finite element model is first reduced using a Craig-Bampton technique. The model is then further reduced and translated into a state-space model which can be integrated in the Simulink environment. The Matlab/Simulink environment is suitable for the implementation of control routines. The strategy is summarized in Figure bellow

Strategy for the implementation of controllers in Matlab starting from a full finite element model

The structure is modeled using shell composite elements with an additional electric degree of freedom for the piezoelectric layer.



Composite plate with piezoelectric patches

Actuator characterization

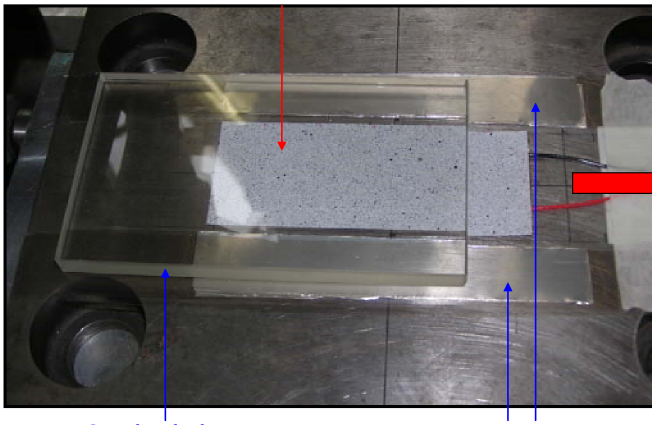
Active vibration control is carried out through the use of vibration actuators placed on the structure.

Experiment description: image correlation

In order to get a complete picture of the actuator behavior, it is interesting to measure the whole in-plane displacement field. This is not possible using regular strain gauges, which would in addition need to be chosen very carefully in order to disturb as little as possible the strains induced by the actuator.

The selected experimental method was **image correlation**. From a set of still pictures of the actuator surface under several voltage levels, it is possible using mathematical correlation to derive the complete displacement field, and, if needed, other useful data (strain in particular).

The challenge with this particular experiment is to measure small displacements, and to avoid spurious movements of the actuator during the experiment. During the first experiments indeed, it was observed that the actuator had a spurious buckling movement which prevented a correct evaluation of in-plane displacement and strains. The following experimental setup was finally selected:



The optical glass leaves enough space for the actuator to move in response to the

Non-linear controller using fuzzy logics

We want to emphasise in this document the primary property of fuzzy logic in control, which is to mimic human control, give an interpretable controller and can be effortlessly designed even by a layman. This work is not intended to be an innovative or an amazing new method for control vibration. Its aim is to show how much is easily to construct and to understand a controller with fuzzy logic. Obviously the performance of such controller will be demonstrated on a control vibration task.

OBJ. 5: OPTIMISATION OF THE LOCATIONS AND SIZES OF THE ACTUATORS AND SENSORS

Development of A finite element model has been developed for the analysis of sandwich laminated plates with a viscoelastic core and laminated anisotropic face layers.

The finite element model is formulated using a mixed layerwise approach, by considering a higher order shear deformation theory (HSDT) to represent the displacement field of the viscoelastic core and a first order shear deformation theory (FSDT) for the displacement field of the adjacent laminated anisotropic face layers. The complex modulus approach is used for describing the viscoelastic material behaviour, and the dynamic problem is solved in the frequency domain, using viscoelastic frequency dependent material data for the core. Optimization of passive damping is conducted by maximizing modal loss factors, using as design variables the viscoelastic core thickness and the constraining elastic layers ply thicknesses and orientation angles. The optimization problem is solved using the Feasible Directions Interior Point Algorithm and applications to a sandwich beam and sandwich plate are presented.

Optimization of Sandwich Structures Using a Genetic Algorithm and the Commercial Code ABAQUS

A multi objective genetic algorithm has been developed to optimize adaptive structures. The code may be linked to several structural analysis codes and may be used in different types of structures and objective functions. This genetic algorithm was linked with the finite element commercial program ABAQUS to maximize damping and minimize weight in beam and plate configurations.

Optimisation of sensor-actuator patch locations in a composite plate for maximum modal loss factor factors

Optimal location of co-located piezoelectric sensor-actuator patches in a composite plate for maximum modal loss factors is envisaged. The mixed layerwise hybrid sandwich plate finite element model used is described in detail in CASSEM Report D8.The objective is to determine the location of a given number of sensor and actuator pairs, in order to maximize modal loss factors of hybrid sandwich plate structures. We formulate an unconstrained minimization discrete problem, where the design variables are element numbers in the finite element mesh where sensor-actuator pairs are to be applied. The number of design variables is chosen to be equal to the number of available sensor-actuator pairs for the sandwich structure. If contiguous elements have patches, we consider that they are independent and individually co-located. Modal loss factors are obtained from the solution of the associated non-linear eigenvalue system. A Genetic Algorithm with binary encoding is used to solve the problem. The algorithm initializes a random sample of individuals with different parameters to be optimized using evolution via survival of the fittest. The selection scheme used is tournament selection with a shuffling technique for choosing random pairs for mating. The micro-GA option has been used, with uniform crossover and elitism.

Refined Models for the Optimal Design of Adaptive Structures using simulated annealing

This work deals with refined finite element models based on higher order displacement fields applied to the mechanical and electrical behavior of laminated composite plate structures with embedded and/or surface bonded piezoelectric actuators and sensors. Simulated annealing, a stochastic global optimization technique is implemented to find the optimal location of piezoelectric actuators in order to maximize its efficiency. The same technique is also used to solve optimization problems of piezolaminated plate structures where the discrete design variables are the ply orientation angles of orthotropic layers. The implemented scheme helps to recover from the premature convergence to a local optimum, without the need of reinitiating the optimal design process, as it is the case of the gradient-based methods with continuous design variables. To show the performance of the proposed optimization methods, two illustrative and simple examples are presented and discussed.

Modelling and Optimization of Laminated Adaptive Shells of Revolution

In this work two shell finite element models are presented for the structural analysis of composite laminated piezoelectric shells. One is an axisymmetric conical frustum with two nodal rings and the other is a conic shell panel with eight nodes. Both models are based in a mixed laminated theory that combines a higher order shear deformation theory for the mechanical displacement field with a layerwise representation with linear functions for the electric potential through each piezoelectric layer. In order to obtain the optimal design sensitivities analysis and optimization techniques based in the non linear mathematical programming are used. The design objectives can be the minimization of the deformed structure or the maximization of the natural fundamental frequency and the design variables are the electric potential difference applied to the actuators or the ply thicknesses among others.

Efficient tools have been developed for order to assess the impact of parameter changes on the controller robustness.

The basic principle is to start from a full finite element model. This model is reduced in the finite element code using the standard Craig-Bampton reduction technique. The so-reduced model is imported in Matlab and transformed into a state-space model. Using the simulink/control toolbox environment of Matlab, different types of controllers can be added to the structure, time-domain simulation can be run, and performance can be assessed.

Development of suitable methods to investigate the parametric sensitivity of dynamically loaded structures with passive and/or active devices and optimization of the size, location and type of actuators and sensors.

More significant and comprehensive information can be found in the deliverable D8 and in the articles and presentations that are listed in the dissemination chapters of the last and the present report. The various teams involved in this task have carried out supplementary relevant contributions. Some details on the additional conducted investigation are listed below. A tool has been developed in order to assess the impact of different parameters on the performance of control strategies. The approach is fully automatic, and allows to assess the robustness of the control strategies adopted. This has been illustrated on an example of a composite boom with MFC actuators and sensors. A study of the sensitivity of the transfer functions between the actuators and sensor with respect to their position has been carried out, resulting in the choice of one pair which was shown to be little sensitive to that parameter. Then, the impact of material parameter uncertainties of the MFCs has been performed, showing which parameters need to be identified properly in order to predict accurately the efficiency of the controller.

Parameter sensitivities analyses for control

The same tools as the ones developed in task 4.1 and 4.2 have been used in order to assess the impact of parameter changes on the controller robustness. An example has been shown for the composite boom described earlier.

Optimal Dynamic Control of Laminated Adaptive Structures using a Higher Order Model and a Genetic Algorithm

This work deals with a finite element formulation based on the third order shear deformation theory, for active control of thin plate laminated structures with integrated piezoelectric layers, acting as sensors and actuators. The control is initialized through a previous optimization of the core of the laminated structure, in order to minimize the vibration amplitude. Also the optimization of the patches position is performed to maximize the piezoelectric actuator efficiency. The genetic algorithm is used for these purposes. The finite element model is a single layer triangular plate/shell element with 24 degrees of freedom for the generalized displacements, and one electrical potential degree of freedom for each piezoelectric element layer, which can be surface bonded or embedded on the laminate. To achieve a mechanism of active control of the structure dynamic response, a feedback control algorithm is used, coupling the sensor and active piezoelectric layers. To calculate the dynamic response of the laminated structures the Newmark method is considered. The model is applied in the solution of an illustrative case and the results are presented and discussed.

Optimal Design in Vibration Control of Adaptive Structures using a Simulated Annealing Algorithm

Advanced reinforced composite structures incorporating piezoelectric sensors and actuators are increasingly becoming important due to the development of smart structures. These structures offer potential benefits in a wide range of engineering applications such as vibration and noise suppression, shape control and precision positioning. In this work, a finite element formulation is presented, based on the classical laminated plate theory for laminated structures with integrated piezoelectric layers or patches, acting as sensors and actuators. The finite element model is a single layer triangular nonconforming plate/shell element with 18 degrees of freedom for the generalized displacements, and one additional electrical potential degree of freedom for each surface bonded piezoelectric element layer or patch. The control is initialized through a previous optimization of the core of the laminated structure, in order to minimize the vibration amplitude and maximize the first natural frequency. Also the optimization of the patches position is performed to maximize the piezoelectric actuators efficiency. The simulated annealing algorithm is used for these purposes. To achieve a mechanism of active control of the structure dynamic response, a feedback control algorithm is used, coupling the sensor and active piezoelectric layers or patches, and to calculate the dynamic response of the laminated structures the Newmark method is considered. The model is applied in the optimization of an illustrative adaptive laminated plate case. The influence of the position and number of piezoelectric patches, as well as the control gain, are investigated and the results are presented and discussed.

Active damping optimization in adaptive and hybrid sandwich plate structures

This part of the work describes the optimization of hybrid damping treatments in sandwich plates. The finite element model that was previously developed for passive damping is extended to include the piezoelectric effect for sensor and actuator layers and proportional feedback and velocity feedback control laws are implemented to account for co-located active control. The finite element model is formulated using a mixed layerwise approach, by considering a higher order shear deformation theory (HSDT) to represent the displacement field of the viscoelastic core and a first order shear deformation theory (FSDT) for the displacement field of the adjacent laminated anisotropic and piezoelectric sensors and actuator face layers. The complex modulus approach is used for describing the viscoelastic material behaviour, and the dynamic problem is solved in the frequency domain, using viscoelastic frequency dependent material data for the core, and the implemented control laws. Optimization of the location of co-located sensor-actuator pairs is conducted as to maximize modal loss factors. The formulated optimization problem is solved using an implementation of a Genetic Algorithm an application to a cantilever hybrid sandwich beam is presented.

Efficient tools have been developed for model reduction.

The basic principle is to start from a full finite element model. This model is reduced in the finite element code using the standard Craig-Bampton reduction technique. The so-reduced model is imported in Matlab and transformed into a state-space model. Using the simulink/control toolbox environment of Matlab, different types of controllers can be added to the structure, time-domain simulation can be run, and performance can be assessed.

The code used for the developments is SAMCEF which allows to model the piezoelectric actuators and sensors as plies in a shell laminate formulation. Examples have been run for a cylindrical 1.5m boom equipped with Macro Fibre Composite types of actuators and sensors. The fully automated translation of the finite element model to the state-space model with the controller allows to study the impact of different parameters on the performance of the controller and the damping added to the structure. This has been illustrated by different studies on the composite boom.

Validation for passive, active and hybrid vibration control:

A comparison is established between two completely independent optimization procedures for passive damping. Results show that, even for different numerical models and different optimization methods, final designs are coincident. Optimization of passive damping in sandwich plates was described previously, using a specifically developed finite element numerical model, along with a gradient based optimization technique. The same task was conducted separately, but using a commercial finite element code, along with a specifically developed genetic algorithm.

OBJ. 6 CONCEPTS EXPERIMENTAL EVALUATION AND ASSESSMENT

At the end of the project, the technologies developed will be validated on representative structures testing. It should be emphasised that the prime objective of this task is the validation of vibration control technology of industrial representative structures. The task is labour intensive as it involves a number of steps such as component selection, test definition, rig design, test structure instrumentation, test assembly, test start up and execution, test follow up, results documentation. It is envisaged that in this workpackage structural panels will be tested.

Achievements made

Viscoelastic properties identification: The inverse technique developed in this project has been successfully applied to characterise viscoelastic material properties of damping polymer ISD-112 used as a core material in the sandwich panels with aluminium faces. In the identification procedure the results of physical experiment have been used instead of the results of numerical experiment. The structural dynamic characteristics, eigenfrequencies and corresponding loss factors, have been obtained from the vibration tests made in EADS by an impulse technique. The material properties identified have been verified comparing the results of physical experiments and results obtained numerically by the complex eigenvalues method.

Shunted damping (experiments): A new experiment, for the PSD concept evaluation and assessment, was designed and tested for a thick/short beam with large piezoceramics, two times longer than the small ones and having the same width as the beam. This aims to confirm the decoupling effect of the EP constraint and the plane strains 2D FE results, and to get higher coupling than that obtained with above experiments in order to confirm the modal effective EMCC as a PSD performance indicator. The patches were mounted in opposite poling since this configuration is less common in literature experimental analyses (details are given in Deliverable D9).

Shunted damping (modelling)

The new PSD concept performance evaluation and assessment experiment was simulated using ANSYS 3D FE according to the same realistic procedure as detailed above for the first experiment/simulation campaign. Besides the above reference method, that uses SC and OC smart structure frequencies, the modal effective EMCC was evaluated in two additional ways; i.e., using either SC smart and baseline structures frequencies or using natural frequencies of the equipped beam modelled with purely elastic FE even for the patches, but with SC and OC properties for the latter. This approach is proposed here for the first time; Compared to the reference approach, it led to acceptable results, while the former classical one led to unacceptable results (details are given in Deliverable D9).

Dynamic analysis of multilayered composite plates

This contribution has been of some help to make appropriate choice for the planned experimental tests. Higher order effects in various frequencies range (lower modes and higher modes) have been investigated on layered plates which datas have been provided by EADS. Activities have been scheduled for the prolongation of the project concerning the evaluation of localized effects in the vicinity of piezoelectric patches. A FEM model will give to EADS important infos for the planned experiments.

Fuzzy logic control

An experimental validation of the developed non-linear fuzzy logic controller has been performed on a cantilever composite beam equipped with two collocated pairs of piezoelectric patches. Different test were performed on the considered structure to evaluate the performance of the proposed fuzzy logic controller. Two collocated sensors are used for absorbed vibration beam. In the framework of this application, the first sensor is used to measure the error and the other one is used to measure the error rate. The experimental results of controlled and non controlled system with two types of excitation fixed frequency and pulse force excitation are reported in D9.

Non linear vibration

The analytical and numerical procedure developed for the non-linear vibration analysis of sandwich beams have been firstly extended to analyse vibration of viscoelastic sandwich plate. Thus, a new finite formulation and a numerical procedure are established and implemented in the commercial software ABAQUS for nonlinear vibration analysis of three layers viscoelastic sandwich plates. The numerical procedure couples the balance harmonic and Galerkin's techniques. In the second, analytical and numerical studies have been developed for the composite structures proposed by EADS. These analytical and numerical developments permitted to find the experimental conditions for the nonlinear vibrations analysis. In collaboration with EADS, several experimental tests have been done where the specimen is a beam. A good agreement between experimental, analytical and numerical results has been obtained. The details of these analytical, numerical models and experimentation will be reported in the deliverable D9.

Experiments have been conducted for the SSD concept validation on composite beams with embedded shear piezoceramic patches; they showed negligible

performance. This unexpected result has been confirmed by analytical closed-form solution and ABAQUS FE analysis for a simply supported beam with Aluminium faces and shear piezoceramic core. It is well known that the material EMCC of the piezoelectric shear-mode response is intrinsically higher than that of the ESD, while the shear MSE fraction is much lower (of second order effect) than the bending (due to patches extensions) one for low frequency vibrations. The higher values of the former are compensated by the lower ones of the latter for the SSD and the reverse behaviour happens for the ESD. This is the main reason of the above negligible performance of the SSD. It is then recommended to use the SSD mainly for shear dominant deformation behaviour.

Experiments have been also conducted for the ESD concept validation on a long/thin Aluminium beam with symmetrically bonded small piezoceramic patches electrically connected either in series or in parallel. These tests have validated in particular the use of the EMCC as a PSD performance indicator.

A new experiment, for the PSD concept evaluation and assessment, was designed and tested for a thick/short beam with large piezoceramics, two times longer than the small ones used earlier and having the same width as the beam. This aims to confirm the decoupling effect of the EP constraint and the plane strains 2D FE results, and to get higher coupling than that obtained with above experiments in order to confirm the modal effective EMCC as a PSD performance indicator. The patches were mounted in opposite poling since this configuration is less common in literature experimental analyses.

An aeronautic-type composite plate without and with central large piezoceramic patch was experimented and simulated using ANSYS 3D FE. It is used for the performance evaluation of the PSD concept. The base plate experiments were used for the validation of the FE model that served to optimise the position of the central patch and to design the adaptive configuration. The latter has been then analysed experimentally under SC and OC electric conditions in the frequency range of [0-1000] Hz. The optimum central position of the single large piezoceramic patch was reached after modal strain energy (MSE) plots analysis of the plate first 4 modes. The obtained frequencies were post-treated in order to get the modal effective EMCCs and expected added PSD. The highest added PSD was found as high as 3%, under resonant shunting, for the 4th mode

II- DISSEMINATION AND USE

Dissemination of knowledge necessary to operate within CASSEM is partly realized through the participation and organization of symposium and conferences. An important aspect of dissemination and spreading of knowledge are partners scientific visits and longer the exchange of students and scientists. CASSEM partners have participated to many dedicated conferences and many CASSEM partners have been (invited) speakers in these events and students were encouraged to attend these events. In this section we provide an overview of dissemination activities (major publications, workshop, conferences, website), carried out over the full project duration. The main dissemination activities are based on: Web site, Conferences and workshops, Publicity Material, - Exhibitions, …, Publications. For each of them we illustrate the obtained results:

III-1 DISSEMINATION

Website

The CASSEM website (www.cassem.lu) has been created to act as a permanent dissemination channel, updated with reports on progress and results emerging from CASSEM. It also provides a mechanism for interested parties to contact the appropriate CASSEM partners in order to find out more about the project or its results, and to give to interested parties the possibility to subscribe to the CASSEM-Interest emailing list. CASSEM is also: 4 Organized conferences and courses, 15 Ph D students, 15 senior scientists, 15 visits and exchange between partners (from 1 day to 5 months), 100 publications in international dedicated conferences, 50 publications in Journals and a presentation on a national TV.

Conference Proceedings:

Dates	Type	Title
July 2006	International symposium	Design, Modeling and Experiments on Adaptive Structures and and Smart Systems. **DeMEASS (Design, Modeling and Experiments on Adaptive Structures and and Smart Systems) (demeass.cassem.lu)** international Symposium will be held from 10-12 July 2006 at Bardonecchia city (Turin, Italy).
June 2006.	Workshop	Organisation of a WFF Workshop “Structural Health Monitoring” together with a CASSEM workshop Wuerzburg,
May 2006	Workshop	Organisation of a WFF Workshop on Functional Polymers), to be held at Wuerzburg, Germany
2006	Local network	Organisation of a local network WFF, Wuerzburg Research Alliance for Functional Materials.
June, 2006.	Mini-Symposia	Smart Materials and Structures” and on “Advanced Composites
Sept. 2006	Special Session	The Eight International Conferences on Computational Structures Technology. Mini-symposium on Smart Materials and Structures

Workshop Proceedings:

- **Benjeddou**, Belouettar. On the evaluation and application of piezoelectric adaptive structures modal properties. Innovation in Computational Structures Technology,

B.H.V. Topping, G. Montero and R. Montenegro, (Editors), Saxe-Coburg Publications, Stirlingshire, Scotland, Chapter 14, 2006.

Publicity materials

In the events attended were distributed about 200 brochures and some printed articles offering a general view of the project. The poster has been shown in different conferences.

PhD Thesis

- Hakim Boudaoud Analytical and numerical modeling of adaptive structures Collaboration between CRP Henri Tudor and Univ. of Metz. Defended in 2007
- Heng Hu: Advanced modeling of sandwich composites. CRP Henri Tudor and Univ. of Metz. Defended in October 2006
- Rechdaoui My S.Dynamique des structures adaptatives. Collaboration between CRP Henri Tudor and Univ. of Metz and University of Tangier in Morocco. Defended in 2008
- Abdoun Farah : (Female) Modélisation des vibrations linéaires et non linéaires des structures sandwichs viscoélastiques Collaboration between Univ. of Metz and University of Tangier in Morocco. Defended in 2008
- RANGER-VIEILLARD Anne-Julie. (Female) Amortissement des vibrations de poutres par des piézo-céramiques shuntés , ISMEP defended in 2007.
- S. Ghorbel (Female) Modélisation de structures composites thermopiézoélectriques amorties. ….
- A Robaldo, Classical and Mixed Finite Elements for Thermoelectromechanical analysis of multilayered anisotropic plate E. Carrera
- S Brischetto Structural model for the analysis of multifield problems related to smart structure. Will be defended in Mars 2009
- Filipa Moleiro (Female) Computational model for the analysis of adaptive plates by by mixed least-squares approachC.M.Mota Soares, defended in ,,
- Eduards Skukis Vibration control of lightweight composite structures. RTU, Defended
- Sandris Rucevskis Methods for damage detection and identification in composite materials. Defended
- Aurélio Lima Araújo Identification of Mechanical and piezoelectric properties IST, defended
- Isidoro Falcao Pinto Correia Computational Models for the Analysis of Adaptive Shells C.M.Mota Soares, defended
- Henrique Santos Borralho Computational Models for the Analysis of Adaptive Axisymmetric Shells, C.M.Mota Soares, defended
- Bruno de Marneffe Shunt technologies for vibration damping, ULB defended in 2008

Articles in Journals

1. A. Deraemaker, H. Nasser, A. Benjeddou, A. Preumont. Mixing rules for Macro Fiber Composites (MFC), Journal of Intelligent Material Systems and Structures, submitted (2008).
2. G. Chevallier, S. Ghorbel, A. Benjeddou. A benchmark for free-vibration and effective coupling of thick smart structures. Smart Materials and Structures, in press (2008).
3. M. A. Al-Ajmi, A. Benjeddou. Damage indication in smart structures using modal effective electromechanical coupling coefficients. Smart Mater. Struct., 2008, 17(3), 035023 (15pp).
4. M. A. Trindade, A. Benjeddou. Effective electromechanical coupling coefficients of piezoelectric adaptive structures: critical evaluation and optimization. Mechanics of Advanced Materials and Structures, in press (2008).
5. M. A. Trindade, A. Benjeddou. Refined sandwich model for the vibration of beams with embedded shear piezoelectric actuators and sensors. Computers and Structures. 2008, 86 (9), 859-869.
6. Benjeddou. Shear-mode piezoceramic advanced materials and structures: a state of the art. Mechanics of Advanced Materials and Structures, 2007, 14 (4): 263-275. 5.
7. H. Santos, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, "A Semi-Analytical Finite Element Model for the Analysis of Cylindrical Shells Made of Functionally Graded Materials", Composite Structures, Elsevier, UK (submitted).
8. A.L. Araújo, C.M. Mota Soares, J. Herskovits, P. Pedersen, "Visco-Piezo-Elastic Parameters Estimation in Laminated Structures", Journal of Inverse Problems in Science and Engineering, Taylor and Francis, USA, (to appear).
9. A.L. Araújo, C.M. Mota Soares, J. Herskovits, P. Pedersen, "Estimation of Piezoelectric and Viscoelastic Properties in Laminated Structures", Composite Structures, Elsevier, UK ,(submitted).
10. H. Santos, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy ", A Semi-Analytical Finite Element Model for the Analysis of Cylindrical Shells Made of Functionally Graded Materials Under Thermal Shock", Composite Structures(to appear).
11. H. Santos, C. M. Mota Soares, C.A. Mota Soares, J.N. Reddy .A Finite Element Model for the Analysis of 3D Axisymmetric Laminated Shells with Piezoelectric Sensors and Actuators: Bending and Free Vibrations, Computers & Structures, doi:10.1016/j.compstruc.2007.04.013.
12. F. Moleiro, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy." Mixed-Least Squares Finite Element Model for Static Analysis of Laminated Composite Plates", Computers & Structures, doi:10.1016/j.compstruc.2007.04.012
13. J.S. Moita, P.G. Martins, C.M. Mota Soares, C.A. Mota Soares." Optimal Dynamic Control of Laminated Adaptive Structures Using a Higher Order Model and a Genetic Algorithm", Computers & Structures, Vol. 86, pp. 198-206, 2008.
14. B. de Marneffe, A. Preumont. Vibration control via enhancement of piezelectric stack actuation: theory and experiment. Submitted to Smart Materials and Structures.
15. Preumont, B. de Marneffe, G. Rodrigues, H. Nasser and A. Deraemaeker, Dynamics and control in precision mechanics, Revue Européenne de Mechanique Numérique, to be published

16. Barkanov E., Chate A., Ručevskis S. and Skukis E. (2007): Characterisation of Composite Material Properties by an Inverse Technique. Key Engineering Materials 345-346, 1319-1322.
17. Skukis E., Rucevskis S., Barkanov E. and Chate A. (2007): Characterisation of Advanced Composite Material Properties by Inverse Technique. In: RTU Zinātniskie Raksti (Scientific Proceedings of Riga Technical University), Ser. 1, Vol. 14, 22-38.
18. CARRERA E., BOSCOLO M. (2007). Classical amd Mixed elements for static and dynamic analysis of piezolectric plates. INTERNATIONAL JOURNAL FOR NUMERICAL METHODS IN ENGINEERING. vol. 70, pp. 253-291 ISSN: 0029-5981.
19. CARRERA E., BOSCOLO M. ROBALDO A. (2007). Hierarchic multilayered plate elements for coupled multifiled problems of piezoelectric adaptive structures: formulation and numerical assessment. ARCHIVES OF COMPUTATIONAL METHODS IN ENGINEERING. vol. 14, pp. 383-430 ISSN: 1134-3060
20. CARRERA E., BRISCHETTO S. (2008). Analysis of Thickness locking in classical, refined and mixed multilayered plate theories. COMPOSITE STRUCTURES. ISSN: 0263-8223., available on line
21. CARRERA E., BRISCHETTO S. (2007). Reissner Mixed Theorem Applied to Static Analysis of Piezoelectric Shells. JOURNAL OF INTELLIGENT MATERIAL SYSTEMS AND STRUCTURES. vol. 18, pp. 1083-1107 ISSN: 1045-389X
22. CARRERA E., BRISCHETTO S. (2007). Piezoelectric Shells Theories with "a priori" Continuous Transverse Electro-Mechanical Variables. JOURNAL OF MECHANICS OF MATERIALS AND STRUCTURES. vol. 2, pp. 377-398
23. CARRERA E., BRISCHETTO S, NALI P. (2008). Variational Statments and Computational Models for Multifiled Problems and Multilayered Structures. MECHANICS OF COMPOSITE MATERIALS AND STRUCTURE. ISSN: 1075-9417. in press.
24. CARRERA E., A GIUNTA G, BRISCHETTO S. (2007). Hierichical Closed Form Solutions for plates bended by localized transverse loadings,. JOURNAL OF ZHEJIANG UNIVERSITY. SCIENCE B. vol. 8, pp. 1026-1037 ISSN: 1673-1581.
25. ROBALDO A, CARRERA E. (2007). Mixed Finite Elements for Thermoelastic analysis of multilayered anisotropic plates. JOURNAL OF THERMAL STRESSES. vol. 30, pp. 1-30 ISSN: 0149-5739.
26. CARRERA E., BRISCHETTO S. (2008). A numerical assessment of classical and refined theories for the analysis of bending and vibration in sandwich plate. APPLIED MECHANICS REVIEWS. ISSN: 0003-6900. in press. A shell element for active-passive vibration control of composite structures with piezoelectric and viscoelastic layers.
27. H. Boudaoud, S. Belouettar, E. Daya, A. Benjeddou, Analytical evaluation of the effective EMCC of sandwich beams with a shear–mode piezoceramic core. 2nd World Congress on Design & Modelling of Mechanical Systems, 19-21, March 2007 Monastir, Tunisia
28. H. Boudaoud, S. Belouettar, E. Daya, A Numerical method for nonlinear complex modes of active-passive vibration damped sandwich structures DeMEASS II : Second International Symposium on Design, Modelling and Experiments of Adaptive Structures and Smart System. October 14-17, 2007, in Bad Herrenalb, Germany
29. H. Boudaoud, S. Belouettar, E. Daya, Non-linear vibration analysis of five layers adaptive sandwich composites using Assymptotic Numerical method. 12th Asia-

Pacific Vibration Conference (APVC2007). August 6-9, 2007, Hokkaido University, Sapporo, Japan, 2007

30. H. Boudaoud, S. Belouettar, E.M Daya and M. Potier-Ferry, Element coque pour l'analyse modale de sandwich 5 couches à amortissement hybride actif/passif. 8ème Colloque National en Calcul des Structures, 21-25 Mai 2007, Giens (Var), France.
31. M.S. Rechdaoui , L. Azrar , S. Belouettar, E.M. Daya et M. Potier-Ferry : Contrôle actif des vibrations non linéaires des pouters sandwich piézoélectriques par la méthode des échelles multiples. 8ème Congrès de Mecanique, 17-20 Avril 2007, El Jadida, Maroc.
32. H. Boudaoud, S. Belouettar, E. Daya, A. Benjeddou, Analytical evaluation of the effective EMCC of sandwich beams with a shear–mode piezoceramic core. 2nd World Congress on Design & Modelling of Mechanical Systems, 19-21, March 2007 Monastir, Tunisia
33. Heng Hu, Salim Belouettar, El Mostafa Daya and Michel Potier-Ferry, Linear and nonlinear analysis in sandwich structures by using Arlequin approach. 7th World Congress on Computational Mechanics, July 16-22, 2006 Los Angeles, Etats-Unis.
34. Duigou L., Boudaoud H., Daya E.M., Belouettar S., Potier-Ferry M. nalytical and numerical modal properties of sandwich viscoelastic and piezoelectric beams submitted to active control. DeMEASS I, Bardonechia 10-12 July 2006.
35. Boudaoud H., Daya E.M., Belouettar S., and Potier-Ferry M. A new shell element for hybrid vibration control of sandwich structures. 8th Conference on Computational Structures Technology, CST. Las Palmas 2006
36. Boudaoud H., Belouettar S., Daya E.M., and Potier-Ferry M. Technique numérique pour l'analyse modale modale de sandwich 5 couches à amortissement hybride actif/passif. 15ème conférence sur les Vibrations Chocs et Bruits, Lyon 2006.
37. Benjeddou, S. Belouettar. On the evaluation and application of piezoelectric adaptive structures modal properties. In Eighth International Conference on Computational Structures Technology, Las Palmas de Gran Canaria (Spain), September 12-15, 2006
38. H. Hu, S. Belouettar, E.M.Daya and M.Potier-Ferry, "Comparison of numerical models for viscoelastically damped sandwich beams", International Conference on Computational Methodes, 15/12/2005-17/12/2005, Singapore
39. H. Hu, S. Belouettar, E.M.Daya and M.Potier-Ferry, Gesellschaft für Angewandte Mathematik und Mechanik e.V. (GAMM 2005), New modelling approach for damped mutilayed composites. Luxembourg; 28/03/2005-01/04/2005, Luxembourg
40. H. Hu, S.Belouettar, E.M.Daya and M.Potier-Ferry, 7ème Colloque National en Calcul des structures, Évaluation des divers modèles analytiques pour les structures sandwich 17/05/2005-20/05/2005, Giens, France
41. S. Belouettar, H. HU, E.M.Daya, Fifth Euromech non linear dynamics conference, Viscoelastically damped sandwich beams, August 7-12 2005, Eindhoven, Nedherlands
42. S. Belouettar, H.Hu, E.M.Daya and M.Potier-Ferry, Comparison of classical models for viscoelastically damped sandwich beams, 7th International Conference on Sandwich Structures 29-31 August 2005, Aalborg, Danmark
43. H. Hu, S. Belouettar, E.M.Daya and M.Potier-Ferry, 17ème Congrès Français de Mécanique (CFR2005), Comparaison des divers modèles pour les structures sandwich, 29/08/2005-02/09/2005 ; Université de Technologie de Troyes, France

44. Heng.Hu, Salim.Belouettar, El.Mostafa.Daya and Michel.Potier-Ferry, An Arlequin multiscale FEM for sandwich structures; International Conference on Mechanical Engineering and Mechanics; October 26-28, 2005, Nanjing, China
45. H. Nasser, S. Belouettar, A. Deraemaeker, Homogenization Properties Analysis for Macro Fiber Composite Using Interdigitated Electrodes. International Conference on Multifunctional Materials and Structures. 28 July to 31 July 2008 in Hong Kong. China.
46. H. Boudaoud, L. Duigou, E.M. Daya, S. Belouettar and M. Potier-Ferry. Journal of Intelligent Material Systems and Structures. Revised Damping analysis of beams submitted to passive and active control.
47. L. Azrar, E.M. Daya, and M. Potier-Ferry. Forced harmonic response of viscoelastic structures by an asymptotic numerical method. F. Abdoun, Computers and Structures. Revised
48. N. Jacques, E.M. Daya and M. Potier-Ferry Nonlinear vibration of viscoelastic sandwich beams by the harmonic balance and finite element methods. . Journal of Sound and vibration, Submitted

International Conferences

1. DeMEASS I, 2006. M. Analytical and numerical modal properties of sandwich viscoelastic and piezoelectric beams submitted to active control. H. Boudaoud, S. Belouettar and E. Daya
2. Computational Structures Technology, 2006. Gran Canaria, Spain, A new shell element for hybrid vibration control of sandwich structures, Boudaoud H., Belouettar and Daya E.M
3. Vibrations Chocs et Bruits, 2006, Lyon France 2006, numerical algorithm for modal analysis of hybridly active/passive damped 5 layers sandwich. Boudaoud H., Belouettar and Daya E.M.
4. 7th World Congress on Computational Mechanics, July 16-22, 2006 Los Angeles, USA. Linear and nonlinear analysis in sandwich structures by using Arlequin approach, Heng HU, S. Belouettar and E.M. Daya. Acknowledged but not paid by CASSEM
5. Duigou L., Boudaoud H., Daya E.M., Belouettar S., and Potier-Ferry M. Analytical and numerical modal properties of sandwich viscoelastic and piezoelectric beams submitted to active control. Number 1. DeMEASS, 2006.
6. Boudaoud H., Daya E.M., Belouettar S., and Potier-Ferry M. A new shell element for hybrid vibration control of sandwich structures. Number 8. Conference on Computational Structures Technology, 2006. Spain
7. Jacques N., Daya E.M, and Potier-Ferry M. Forced Non-Linear Vibration of Damped SandwicH Beams by the Harmonic Balance - Finite Element Method. Number 8. Conference on Computational Structures Technology, 2006. Spain
8. Boudaoud H., Belouettar S., Daya E.M., and Potier-Ferry M. Technique numérique pour l'analyse modale modale de sandwich 5 couches à amortissement hybride actif/passif. numerical algorithm for modal analysis of hybridly active/passive damped 5 layers sandwich. Number 15. Vibrations Chocs et Bruits, 2006.

9. H.Hu, S.Belouettar, E.M.Daya and M.Potier-Ferry, Linear and nonlinear analysis in sandwich structures by using Arlequin approach. 7th World Congress on Computational Mechanics, July 16-22, 2006 Los Angeles, Etats-Unis.
10. F. Abdoun, L. Azrar, EM Daya et M. Potier-Ferry "Dynamic harmonic response of viscoelastic sandwich plates by an asymptotic numerical method. Conference on Differential Equations and Applications, Marrakech, Morocco, June 15-20 2006.
11. Boudaoud H, Benjeddou A., Daya E.M., Belouettar S., Analytical evaluation of the effective EMCC of sandwich beams with a shear-mode piezoceramic core" CMSM 2007. Monastir.
12. Boudaoud H., Belouettar S., Daya E.M Elément coque pour l'analyse modale de sandwich 5 couches à amortissement hybride actif /passif ». Colloque de Calcul de structures, Giens2007.
13. Boudaoud H., Belouettar S., Daya E.M, M. Potier-Ferry A computational model based on homotopy and asymptotic numerical techniques for non-linear vibration analysis of five layers adaptive sandwich composites. DeMEASS II 2007, Bad Herrenalb, Germany.
14. F. Abdoun, L. Azrar, E.M. Daya, and M. Potier-Ferry, "Modélisation des vibrations linéaires des plaques sandwich viscoélastiques', 8ème Congrès de Mécanique, du 17 au 20 Avril 2007, El Jadida- Maroc.
15. EL Hassan Boutyour, EL Mostafa Daya, Michel Potier-Ferry : Vibrations non linéaires des structures sandwich viscoélastique. 8ème Congrès de Mécanique, du 17 au 20 Avril 2007, El Jadida- Maroc.
16. F. Abdoun, L. Azrar, E.M. Daya, and M. Potier-Ferry, " An Asymptotic Numerical Method for forced harmonic response of viscoelastic sandwich plates ', International Days of Applied Mathematics-MATH07-, du 11 au 12 Mai 2007, Tanger- Maroc
17. F. Abdoun, L. Azrar, E.M. Daya, and M. Potier-Ferry, " Modélisation des vibrations forcées des structures sandwich viscoélastiques', Congrès Français de Mécanique, Grenoble, 27 au 31 Août 2007.
18. N. Jacques, E.M. Daya, and M. Potier-Ferry, " Vibrations non linéaires de poutres sandwich viscoélastiques », Congrès Français de Mécanique, Grenoble, 27 au 31 Août 2007.
19. S. Ghorbel, G. Chevallier, A. Benjeddou. Détermination expérimentale et numérique du coefficient de couplage électromécanique généralisé de structures piézoélectriques. In XVI Symposium on Vibrations, Shocks & Noise, Lyon (France), 10-12 juin 2008.
20. M. Al-Ajmi, A. Benjeddou. Damage indication in smart structures using modal effective electromechanical coupling coefficients. 4th European Workshop on Structural Health Monitoring, Krakow (Poland), 2–4 July 2008.
21. A. Benjeddou. Piezoelectricity experimentation, modelling and simulation: common practices and realistic considerations. In CIMTEC International Conference on Smart Materials, Structures and Systems, Acireale (Sicily Italy), 8–13 June 2008 (Invited Lecture).
22. Benjeddou A, J.-A. Ranger. Vibration damping using shunted shear-mode piezoceramics. In First International Symposium on Design, Modelling and Experiments of Adaptive Structures and Smart Systems, Bardonecchia (Italy), 10–12 July 2006.
23. Benjeddou, S. Belouettar. On the evaluation and application of piezoelectric adaptive structures modal properties. In Eighth International Conference on Computational

Structures Technology, Las Palmas de Gran Canaria (Spain), September 12-15, 2006. (Special invited lecture).

24. Benjeddou A., J. Ranger. Vibration damping using resonant shunted shear-mode piezoceramics. In Proc. III European Conference on Computational Mechanics: Solids, Structures and Coupled Problems in Engineering, C.A. Mota Soares et al. (Eds.), Lisbon, June 5-9, 2006.
25. Chevallier G, Ranger JA, Benjeddou A, Sebbah H. Passive vibration damping using resistively shunted piezoceramics: an experimental performance evaluation. In Proc. 2nd Int. Congr. Des. Modell. Mech. Syst., Hammamet (Tunisia), March 19-21, 2007.
26. Trindade MA, Benjeddou A. On the evaluation of effective electromechanical coupling coefficients for structures with piezoelectric elements. In W. Ostachowicz, J. Holnicki-Szulc, C. A. Mota Soares (Eds.), Proc. III ECCOMAS Thematic Conf. Smart Struct. Mater., Gdansk (Poland), July 9-11, 2007. 4.
27. A.L.Araújo, C.M. Mota Soares, C.M. Mota Soares, J.Herskovits. "Visco-Piezo-Elastic Parameter Estimation in Laminated Plate Structures, Inverse Problems, Design and Optimization Symposium ", Miami, Florida, USA, April 16-18, 2007.
28. A.L. Araújo, C. M. Mota Soares, J.Herskovits, P.Pedersen, "Estimation of Properties in Piezolaminated Stuctures", Proc. (CD-ROM), Sixth International on Composite and Science Technology, Durban , South Africa, 22-24 January 2007.
29. J.S. Moita, C.M. Mota Soares, C.A. Mota Soares, "Analyses of Magneto Electro_Elastic Plates Using a Higher Order Finite Element Model", Proc. (CD-ROM), Sixth International Conference on Composite and Science Technology, Durban, South Africa, 22-24 January 2007.
30. H.Santos, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, "A Semi.Analytical Finite Element Model for the Analysis of Cylindrical Shells Made of Functionally Graded Materials", Proc.(CD-ROM) Sixth International Conference on Composite Science and Technology, Durban, South Africa , 22-24 January 2007.
31. L. Araújo, C.M. Mota Soares, J. Herskovits, "Parameter Estimation in Active Laminated Structures with Adhesive Interfaces", Proc. First International Symposium on Design Modelling and Experiments of Adaptive Structures and Smart Systems (DeMEASS I) , July 10- 12, Turin, Italy, 2006
32. C.M. Mota Soares, I.F. Pinto Correia, C.A. Mota Soares, J.Herskovits, "Modelling and Design of Adaptive Shells Using Higher Order Models ", Proceedings 14 th Annual International Conference on Composites/ Nano Engineering,(CD-ROM) Ed D. Hui, University of New Orleans , USA, 2006.
33. I.F.Pinto Correia, C.M. Mota Soares, C.A. Mota Soares, J.Herskovits, "Developments in Modelling and Optimal Design of Laminated Cylindrical and Conical Shells with Integrated Sensors and Actuators", Proceedings(CD-ROM) Workshop Variational Formulation in Mechanics: Theory and Applications, Ed. by E. Taroco, E.A. de Sousa Neto, A.A. Novotny, L.N.C.C., Petrópolis, Brazil, 3-5 September 2006.
34. J. M. Simões Moita, J. Herskovits, C.M. Mota Soares, C.A. Mota Soares , " Design of Laminated Stuctures Using Piezoelectric Materials, Proceedings CILAMCE, Brazil 2006.
35. F. Moleiro ,C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, "A Mixed Finite Element Model Based on Least-Squares Formulation for Static Analysis of Laminated Composite Plates", Proceedings of the Eight International Conference on Computational Structures Technology (CD-ROM), Ed. B.H.V. Topping, G. Montero

and R. Montenegro, Civil-Comp Press, Stirlingshire, Scotland, Paper 106, pp 1-18 , 2006.

36. H. Santos, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, " A Three Dimensional Semi- Analytical Finite Element Model for the Analysis of Piezoelectric Shells of Revolution", Proceedings of the Eight International Conference on Computational Structures Technology(CD-ROM), Ed. B.H.V. Topping, G. Montero and R. Montenegro, Civil-Comp Press , Stirlingshire, Scotland, Paper 105, pp 1-18, 2006.
37. H.Santos, C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, "A Finite Element Model for the Analysis of 3D Axisymmetric Laminated Shells with Embedded Piezoelectric Sensors and Actuators ", Proc. III European Conference on Computational Mechanics: Solids , Structures and Coupled Problems in Engineering, C.A. Mota Soares et al.(eds.), Lisbon, Portugal, 5-8 June 2006.
38. J.S. Moita, C.M. Mota Soares, C.A. Mota Soares, "Higher Order Model for Analysis of Magneto-Electro-Elastic Plates", Proc. III European Conference on Computational Mechanics: Solids, Structures and Coupled Problems in Engineering, C.A. Mota Soares et al (eds.), Lisbon, Portugal, 5-8 June 2006.
39. F. Moleiro , C.M. Mota Soares, C.A. Mota Soares, J.N. Reddy, "Mixed Least –Squares Finite Element Model for the Static Analysis of Laminated Composite Plates, Proc. III Conference on Computational Mechanics: Solids, Structures and Coupled Problems in Engineering, C.A. Mota Soares et al. (eds.) Lisbon, Portugal, 5-8 June, 2006.
40. C.M. Mota Soares, H.Santos, C.A.Mota Soares, J.N. Reddy,"A Semi-Analytical Finite Element Model for the Analysis of Piezoelectric Cylindrical Shells", Proc. Smart Structures and Materials 2006: Modeling , Signal Processing, and Control, Ed. By D.K. Lindner, Proc. of SPIE Vol. 6166, 61661 Q-1-8,2006 (doi:10.1117/12.655605). ULB
41. Cristóvão M. Mota Soares , A.L. Araújo, J. Herskovits "Identification of Elastic and Piezoelectric Properties of Active Structures", Invited Lecture on The US Air Force Sponsored Specialist International Workshop on Structural Assessment of Composite Structures, Department of Mechanical and Aerospace Engineering, University of Monash, Melbourne , Australia, 22 November 2007.
42. H.Santos, C.M. Mota Soares, C.A. Mota Soares,J.N. Reddy, "Development of a Semi-Analytical Model for the Analysis of Axisymmetric Shells Made of Functionally Graded Materials", (CD-ROM) Proceedings of the 15th Annual International Conference on Composites/Nano Engineering, July 15-21, 2007, Haikou, Hainan, China, Ed. By D. Hui, University of New Orleans, USA.
43. J. M. Simões Moita, C.M. Mota Soares, J. Herskovits, "Shape Control of Laminated Panels Using Piezoelectric Actuators ", "CMNE/CILAMCE (CD-ROM), Ed. A.R. Rodriguez-Ferran, J. Oliver,P.R.M. Lyra, J.L.D Alves, APMTAC, FEUP, 13-15 June, 2007.
44. M.A.R. Loja. C.M. Mota Soares, J.I. Barbosa, C.A. Mota Soares, " Localização Óptima de Piezoactuadores em Estruturas Laminadas ", Proc. CMNE/CILAMCE, (CD-ROM), Ed. A.R. Rodriguez-Ferran, J. Oliver, P.R.M.Lyra, J.L.D. Alves, APMTAC, FEUP, 13-15, June, 2007.
45. A.L. Araújo, C.M. Mota Soares, J. Herskovits, "Identification of Visco-Elastic Properties in Active Structures ", CMNE/CILAMCE, (CD-ROM), Ed. A.R. Rodriguez-Ferran, J. Oliver, P.R.M. Lyra, J.L.D. Alves, APMTAC, FEUP, 13-15, June, 2007.

46. F. Moleiro, C.M. Mota Soares, C.A. Mota Soares, J. N. Reddy, "New Developments on Mixed Least-Squares Finite Element Models for Laminated Composite plates: Static and Free Vibration Analysis, Invited Communication on The Mini-Symposium on Computational Solid Mechanics: Recent Advances, 9th US National Congress on Computational Mechanics, University of California, Berkley, July 22-26,2007.
47. A.L. Araujo, C.M. Mota Soares, C.M. Mota Soares, J. Herskovits. "Visco-Piezo-Elastic Parameter Estimation in Laminated Plate Structures, Inverse Problems, Design and Optimization Symposium ", Miami, Florida, USA, April 16-18, 2007.

48. de Marneffe, A. Deraemaeker, M. Horodinca, I. Romanescu, and A. Preumont. Active and passive damping of structures with piezoelectric transducers. In Proc. 7th Nat Congress on Theoretical and Applied Mechanics, Mons, Belgium, May 2006.
49. Deraemaeker and A. Preumont. Piezoelectric structures : modeling for control. In Proc. Ninth International conference on Recent Advances in Structural Dynamics, Southampton, UK, July 2006.
50. Deraemaeker and A. Preumont. Modelling of an active composite boom with piezoelectric composite actuators and sensors. In Proc. DeMEASS, Bardonecchia, Italy, July 2006. Extended abstract.
51. de Marneffe, M. Horodinca, A. Preumont, A new semi-active method for the damping of a piezoelectric structure. In Proc. ISMA 2006, Leuven, Belgium, Sept 2006.
52. Deraemaeker, S. Benelechi, A. Benjeddou, A. Preumont. Analytical and numerical computation of homogenized properties of MFCS: Application to a composite boom with MFC actuators and sensors. In W. Ostachowicz, J. Holnicki-Szulc, C. A. Mota Soares (Eds.), Proc. III ECCOMAS Thematic Conf. Smart Struct. Mater., Gdansk (Poland), July 9-11, 2007.
53. Deraemaeker, H. Nasser, A. Preumont, Some issues in the modelling and design of MFC actuators and sensors, In Proc ISPA 2007, Dresden, Sept 2007
54. Preumont, B. de Marneffe, G. Rodrigues, H. Nasser and A. Deraemaeker, "Dynamique et contrôle en mécanique de précision", 8ème colloque national en calcul des structures, Giens,France, May 21-25 2007, Keynote lecture
55. Preumont, B. de Marneffe, G. Rodrigues, H. Nasser and A. Deraemaeker, Issues in modelling, isolation and shape control of precision structures for space and other applications, II ECCOMAS thematic conference on Smart Structures and Materials, Gdansk, Poland, July 2007, oral presentation, keynote lecture.
56. Barkanov E., Chate A. and Skukis E. Identification of Nonlinear Material Properties from Vibration Tests. In: Proceedings of the International Conference on Nonlinear Analysis and Engineering Mechanics Today, Hochiminh City, Vietnam, 2006, 12 P., on CD-ROM.
57. E. Barkanov, A. Chate and E. Skukis. Identification of Nonlinear Material Properties from Vibration Tests. In: Book of Abstracts of the International Conference on Nonlinear Analysis and Engineering Mechanics Today (NA-EMT2006), Hochiminh City, Vietnam, 11-14 December 2006, 10.
58. E. Skukis, S. Rucevskis and E. Barkanov. Characterisation of Advanced Composite Material Properties by Inverse Technique. In: Programme and Proceedings of the Baltic Polymer Symposium (BPS 2006), Birini Castle, Latvia, 20-22 September 2006, 85.

59. Barkanov E., Chate A., Ručevskis S. and Skukis E. (2007): Characterisation of Composite Material Properties by an Inverse Technique. In: Proceedings of the 10th International Conference on Mechanical Behavior of Materials, Eds. S. W. Nam, Y. W. Chang, S. B. Lee and N. J. Kim. (Trans Tech Publications Ltd, Switzerland), 4 P., ISBN 13: 978-0-87849-440-8 CD-ROM.
60. E. Barkanov, A. Chate, S. Ručevskis and E. Skukis (2007): Characterisation of Composite Material Properties by an Inverse Technique. Book of Abstracts of the 10th International Conference on Mechanical Behavior of Materials (ICM10), Busan, Korea, 27-30 May 2007, 155.
61. E. Barkanov, A. Chate, E. Skukis and M. Wesolowski (2007): Characterisation of Viscoelastic Layers in Sandwich Panels by an Inverse Technique. Book of Abstracts of the 14th International Conference on Composite Structures (ICCS-14), Melbourne, Australia, 19-21 November 2007, R14.
62. CARRERA E., FAGIANO C. (2006). Hierarchical Finite Element Analysis og Multilayered Plates subjected to mechanical, thermal and mechanical loadings. ESDA 2006, 8th Biennal Conference on Engineering Systems Design and Analysis. 4-7 luglio 2006.
63. CARRERA E., GIUNTA G, BRISCHETTO S. (2006). Evaluation of failure parameters in laminates by means of Hierarchical Plate Mode. In: Conference on Damage in Composite Materials,. Conference on Damage in Composite Materials, CDCM06. 18-19 September. (pp. 1-10). published in ww.ndt.net. STUTTGART: www.ndt.net (GERMANY).
64. ROBALDO A, CARRERA E. (2007). Hierarchic finite elements based on unified formulation for the static analysis of shear actuated multilayered piezoelectric plates. 15th AIAA/ASME/AHS Adaptive Structures Conference. 23-26 April 2007.
65. CARRERA E., G. GIUNTA. (2007). Hierarchical plate models and their application to compute failure parameters for composites materials plates. Theplac 2007 conference. 28th-29th 2007.
66. CARRERA E., NALI P. (2008). A comprehensive FE model for the analysis of Multilayered Structures Subjected to Multifiled Loadings. 49th AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics, and Materials Conference. Schaumburg, IL (USA). 7 - 10 Apr 2008. accepeted.
67. G.M. KULIKOV, CARRERA E., S.V. PLOTNIKOVA, S. BRISCHETTO. (2008). Geometrically Exact Assumed Stress-Strain Four-Node Element Based on the 9-Parameter Shell Model. ICCES'08: International Conference on Computational & Experimental Engineering and Sciences. Honululu, Hawai. 17-22 marzo 2008. Accepted.
68. CARRERA E., BRISCHETTO S. (2007). Extension of Unified Formulation to Bending Analysis of Functionally Graded Plates. DeMEASS II,. Bad Herrenalb, Germany. October 14-17
69. CARRERA E., BRISCHETTO S. (2007). Classical and mixed theories for bending analysis of Functionally Graded Materials shells. APCOM'07 in conjunction with EPMESC XI. Kyoto (Japan). Kioto, Japan. 3-6 December
70. CARRERA E., BRISCHETTO S, ROBALDO A. (2007). Comparison of various kinematics for the analysis of Functionally Graduated Materials. ACME 2007. Glasgow (UK). 2-3 April 2007

71. CARRERA E., BRISCHETTO, NALI. (2007). Variational Statements for Vibration Analysis of Multifields Problems and Multilayered Structures. ISVCS IV. Squaw Valley, California, USA. July 24-28.
72. G. GIUNTA, S. BRISCHETTO, CARRERA E. (2007). Hierarchical Models for Laminated Composites Shells under Localized Bending Loading. APCOM'07 Eleventh International Conference on Enhancement and Promotion. Kioto, Japan. Decembre 3-6.
73. DeMEASS II, conference on Design, Modelling and Experiments of Adaptive Structures and Smart Systems in Bad HerrenalbOctober 15th to 17th 2007WBI contribution: Engelhardt, Friedmann, Henkel: Safe Pipes, Vibration Control by Active Vibration Absorbers, AVA.
74. Friedmann, Henkel, Schmaus, "Lastfallspezifische Materialdaten für die FEM Simulation von Polymerbauteilen" (~ Load case-specific Material Data for the FEM-Simulation of Polymer Components), contribution to the WS "Funktionspolymere" (~ Functional Polymers),m held at Wuerzburg, May 17/18, 2006
75. Pankoke, "CMS im Maschinenbau am Beispiel einer aktiven Ratterunterdrückung für eine HSC-Spindel" (~ CMS in the Area of Mechanical Engineering, using the Example of an active Chatter Control for an HSC-Spindle), WBI contribution to this Workshop "Structural Health Monitoring", held at Wuerzburg June 29, 2006
76. Participation in BMBF-Forum für Nachhaltigkeit (~ Forum for Sustainability held by Federal Ministry of Education and Research), held at Berlin October 24, 2006
77. WBI contribution to this Forum: Friedmann, "Forschungsintensives KMU als Vermittler zwischen Wissenschaft und wirtschaftlicher Anwendung" (~ Research-oriented SME as Negotiator between Science and commercial Use)
78. DeMEASS I, Bardonecchia, July 10 to 12. 2006-11-08, lecture on "Active Vibration Reduction in fast rotating Machinery. Industrial Requirements and first Applications

Seminars

- Benjeddou. «Couplage électromécanique effectif modal dans les structures piézo-électriques vibrantes : caractérisation expérimentale & évaluations numériques ». 2h00 at LEMTA of l'ESSTIN, Vandoeuvre-Les-Nancy (France), 30th Jan., 2008.
- Benjeddou. "Piezoelectric adaptive structures: modelling, simulation and experimentation". An advanced seminar (1h30) organised by CETIM, Cité des Sciences, Paris-la-Villette, 6th Dec. 2007

Another additional dissemination action

- Short Course on Active Vibration Control, Lyon, France, April 24-26, 2007
- CISM course: Semi-active vibration suppression: the best from active and passive technologies, Udine, Italy, Oct 1-5

Organized events and meetings

- Participation in Hannover Fair 2007, announcement of abilities of materials parameter identification (see attached photo "Hannover Messe 2007"
- Use of the new method and dissemination of the results in a European project I-SSB, The INTEGRATED SAFE & SMART BUILT CONCEPT, Proposal no.: IP 026661-2

- Organisation of a local network WFF Würzburger Forschungsverbund Funktionswerkstoffe (~ Wuerzburg Research Alliance for Functional Materials)
- 5th Cassem Steering Committee Meeting, May 3rd to 4th 2007, in Würzburg · Workshop "Non-destructive parameter identification", August 27th to 30th 2007 in Würzburg · 6th Cassem Steering Committee Meeting, September 23th to 25th 2007 in Riga
- 7th Cassem Steering Committee Meeting, January 28th to 29th 2007 in Metz
- Internal Promotion: Material data identification of plaster boards with the method developed by IST within the Cassem project.
- PoliTo and CRPHT, in the framework of CASSEM, have promoted an International Symposium on Smart Systems, named DeMEASS II. A special Issue of Mechanics of Advanced Materials and Structures, will collect selected paper of DeMEASS II. The success of the first two editions has motivated DeMEASS III that will be hosted by Paris X in the coming May 2009.
- External Promotion: Organisation of a local network WFF Würzburger Forschungsverbund Funktionswerkstoffe (~ Wuerzburg Research Alliance for Functional Materials)
- Participation in Hannover Fair 2007, announcement of abilities of materials parameter identification · Use of the new method in I-SSB, a European R+D project FP6-NMP2-CT-2006-026661. First presentation in a workshop at Dübendorf/Zürich 28th November 2007
- Workshop "Non-destructive parameter identification", August 27-30, Wuerzburg. Experimental Evaluation of carbon fibre plates delivered by EADS and of carbon fibre plates with attached PZT plates
- Organisation of International Conference on Smart Materials and Adaptive Structures: Mathematical Modelling and Computation in partnership with PAI MA/05/117 (Action integrée Franco-Marocaine) and the Faculty of Sciences and Techniques of Tangier, University Abdemalek Essaadi, Tangier, Morocco
- Co-Organization of the IIIECCOMAS Thematic Conference on Smart Structures and Materials, Gdansky, Poland, 9-11 July, 2007 (Co-Chairmen: C. A. Mota Soares). http://www.imp.gda.pl/ECCOMAS2007/index.html
- Session on Composite Structures : CMNE/CILAMCE/2007-Métodos Numéricos e Computacionais em Engenharia, APMAC/SEMINI/ABMEC, Porto, Portugal, June 2007(Co-Organizer : C.M. Mota Soares). http://www.fe.up.pt/cmne2007

III CONCLUSION

CASSEM formal project line Knowledge acquired and lessons learn

Besides the concrete results presented in the table included in the Executive summary, we think worth mentioning the results achieved in terms of knowledge acquired and lessons learnt by the formal learning project line during the execution of this project. Without entering in too many details, in general we have acquired knowledge with respect to methodological and technological aspects of dynamic structural analysis and control.

Methodological aspects

With respect to this point, the knowledge acquired refers mainly to the aspects described below.

- Inverse techniques, consisting of the experimental set-up, numerical models and material identification procedures,
- Several aspects concerning the formulation and solution of amplitude equations for non-linear vibration
- Advanced numerical methods that have been developed and implemented in order to calculate the dynamic characteristics of viscoelastic structures as well numerical tools for computing the nonlinear forced response of sandwich beams subjected to harmonic excitations.
- On the non-linear vibration of sandwich structures with complex geometry, an approximated harmonic balance method
- Nonlinear vibrations of piezoelectric/elastic/piezoelectric sandwich beams submitted to active control are studied using proportional and derivative potential feedback controls via sensor and actuator layers.
- The Unified Formulation (UF) by Carrera that has been considered for electrical voltage and the coupled electro-mechanical problem has been formulated in both PVD and RMVT framework.
- Finite elements have been developed for flat geometries. Numerical solution has been considered for various problems in both dynamic and static cases. Some benchmarks have been proposed for shells
- Quadrangular nine-node Lagrangian and flat three-node triangular finite element models based on higher order displacement fields have been developed for the static, dynamic and buckling analysis of plate/shell type composite laminated structures with integrated piezoelectric sensors and actuators.
- A conical shell finite element model, which has the possibility of having embedded piezoelectric actuators and/or sensors patches, has been developed.
- A Reissner mixed variational theorem was used to formulate the finite element model. The mixed functional was formulated using transverse stresses, displacement components and electrical potential as primary variables and mixed plate finite element model based on Least-Squares formulation for the static analysis of laminated composite plates has been investigated.
- Analytical and closed form solution as well plate Finite Element have been developed for modelling thermo-piezoelectric composites with piezoelectric sensors-actuators and the problem of increasing the damping capabilities of shunted piezoelectric elements by using negative-capacitance (semi-active) concepts has been considered

LIST OF DELIVERABLES PRODUCED BY THE CONSORTIUM

Deliverable No	Deliverable title
D1	Full report and database of the mechanical properties of multilayered composite material, on piezoelectric and viscoelastic material parameters and on the mathematical and experimental used methods.
D2	Full report on the inverse and direct approach used for the determination of viscoelastic and piezoelectric material properties..
D3	Full report on the new theoretical and finite element models for damped composite structure, and on the analytical and numerical methods for non-linear vibration analysis and their validation.
D4	Full report on the developed numerical models for adaptive composite structures with piezoelectric sensors/actuators, on the analytical and numerical modeling of thermal and piezoelectric effects in piezoelectric composites, on Piezoceramic shunted damping modelling as well as their validation.
D5	Full documented report on the analysis method and Matlab® implemented routines for uncertainties and on developed reduced dynamic models.
D6	Control strategies and new linear, robust and adaptive controller and validated concept for vibration control.
D7	Full report on optimization problems formulations, on the developed algorithms and programs, as well as on the validation concepts.
D8	Full report on the proposed validation experiments
D9	Full report on full scale testing of real structure components with integrated vibration control technology.
D10	Full report on test articles characteristics.
D11	Full report on dissemination and innovation related activities.