Book of Abstracts

22nd International Conference on Adaptive Structures Technologies (ICAST 2011)

Corfu, Greece
October 10-12, 2011

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Foreword

Welcome to the 22nd International Conference on Adaptive Structures Technologies (ICAST 2011)!

ICAST is the longest running international conference on adaptive, intelligent and smart materials and structures, which has followed these fields from their emergence to their current rapid maturity. The conference takes place annually and the venue of the conference rotates between the Americas, Europe and Asia. By tradition, ICAST meets for three days and typically follows a single session format with integral poster sessions.

The exceptional setup of ICAST provides a unique forum for the presentation and discussion of recent advances in the highly multidisciplinary field of smart materials and structures, which encourages transfer of advanced scientific results from research to application; in ICAST 2011, a focus area of applications is on “Adaptive Wind Turbine Rotors”. Many ICAST participants are leading international scholars and scientists, who have followed the long-term evolution of this exciting field. The exclusive setting of the conference, provides the opportunity to present our works in a large and broad audience, and to have direct interactions and exchanges of scientific results and ideas with leading international scholars and specialists from all over the world. Most importantly, this unique Conference has promoted international interactions and lunched long-lasting friendships and collaborations.

We wish to thank all sponsors for their contribution to the success of the conference. We gratefully acknowledge financial support of ICAST2011 from the European Office of Aerospace Research (EOARD/AFOSR), the NSF International Institute of Multi-functional Materials for Energy Conversion (IIMEC), the Research Committee of the University of Patras, and the Institute of Chemical Engineering of the National Foundation of Research and Technology (ICE-HT/FORTH). Also, we acknowledge the technical sponsoring of the Adaptive Structures and Material Systems TC of the American Society of Mechanical Engineers (ASME) and of the Adaptive Structures TC of the American Institute of Aeronautics and Astronautics (AIAA). We express our appreciation to the Keynote Lecturers for their contribution, and to the members of the International Organizing Committee and the Local Organizing Committee for their assistance and support.

We are deeply honored to be your conference hosts this year, and delighted to welcome you to the beautiful island of Corfu, Greece. We are looking forward to contribute to the success of the conference, and with your participation to offer a productive, memorable and enjoyable event.

Dimitris A. Saravanos
Conference Chair

Costas Galiotis
Conference Co-Chair
ICAST Chronology

1st Joint U.S.A.-Japan Conference on Adaptive Structures
Maui, HI (USA) Nov. 13-15, 1990

2nd Joint Japan-U.S.A. Conference on Adaptive Structures
Nagoya (Japan) Nov. 12-14, 1991

3rd International Conference on Adaptive Structures
San Diego, CA (USA) Nov. 9-11, 1992

4th International Conference on Adaptive Structures
Cologne (Germany) Nov. 2-4, 1993

5th International Conference on Adaptive Structures
Sendai (Japan) Dec. 5-7, 1994

6th International Conference on Adaptive Structures
Key West, FL (USA) Nov. 13-15, 1995

7th Int. Conference on Adaptive Structures and Technologies
Rome (Italy) Sept. 23-25, 1996

8th Int. Conference on Adaptive Structures and Technologies
Wakayama (Japan) Oct. 29-31, 1997

9th Int. Conference on Adaptive Structures and Technologies

10th Int. Conference on Adaptive Structures and Technologies
Paris (France) Oct. 11-13, 1999

11th Int. Conference on Adaptive Structures and Technologies
Nagoya (Japan) Oct. 23-26, 2000

12th Int. Conference on Adaptive Structures and Technologies
College Park, MD (USA) Oct. 15-17, 2001

13th Int. Conference on Adaptive Structures and Technologies
Potsdam (Germany) Oct. 7-9, 2002

14th Int. Conference on Adaptive Structures and Technologies
Seoul (Korea) Oct. 7-9, 2003

15th Int. Conference on Adaptive Structures and Technologies
Bar Harbor, ME (USA) Oct. 25-27, 2004

16th Int. Conference on Adaptive Structures and Technologies
Paris (France) Oct. 10-12, 2005

17th Int. Conference on Adaptive Structures and Technologies
Taipei (Taiwan) Oct. 16-19, 2006

18th Int. Conference on Adaptive Structures and Technologies
Ottawa (Canada) Oct. 3-5, 2007

19th Int. Conference on Adaptive Structures and Technologies
Ascona (Switzerland) Oct. 6-9, 2008

20th Int. Conference on Adaptive Structures and Technologies
Hong Kong (China) Oct. 20-22, 2009

21st Int. Conference on Adaptive Structures and Technologies
State College, PA (USA) Oct. 4-6, 2010

22nd Int. Conference on Adaptive Structures and Technologies
Corfu, (Greece) Oct. 10-12, 2011
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A. Tzes  University of Patras, Dept. of Electrical Engineering
Keynote Lecture I
Application of Piezo Actuators in Aerospace
Dr. Peter Jaenker
EADS Innovation Works, Germany
Monday, October 10, 2011, 09:00-10:00

Abstract

Piezoelectric actuation is an emerging technology with an ever increasing number of successful applications in recent years. The suitability of piezoelectric actuation systems to provide high bandwidth, high forces, precise travel while requiring small integration volumes and withstanding high external steady and dynamic loads is well known. These characteristics are of specific value for the Aerospace industry.

EADS and its business units Airbus, Astrium, Cassidian, and Eurocopter have a long history of cooperation to push ahead research on new actuation systems and smart structures for aircraft and spacecraft platforms. Some of these concepts have been developed to advanced levels and tested in relevant environment and even in flight.

Based on an introduction into pertinent characteristics of piezoelectric materials, actuators, active structures, and the power electronics and power supply, this research is illustrated by means of several application examples. Target platforms considered are helicopters, aircraft, and space launchers. However, the applications described can be widely diversified towards other vehicles and even other industries.

In detail, the control of helicopter blades by hinged servo flaps or by actively bending trailing edges are presented. This increased aerodynamic control capability allowing reductions of vibration excitation and noise, emanating from the rotor blades.

A variety of system solutions is described, that have been developed and tested to address different noise phenomena: structure born noise caused by gear meshing, buzz saw noise tones generated by jet engines which occurs in aero engines at take-off conditions...

Further examples elaborated in this paper are Piezo-based vibration absorbers, which can be mounted in the helicopter fuselage to tackle the dynamic rotor loads transferred by the main gearbox to the cabin.

For launchers such as Ariane V active isolation systems are illustrated, allowing an efficient protection of the payload against high level of vibration.

Finally an outlook is given on the expected expansion of the field of application of electric energy (on air- and spacecraft) starting from electric actuation over hybrid propulsion towards fully electric aircraft and helicopters, allowing a unified electrical (energy and power) management of the entire vehicle.

Vitae

Dr. Peter Jaenker is a Senior Expert, Head of Team EPPA - Electrical Power and Actuation, In the Department IW-EP - Energy and Propulsion, at EADS Innovation Works in Munich, Germany.

Dr. Peter Jaenker graduated from the Ludwig-Maximilian-Universität in Munich, Germany, in 1992 with a doctoral degree in physics. He then joined Daimler Benz corporation as a research engineer in the domain of smart materials and structures for aerospace as well as automotive applications.

He has developed and pitched numerous technical concepts and contributed more than 100 invention disclosures. Dr. Jaenker contributed to the development of piezoelectric injector technology for Mercedes Benz passenger cars and developed piezoelectric actuation systems for active rotor systems for helicopter as well as active vibration cancelling systems.
Dr. Peter Jänker's areas of research are novel actuator systems, lightweight electrical drives, electrical power systems as well as their application to all-electric aircraft platforms.
Abstract

Since the 1990s, there has been a major growth in smart structures technology, both in individual technological constituents as well as in their applications in various disciplines. Applications include vibration and noise suppression, stability and damping augmentation, shape control, structural integrity monitoring and condition-based maintenance. Various disciplines include: space vehicles, fixed-wing aircraft, rotary-wing aircraft, civil structures, marine systems, automotive systems, robotic systems, machine tools, and medical systems. Major goals have been to enhance system performance (beyond current levels) at a low cost, increase comfort level (minimize noise and vibration) with minimum weight penalty, reduce life-cycle cost (decrease vibratory loads, perform condition-based maintenance), improve precision pointing (space telescope), improve low observable characteristics, and increase product reliability (damage detection, mitigation and repair). Development of smart materials and structures is possible through one of the three approaches. In the first approach, the new materials with smart functionality can be synthesized at the atomic and molecular level. Sometimes, this is referred to as a nano-structured material. A lot of it is hypothesized and is in an embryonic state at this time. In the second approach, actuators and sensors are attached to a conventional structure, which adaptively responds to external disturbances. The actuators and sensors normally do not constitute the load carrying structure. Even though this is a relatively mature methodology, it is not expected to be a structurally efficient scheme. In the third approach, active plies representing actuators and sensors are synthesized with non-active plies to form a laminated structure. A major drawback is that once the structure is cured, it is not possible to replace non-functional plies. Even though this approach appears attractive in terms of structural efficiency, there are issues related to the integrity of the system.

The key elements of smart structures are: actuators, sensors, power conditioning, control logics and computational processing. Conventional displacement actuators are: electro-magnetic (including voice coils), hydraulic, and servo- or stepper-motors. The principal disadvantages of conventional actuators are their weight, size and slow response time. Their advantages are their large stroke, reliability and low cost. Smart material actuators are normally compact and change their characteristics under external fields such as electric, magnetic and thermal. Typical smart material actuators are: piezoelectric, electrostrictive, magnetostrictive, shape memory alloys and ER/MR fluids. Conventional sensors are strain gages, accelerometers and potentiometers, whereas smart materials sensors can be fiber optics, piezoelectrics (ceramics and polymers) and magnetostrictives. There is a wide variation of power requirements for different actuators. Key factors for a power conditioning system are compactness including weight and size, efficiency, and cost. For an efficient adaptive system, modeling and implementation of robust feedback control strategies is important. A centralized compact and lightweight computer with sufficient memory is vital to generate input signals for actuators, perform system identification techniques with output data from sensors, and implement control feedback strategies.

The basic idea of the synthesis of smart structures appears to have been first conceptualized by Clauser in 1968. Seven years later, Clauser himself demonstrated the concept. After this work, activities in this area started increasing and grew rapidly in 1990s. The historical development of key smart materials will be discussed first, followed by their applications in various industrial disciplines. Even though the discovery of many of the smart materials has taken place during the past century, the commercial availability, cost and understanding of their behavior have been major inhibitions to their wide spread use in commercial products. The state-of-art in smart structures technology will be discussed, keeping in view potential applications.
Dr. Inderjit Chopra is the Alfred Gessow Professor in Aerospace Engineering and Director of Alfred Gessow Rotorcraft Center at the University of Maryland. He received his Sc.D. (Aero & Astro) from MIT in 1977. At MIT, he worked on dynamic analysis of wind turbines. In 1977, he joined NASA Ames/Stanford University Joint Institute of Aeronautics & Acoustics, where he worked for four and half years on the development of aeroelastic analysis and testing of advanced helicopter rotor systems in full-scale wind tunnel. In 1981, he joined the University Maryland as a faculty member and has been working on various fundamental problems related to aeromechanics of helicopters including aeroelastic stability, active vibration control, composite blades, rotor head health monitoring, aeroelastic optimization, smart structures, micro air vehicles, and comprehensive aeromechanics analyses. His direct graduate advising resulted in 42 Ph.D. and 80 M.S. degrees, and his students are now playing dominant role in rotorcraft industry, academia and federal labs. He has been the principal investigator of six major research programs: Army's "Rotary-Wing Center of Excellence" (1992-2006), Army's URI on “Smart-Structures Technology: Innovations and Applications to Rotorcraft Systems” (1992-97), Army's MURI on "Innovative Smart Technologies for Actively Controlled Jet-Smooth Rotorcraft" (1996-2001), Army’s MURI on “Micro Hovering Air Vehicles: Revolutionary Concepts and Navigational Advancements” (2004-09), Army’s CTA-MAST on “Center for Microsystem Mechanics” (2008-13), and Army/Navy/NASA’s “Vertical Lift Research Center of Excellence (VLRCOE)” (2011-16). An author of over 180 archival journal papers and over 300 conference proceedings papers, Dr. Chopra has been an associate editor of the Journal of the American Helicopter Society (1987-91), Journal of Aircraft (1987-cont.) and Journal of Intelligent Materials and Systems (1997-cont.). Also, he has been a member of the editorial advisory board of five journals, VERTICA (1987-91), Smart Materials and Structures (1994-01), SADHANA (1991-95), Journal of Aircraft (2002-cont.) and International Journal of Aerospace Engineering (2007-09). He was awarded the 1992 UM's Distinguished Research Professorship, 1995 UM's Presidential Award for Outstanding Service to the Schools, 2002 AIAA SDM Award, 2002 AHS Grover E. Bell Award, 2001 ASME Adaptive Structures and Material Systems Prize, 2002 A. J. Clark School of Engineering Faculty Outstanding Research Award, 2004 SPIE Smart Structures & Materials Lifetime Achievement Award, 2008 Indian Institute of Science Centenary Distinguished Alumni Award, 2009 AHS Alexander Klemin Award, and 2011 American Helicopter Museum & Education Center’s Achievement Award. He has been a member of the Army Science Board (1997-2002) and NASA Aeronautics and Space Engineering Board (2007-cont.). He is a Fellow of AIAA, a Fellow of AHS, a Fellow of ASME, a Fellow of National Institute of Aerospace, a Fellow of Aero Society of India and an Honorary Fellow of AHS.
Keynote Lecture III
Recent Advances in the Modeling, Analysis, and Characterization of SMA-Based Structures
Prof. Dimitris Lagoudas and Dr. Darren J. Hartl
Texas A&M University, USA
Wednesday, October 12, 2011, 8:30-9:30

Abstract

This talk provides an overview of fundamental and applied research being performed at Texas A&M regarding the use of active materials in the development of active or “smart” structures. Different research areas are introduced, including the work on shape memory alloys (SMAs), magnetic shape memory alloys (MSMAs), and shape memory polymers (SMPs). In particular, the phenomenological constitutive modeling of shape memory alloys, the numerical analysis of components composed of these materials, and the utilization of such components in the design of engineering applications are all discussed in detail. As the number and complexity of proposed SMA applications increases, engineers and designers must seek out or develop more capable predictive methods. A focused discussion on recent work regarding constitutive modeling and analysis tool development is therefore provided. An overview of conventional SMA modeling which considers only the martensitic transformation is first presented, including discussions of the mathematical model, its implementation, and example analyses. The concept of irrecoverable deformations in these alloys is then introduced. Such deformations include rate independent plastic yielding, which may occur at stress concentrations such as crack tips, and rate dependent viscoplastic creep/relaxation as observed at significantly elevated temperatures. In some materials, the processes of transformation, yield, and creep may occur simultaneously. The numerical implementation of each of these advanced models is described and example analyses relating to each are provided. The talk concludes with a discussion of SMA engineering problems at the structural and system scales. The analysis of multiple coupled physical phenomena is briefly addressed, including such concepts as heat transfer and fluid-structure interactions. Finally, current work being performed on the optimized design of SMA active structures in collaboration with The Boeing Company is discussed.

Vitae

Dr. Dimitris C. Lagoudas is the John and Bea Slattery Chair Professor of Aerospace Engineering at the Dept. of Aerospace Engineering, Texas A&M University, in College Station, Texas, also the Director Texas Institute for Intelligent Bio-Nano Materials and Structures for Aerospace Vehicles (TiiMS). Dr. Dimitris C. Lagoudas received his B.S. from the Aristotle University of Thessaloniki, Greece in 1982 and his Ph.D. from Lehigh University in Bethlehem, PA in 1986. Dr. Lagoudas arrived at Texas A&M in 1992 and currently serves as the Department Head and the inaugural recipient of the John and Bea Slattery Chair in Aerospace Engineering. As Director for the Texas Institute for Intelligent Materials and Structures (TiiMS), his research involves the design, characterization and constitutive modeling of multifunctional material systems at various length scales and considering various functionalities, including mechanical, thermal and electrical. His research team is recognized internationally, especially in the area of modeling and characterization of shape memory alloys. He has authored or co-authored about 340 scientific publications, including 140 in archival journals, several of which are now considered classic
papers in the field. The theoretical models that his research group developed have been implemented into finite element analysis software and utilized by many industrial and governmental entities (Boeing, DoD and NASA), as well as academic institutions worldwide.
Bio-Inspired Galfenol-Based Whisker-Like Flow Sensors

Michael Marana\(^1\), Suok Min Na\(^1\), Alison Flatau\(^1\)

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A prototype flow sensor inspired by the flow sensing capabilities of mammalian whiskers was designed, manufactured, and evaluated. The sensor was made using the unique combination of structural and magnetostrictive properties of the iron-gallium alloy known as Galfenol. To make the whisker sensors, a Galfenol (Fe\(_{81}\)Ga\(_{19}\) + 1.0\% NbC) ingot was hot rolled and reduced to a sheet of thickness .45 mm. Whisker-like beams were cut from the rolled sheet using wire electrical discharge machining. The Galfenol whiskers were cut to be .45 mm wide for a square cross section, with a length of 19 cm. The whiskers were annealed under hydrogen sulfide gas to develop a \(<100>\) orientation along the direction of the whisker. Whiskers were individually assembled into prototype flow sensor designs. Each whisker was cantilevered in a non-magnetic clamp. The fixed end of the whisker was attached to a giant magnetoresistance (GMR) sensor. A permanent magnet was also attached to the fixed end of the whisker to magnetically bias the whisker. The free end of the whisker was inserted into fluid flow. The fluid imparted drag on the Galfenol whisker, causing it to bend. The bending caused a net change in the whisker’s magnetization. The GMR sensor detected the resulting change in magnetic field. The GMR sensor signal was correlated to the velocity of the fluid. In addition to experimental evaluation, the prototype designs were improved using computational modeling and simulation. A bidirectionally coupled magnetoelastic model (BCMEM) was created and implemented using COMSOL Multiphysics software. The whisker prototypes were modeled using the BCMEM under quasi-static bending conditions. Results from these experiments and modeling studies along with directions for whisker sensor applications will be presented.
Recent Advances in Fluidic Flexible Matrix Composite Based Multi-Cellular and Multi-Functional Structures

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The fluidic flexible matrix composite (F²MC) is a novel adaptive structure concept developed based on observations of the fibrillar organization of plant cell walls. The F²MC cell is essentially a composite tube made of layers of helix fibers embedded in soft resin matrix, and filled with pressurized working fluid. The fibers are laid out with a prescribed angle to give the cell wall some desired anisotropic properties. This anisotropy, together with the fluid bulk modulus, makes F²MC cell multi-functional under different operation conditions: it can be an actuator or a variable stiffness element. Recent advances in F²MC based cellular structure development have branched into the following two areas.

The first area is on multi-cellular adaptive structures, in which different F²MC cells are connected through fluidic circuits. The dynamic characteristics of such structures are investigated to explore new functionalities. An analytical model is developed and analyzed, and experimental investigations are performed. In a passive operation, the dual cellular structure can be used as a vibration absorber. On the other hand, in an active operation, the dual cellular structure can be used as a resonance actuator with enhanced authority in certain bandwidth as compared to the single cell actuator. The fiber angle combination of the F²MC cells and the flow port inertance are the key parameters that can be used to tailor the system performance.

The second is on multi-functional F²MC structures where different functions can be achieved in an integrated system. To demonstrate the concept, a variable stiffness actuator utilizing the piezoelectric-hydraulic pump is proposed to integrate the two F²MC functionalities, actuation and variable stiffness, in a stand-alone system. Experimental results show that the proposed approach can achieve the dual-mode of operation and effectively switch between the actuation mode and variable stiffness mode.
Kinetic Actuation Experimental Study of Representative Active Knit Architectures

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Hierarchical architectures are employed in all aspects of our lives; this is particularly true in engineering where customized materials and composites, artificially generated tissue, and intricate high-performance machines are all results of hierarchical structures. Applying the hierarchical architecture paradigm to smart materials can provide a basis for a new genre of actuators. This paper presents an experimental study of active knitted actuation architectures made from shape memory alloys (SMA) that produce large strains (276% recoverable and 111% actuation) distributed across a surface against moderate forces (tens of Newtons or more). Hierarchical knit architectures are built upon unit cells arranged into textiles with varying topologies. Experimental studies on the kinetic actuation potential were conducted on three representative stitches: garter, I-cord, and rib. The first stitch, garter, is a flat symmetric textile that provides planar distributed surface contraction. The impact of geometric parameters (wire diameter, loop size, and number of rows and columns) on kinetic actuation performance (force, strain, and stiffness) is characterized. The second stitch, I-cord, is a helically knit tube that coils when actuated. A parameter study characterizes the functional dependence of the kinetic actuation performance on I-cord geometric parameters (wire diameter, loop size, and number of loops per helical rotation). The third stitch, rib, is nearly planar, but accords into raised ridges when actuated. An additional layer of the hierarchy, series and parallel combinations achieved by stacking and nestling prototypes, is examined to further improve the kinetic actuation performance. The hierarchical knit architecture provides structure to the base smart material fiber which results in improved actuator capabilities. Active knits afford performance tailorability because they enable architecture-dependent actuation motions and control kinetic actuation performance with geometric parameters.
Characterization of Fatigue and Degradation of Ni-Ti Shape Memory Alloy (SMA) Actuator for Potential Applications in Space Systems

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One of the major challenges for design and use of SMA actuators in space systems is its potential fatigue and degradation resulting from multi-cycle applications. A number of studies have demonstrated that the SMA is prone to degradation during its cyclic actuation due to two major factors: the mechanical fatigue of the material and the gradual loss in the shape memory effect. The fatigue of SMA is further complicated by the presence of martensitic phase transformation. To better understand the degradation mechanism in term of designing SMA actuator for potential space applications, characterization experiment is performed on two typical types of SMA (Ni-Ti and Ni-Ti-Cu) actuators to obtain their stability and change in strain output profile over the course of multi-cycle actuation. A specially designed laboratory testing fixture was utilized to test SMA actuator samples for up to 40,000 cycles under various thermomechanical loading conditions. Parameters associated with SMA actuator were examined, which are the permanent plastic strain accumulation and the maximum strain output. The experimental results show that the gradual accumulation of permanent plastic strain is the major deteriorating factor for the performance of the SMA actuator. Experimental result also indicates that as the number of actuation cycle increases, the maximum strain output of SMA actuator decreases. Comparison between Ni-Ti and Ni-Ti-Cu SMA actuators is specifically made and results indicates that Ni-Ti-Cu has generally better fatigue resistance in terms of permanent plastic strain accumulation and stability for high-cycle actuation.
Microstructural Dielectric Elastomer Actuator with Negative Poisson's Ratio

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In this paper, the modeling, fabrication and testing of a dielectric elastomer actuator with negative Poisson’s ratio are carried out. Conventional dielectric elastomer actuator uses the elastomeric dielectric materials sandwiched by compliant electrodes. The dielectric elastomer subjected to a bias voltage will undergo thickness reduction and area expansion. A novel dielectric elastomer actuator with negative Poisson’s ratio is proposed in this paper. When a bias voltage is applied, the resulting electrostatic forces compress the film and shrink in area as well due to the microstructural design of the dielectric material.

The proposed dielectric elastomer actuator consists of two electrode layers, two flexible layers and a microstructural layer, respectively (Figure 1). The microstructural layer possesses the grating patterns which serve as the spacers to define the gap between the top and the bottom flexible layers. When the applied electrostatic force pulls together the bottom and the top flexible layers, these two layers bend inwardly and shorten the distance between the spacers. The fabrication uses Parylene as the flexible layers, SU-8 as the microstructural layer and gold as the electrode layers.

According to the analytical results, area strain will increase 5% when the bias voltage is increased to 1000V. In addition to the design of orthogonal contraction actuation, a bending actuation is also demonstrated utilizing the asymmetric thickness design of the flexible layers.

Figure 1. When a bias voltage is applied, the resulting electrostatic forces compress the film in thickness and shrink in area.
Design and Generation of a New Biocompatible Piezoelectric Material

\( \text{MgSiO}_3 \)

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Recently, the lead free piezoelectric material for the micro actuator, which could be used for the biomedical–micro electro mechanical system (Bio-MEMS), such as the health monitoring system (HMS) and the drug delivery system (DDS), is strongly required. Until now, the lead-based perovskite type piezoelectric materials, such as PbTiO\(_3\) and Pb(Zr,Ti)O\(_3\), have been widely adopted for actuators and sensors due to their high piezoelectric and dielectric properties. However, these materials include hazardous lead. Recently, lead and hazardous material are prohibited to use by Restriction of Hazardous Substances (RoHS). Therefore, interest has emerged recently in the possibility of the lead-free piezoelectric material generation. Zhang S. et al. doped Ca and Zr in BaTiO\(_3\) and succeeded in generating the piezoelectric material with high piezoelectric and dielectric constants. Fu P. et al. also generated Bi based \((\text{Bi}_{0.5}\text{Na}_{0.5})_{0.94}\text{Ba}_{0.06}\text{TiO}_3\) doped with La\(_2\)O\(_3\). However, these materials had problem of biocompatibility, and were not adequate for Bio-MEMS devices. In this study, we invent a new biocompatible piezoelectric MgSiO\(_3\) thin film for the implantable actuator and sensor of medical device, by using the first-principles calculation and crystallographic process analysis scheme. At first, crystal structure was calculated by using the first-principles density functional theory (DFT). Secondly, the best substrate for the epitaxial growth of MgSiO\(_3\) thin film was searched by using the process crystallography simulation. Lattice parameters of MgSiO\(_3\) with the tetragonal structure were obtained as \(a=b=0.3449\)nm and \(c=0.3538\)nm, and its aspect ratio was 1.026. Finally, we generated a MgSiO\(_3\) thin film on Cu/Ti/Si (100) substrate by using RF-magnetron sputtering system. We measured the crystallographic orientation and piezoelectric property of the thin film and confirmed that MgSiO\(_3\) (101) crystal grew well. The strain constant \(d_{33}\) was calculated as 179.4 pm/V using the displacement–voltage curve.
Compliant Morphing Wing

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Morphing wings have a high potential in increasing performances and reducing fuel consumption of modern aircrafts. On the other hand, these systems cause penalties, especially in term of weight and complexity, which usually overcome the achieved advantages.

Campanile and Hasse considered replacing, in a wing structure, traditional stiff ribs with structures possessing selective compliance. The so called belt-rib is able to modify its shape so that the aerodynamic properties of the 2D profile are changed in a desired way.

\textbf{Figure 1:} CAD model of the compliant wing

A compliant morphing wing based on the belt-rib from Hasse is designed (Error! Reference source not found.): innovative methods for optimal placing of the actuation and for the quantification of the morphing are used. A mock-up is constructed to provide experimental evidences (Error! Reference source not found.).

The structural coupling effects were analysed and 2D and 3D aerodynamic performances were calculated. Additional investigations considered actuation forces and static aeroelastic effects.

Although results showed a relevant improvement in the aerodynamic efficiency with limited structural penalties, the performances are still far from the ideal case and they need to be further optimized.
In order to improve performances, a new structural optimization was undertaken to identify the optimal topology for the rib; a detailed optimization for the identification of the optimal topology and size is in progress and a new enhanced belt-rib design is being developed.
Bi-stable or multi-stable structures are candidates for morphing structures because of their ability to remain in natural equilibrium after a shape change occurs. These equilibrium positions require zero power to hold. By designing the system to have a stable equilibrium in both the primary and secondary configurations, the system will maintain either configuration once placed there. The change between stable configurations is achieved by a strongly non-linear mechanism known as snap through. By coupling bi-stable specimens with actuators to induce changes of shape (snap through), morphing structural elements are created with the potential to be incorporated into more complex structures.

This paper investigates the large deflection of an elastic arc coupled with a linear spring subject to concentrated loading on its midpoint. Both numerical and experimental investigations are carried out. Non-linear FE analyses are produced with Ansys solver to predict the behavior of the arc. The effect of several design parameters on its snap through capability and bi-stability are examined. High local strains are induced in the arc by the large displacement. Therefore, material able to withstand high strain must be used for the arc. In this investigation, Delrin polymer and a superelastic Nitinol alloy have been selected. Experimental static tests have been executed on several specimens. Good correlation has been found with the FE simulations. Dynamic investigations are currently being developed.
Scale Effects on the Performance of an Adaptive Torsion Wing

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This paper focuses on the high-end low-fidelity dynamic modelling of an Adaptive Torsion Wing (ATW) concept. This consists of a thin-walled closed-section two-spar wing-box, whose torsional stiffness and shear centre can be adjusted by changing the area enclosed between the front and rear spar webs. This is achieved by translating the spar webs in the chord-wise direction towards each other using internal linear actuators. As the webs move closer to each other, the torsional stiffness of the structure reduces, while its bending stiffness in the span-wise direction is unaffected. This study addresses the two dimensional dynamics of the ATW system in flight and it is based on assuming that the ATW is installed within a representative airfoil. The full equations of motion of the airfoil are developed using Lagrangian mechanics. This allows studying the response of the airfoil as the webs positions are altered in a static, quasi-static, and fully dynamic fashion. Throughout the modelling process, three primary independent variables will be considered, namely: the position of front web, the position of rear web, and the twist of the airfoil. This allows estimating the minimum actuation forces required to drive each of the webs depending on the instantaneous flight conditions, the distance travelled by each of the webs, and their relative position. Since various combinations of webs positions can be used to achieve a target aeroelastic wing twist, an optimization study is performed in order to obtain the optimum combination of positions that will minimize the actuation forces in a quasi-steady regime, i.e. for trimmed flight with minimum induced drag for a prescribed torsional deformation. Baseline unsteady aerodynamics considerations also allow estimating the characteristic time-response of the ATW system in manoeuvre. The associated dynamic actuation requirements are here examined. Based on a specified speed of response of the system, the actuators can be designed and sized.
Conceptual Design of an Actuation System for a Morphing Leading Edge High-Lift Device Using Topology Optimisation

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A design method for an actuation system of a morphing leading edge using topology optimisation is proposed. Seamless morphing high-lift systems reduce the aerodynamic drag and noise emanating from slotted high-lift devices. An actuation topology is designed and tested within the EU JTI Green Regional Aircraft project entitled “Leading Edge Actuation Topology Design and Demonstration” (LeaTop) to design a kinematic topology to deflect a morphing leading edge and investigate the corresponding forces occurring at the skin/spar connection.

Two optimisation stages are defined to obtain a concept of a smooth morphing leading edge high-lift device. A topology of an actuation system is found in the first stage, which is consequentially used in the second stage to optimise a skin stiffness distribution. The methodology of the first stage is outlined in the present work, whereas the second stage uses an existing aero-servo-elastic framework.

A two-dimensional aero-elastic analysis is performed where a chord-wise cross-section of a wing is analysed. The airfoil skin is modelled using Euler-Bernoulli beam elements, while the actuation system is defined using triangular membrane elements with drilling degrees-of-freedom. Topology optimisation employing the simple isotropic material with penalisation (SIMP) approach is used to design an actuation system to deflect a morphing leading edge.

The objective function is defined using a target shape for the deflected leading edge, provided by a project partner. Such a two-step approach is used to avoid using an expensive aerodynamic analysis during the optimisation process. A fast low-fidelity doublet-lattice panel method is used instead to define the aerodynamic characteristics. Skin strain constraints are added to the present framework to avoid unrealistic skin stretching as observed by Maute and Reich.

The resulting actuation topology is built and used in the LeaTop project. This test model is moreover used to verify the topology optimisation framework.
Experimental and Theoretical Analyses on Deployment Behavior of Inflatable Tube Elements

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Effective structure concepts and construction scenarios should be necessary and required in order to realize future large scale space structure systems such as several hundred meters’ solar sails, several kilometers’ solar power satellites and/or space colonies. Corresponding to future several kilometers’ space structure systems, combined use of both erectable and deployable structure concepts, which are two major structural concepts of space structures, using available adaptive and/or gossamer structure elements would be most effective. It is also thought that membrane structures with inflatable structures combined cable networks are much effective for future large space structure systems. Considering hierarchical modular patterns and installing automatic construction schemes for these structures, it might be achieved innovatively to construct several kilometers’ scale space structure systems. Some preliminary deployment experiments of these combined structures have carried out, and it is found that the stable deployment of inflatable tubes is mostly important for the stable deployment behaviors of these combined structures. In this paper, aiming to their stable deployment, the deployment behavior of inflatable tube elements is investigated both experimentally and theoretically.

In the theoretical simulation, the effect of the shape of fold line and its stress condition for deployment behavior is considered to analyze folding process, and the deployment behavior taking over the stress condition and the shape of fold line are simulated using finite element method (FEM). As for folding analysis, clump, rotation and expand tools modeled as the rigid wall shell material are well combined and located to create some fold line patterns. As for deployment analysis, the inflation gas and the inner space of the tube model treated as the finite points in finite point method (FPM), and the flow of inflation gas at the fold line is visualized.
Gust Alleviation for UAVs Using a Multifunctional Piezoelectric Wing Spar

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A multifunctional wing spar is presented integrating a flexible solar cell array, piezoceramic wafers, a thin film battery and a flexible PCB into a composite structure. This multifunctional wing spar therefore performs the functions of energy harvesting and storage, control computation, sensing and actuation for the purpose of gust alleviation for small UAV systems. Piezoceramic wafers are used here as sensors, actuators, and harvesters. The global modulus and stiffness of this multifunctional wing spar are estimated using both the rule of mixtures and the cross section transformation method. These values are then used in an Euler-Bernoulli cantilever beam model of the multifunctional spar. The first five modes are predicted analytically for the distributed parameter model. The finite element method is employed to confirm the analytical mode estimation. Special attention is given to the self-contained gust alleviation with the goal of using minimum control energy. The gust signals on different wing body locations are generated using a Gaussian white noise source to feed into a linear filter, with the required intensity, scale lengths, and power spectral density (PSD) function for a given flight velocity and height. Two classical PSD functions used for atmospheric turbulence modeling are given by Von Karman and Dryden. The Dryden PSD function is used here due to its simpler form (without non-integer index), and better fit to the spectrum records of atmospheric turbulence especially for small, high performance aircrafts. A saturation control is integrated with an active controller to reduce the control energy, which includes the actuation energy and the dissipated energy in the circuit board.
Resonance frequency detuning is a vibration control technique applicable to structures subjected to variable-frequency excitation. Swept-frequency excitation is considered here as representative of engine speed changes. Rapid sweeps result in peak vibratory response that is small relative to that experienced at resonance; however, high sweep rates are often impractical, making vibration reduction desirable. Resonance frequency detuning involves switching between two stiffness states: when the excitation frequency approaches a structural resonance frequency, the switch detunes the structural resonance from the excitation, reducing the vibratory response. The stiffness states are realized here using the short- and open-circuit stiffnesses of piezoelectric material.

Three system parameters govern the vibration response and achievable reduction: the sweep rate, the intrinsic modal damping, and the electromechanical coupling coefficient (which also determines the relative stiffness change). While any increase in sweep rate, damping, or coupling reduces the vibration level, resonance frequency detuning has the greatest effect on, and is thus ideally suited for, structures with low intrinsic damping subjected to slow sweeps, such as turbomachinery bladed disks. The trigger that initiates the stiffness switch also plays a significant role. For example, an ill-timed switch could actually tune the structural resonance to the excitation, and result in increased vibration. This paper examines some general rules for an optimal switching approach that minimizes the peak vibration response, considering in particular its implementation in a turbomachinery blade.

The effect of rotation-dependent dynamics on blade modal coupling coefficients is also examined. Typically, piezoelectric material is placed in a region of high strain to maximize the corresponding modal coupling coefficient. However, the rotating nature of turbomachinery induces large centrifugal forces that alter the blade mode shapes. As a result, the effective modal coupling can change with rotation speed; an understanding of this rotation dependence allows for refined predictions of resonance frequency detuning performance.
Semi-active Vibration Control of Smart Structures with Piezoelectric Elements

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A semi-active vibration suppression system is developed for flexible structures. The vibration suppression system comprises bimorph piezoelectric ceramic tiles shunted by an RL electrical circuit with a switching part. A general design method for the vibration suppression is theoretically analyzed using the mode analysis assuming that the piezoelectric element is sufficiently thin and does not change the mode shape of the beam. Under this assumption, the vibration suppression system for the beam is designed by tuning the optimal resistance and inductance parameters of the shunted RL network. In this paper, we propose a semi-active vibration control technique to improve the damping effect while maintaining the stability of the passive control system. The proposed control law is similar to a sliding-mode control that accelerates the convergence of the system by using switching functions. As an example, numerical simulations have been carried out for a cantilevered beam. This study shows that the resonant circuit functions as a type of a dynamic damper for mechanical systems and the sliding-mode control is very effective for damping the multi-mode responses. The results of the numerical simulations and experiments show that the semi-active vibration control system is practically more effective in damping vibrations than the passive control system.
Instability Prediction of Smart Aeroelastic Systems in Process of Structural Adaptation by Digital Stability Criterions

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This paper presents a preliminary study on prediction of the critical boundary of aeroelastic dynamic or static instability of a smart adaptive multimode system, flying or being exposed to a flow, for which the instability takes place in the nonstationary process of structural adaptation, even while the flow speed is kept fixed.

In such a new situation characterized by nonstationary structural adaptations, one can easily consider that the conventional prediction method for flutter based on measured modal damping coefficients will hardly function in an experiment performed at a wind tunnel or during a flight in an open air. Therefore, we use the prediction method using sampled data of the system response and the stability criterion for digital systems proposed by I.E. Jury, which is mathematically equivalent to Routh’s stability test in the continuous-time domain. Many adaptive systems are often very flexible, so that higher-modes of the dynamic systems are easily involved in their instability. In this analysis, therefore, the dynamic instability due to the effect of involvement of a high-mode(s) will be treated.

According to a recent overview on instability predictions referred below, the digital stability criterions are more effective in predicting the instabilities caused by a coupling of a higher-mode than the traditional damping method. Numerical results confirm that the digital stability criterions are very useful in predicting the dynamic instability taking place in the nonstationary process of structural adaptation of the multi-mode aeroelastic system.

Piezoelectric Structural Damping based on the Pulse Width Modulation Switching Circuit

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Piezoelectric switching shunt damping techniques are widely adopted in the vibration suppression. In such a technique, piezoelectric element is attached on a host structure and is connected with a switching shunt circuit. The vibration energy of the host structure dissipates in the switching shunt circuit to increase the structural damping of the host structure. One of most popular switching shunt damping technique is SSDV (Synchronized Switching Damping on a Voltage source) technique. In SSDV technique, the switching shunt circuit only turns “ON” at the extreme of the displacement to control the voltage across the piezoelectric element so as to enlarge the dissipated power in the shunt circuit. The practical problems in the SSDV technique are the stability and the high frequency noise. The problem of the stability can be solved by adopting an adaptive voltage source, but the problem of the high frequency noise is not yet solved effectively so far.

In SSDV technique, the voltage waveform across the piezoelectric element is non-sinusoidal. The higher frequency components of the voltage may excite the host structure. In practice, we can hear the noise clearly when we apply the SSDV or other similar techniques to observe this phenomenon directly. This high frequency noise may leak into the sensing signal as well as the driving signal of the switch. It may cause the switching action incorrect. In the low-coupling piezoelectric/structure system, the velocity of the host structure does not vary with the switching action of the shunt circuit significantly, so the error switching action may not often occur. As the coupling factor between the piezoelectric element and the host structure increases, this problem becomes important.

To solve this problem, this paper proposed a new switching strategy and a new shunt circuit topology to avoid the high frequency noise but can have the same performance as the SSDV technique. Different from the SSDV technique, we proposed to modulate the sensing signal and switching signal to the ultrasonic frequency range which is far from the fundamental frequency of the host structure. The switching circuit generates the modulating voltage at high frequency and can be easily recovered to a by a filter. Accordingly, by connecting a filtering inductor between the piezoelectric element and the switching circuit, the voltage across the piezoelectric element can be sinusoidal but not a square-like waveform in the case of signal frequency excitation. It should be mentioned that the filtering inductance is small according to the switching frequency is very high compared to the vibration frequency. In this paper, the PWM (Pulse Width Modulation) method was adopted due to its simplicity, but it is possible to use other modulating techniques.

We analyzed the problem of high frequency noise in the SSDV techniques first. Then, we explained the basic thinking of proposed switching strategy to alleviate the problem. The implemented circuit topology of the proposed techniques also demonstrated in the full paper in detail. The experimental waveforms and the total performance between the SSDV and proposed techniques will be compared with a cantilever beam to verify our design. Our experimental result was shown that the suppressed displacement in steady state can be set to nearly match the displacement at off-resonance frequency under the new damping scheme, but there is no high frequency noise generation.
Optimization of Distributed Shunted Piezocomposite Devices for Semi-Active Control of Sound Radiation

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Based on recent works on application of Floquet-Bloch theorem to periodical mechanical systems including frequency-dependent parameters [1], we propose in this paper an extension to vibroacoustic behavior analysis of smart structures. The objective is to optimize electronic circuits used to shunt some piezoelectric patches distributed on the structure, in order to minimize the acoustic radiation of the structure. The proposed approach is based on the computation of the multi-modal wave dispersion curves into the whole first Brillouin zone of the structure, and associated propagation characteristics in the acoustic fluid. The impedance of the shunt circuit is then optimized in order to render the acoustic waves evanescent.

Fabrication and Characterization of Magnetorheological Elastomers for an Adaptive Spring Element

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This work presents the fabrication and characterization of magnetorheological elastomers (MREs) for a potential application in an adaptive MRE spring element. MREs are composite materials that consist of micron-sized iron particles embedded in an elastomer matrix. Using this class of adaptive materials, their mechanical properties, notably their stiffness, can be dynamically varied under the influence of a magnetic field. This makes MREs attractive for adaptive structures. The MRE’s are fabricated to serve in compression as an adaptive spring element. The design goals include large cyclic deformations, high stiffness and a wide stiffness range between the field-off versus the field-on stiffness. The manufacturing process of the MREs is described, including the properties of the iron particles and the matrix. The iron particles are aligned within the matrix material with the help of permanent magnets. Images are shown confirming the alignment of the iron particles. Various concentration of iron particles are tested, ranging from 0\% to 40\%, by volume. The particles have either isotropic or aligned distribution within the matrix material. The force-displacement curves of the materials, versus the magnetic field, are experimentally evaluated with a test-rig. The experimental test-rig setup is described for both field-off- and field-on measurements. Cyclic load testing is conducted. Results indicate that the MRE materials can be used in an adaptive spring element in compression. Aligned MREs provide considerably higher stiffness range, between field-off and the field-on stiffness, compared to the isotropic MREs. The change in stiffness in aligned MREs decreases logarithmically with increasing strain amplitude; however, considerable effect is exhibited at high strains. A design proposal for a lightweight MRE adaptive spring element device is presented, with an adaptive spring constant of approximately 100 N/mm.
Influence of Graphite Particles on the Damping Property of Magnetorheological Elastomers

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Magnetorheological elastomers (MREs) are a kind of novel smart material and shown to have a controllable, field-dependent shear modulus. MREs have attracted increasing attentions and broad application prospects. However, the performance of MREs is not high enough at present, limits its application in engineering. This paper aims to study influence of graphite particles on the damping property of MREs. In the presence of a magnetic field strength of 700mT, four kinds of structured MREs samples were fabricated by using carbonyl iron particles, silicon rubber, silicone oil and graphite particles. Weight fractions of graphite particles were 0%, 1%, 2%, 4%, respectively. Their microstructures were observed using an optical digital microscope. The damping of MREs samples were characterized under shear mode with different strain, different frequency and different magnetic field strength. A dynamic mechanical properties testing system designed by our research team can investigated the damping property of MREs samples. An electromagnetic vibration table was used to provide sinusoidal loading with different strain amplitudes and different vibration frequency, force sensor and laser displacement sensor were fixed to monitor signal of force and vibration table displacement, which represented shear stress and the deformation of MRE samples. The damping ratio can be calculated through phase angle between shear stress and strain. The experimental results indicated that MREs sample have a more obviously damping ratio with high content of graphite particles, the variation range of damping ratio is more larger than MREs sample without graphite particles under testing magnetic field strength of from 0 to 600mT, the higher the graphite content have, the more sensitive to variation of strain and frequency. In addition, MR effect of MREs shows a decreasing trend with increasing of graphite particles content. This study is also expected to solve a key problem in the application of MREs in practical devices, such as in isolation buffer.

Keywords: Magnetorheological Elastomers; Damping Property; Graphite Particles; MR effect
Controlled Impact Testing of Carbon Fibre Composites with and without Carbon Nanotubes

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Reinforcement and strengthening mechanisms of critical areas of both matrix and interlayer regions of composites with carbon nanotubes (CNTs) have been developed to enhance strength and toughness, and to introduce electrical and thermal tailoring opportunities using nano- and micro-engineering. In this work, carbon fibres woven fabric reinforced epoxy composite panels, with and without additional carbon nanotubes, have been impacted at constant velocity of 4 mm/s using a servo-hydraulic testing machine, and a digital video camera has been used to monitor the impact event. Both single and multiple impact tests have been carried out and the energy absorption and damage development are similar in both cases for the same material. Specimens with carbon nanotubes absorbed more energy during the impact event than specimens without carbon nanotubes.
Effects of Cr Content on Microstructure of Multilayer and Nanocomposite Cr-C Coatings

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Cr-C coatings with Cr/CrN/CrCN gradient interlayers were prepared by a closed field unbalanced magnetron sputtering (CFUBMS) with Optical Emission Spectrum (OES) system. The effects of Cr content on the microstructure and mechanical properties of coatings were investigated in this study. The Cr content were varied from 5 at.% to 30 at.%. Microstructures of the films were characterized by SEM and high resolution TEM. Mechanical properties of the coatings were evaluated with nano-indenteter, scratch tester, ball-on-disk tribo-tester and ball crater. TEM analysis revealed layered structure of about 35 nm period. On the top layer, when Cr content more than 10% nano-composite structure of fine CrC crystallite nanometer in size imbedded in the amorphous Cr-C substrate were observed. Mechanical property analysis show that an increase in Cr content from 5 at.% to 30 at.% for the Cr-C coatings results in the increase of the hardness, Young’s modulus, adhesion and friction coefficient. A minimum abrasive wear rate was found at about 10 ~ 15 at.% Cr content.
Model-Based Multi-Stage Design Tool for Shape Memory Alloy Devices

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As Shape Memory Alloy (SMA) wire is increasingly utilized in industry for actuation applications, there is a growing need for computer aided design tools. Design of SMA devices is complicated due to material complexities such as hysteresis, path dependency, stress-temperature dependent phase transformation, and shakedown. As usage of SMA advances to more sophisticated applications, the device architectures combine with material complexity to make design even more challenging. This paper presents a model-based computer aided design tool for SMA wire devices encompassing material, architectural, and external system models. Built into the tool is a phenomenological SMA model, although the model incorporation methodology can be extended to any standard phenomenological or thermodynamics and free energy based model. Two modes of design are described a) decoupled, where the performance is predicted by intersection of independently generated system and material curves through the device architecture and b) coupled, where the system and material are combined through the device architecture first, then the performance is analyzed with transient time solutions. The decoupled approach is useful in the early stages of design where the designer needs to explore many device design options to find better candidate designs, thus a faster interaction is more important than the fidelity of the performance prediction. The coupled design approach is useful in the later stages once a final candidate design is selected when precise performance evaluation of the device is required that includes interdependency of the material and system. This is especially important in transient behavior analysis and to capture the path-dependent material behavior. The formalization of architectural transformations is described which expedites integration of a broad range of device architectures in a straightforward method. The architectural basis combined with selected component lumping provides the foundation for user views which enable an intuitive interactive examination of the design space tailored to the needs of a specific user. Combining various aspects of design with material, architectural, and system models in a combined multi-stage design tool streamlines the design process enabling designers to develop competitive designs in less time.
Improving Electret Diaphragm Materials for Wide-Band Flexible Electret-Based Loudspeakers

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A newly developed process that can enhance the surface potential of electret film as well as keep the 1st resonance frequency \(f_o\) low so as to make a wide-band electret loudspeaker will be presented. The flexible electret-based loudspeaker studied is made by integrating small cell actuators to form an array structure. The porous polytetrafluoroethylene (PTFE) was traditionally chosen as the most suitable electret diaphragm material due to its advantages such as low mass and good charge stability. To further improve the electret speaker performance, higher charge storage capability and better mechanical strength can be adopted.

The above-mentioned improvements to the properties of porous PTFE have been attempted by coating, vapor deposition, and even lamination to form a composite diaphragm. It was discovered that although these processes could increase the charge storage capability and mechanical strength of porous PTFE, the \(f_o\) of the cell actuator was also raised. The higher \(f_o\) leads to narrower bandwidth for the flexible electret-based loudspeaker.

In this paper, the Parylene C was deposited onto the porous PTFE according to a specific pattern located at the center of each single cell actuator. This patterning was done by using a mask and the deposition process will not change the stiffness and damping of the cell actuator. The Parylene C deposited was found to be a great electret material as its excellent charge storage ability significantly enhance the surface potential of diaphragm created. Both the simulation and the experiment results reveal the newly developed process can effectively enhanced the performance of flexible electret-based loudspeaker.
Polymers are usually utilized in electrical and electronic applications as insulators where advantage is taken of their very high resistivity. Typical properties of polymeric materials are strength, stability, flexibility, elasticity, mould-ability, ease of handling. Electrically conductive polymers find applications in electromagnetic shielding, antistatic coating, organic light emitting diodes (OLEDs), electrochemical sensors, rechargeable batteries and solar cells. Unfortunately, mechanical properties of these materials are not very high to compare with their insulator challengers. The aim is to combine mechanical properties and ease of processibility of polymers with the electrical properties of conducting polymers.

Polyaniline (PANI) received considerable attention over recent years as a promising conducting polymer because of its tuneable conductivity, doping/de-doping properties and ease of synthesis. Chemical oxidative polymerization is the easiest way for making conductive polyaniline (PANI) powders. H2SO4 will be major dopant in polymerization. Using of a co-dopant in doping process of polyaniline will give a higher conductivity and more solubility but lower mechanical properties. Blending of conductive PANI with conventional polymers such as rubbers is the most effective method to make a material with conductivity and mechanical properties. Resistivity of pure rubber must be considered because of the purpose of study. Copolymers and terpolymers have low volume resistivity with high flexibility and good ozone resistance. Different weight ratios (1% and 40 %) of PANI/Rubber are going to be used for comparison.

Properties of particle reinforced composites are significantly influenced by the size, orientation, morphology and distribution of the reinforcement particles. ANSYS is most common finite element (FE) software to evaluate influences of these criteria on properties of particle reinforced composites. There are different approaches for modelling of particle reinforced composites. Because of the blending method, particles may be connected with each other. Interface and inter-phase methods can be used for these connections.
Dynamic Modelling of an Adaptive Torsion Wing

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This paper presents a novel Active Aeroelastic Structure (AAS) device, which allows tailored twist deformations of wing structures to be achieved. The Adaptive Torsion Wing (ATW) concept is a thin-walled closed section two-spar wing-box whose torsional stiffness can be adjusted by changing the area enclosed between the front and rear spar webs. This is done by translating the spar webs in the chord-wise direction inward and towards each other using internal actuators. As the webs move closer to each other, the torsional stiffness of the structure reduces, while its bending stiffness in the span-wise direction is unaffected. The reduction in torsional stiffness allows external aerodynamic loads to induce twist on the structure and to maintain its deformed shape. These twist deformations can be controlled by changing the relative position of the webs as a function of the flight conditions to obtain an optimal or targeted level of performance. A conceptual parametric study will be performed by employing the ATW concept along the rectangular wings of number UAVs of different sizes, MTOWs, and aspect ratio to determine the impact of the vehicle size on the behavior of the concept. The UAVs considered in this work belong to the high altitude long endurance category. A representative figure of merit, possibly the span loading, will be used to represent the scale of the air-vehicle. Design nomographs demonstrating the variation of structural figures of merits such as tip twist, power density as function of air-vehicle size and web positions will be synthesized, presented, and discussed. Furthermore, the power density of various actuation systems will be examined; this allows the selection of the optimum actuation system for a specific size/scale of air-vehicles. This parametric study will define the region on the scale axis where the ATW concept can be employed and provide significant improvements. The nomographs provide a visual feasibility study when investigating the use of the ATW concept for a specific air-vehicle. Finally, based on previous work by the authors, this paper will discuss the impact of ATW on the conceptual design process for UAVs.
Virtual Processing of Hybrid SMA Composites

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The capability of Shape Memory Alloys (SMAs) to modify the residual stress state of hybrid SMA composites through martensitic transformation is explored. It is shown that through careful selection of a thermomechanical loading path the composite can be processed such that the constituent phases are in a beneficial residual stress state. Specifically, for materials which have preferred loading conditions (i.e., compression versus tension), such processing results in a residual stress state which takes advantage of the improved material behavior. This processing is explored here by considering composites consisting of an SMA phase whose constitutive behavior is described by a recent phenomenological model and an elastic-plastic second phase. To consider realistic microstructures, a numerical representation of the composite is generated from results of x-ray tomography and incorporated in a Finite Element Model. By then virtually processing the material, it is shown that through an actuation (isobaric) loading path transformation generates plastic strains in the elasto-plastic phase which, upon unloading, results in a new composite residual stress state. Different material properties of the elasto-plastic phase are then investigated to consider a variety of different compositions. The effect of the microstructure is then considered to determine features responsible for stress concentrations. Specific features are identified through the finite element results. Statistical methodologies are then used to both identify other such features and quantify their effect in developing new residual stress states. Through such analysis, dominant features are identified.
On the Development of a Morphing Chevron with SMA Wire Actuators

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The unique properties of Shape Memory Alloys (SMA) are recently exploited in the field of adaptive and morphing structures. The high actuation strain, stress and power density they can produce makes them adequate for use as actuators, especially in applications where volume restrictions apply. In this work SMAs in wire form are used as actuators for developing a morphing chevron capable to achieve a predefined target shape deflection. The work entails both analytical and experimental part.

A new finite element was first developed to provide initial prediction of the adaptive chevron response through Finite Element Analysis and to subsequently facilitate the adaptive chevron design. To this end, the constitutive model of Lagoudas and coworkers for the prediction of SMA behavior was implemented in Abaqus FE code through the formulation and encoding of a new UMAT subroutine. The new FE is capable of predicting the actuator response of the SMA wire and related phenomena (stress and strain generation) caused by thermally induced phase transformation between the highly symmetric austenitic phase and the less symmetric martensitic phase of the material. Conversely, the FE can also predict mechanically induced phase transformation of the SMA materials, or combinations of thermomechanical response, as is the case of a mechanically loaded adaptive chevron.

For the calibration of the analytical models and the validation of the numerical FEA models, characterization test of NiTi alloy wires were conducted. Initially the elastic properties of NiTi alloy were derived through isothermal loading tests. After sufficient material training, isobaric thermal loading at various stress levels were also conducting for derivation of transformation properties. The derived SMA properties were used as input to the FEA code for the evaluation of the numerical results.

A simple adaptive strip model with two wire actuators was analyzed and subsequently optimized in order to assess the feasibility and effectiveness of the SMA wire actuators. The Abaqus FEA code combined with the developed UMAT was used for the calculation of the adaptive strip response under the temperature load applied on the SMA wires. An adaptive strip prototype was subsequently manufactured and its response was measured in the lab. Experimental and numerical results demonstrating the feasibility of the adaptive chevron concept will be presented. Moreover, correlations will be shown demonstrating the good agreement between the measured response and FEA predictions.

Acknowledgements

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Nonlinear Finite-Element Model of Piezoelectric Composite-Based Actuator

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The lightweight piezo-composite curved actuator (LIPCA) was designed as a lighter alternative to THUNDER, with greater achievable specific force and displacement. The LIPCA systems are composed of a PZT layer embedded in a low coefficient of thermal expansion (CTE) carbon layer and higher CTE base glass layers.

Within LIPCA, there’re two major nonlinear effects: first is the geometric nonlinearity of the actuator itself due to the actuation displacement is greater than its thickness, second is the nonlinearity from the piezoelectric response due to the operational range of the LIPCA which is under high electric field. Beside the two nonlinear effects; hysteresis inside the piezoelectric also shows a major effect to the actuation response. Within the piezoelectric response scale; these effects are very small compared to other types of smart materials. However, once the piezoelectric is embedded inside the composite layers such as LIPCA; these small piezoelectric responses are amplified and the actuation response is in turn show large influence due to these nonlinearities. Due to its complicated sources of nonlinearities; it is essential to take into account these effects into the predictions prior the applications.

In this paper, linear and nonlinear COMSOL multi-physics FEM models are verified with the actuation response of the LIPCA under static condition. The linear model incorporates the linear piezoelectric coefficient given from the manufacturer; while the nonlinear model incorporates the nonlinear piezoelectric coefficient plus hysteresis of the piezoelectric material. The nonlinear piezoelectric coefficient and hysteresis of the piezoelectric are experimentally determined.

The results show very well predictions between the nonlinear model and the actuation response of the actuator. The linear model significantly underestimates the actuator response.
Flutter Suppression and Load Alleviation Using Piezo-Driven Tab-Actuated Flaps

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In order to prevent aeroelastic instabilities, resulting from LCO problems of a control surface, from occurring, it would be desirable to install an active flutter suppression system on the rudder. In order to provide the control system with sufficient control authority and frequency bandwidth, piezoelectrically driven flaps are chosen. Piezoelectric material have a large frequency bandwidth, but lack the required blocked force to actuate a complete flap. Therefore the flaps are actuated aerodynamically by tabs, which are driven by piezoelectric bimorph benders. In such a configuration, the blocked force of the piezo benders is sufficient because of the reduced aerodynamic loading on the tabs as compared to the whole flap. The proposed paper describes in detail the design of the piezoelectric bimorph benders and their implementation in the flap to actuate the tab. The complete wind tunnel model, which was used to demonstrate the feasibility of the technology, is described in detail as well. For the design of the controller, two numerical models were developed and compared to each other. One model was built in ZAERO, while the other model was the implementation of Theodorsen’s theory for unsteady aerodynamics. As a control variable, the acceleration of the wing tip was chosen, while the control signal (voltage) was sent to the piezo benders which actuated the tabs of the rudder flap. The proposed paper also describes the full wind tunnel test, and the way the actual test model was identified to tune the numerically designed controller further. Comparisons of the identified model with the two numerical models is given as well. It was demonstrated experimentally that the flutter speed of the wing could be increased by 80%. Moreover, the same controller could be used to alleviate the aeroelastic load on the wing, which was reflected in a significant decrease in root-bending-moment of the wing.
The study of large vibration amplitude of beams with variable cross-sectional properties such as sandwich beams, functionally graded beams and laminated composites beams are widely used in civil and mechanical engineering applications such as nuclear reactors, aircraft, building slabs… In many cases, these beams are subjected to relatively large amplitude vibrations with respect to their thickness, which may lead to the material fatigue and structural damage. These phenomena become more significant around the natural frequencies of the structure. Therefore, the non-linear vibration analysis is essential for a reliable design. For these reasons this study has attracted much interest from researchers because such vibration must be considered in designing resonance free composite structural components. Due to the complexity of the problem, it is difficult to obtain exact analytical solutions for non-linear vibration of composite beams and plates. As far as we know, researchers have concentrated on experimental investigation, approximate analytical and the finite element method.

The purpose of the present paper is to show that the problem of geometrically non linear free vibration of symmetrically and asymmetrically laminated composite beams with immovable ends can be reduced to that of isotropic homogeneous beams with effective bending stiffness and axial stiffness parameters. The theoretical model of the proposed formulation is based on Hamilton’s principle and spectral analysis using the governing axial equilibrium equation of the beam in which the axial inertia and damping are ignored. Iterative solutions are presented to calculate the fundamental non-linear frequency parameters and the associated non-linear mode shape. It has been shown that the extension-bending coupling affects the amplitude-frequency response of asymmetric laminated beams in comparison with symmetric laminated ones. The theoretical formulation has been validated through a good comparison of the numerical results obtained with the published literature.
In this study, we propose vibration testing methodology with a non-contact laser excitation method that uses an impulse force generated by laser ablation, and develop a technique and system for measuring the vibration characteristics of membrane structures in a vacuum environment. Using a high-power pulsed laser for the impulse excitation and a laser Doppler vibrometer (LDV) for the output detection, both input action and output measurements can be performed in a non-contact manner, thereby maximizing the reliability of the measurements and simplifying the measuring system. By fully utilizing these features, we can realize simpler equipment and devices for performing experiments on membrane structures within a vacuum chamber, and measure vibration characteristics with high reliability.

The measurement system in this study consists of YAG pulsed laser, dielectric mirror, condenser lens, membrane structure, LDV, and vacuum chamber. The membrane structure is fixed inside the vacuum chamber, and experiments are conducted by adjusting the air pressure within the vacuum chamber from an atmospheric environment to a vacuum environment. The membrane used in this experiment is Kapton, because it can withstand a wide range of temperatures from −269°C to 400°C, and thus, is often used in actual space environment. In this study, we use a YAG pulsed laser and LDV with membrane structure made up of Kapton as targets, and measure the vibrations of the membrane structures through non-contact input application and response detection. In this experiment, we evaluate and compare the vibration characteristics of impulse hammer excitation and laser excitation, membrane tension, laser output, and air pressure in the chamber by varying the characteristics under each of these conditions. Then, we verify the effectiveness of this vibration testing system and measurement technique through experiments simulating the system’s use in an actual space environment.
Oscillations of Footbridge Hangers at Very Low Wind Speed

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This paper describes vortex-induced oscillations of footbridge hangers at very low wind speed. The two spans (2x50m) reinforced concrete construction with the central pylon (25m height) has the harp system of hangers.

The hangers consist of 3 ropes ($\Omega = 3 \times 140$ mm\textsuperscript{2}) which are covered by very smooth plastic tube ($\Omega$ 54 mm). The oscillations were observed wind speed around 2 m/s. The measured amplitudes at loops were up to 5mm. The exited form includes the $6^{th}$, $7^{th}$ and $8^{th}$ natural modes of hangers.

The vortex induced oscillations do not influence the reliability of footbridge, but the look on the amplitudes could start panic and could start vandals action – increasing the amplitudes.

The supposed ways to reduce or to remove wind – induced vibration are:

- modifying the flow regime – to raise the flow turbulence due to roughness enlargement of the smooth plastic tubes of hangers,
- so-called Stockbridge dampers, connected to the vibration loops on $9^{th}$ and $8^{th}$ hangers,
- additional ropes attached to the $9^{th}$, $8^{th}$ and $7^{th}$ hangers and anchored to the bridge deck.

The chosen way is the third one: additional ropes. The more elegant way (the first one) due to glue the stone grains on the upper half cross-section of hangers was reject.
Validation of Modal Data in Rotating Machinery Using Finite Element Analysis

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Rotor dynamics is the study of vibration behavior in axially symmetric rotating structures. Devices such as engines, motors, disc drives and turbines all develop characteristic inertia effects that can be analyzed to improve the design and decrease the possibility of failure. At higher speeds, the inertia effects of the rotating parts must be represented in order to predict the rotor behavior. Excess vibration can cause noise and wear in structure. It is important to identify all the critical speeds within the range of operation and analyse the damping effects, mass unbalance and other phenomena also their effects in the safe operation. There are several phenomena need to be detected such as centrifugal and gyroscopic effect which would create complexity in the mathematical procedures in modal analysis before they could be used in modal testing of rotating structure.

The experimental technique used thus far is called Modal Testing, a well known and widely used technique in research and industry to obtain the Modal and Dynamic response properties of structures. The technique has recently been applied to rotating structures and some research papers been published, however the full implementation of Modal Testing in active structures and the implications are not fully understood and are therefore in need of much further and more in depth investigations.

The raw data obtained from experiment was used in finite element (FE) model for comparison. Since it has good capability for Eigen analysis and also good graphical facility, and obtained good result. 3-D models result large number of nodes and elements. This paper demonstrates how to extract a plane 2-D model from the 3-D model that can be used with fewer nodes and elements because of ease of use, accuracy and performance.

The aims is to establish a system identification methodology using the analytical/computational techniques and update the model using experimental techniques already established for passive structures but to active rotating structures, which subsequently help to carry out health monitoring as well as further design and development in rotating machinery.
Adaptive Wire Rope Isolator

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Machinery, equipment, personnel and buildings often have to be protected from vibrations and shocks. The wire rope isolator is widely used to reduce the vibrations of structures in military applications. In the structures where the mass of the isolated object is changing an adaptation of the isolator is useful. In this study adaptive wire rope isolator was developed using shape memory alloy to change the stiffness of the isolator. This paper describes the principle of the prototype isolator and laboratory tests of prototype isolator based on field measurements of tracked vehicle. The studied adaptive isolator can be used in industrial and transport applications where low power consumption is required. The adaptive wire rope isolator contains basic wire rope and transversal element including locking mechanism. If the power is lost the adaptive wire rope isolator will stay in “stiff mode”. When activated the heated shape memory alloy will open the locking mechanism and adaptive wire rope isolator will change into “loose mode”. More tuning to the stiffness can be achieved by using more transverse elements or activating / deactivating one or more isolators under the protected mass. The change in isolator stiffness was fourfold which was comparable to the protected mass that was varied. The adaptive isolator proved to work excellent in realistic laboratory tests. The tests were conducted using: 1) dynamometer in all three principal directions of the isolator, 2) shaker table in horizontal and vertical directions and 3) shock table in vertical direction. Response of the adaptive wire rope isolator was decreased even 80 % compared to existing passive isolator when vibration excitation was used with shaker table. The difference between passive and adaptive isolator was even higher when shock loading was used with shaker and shock table.
Panel Resonance Control and Cavity Control in Double-Panel Structures for Active Noise Reduction

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An analytical and experimental investigation of the panel resonance control and the cavity control in a double panel structure is presented in this paper. The double panel structure, which consists of two panels with air in the gap, is widely adopted in many applications such as aerospace due to its light weight and effective transmission loss at high frequency. However, the resonance of the cavity and the poor transmission loss at low frequency limit its noise control performance. In this paper, the resonance of the cavity and the panels are considered simultaneously to increase the noise transmission loss. A structural acoustic coupled model is developed to investigate the vibration of the two panels, the acoustic resonance in the air cavity, and the control performance. The control design can be optimized through the model using a combined stability analysis incorporating both structural and acoustic control. Finally, the results will be presented and discussed.
Analysis of Energy Conversion in Switched-Voltage Control with Arbitrary Switching Frequency

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In a structural system with piezoelectric actuators, the damping effect can be achieved by properly switching the voltage on the actuators. Semi-active synchronized switch damping (SSD) approaches are typical switched-voltage control methods, which has recently been a topic of active research. In this study, the energy conversion of a SSD control system with an arbitrary switching frequency is investigated theoretically and validated numerically. First the general expression of the switched voltage on the piezoelectric actuator is derived. The results show that maximum voltage magnitude is obtained on the piezoelectric actuator when piezoelectric is switched at every odd number of displacement extrema. Next the average converted energy per vibration cycle is derived for an arbitrary switching frequency. The results show that the efficiency of energy conversion is reduced drastically even if the switching frequency is slightly deviated from the optimal frequency. Finally some numerical results are given to support the theoretical results.
Piezoelectric Cantilever with Oscillators: a Low-Frequency Multi-Mode Vibration Energy Harvester

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Piezoelectric cantilever energy harvester usually works at its fundamental frequency which matches only one ambient exciting frequency. Since the higher resonant frequencies of the piezoelectric cantilever are too far from its fundamental one, it is difficult to match them with known low driving frequencies. Moreover, the higher vibration modes of the piezoelectric cantilever have certain strain nodes which reduce the energy harvesting efficiency greatly. By attaching oscillators on a piezoelectric cantilever, a multi-mode energy harvester is developed to harvest more power from several matched ambient driving frequencies. A distributed parameters model of the presented harvester coupling a pure resistor was established to analyze the power output of different modes. And the explicit expressions of the operating frequencies and the optimum load resistance were deduced to design the energy harvester. Simulations indicate that the multi-mode energy harvester has competitive ability to achieve low-frequency energy harvesting with small mass and light weight involved, and therefore this is especially valuable for small scale piezoelectric cantilevers.

A typical piezoelectric cantilever with one oscillator was constructed, and their power response-to-base acceleration was measured to evaluate the performance of the proposed harvester. Experimental results show that, compared with that of the traditional piezoelectric cantilever with the same weight, the energy harvesting efficiency of the presented harvester increases by 64% at the first vibration mode, and that one operating frequency is introduced whose efficiency is several times higher than that of second mode of the traditional one. Also, the analytical model was validated by the experiments, and their results show good consistency. Finally, a modal shape analysis indicates that the efficiency enhancement of the multi-mode energy harvester derives from the resonant motion of the attached oscillator at the first mode and the strain node cancelation at the low-frequency increased mode, respectively.
A Novel 2-DOF Piezoelectric Energy Harvester

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Harvesting energy from ambient vibrations using piezoelectric effect is a promising alternative solution for powering small electronics like wireless sensors. A conventional piezoelectric energy harvester usually consists of a cantilevered beam with a proof mass at its free end. For such a device, the second resonance of the harvester is usually ignored because of its high frequency as well as low response level compared to the first resonance. Hence, as reported in the literature, only the first mode is usually exploited for energy harvesting. Considering the wide bandwidth of actual vibrations in the environment, the conventional harvesters using only single mode are definitely inefficient. In this paper, a novel design of energy harvester utilizing multiple modes is developed. The harvester comprises one main cantilever beam and a secondary cantilever beam, each of which is bonded with piezoelectric transducers. By varying the proof masses, the first two resonance frequencies of the harvester can be tuned close enough such that useful wide bandwidth is achieved. Besides wider bandwidth, the proposed novel harvester also provides better performance at resonances than that of its conventional counterpart with similar dimensions. The positive experimental results show that the harvester has two peaks in response at two different resonant frequencies, indicating that the frequency bandwidth is broadened. This proposed novel energy harvester is more adaptive and functional in practical vibrational circumstances compared to the conventional ones.

Keywords: energy harvesting; vibration; 2 DOF system; broadband; resonant frequency
Design and Simulation of Current-fed Piezoelectric Switching Damping Circuit

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Piezoelectric material not only has the ability to converse mechanical properties into electric energy and has been used widely on the active vibration damping control for years. However, there are more and more studies focused on the merits of portability and low temperature sensitivity, which are gradually being substituted for the traditional mechanical damping. As a result, our active switching circuit research aimed to dissipate the maximum energy via capitalizing on the circuit of the full bridge parallel connection with voltage source, and making use of the same-phase current and voltage from the semi-active vibration control of velocity-controlled switching piezoelectric damping (VSPD). Nevertheless, since the vibration control belongs to the stage of the transient mode of ultrasonic sensors, the original voltage source of the circuit of Adaptive VSPD were superseded by a capacitor to control damping. Accordingly, we control the residual vibration changes by way of utilizing the characteristic of the decline of capacitor voltage caused by the vibration signals to work out the damping effect. In this study, our research puts emphasis on the analysis of the first conduct of driving and damping circuits. Nevertheless, if the capacitor in VSPD can be replaced by an inductive as an adaptive damping control source, the circuits will turn into current-fed topology, which means the piezoelectric transformer will turn from voltage-control into current-control and will have several known advantages. The control mechanism, circuit simulation and experiment verification of the newly current-fed topologies will all be detailed in this paper.

**Keywords**: vibration control, control damping, inductive circuit, current-fed
Wireless/ Integrated Strain Monitoring and Simulation System

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The paper describes the development and verification of a hardware and software tool that will be able to evaluate and optimize sensorized aerospace structures is proposed. The tool will be an extension of an existing suite of structural health monitoring (SHM) and diagnostic prognostic system (DPS). The goal of the extended SHM-DPS is to apply multi-scale nonlinear physics-based finite element analyses to the “as-is” structural configuration to determine residual strength, remaining service life, and future inspection intervals and procedures. Information from a distributed system of sensors will be used to determine the “as-is” state of the structure versus the “as-designed” target. The proposed approach will enable active monitoring of aerospace structural component performance and realization of DPS-based maintenance. Software enhancements will incorporate information from a sensor system that is distributed over an aerospace structural component. In the case of the component will be a stiffened composite fuselage panel. Two stiffened panels is instrumented with wireless sensors; the second with an optimized sensor network. It is shown that the sensor system output will be routed and integrated into a nonlinear multi-scale physics-based finite element analysis (FEA) tool to determine the panel’s residual strength, remaining service life, and future inspection interval. The FEA will utilize The effort will utilize a building block validation strategy, and real-time structural health monitoring system. The FEA will utilize the web/internet based GENOA progressive failure analysis commercial software suite, durability and damage tolerance (D&DT), and reliability software capable of evaluating both metallic and advanced composite structural panels under service loading conditions.
On the Detection of Buckling on Composite Strips Based on Frequency and Damping Monitoring

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The utilization of composite material systems is widely increased in applications involving large deformations and extreme tension and buckling loading cases, such as new pressurized composite fuselage structures and long wind-turbine rotor blades exceeding 60m. Understanding and predicting the effect of complex nonlinear stiffness and damping structural behavior of composite laminates subject to compressive loads are important steps for predicting the vibrational and aeroelastic response of many composite structures.

The proposed paper presents a theoretical framework for detecting the transition from the pre- to the post-buckling region of composite strips subject to in-plane compressive loads. A novel beam finite element (Fig. 1) is developed capable of monitoring the natural frequency and modal damping values of composite strips under small-amplitude free-vibrational response. The formulation is built on the first order shear deformation theory (FSDT) considering nonlinear Green–Lagrange strain expressions in the governing equations and a Kelvin viscoelastic solid model. The Newton–Raphson iterative technique is used and the displacement control method is incorporated into the finite element code. The damping and the stiffness effective and tangential (linearized) matrices of the structure are predicted through a multi-scale model, first in the beam section level, and finally in the structure system.

Numerical results will firstly evaluate the contribution of new first and second stiffness and damping nonlinear cross-section terms on the modal characteristics of composite strips under in-plane compressive loads. Experiments are conducted on a Glass/Epoxy [0/90]s cross-ply composite beam and its modal characteristics are measured for various values of in-plane loads. Validations between predicted and experimental modal loss factors and natural frequencies will outline the ability of the developed beam finite element to detect the buckling of the composite strips by monitoring its modal characteristics values.
Modeling and Experimental Verifications of the Directivity of an Electret Cell Array Loudspeaker

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A model which provides us with a way to investigate the three-dimensional directivity characteristics within arbitrarily configured flexible electret-based loudspeaker is proposed. In recent years, novel electret loudspeakers have attracted much interest due to their light weight, paper-thin thickness, and excellent mid to high frequency responses. The electret-based loudspeaker was constructed by integrating many small capacitance type actuators to form an array structure. The radiated sound beam forming has been done to achieve a directional response with an array of actuators. Increasing the directivity of an electret loudspeaker certainly leads to more useful applications, which can include supermarkets or exhibition areas or any other areas that require sending sound to a particular area. On the other hand, the electret loudspeaker can find another application scenario for many common audio environments if its directivity is decreased to approach omnidirectional. Furthermore, the directivity of the flexible electret loudspeaker can also be dynamically changed corresponding to its bended shapes and configurations. Another design factor worth noting is to use cell actuator of various sizes and shapes to achieve different frequency responses and weighting functions. Hence, a novel electret loudspeaker with various directivities can be achieved by designing smart structures based on various electret cell actuators without resorting to multi-channel amplifiers and complicated digital control system.

In order to study the directivity of the electret loudspeaker with an array structure for diverse demands and applications, the horizontal and vertical polar directivity characteristics as a function of frequency were simulated by this FEA model. To validate the FEA model, the beam pattern of the electret loudspeaker was measured in an anechoic room. Both the simulations and the experimental results will be detailed in this paper to validate the various assertions related to the directivity of electret cell-based smart speakers.
Fig. 1. The sound pressure level distribution of an electret array
Extension Stability and Dynamic Behavior Analyses of Extendible Rod in the Direction of the Spin Axis

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The radio and plasma investigation mission in the sphere of the earth using a five small satellites constellation is under consideration in ISAS/JAXA. To investigate radio and plasma by three-dimension, the 5m length of antennas in both direction of the spin axis are needed besides the wire antenna of two axes in the spin plane. These spin axis extendible rods are open section tubular shape made of CFRP triaxial woven fabric composites. These are packed at launch by as same method as the STEM (Storable Tubular Extendible Member). Two of these elements are combined each other as bi-STEM when the spin axis rod is extended in order to prevent anisotropic feature of single STEM and improve rigidity of such a long flexible rod. To confirm this rod design is feasible to succeed this mission, it is important to predict the behavior of rod while extension and after extended condition. The numerical analyses using differential equation of the beam was studied, but the model was not considering about the complex shape in the root of the rod. In the present study, this structure regarded as the large deformation structure problems is modeled using the finite element method and the eigenvalue analysis using this model is performed. Also, simulating motion of long flexible solid rod extension while rotating condition is conducted. In this simulation, the motion and strength of rod are examined when the disturbances, which are generated by the satellite condition including the centrifugal force and Coriolis force, are applied. Additionally, the simulation results are evaluated by comparison with the data that are acquired by experiment. Besides, dynamic behavior analyses that considered above-mentioned simulation are carried out by using the finite element model.
Designing Composite Structures for a Wide-Band Flexible Loudspeaker

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A composite structure that enables a flat loudspeaker to have good response across the whole bandwidth is designed and developed. The flexible electret based actuator is known to be light weight, flexible, energy efficient, and possesses excellent response in the mid to high frequency range. Nevertheless, the poor low-frequency performance of an electret loudspeaker limits it to have even broader applications. This limitation can be attributed to its small vibration amplitude, i.e., not enough strokes. Earlier attempts to improve the low-frequency response include modifying the electret material properties, changing the assembly method, and tailoring the structure design, etc. Very limited improvements were achieved.

In this paper, we will disclose the structure of an electret loudspeaker, which consisted of an electret film and a spacer layer sandwiched between the upper and lower electrodes. Six 10 cm by 10 cm electret loudspeakers were assembled on a 20 cm by 30 cm metal back plate (electrode) to form a large-area electret loudspeaker. Furthermore, we added an actuator on the back plate to drive the plate. Hence, the audible frequency range has good performance due to the low frequency sound generated by the plate vibration and mid to high frequency sound radiated by electret loudspeakers. Simulation model was established to study its modes and resonant frequency. Then, the simulation results were verified by experiments. It was identified that through proper signal processing and parameter matching, the composite structure utilized to form the electret loudspeaker can circumvent the lack of low frequency response limitation so as to achieve ultra-wide flat bandwidth performance.
Optimization of Space Structure Modules Composed of Booms and Membranes

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For future large space structure systems such as space solar power satellites, some adaptive construction scheme using both erectable and deployable structure modules seems to be efficient, and gossamer membrane polygonal modules having some erectable elements at each vertex have already introduced. Such membrane modules are composed of booms and membranes. One of their representative configurations consists of membranes and radial rib booms (rib design), and another consists of a membrane and peripheral edge booms (hoop design). There are many other possible module configurations between the two designs, which consists of membranes and both radial rib booms and peripheral edge ones. To correspond to some solar power satellite programs in near future those modules might be deployable and placed at geosynchronous orbit, and they might be 30-50 meter class space structures. And square and hexagonal shapes would be suitable for future extension to erectable construction.

In this paper, total structural stiffness characteristics (vibrational frequencies) of various square and hexagonal modules composed of booms and membranes in geosynchronous orbit are compared to obtain more efficient space structure modules. Some finite membrane element code including membrane wrinkle effects is used, and the booms are also treated by the nonlinear finite beam elements. Some optimized solutions are presented among various types of modules composed of under some constraint conditions such as that mass and size of the module are constant, and so on.
Concept of deployable space structures is one of typical adaptive structure systems in space, which should be deployed in orbit from its stowed launch configuration. Recently technology to develop more efficient space structure systems using membrane elements seems to be well matured, and some of solar sail spacecraft actually succeeded to be deployed and functioned in space. Solar sail spacecraft are classified roughly into two types; one is a spinning type, and the other is non-spinning type. The former deploys and keeps its deployed configuration using the centrifugal force due to spinning, and the latter using deployable booms. The former might be suitable for future huge space structure systems, but the latter for present and near future large ones from the viewpoint of spacecraft maneuverability.

Safe and sure deployment is the first issue of deployable space structures, but for solar sail spacecraft it is almost impossible to ensure it through ground tests, because they have large flexible membrane, and some numerical simulations must be necessary. It is generally considered that after detailed designs of the spacecraft are fixed, the deployment simulation is carried out using some finite element method, which usually needs long computation time. To get more efficient membrane space structure systems it is necessary to include the deployment simulation at the initial phase of spacecraft design using some of more simplified simulation tools. In this paper, deployment simulations of spinning and non-spinning solar sail spacecraft are presented using the multi-particle approximation method. Some of typical non-spinning types and spinning ones of solar sail spacecraft stowed in spiral folding patterns are treated, and the effects of spacecraft spinning for their deployment characteristics are clarified.
Design and *In Vivo* Validation of an Implantable SMA Driven Bowel Extender for Correcting Short Bowel Syndrome

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Short Bowel Syndrome is a devastating medical condition caused by insufficient small bowel length for proper nutrient absorption with mortality rates as high as 40%. Current treatment strategies have lethal complications and dismal success rates. Mechanotransduction, tissue growth induced by mechanical loading, has achieved functional growth in small animal models. However, the technical approaches utilized are not extendable to large animal studies or for clinical use because they are not fully implantable and difficult to monitor and control load/displacement profiles. This paper introduces a shape memory alloy ratchet driven bowel extender which is fully implantable and instrumented to monitor and control load/displacement profiles for variation in growth research studies and eventually safe use in clinical application. To design a safe device for *in vivo* use, short-term experimental studies defined the porcine cavity size, the maximum load that can be safely applied to small bowel, appropriate flow-through dimensions to minimize obstruction, and maximum tension before detrimental reduction in blood flow. The overall system comprises two key subsystems: the mechanical subsystem, built upon an SMA driven linear ratcheting mechanism, and the electrical subsystem, which consists of a series of electrical circuits that enables control of the ratcheting mechanism, samples and conditions sensor data, and wirelessly transmits and receives data. The architecture, operation, design, and validation of each subsystem is presented, as well as unique issues and resulting methods developed to ensure their proper operation within the hostile operating environment of a large animal. The bowel extender was implanted in a living pig for a nine day experiment in which a constant daily incremental displacement of the device was induced. The *in-vivo* experiment demonstrated the bowel extender system’s ability to apply and measure loading on the pig’s bowel. Most importantly, the experiments successfully achieved growth of fully functional and healthy small bowel tissue.
Feasibility Study on Piezoelectric Energy Harvesting in Helicopter Blades

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Converting aeroelastic vibrations into electricity for low-power generation has received growing attention over the past few years. Helicopter blades with embedded piezoceramics can provide electrical energy based on the concept of vibration energy harvesting to power low consumption electronic devices, such as a Structural Heath Monitoring (SHM) system placed in the helicopter rotational frame. Aeroelastic vibrations of a blade can be converted into electricity using the direct piezoelectric effect. In this paper, a reduced-scaled, dynamically-scaled (1-meter radius) composite articulated helicopter blade will be modeled for energy harvesting in the hover flight case. A resistive load is considered in the external electrical circuit (generator circuit) in order to quantify the electrical power output. The shunt damping effect of resistive power dissipation is also investigated. A procedure to obtain the optimum load resistance (for the maximum power and the maximum damping) is presented. The non-linear electromechanical model is based on the Variational-Asymptotic Method (VAM) applied for a rotating beam structure with Anisotropic Piezo-Composite Actuators (APA) embedded in the structure. In this feasibility study, aiming at applications to the SHARCS (acronym for Smart Hybrid Active Rotor System) project under development at Carleton University's Rotorcraft Research Group, the aerodynamic forces and moments loads are represented by the blade-element theory. The coupled non-linear rotary piezaeroelastic system is solved in the time-domain using an explicit integration strategy that addresses both the transient (from zero up to the nominal rotational speed) and the steady-state responses.
Active and Passive Peak Detection for Energy Harvesting

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Development of portable devices and wireless electronics has led to an increase in the demand on power sources. Readily available energy from the environment either in the form of heat, light or vibration is being considered as an alternative to batteries that has limited application due to size and sometimes weight. Research on any energy harvesting technology, though promising, is limited by the amount of power that can be generated for continuous operation of a device. Maximum power point tracking and switching techniques have been commonly used for energy extraction from light and vibration respectively. Extracted power generated is further lost in these accompanying circuit that is needed for energy conversion.

Numerous methodologies for harvesting vibrational energy via piezoelectric materials have been put forth. These methods generally require knowledge of the occurrence of peak deflections in the vibrations, so that the amount of harvested energy can be maximized, though how this is to be achieved has not previously been specified. Below, a method of peak detection is outlined that may satisfy the missing link between mechanical vibrations and systems that harvest energy from those vibrations. The system employs passive differentiation to initially identify peak positions in the time domain, followed by a zero-crossing detector coupled with a latch circuit to record the peak detection. A microprocessor is used to check the state of the latch and begin harvesting when a peak is identified. A comparison of various switching methods and the effect of error in peak detection is also discussed. Based of the permissible error and switching frequency, conditions for active or passive peak detection is suggested.
A Self-Powered, Self-Sensing Rotary Magnetorheological Actuator

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This paper aims at investigating the feasibility of a self-powered, self-sensing rotary magneto-rheological (MR) actuator. MR fluids were utilized in rotary devices to generate controllable torques. On the other hand, motors have been used to provide active torque for motive force output. In some cases, it is desired to have these two devices work together. To decrease size and weight, we have integrated motor and MR fluids into one single device with multiple functions - motor, brake and clutch. A prototype of the multifunctional MR actuator was fabricated and their characteristics on motor, clutch and brake functions were investigated. In this paper, experiments were conducted on power generation and sensing capability of the developed multifunctional MR actuator. The self-powered part is focused on the brake function of the actuator. When the actuator was rotating, power was generated and stored in a rechargeable battery. The rechargeable battery was connected to the inner armature of the actuator; when needed, power was fed back to the inner armature of the actuator so that resistive torque was generated by MR fluids inside the armature to provide the brake function. It was found that when the rotational speed was less than 171.6 rpm, braking force was sufficient to bring the actuator to a full stop; when its rotational speed was higher than that but less than 418 rpm, it could lead to a speed reduction. The power required in the two cases was 14.3 W and 7.04 W, respectively. The self-sensing function of the actuator mainly refers to rotational speed sensing. It was found that rotational speed of the actuator could be estimated from the induced voltage waveform obtained from power generation process. Due to the multifunctional features, the size and weight of the MR actuator could be reduced and be applied to various applications.
An Energy Management Circuit for Self-Powered Self-Sensing Magnetorheological Dampers

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Wang et al. (Smart Mater. Struct. 18(2009) 095025; Proc. ICAST 2010 (2010)) proposed and explored a principle of a self-powered self-sensing magnetorheological damper (SPSSMRD) to let the integrated relative displacement sensor (IRDS) of the SPSSMRD and the corresponding electronic system be self-powered by harvesting and converting the mechanical energy from ambient vibration and shock into electrical energy. The research works have shown that the induced voltages from the induction coil of the SPSSMRD are low voltages with low frequency, and cannot be harvested efficiently by classical energy harvesting circuits based on bridge rectifier circuits and voltage doubling rectifier circuits. In this paper, aiming to harvest energy from energy harvesters that generate low voltages with low frequency, the principle of an energy management circuit is proposed and explored. The proposed energy management circuit consists of an energy harvesting circuit, a start-up circuit, a control circuit, and an energy storage circuit, and the energy harvesting circuit operates in discontinuous conduction mode by utilizing a bidirectional switch composed of two MOSFETs to avoid the front-end bridge rectifier. In this case, via the energy management circuit, a low voltage with low frequency can be converted into a steady DC voltage and charge a rechargeable battery or supercapacitor. Based on the proposed principle, an energy management circuit is designed and developed, and is used to harvest the energy from the SPSSMRD. The characteristics of the output voltage and the energy storage of the energy management circuit, as well as induced voltages from the induction coil of the SPSSMRD, are theoretically predicted and experimentally tested. The experimental results show that the developed energy management circuit according to the proposed principle of the energy management circuit can convert low voltages with low frequency into a steady DC voltage and charge a rechargeable battery or supercapacitor.
Influence of Actuator Dynamics on the Load Reduction Potential of Wind Turbines with Distributed Controllable Rubber Trailing Edge Flaps (CRTEF)

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The potential load reduction using Controllable Rubber Trailing Edge Flaps (CRTEF) on the 5MW NREL Reference Wind Turbine is investigated based on aeroservoelastic simulations using the HAWC2 code. A realistic case in terms of structural implementation is modeled, using one flap per blade located close to the tip, strain sensors at the blade root and inflow sensors at the flap position. The flap structural and aerodynamic characteristics are derived from numerical analysis and wind tunnel measurements on existing CRTEF prototypes developed at Risø – DTU. In HAWC2, the flap actuator dynamics are modeled as a first-order system and the unsteady aerodynamic effects of the flaps are modeled using the Gaunaa-Andersen dynamic stall model. Linear state-space models are obtained from HAWC2 using Subspace System Identification methods, for below-rated power and above-rated power operating points. Model Predictive Controllers (MPC) incorporating actuator constraints and using the strain and inflow signals on the blades are designed, based on the linear models. The effect of including the realistic actuator dynamics on the identified linear models and on the controller design is shown. The controllers are evaluated in non-linear HAWC2 simulations at various operating points and turbulence levels. Focus is put on the influence of the flap actuator dynamics on the load reduction performance. The CRTEF implementation is shown to provide substantial blade root fatigue load reduction for normal power production load cases in turbulent wind. The actuator time constant is shown to considerably influence the predicted load reduction performance in an adverse manner. Conclusions are drawn regarding the effect of including the CRTEF actuator dynamics model in the full control design cycle (system identification, controller design and aeroservoelastic simulations) for load reduction predictions with active flaps.
R-Phase Actuated SMA Composites in Adaptive Wind Turbine Blade Trailing Edge

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There is an interest of doubling or quadrupling the rated power of wind turbines from the present maximum of about 5 MW, especially for offshore applications. This increases the blade length to about 80 or 100 m. The growth in size of blades is not feasible using the present technologies and materials. Also the slenderness of wind turbines leads to increased importance of vibration and fatigue control of blades and supporting structures. These increasing requirements call for new structural concepts and advanced materials and also for more adaptive solutions. Better control of the turbine such as advanced blade pitch control or shape control or their combination has to be developed and utilized. The one key issue is reduction of the fatigue loads of blades and that way increase the life of the structure and enable use of the turbine at higher wind speeds and gusty winds, which would increase the power production. Shape memory alloy (SMA) composites as morphing structures have been studied widely. In this study possibilities of SMA composites based on utilization of pre-martensitic R-phase transformation were determined. Special treatments to achieve pure R-phase transformation were developed and thermo-mechanical properties of the wires were determined. R-phase actuation has been found to offer several beneficial features compared traditional austenite-martensite transformation. The studies revealed that hysteresis can be remarkably decreased, leading to higher operating frequency at lower temperatures. One of the most important features of R-phase actuated wires is their superior resistance against functional fatigue. A novel manufacturing route for SMA composites was developed. Laminate and actuator test structures were designed by FE modeling. R-phase actuated SMA composites were demonstrated on wind turbine blade adaptive trailing edge. In laboratory condition 5° change in camber of trailing edge was achieved when wires were heated up 60 °C. Effect of wind speed on the achieved shape changes was studied by preliminary wind tunnel tests.
Active control of the aeroelastic performance of wind turbine blades has recently attracted the interest of several research groups worldwide. The motivation originates from the fact that the trend over the last ten years indicates that the size of commercial wind turbines is systematically increasing. At present there are wind turbines in the size of more than 5MW having rotor diameters greater than 120m. For future designs especially in offshore sites the interest for larger machines is clear. At this size level, wind turbines become and in fact are operated as power plants and therefore active control of the performance of wind turbines becomes attractive and in certain aspects necessary. Modern wind turbines already control the output based by means of variable speed at lower speeds and variable pitch at speeds above rated that acts globally on the rotor and does not allow finer tuning and more importantly load control. In order to meet the target of finer control other schemes already known from aeronautics have been introduced at research level. Concepts of this kind include: the individual pitch control; the deformable trailing edge flap either in single or multiple configurations; and the deformable tip. The objective of these controls is to act as supplements to the existing power control as a means of reducing loads.

In the above examples actuation results in a variable blade geometry which will primarily affect the aerodynamic loading. Depending on the feedback in closed loop operation it is possible to control the loading without affecting substantially the power production. In order to assess the consequences any of these concepts have, the modeling must take into account the specific geometry changes. In previous work the deformable trailing edge concept has been assessed based on free-wake aerodynamic modeling and the same was recently done for the tip deflection. In the present paper, results from a systematic aeroelastic modeling are reviewed and the effect on loading is assessed for the three aforementioned concepts.
Adaptive Trailing Edge Geometry for Load Alleviation on Wind Turbine Blades

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The loads on wind turbine components are primarily from the blades. It is important to control these blade loads in order to avoid damaging the wind turbine. Rotor control technology is currently limited to controlling the rotor speed and the pitch of the blades. As the size of wind turbine blades increases the loads along the blade can vary considerably due to a combination of turbulence, varying wind speeds, wind shear and other effects. Adaptive structures are good candidates for wind turbine blade control surfaces because they have the potential to create low drag flaps that have the conflicting abilities of being load carrying, lightweight and shape adaptive. In addition, the low parts count and simple construction of adaptive structures can promote simple manufacturing techniques, high reliability, low maintenance, and reduced backlash.

This paper presents the structural design, analysis and testing of a morphing wind turbine blade flap. The flap has a highly anisotropic cellular composite structure covered with a silicone skin which enables large deflections and high strains to be achieved without a large actuation penalty. A full size wind turbine blade section with a 1.3m chord and a 1m span is fitted with this adaptive trailing edge and wind tunnel tested up to 60m/s. The 20% chord flap is divided spanwise into four 250mm flap segments which are each controlled by a servo motor enabling the flaps to deflect +/-10 degrees even when subject to high aerodynamic loading. As well as operating the motors collectively the four flap segments have the additional function of operating independently.
Analysis of Coupling Effects in Belt-Rib Airfoils

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The belt-rib construction principle aims at realising lightweight, shape-adaptable airfoils by joining the idea of compliant mechanisms with the conventional semi-monocoque architecture widely used in aircraft design. The core element of the belt-rib construction is a planar compliant mechanism (the belt-rib) designed to be essentially sensitive to only one mode of deformation by keeping high stiffness with respect to the remaining deformation components. The belt rib is built in a monolithic fashion and interfaces to the rest of the airfoil construction in a conventional way, leading to a seamless, shape-adaptable wing design. In a previous work, belt ribs were successfully designed and tested, which are able to deform along a standard NACA profile family (fixed camber distribution and overall amount of camber selectable by elastically deforming the rib). In this two-dimensional proof, rigid rotations of the rib were suppressed by supporting the rib in a statically-determinate fashion. In a wing construction, however, the ribs are elastically supported by the rest of the structure and can therefore translate and rotate. Especially the rotational motion is essential since it directly influences the section’s angle of attack with respect to the undisturbed flow. Due to this reason, the analysis of coupling effects between the rib deformation and the torsional behaviour of the wing is of high relevance to a practical application of the concept.

In this work, a parametric analysis of such coupling effects and of their impact on the aerodynamic forces is performed by means of a multidisciplinary tool. The tools allows for variations of the skin stiffness (assumed as isotropic and with constant thickness in this stage), the undeformed wing section (assumed as constant along the span) as well as the in-plane stiffness properties of the belt-rib structure, parameterised by means of a FEM-substructuring technique. Selected results are presented and discussed.
Profile Beams with Adaptive Bending-Twist Coupling by Adjustable Shear Center Location

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The integration of structural elements with time-variable stiffness represents a promising approach to the solution of the conflict of requirements between load-carrying capability and efficient shape adaptivity that is characteristic of morphing structures. In shape-adaptable airfoils, the adjustment of stiffness components related to anisotropic coupling effects as bending-twist coupling according to changes in operating conditions permits a powerful “adaptive aeroelastic tailoring” of the structural behaviour.

Previous investigations on variably bending-twist coupled laminated plates based on adjustable shear stress transfer at laminate interfaces have stimulated two main areas of further research that require new structural concepts: First, overcoming the conceptual limits in maximum achievable degree of coupling of laminated plates, second, putting substantial changes in torsional stiffness into practice while maintaining high values of flexural stiffness. The present work pursues both of these objectives by the conceptual design and analysis of profile beams with adaptive shear center position on the basis of variable stiffness elements.

A rectangular box section is used as an example to evaluate this concept: If the section is double-symmetric in terms of thickness and elastic modulus, the location of its shear center coincides with the one of its geometric center. Varying the shear stiffness of one of the webs of the section, in contrast, allows moving the shear center along the profile’s symmetry line normal to the webs and thus, if a bending force parallel to the webs is active, inducing an adjustable torsion.

Parametric studies by means of finite element models of beams with adaptive box section in different configurations as well as experiments are performed in order to characterize the main influences on the elastic behaviour of suchlike structures and to assess their potential of application in morphing systems. In preliminary analyses, changes in torsional stiffness of the order of magnitude of the variations in the web material’s modulus and changes in flexural stiffness of almost one order of magnitude smaller have been achieved, which demonstrates the effectiveness of the concept.
Development of a Morphing Wing Using Agonist-Antagonist Rubber Muscle Actuators and Controlled Buckling of Composite Materials

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Since the beginning of science humans have pushed the boundaries of knowledge by attempting to recreate nature. The current research presents the design and testing of a morphing wing concept which was actuated by a nature-inspired, agonist-antagonist muscle mechanism. This prototype enabled controlled wing-morphing by using six pneumatic Rubber Muscle Actuators (RMA). The main structure of the RMA-actuated morphing wing-section was a fiberglass-composite shell that enveloped an aluminum internal structure. The morphing mechanism was also characterized by controlled composite-shell buckling. The wing section morphed from a 2412 airfoil to a new shape new shape designated as MW XX412 SERIES airfoil. Characteristic experimental aerodynamic results were obtained and presented. The wind tunnel testing conducted proved the feasibility of the concept by demonstrating that the morphing wing section could deform and remain stable under actual aerodynamic loading.
Morphing Dynamic Control for Bi-stable Composites

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Adaptive structures have been the focus of much research due to performance gains not possible to achieve using conventional design. Within this context, the idea of morphing promises augmented capabilities in terms of manoeuvrability, fuel efficiency, and the ability to perform dissimilar tasks in an optimal manner. To achieve morphing intelligent materials capable of changing shape while minimising the actuation to be deflected are required. Bi-stable composites are a type of composites capable to attain two statically stable configurations with no energy drain. This bi-stability property, resulting from locked in-plane residual stresses, has attracted considerable attention from the adaptive structure community for morphing structures [1].

The mechanism of bi-stable composites for changes between stable states is based on warping of the structure, which results in opposite sign curvatures for each stable state. The change between stable states is physically realised as a jump phenomenon or snap-through, which is strongly nonlinear in nature. As a result, these composite structures exhibit rich dynamics including subharmonic and chaotic oscillations [2]. Morphing strategies exploiting these dynamic characteristics have been studied showing encouraging preliminary results [3]. This paper exploits the dynamic response of bi-stable composites as a means of augmenting the actuation for morphing control. A morphing strategy targeting modal frequencies and nonlinear oscillations leading to snap-through of the structure is successfully developed. This results in a full state configuration control by inducing and reversing snap-through as desired. The strategy is tested on a specimen using macro fibre composites as smart actuators validating the proposed concept. Finally, conclusions are presented and future research directions discussed.

References:

Intelligent Control of Smart Actuators in a New Closed Loop Morphing Wing Mechanism

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The objective of the research presented here is to develop a new morphing mechanism using smart materials such as Shape Memory Alloy (SMA) as actuators and fuzzy logic techniques. These smart actuators deform the upper wing surface, made of a flexible skin, so that the laminar-to-turbulent transition point could move close to the wing trailing edge. The ultimate goal of this research project is to obtain a drag reduction as a function of flow condition by changing the wing shape. The transition location detection is based on pressure signals measured by optical and Kulite sensors installed on the upper wing flexible surface. Depending on the project evolution phase, two architectures are considered for the morphing system: open loop and closed loop. The difference between these two architectures is given by the use of the transition point as feedback signal. This research work was a part of a morphing wing project developed by the Ecole de Technologie Supérieure in Montréal, Canada, in collaboration with the Ecole Polytechnique in Montréal and the Institute for Aerospace Research at the National Research Council Canada (IAR-NRC).

Recently, morphing wing system studies have branched out into new research directions. Extremely complex and catalogued as interdisciplinary and multidisciplinary studies, morphing wing studies continue to ‘push’ the science, up to the extreme boundaries of mathematics and physics. These multidisciplinary studies therefore require knowledge in the following disciplines: aerodynamics and computational fluid dynamics, aeroelasticity, automatic control, intelligent materials, signal detection using the latest miniaturized sensors, high computer-time calculations, wind tunnel and flight testing, instruments, and signal acquisition - these signals have such speed that they are raising serious problems for the existing calculus technology. Consequently, real-time system functioning is conditioned (in addition to other factors) by the obtaining of the best data processing algorithms, easy to implement software within the command and control unit. Fuzzy logic theories, which offer remarkable facilities, may therefore be used in these algorithms. They facilitate signal processing by allowing empirical models to be designed based on experimental data; and thus, the complex mathematical calculus currently in use can be avoided. In addition, fuzzy logic can be used to model highly non-linear, multidimensional systems, including those with parameter variations, or where the sensors’ signals are not accurate enough for other models. This research project included the following: optical sensor selection and testing for laminar-to-turbulent flow transition validation (by use of Xfoil code and Matlab), smart material actuator modeling, aeroelasticity wing studies using MSC/Nastran, open loop and closed loop transition delay controller design, integration and validation on a wing equipped with SMAs and optical sensors.

A first phase of this project involved the determination of optimized airfoils available for 35 different flow conditions expressed in terms of five Mach numbers and seven angles of attack combinations. The optimized airfoils, derived from a laminar WTEA-TE1 reference airfoil were calculated and were used as a starting point in the actuation system design. Two steps were completed in the actuation system design phase: optimization of the number and positions of flexible skin actuation points, establishment of each actuation line’s architecture. The next phase of the project was about the design of the actuation control in open loop architecture of the morphing wing, for which an integrated on-off versus a fuzzy PID architecture was chosen. In this design, numerical simulations of the open loop morphing wing integrated system, based on a SMA non-linear model, were performed; as subsequent validation methods, a bench test and a wind tunnel test were conducted. In the final phase a closed loop controller was developed and experimentally validated.
Active Control of Sound Transmission through a Curved Carbon-Fiber-Reinforced-Plastic (CFRP) Panel

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This article is focused on the development and experimental realization of an active structural acoustic control (ASAC) system for a curved carbon-fiber-reinforced-plastic (CFRP) panel. The research aims at the development of a smart lightweight fuselage structure for future aircrafts with an improved sound transmission loss at frequencies well below 1 kHz.

A numerical pre-design is performed in order to define the transducers of the active system and to derive optimal sensor and actuator locations with regard to an acoustically relevant performance metric. The optimization of the type, number and location of the actuators is based on a full system description using numerical models for the disturbance excitation (diffuse sound field), the passive composite structure, the actuators (piezoceramic patch transducers) and sensors (accelerometers) as well as the fluid-structure interaction causing the sound radiation. A simulation of the system in the frequency domain yields a numerical performance prediction for a specific transducer configuration. A genetic search algorithm is used for the derivation of optimal positions for the selected actuators. The optimal number of sensors is determined by using the singular values of the cross-power spectral density matrix. All potential sensor positions are spanned by a fine sensor grid. The optimal placement is guided by the evaluation of the Observability Gramian calculated for a state-space description of the system.

For the experiments, the active CFRP panel is mounted in an acoustic transmissions loss test facility with a reverberant sending and a semi-anechoic receiving room. High-order system models are derived by the use of a multiple-reference test and subsequent system identification. Different controllers are designed and implemented on a rapid-control-prototyping system. The acoustic performance is evaluated by means of sound power measurements in the receiving room.
This paper focuses on the structural control based on a Tuned Mass Damper (TMD) with adaptable stiffness. The concept [Fig.1], which is denoted as PLA-TMD, is based on leaf-springs, which bending stiffness can be externally controlled by piezoceramic (PZT) stack actuators. Experiments performed on a prototype showed that it is continuously tunable in a broad frequency range. Thus the PLA-TMD may always retain the proper tuning by adapting online its stiffness to follow the modifications of the slender structure under control. This is expected to confront the reduction of the vibration mitigation performance caused by the "detuning" of the passive TMDs. This appears when the operational natural frequency of the slender structure changes (i.e. due to environmental conditions, fluctuating live loads, etc) and therefore the passive TMD has to operate at different frequency to that it was initially tuned.

The establishment of a proper PLA-TMD-based adaptation strategy is a pending and challenging issue. This is because some dedicated experiments revealed that the prototype has nonlinear structural behavior, which cannot be ignored. This issue is addressed here via elaborating an experimentally verified structural model of the prototype to express the nonlinear backbone of the prototype as a function of the deformation of its leaf-springs and the applied voltage at its PZT stack actuators. By measuring the current deformation of the leaf-springs, the PLA-TMD can be online tuned to a specific frequency via inversing the nonlinear backbone function for obtaining the corresponding voltage to achieve so. It is currently demonstrated that if the PLA-TMD is tuned to the excitation frequency, then not only the detuning effect can be effectively confronted, but also the achieved vibration mitigation performance is even better than that achieved by an ideal and perfectly tuned passive TMD. This clearly indicates the potentials of the PLA-TMD for vibration control.

Figure 1. The concept of PLA-TMD.
A Finite State Strategy for the Control of Adaptive Structural Envelopes

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In a civil-architectural engineering context, non-conventional structural systems like deployable, inflatable and morphing structures may provide innovative solutions for the construction industry. Specifically some benefits can be achieved when looking at the performance of structures subject to dynamic or variable loads, where a change of the configuration can better support a different load distribution. This is, for instance, the case of high-rise buildings or bridges under wind action or the case of a pipe traversed by a turbulent fluid. Moreover, applications of such structural systems can also be thought to enhance other functions of the architectural space, not necessarily related to its static or dynamic performance. Acoustics, lightening, energy harvesting are all aspects of the building which depend on variable inputs and, consequently, suitable to be enhanced by working on the configuration of the envelope.

Starting from these considerations, the paper concerns the control and the optimization of adaptive structural systems and particularly describes a general procedure for the design of adaptive structural envelopes. The proposed procedure is applicable to every structural envelope which can be associated to a framework with a mixed triangular and quadrilateral pattern. So, although the civil-architectural engineering context remains as a reference, the application of the proposed procedure is not limited to it.

The procedure is basically a combination of two main parts: an evolutionary optimization process, which aims at discovering new optimal configurations according to some defined purpose, and a topology optimization process which aims at decreasing the number of DOFs of the structure while retaining its ability to achieve the optimal configurations. While the evolutionary algorithm leads the search for optimal solutions, the compatibility of the resulting configurations of the adaptive envelope is ensured by the Virtual Force Density Method.

An example of the proposed procedure concerning a fluid structure interaction problem is finally illustrated.
Skin is a natural paradigm for biomimetic soft active materials. Here, we introduce a new multifunctional microvascular polymer composite capable of undergoing large stiffness changes. The material is based on the biological concepts of thermoregulation and muscle activation. The composite is an actively heated and cooled shape memory polymer with embedded microchannels for fluid flow. The active heating/cooling by this local mechanism significantly increases the response time of the material, which to date has been a major drawback. The change in stiffness is due to the shape memory effect. Changing the temperature of the solid above and below its transition temperature, transforms the solid from a glassy phase to a rubbery phase. If the polymer is coated with compliant electrodes, then the electrostatic effect or Maxwell stress effect can be used to deform the soft rubbery SMP to different stable deformation states that can be maintained after the removal of the electric field. We have successfully fabricated multifunctional microvascular polymer composites with stable hollow channels (100 μm in diameter). Thermomechanical characteristics and electro-thermo-mechanical characteristics of the microvascular composite with different fiber architectures will be presented.
Etching Holes Effects for CMOS-MEMS Capacitive Structure

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Etching the large-area sacrificial layer under the microstructure to be released is a common method in Micro-Electro-Mechanical-Systems (MEMS) technology. In order to completely release the microstructures, it usually requires making many etching holes on the microstructures to enable the etchant to etch the sacrificial layer completely. However, the etching holes often alter the electromechanical properties of micro devices, especially the capacitive devices because the fringe fields induced by the etching holes can alter the electrical properties significantly. For example, the etching holes will limit the tuning range of a variable capacitance to 16%. Therefore, to determine the effects of etching holes on the capacitive microstructures is a very critical issue for capacitive or electrostatic devices. This paper aims at evaluating the fringe field capacitance caused by the etching holes on microstructures. The authors try to find a general capacitance compensation formula for the fringe capacitance of etching holes by the use of ANSYS simulation. Geometry property of the capacitive structure where L, w, g, t, d_module, and d_hole, represent the length, width, gap, thickness, the side length of a square unit module, and the side length of an etching hole, respectively. The simulation results about capacitance compensation variation of a structure with large or small etching holes where the sum of etching holes area is the same for a chosen range $4 < d_{module} < 16$, $2 < d_{hole} < 8$, $0.5 < g < 4$, and $t = 0.5$. It is obvious that capacitance compensation with the increasing of the ratio $d_{hole}/g$, and the structure with large etching holes will make this trend more serious than that with small etching holes. According to the simulation results, the design of capacitive structure with small etching holes is recommended to prevent the extreme capacitance decrease. In conclusion, this paper provides a fringing field capacitance estimation method which shows the capacitance compensation of the design of etching holes, and this method is expected to be applicable to the design of capacitive devices of CMOS-MEMS technology.
Experimental Evaluation of the Electromechanical Coupling of Smart Structures with d_{15} Shear-Mode Piezoceramic Cores

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It is now well known that the so-called effective electromechanical coupling coefficient (EMCC) measures the energy conversion efficiency of a piezoelectric structure as the electromechanical coupling factor (EMCF) does for the piezoelectric material \cite{1, 2}. Its analysis, in particular under different electrical connections of the bonded or integrated piezoelectric patches, plays then a crucial role in these smart structures coupling performance evaluation \cite{3, 4}.

In this study, smart sandwich structures with aluminum faces and d_{15} shear-mode piezoceramic single cores (Fig. 1) formed by assembled patches, with identical poling are studied first. The effective EMCC is experimentally analyzed and compared to three-dimensional (3D) finite element (FE) simulations, in order to evaluate the efficiency of the sandwich structure to convert mechanical energy into electrical energy and vice versa.

![Figure 1](image1)

\textbf{Figure 1.} Piezoceramic patches electrical connections for a single piezoceramic d_{15} shear core: (a) \textit{oc} (b) \textit{sc}

Secondly, double piezoceramic shear cores (Fig. 2) are also manufactured and similar experiments as above are performed and compared to 3D FE computations.

![Figure 2](image2)

\textbf{Figure 2.} Piezoceramic patches electrical connections for double piezoceramic d_{15} shear cores: (a) \textit{sw} (b) \textit{pw}

The benchmarks are excited by using an electrodynamic shaker and the velocity is measured by using a laser vibrometer. The measurements were made in the thickness z-direction. The modal effective EMCC is then post-processed from free-vibration tests under open-circuit (\textit{oc}), short-circuit (\textit{sc}), series (\textit{sw}) and parallel (\textit{pw}) wiring of the electrodes of the patches; the EMCCs are computed from the radial frequencies $\omega_{oc}$, $\omega_{sc}$, $\omega_{sw}$ and $\omega_{pw}$ using the formulas:

\begin{align*}
K_{oc}^2 &= \frac{\omega_{sw}^2 - \omega_{sc}^2}{\omega_{sw}^2} \\
K_{sw}^2 &= \frac{\omega_{oc}^2 - \omega_{sc}^2}{\omega_{sw}^2} \\
K_{pw}^2 &= \frac{\omega_{pw}^2 - \omega_{sc}^2}{\omega_{sc}^2} \quad (1a, b, c)
\end{align*}

The first two modes, for which the EMCCs are non-zero are the first and second x-z modes; exemplarily, the experimental frequency response functions (FRF) are shown in Fig.3a and 3b for the \textit{sw} and \textit{pw} electric connections and the \textit{sc} conditions.
Figure 3. (a) First mode $sw/sc$ FRF and (b) second mode $pw/sc$ FRF of the benchmark with double $d_{15}$ shear cores.

All tests are simulated using the commercial FE code ABAQUS®. The different electrical boundary conditions (BC) are handled by imposing nil electric potential on all electrodes of piezoceramic patches for the $sc$ condition, and by grounding one side of the electrodes and leaving the other sides free for the $oc$ one. The realistic simulation feature, which considers the equipotential area condition at the electrodes, in particular for $oc$ condition [3, 4] is separately implemented for each individual piezoceramic patch. Due to the sensitivity of the $d_{15}$ shear response the bonding adhesives, the effect of the latter on the EMCC of the smart structures is also studied.

The obtained results show that reasonable test/model correlations require considering the bonding layers in the FE models. The present work contributes originally with: (i) $d_{15}$ shear piezoceramic response experimental modal tests; (ii) with the $d_{15}$ shear piezoceramic double core smart sandwich structure configuration, which has an increased performance; and (iii) the experimental evaluation of the modal effective shear EMCC introduced theoretically first in [1].

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References


MEMS gyroscope has many advantages of a small size, light weight, low cost, mass production. Currently, most MEMS gyroscopes with capacitive sensing are sold on the market. The method with capacitive sensing is simple, but its accuracy is very low. To improve the MEMS gyroscope’s accuracy, the system with dual optical interference and phase detection technology is proposed in this paper. Its main principle is to measure micro-vibration displacement of the mass in MEMS gyroscope by dual optical interference and phase detection, and process the interference signal by the circuit of phase subdivision and counter, and then the vibration displacement can be obtained, finally the angular velocity can be calculated by the formula \( \Omega = \frac{F_c}{2MA\omega\cos\omega t} \). By fractionizing the phase and comparing phase difference of two signals, the detection accuracy of MEMS gyroscopes are greatly improved. The system consists of vibration block of MEMS gyroscopes, optical module and circuit module. Optical module consists of a semiconductor laser source, beam splitters of single-mode fiber and photodetectors, whose function is to convert the micro-vibration signals to optical signals and then to convert optical signals to electrical signals. Circuit module provides the power drive for the semiconductor laser and photodetectors, processes the optical and electrical signals, and finally transfers the signals processed to the computer. The feasibility of the technology is analyzed theoretically and simulation experiment is performed in this paper. The experimental results show that the detection accuracy of MEMS gyroscope can reach \( 1.39\times10^{-4}\)°/s (equals to 0.5°/h), and the cost is very low. So, MEMS gyroscope with a high precision and low cost may be manufactured. The method proposed not only can improve the precision of MEMS gyroscope, but also detect other weak vibration signals, such as mechanical vibration, sound vibration and so on. It has important practical significance and promising market.
Magnetic Shape Memory Multifunctional Hybrid Materials

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NiMnGa FePd και FeNiCoTi alloys are part of a new class of active materials, the magnetic shape memory alloys (MSM). MSM can recover large deformation when subjected to a magnetic field. Among them, NiMnGa is the most promising since it can recover deformation of about 6\% under ambient conditions and moderate magnetic fields. Hybrid materials made by MSM embedded into polymer matrices can be used in a diverse of technological applications where multifunctional materials is a prerequisite. Typical applications include transducers, active noise and vibration suppression, micro-positioning and sensing.

In this work MSM hybrid material was fabricated by laminating a NiMnGa single-crystal plate with a specially designed elastomeric compound using hot-pressing. The low stiffness of about 37MPa for strains below 3\% of the elastomer makes it promising for hosting MSM materials. Hybrid composites were then characterized magnetomechanically. It is found that the produced hybrid materials can recover compressive strains of about 3.5\% using moderate magnetic field of about 0.4 T (Fig. 1a). Finally, the hybrid material can also be operational (strain recovery) even at low temperatures. For temperatures below 5 \degree C, the slope $d\sigma/d\epsilon$ during martensitic transformation (almost zero at ambient) is increasing following the increment of matrix stiffness. At about -50 \degree C the MSM effect is prevented and the matrix behavior prevails (Fig. 1b).

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{figure1.png}
\caption{(a) Strain recovery of MSM hybrid composite as a function of the magnetic field and (b) $\sigma - \epsilon$ curves for MSM composite for various working temperatures}
\end{figure}
Adaptive De-Icing System Conceptual Design and Simulation

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Icing of structures can be a reason of mechanical and electrical serious failures as well as can be danger for people who are in close distance to rotating wind turbine blades. The ice detection methods formulation, de-icing system design and power supply for de-icing system design have to be considered during implementation of system which is dedicated to prevent structures from influence of ice. The authors formulated idea of new concept of ice protection system for aviation structures, power lines and wind turbines blades. The idea consists of detection of icing on structure surface using ultrasonic waves propagation measurements, deicing using the same effect of wave propagation on surface with ice layer and energy harvesting using piezo elements. All three elements are integrated in adaptive autonomous ice protection system.

In present paper behaviour at the ice/aluminium interface in order to simulate de-icing was used. The cohesive material theory is used to model de-icing and damage at the interfaces[1]. The zero thickness adhesive behaviour between aluminium plate and ice is used. The cohesive behaviour defined directly in terms of traction separation law is used to simulate the delamination at the ice/aluminium interface. To specify interface behaviour fracture energy as a function of the ratio of normal to shear deformation at the interface is defined. A linear elastic traction separation law prior to damage and progressive degradation of the material stiffness after failure is assumed. These models have been used to simulate the de-icing if the aluminium plate under ultrasonic vibration [2] caused by the piezoelectric ultrasonic actuator disk made of PZT-PIC 151[3].

Results showed that water particles freezing on the investigated surfaces can be detected by using PZT actuator and detector system. Time of ultrasonic wave passing through the specimen length vary with the ice appearing. The same PZT actuator can be used to generates delaminating ultrasonic transverse shear stresses at the interface accreted ice.

References:
Debonding Monitoring of Adhesive Layer in Composite Structures Using Embedded/ Multiplexed FBG Sensors

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The fiber Bragg grating (FBG) sensor has been recognized as an excellent sensor for damage detection and monitoring due to excellent sensitivity, wide dynamic range, high reliability, small size, multiplexing, embedding capacity, and others. The FBG sensor can either be surface mounted or embedded in the structures to evaluate strain and temperature. In this study, multiplexed FBG sensors were embedded for the structural health monitoring (SHM) of composite structures, especially an adhesive layer between two composite skins. The adhesive layer of large composite structures has a lot of voids which can induce severe problems of FBG sensors such as peak splits during the embedding process, and thus embedding techniques are required to prevent the problems. Composite specimens were designed to demonstrate the capability of embedded/ multiplexed FBG sensors for debonding monitoring and fabricated as sandwich structures consisting of a glass fabric reinforced polymer (GFRP) composites and an adhesive layer. All materials used in these experiments are identical to those used in actual commercial wind turbine blades. An artificial debonding using release agent was applied to the specimens, and the multiplexed FBG sensors were embedded into adhesive layer with the embedding technique.

The signal characteristics of the reflected wavelengths of the FBG sensors were investigated when the external load was applied to the structures. The FBG sensors embedded near the artificial debonding exhibited peak splits (double peaks or multi peaks), bandwidth broadening, sudden wavelength changes, reflective power changes when debonding occurs. Moreover, finite element analysis (FEA) was also performed to investigate the strain distribution around internal debonding. The strain distribution was compared to the observed one in the test. They showed good agreement each other. Therefore, the FBG sensors have a sufficient capability to monitor the states of adhesive layer in composite structures when they are embedded in adhesive layer of composite structures.
The increase of lift force required by an aircraft during take-off and landing phases is obtained through wing flaps deflection. The shape change locally induced by flaps to wing airfoils is clearly limited by the allowable flaps excursion; it follows that, in operative conditions, only a discrete set of few airfoil shapes can be achieved, each shape being related to a precise flap deflection angle within the allowable range. From an aerodynamic standpoint, this implies that a conventional flap can generate just a finite number of extra-lift (and extra-drag) values each one corresponding to the finite number of deflections the flap may perform within the allowable range. The naturally foreseen advantages related to an adaptive high lift device able to smoothly change its shape according to flight parameters as well as the intent of reducing high-lift devices friction drag and emitted aerodynamic noise, represent all valid motivations to search for innovative flap architectures able to replace and/or improve conventional flaps system thanks to morphing camber capability. Such an adaptive structure must be conceived under contrasting design requirements: it has to be stiff enough to withstand external aerodynamic loads without appreciable deformations while being flexible enough to dramatically change its external shape. In this work, authors investigated a structural solution for a morphing flap element to be implemented on a real-scale regional transportation aircraft. On the base of specific aerodynamic requirements in terms of morphed shapes and related external loads, the general layout was set, providing a description of flap architecture’s working principle. Then, the structural design phase was addressed; by means of advanced FE models and analyses, main structural properties were assessed and performances were predicted in terms of morphed shape matching, stress levels distributions as well as architecture’s capability to safely maintain prescribed shape under external aerodynamic loads.
A Nonlinear Piezoelectric Plate Model

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Owing to the valuable capability of coupling the mechanical and the electrostatic behavior of a system, piezoelectric materials have seen a wide diffusion in the last decades in several different engineering applications. In particular, the possibility of generating a strain field as a consequence of an imposed electrostatic field and vice versa, has made them useful to perform sensing and actuation within a structural system. Despite their large use and the considerable body of literature produced about the topic, a complete understanding of the electro-mechanical coupling implications, mainly those concerning the development of an appropriate mathematical model for the structure, has not been clearly achieved yet. In this sense, linear models of piezoelectric plate, i.e. Reissner-Mindlin models, can be found in the literature, in contrast with the ascertained need for a nonlinear dependence of the strain field on the plate thickness. In other cases, nonlinear plate models are taken into account, yet often lacking assessments on whether the degree of nonlinearity of the considered mathematical model is consistent with the system requirements.

Leaded by these considerations, a nonlinear piezoelectric plate model capable of accurately expressing the direct and the converse piezoelectric effect is presented. The developed semi-intrinsic theory is meant to encompass large strains, displacements and rotations that can occur in the plate as a consequence of a complete coupling between the mechanical and the electrical field. In this sense, based on the assumption that a linear dependence of the electric potential on the plate thickness is not adequate to represent the potential electric energy, a specific structure to the field of admissible displacement is taken into account. Particular warping functions characterized by the use of an ad hoc polynomial expansion adopted to express their dependence on the plate thickness direction are here considered to describe the shear and the extensional deformability of the plate transverse fibers. Linear constitutive relations for a transversely isotropic continuum are considered. The governing equations of motions for the model are finally obtained.
A Comprehensive Model for Piezoelectric Ceramic Stack Actuators

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In order to achieve large output displacement of piezoelectric ceramic actuators, piezoelectric ceramic stack actuators (PCSAs) are fabricated by layering/stacking multi-chip piezoelectric ceramic wafers in series mechanically and connecting electrodes in parallel electronically. The layering/stacking processes of piezoelectric ceramic wafers can be categorized as three types: gluing piezoelectric ceramic wafers and electrodes, sintering piezoelectric ceramic wafers and electrodes layer by layer, and direct sintering piezoelectric ceramic wafers and electrodes as a whole (the co-fired technology). Experimental investigations show that the apparent properties differences of the bonding layers between piezoelectric ceramic wafers and electrodes exist due to different layering/stacking processes, and the properties differences greatly affect the dynamic performances of PCSAs. In order to explain the influence of layering/stacking processes on the properties of PCSAs and provide reference for designing PCSAs with high-performance, it is very meaningful to model the dynamic characteristics of PCSAs accurately. In this paper, considering that both a hysteretic force and a linear force will be generated by each single piezoelectric ceramic wafer under a voltage applied to a PCSA, and the total force of all piezoelectric ceramic wafers will result in the forced vibration of the two degree-of-freedom system composed of the mass, spring, and damper of the piezoelectric ceramic wafers and the bonding layers, a comprehensive model of PCSAs is put forward by using a Bouc-Wen hysteresis operator and linear function to model the hysteretic force and linear force, respectively. Three PCSAs fabricated by three different processes are experimentally tested and the proposed comprehensive model is experimentally verified. The research results show that the proposed comprehensive model of PCSAs can accurately portray the different dynamic characteristics of PCSAs fabricated by three different processes, and can reflect the properties differences of the PCSAs with different layering/stacking processes, which can’t be reflected by existing traditional models.
Altering the Stiffness of Thin Walled Laminated Composite Beams Using Piezoelectric Patches-a New Insight

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Altering the natural frequencies of slender thin walled laminated composite beams, by reducing its stiffness has been reported in the literature. This had been performed either using optimal mechanical and thermal induced stresses or by using collocated piezoelectric patches bonded on the structure. It was shown that for the cases of a beam equipped with piezoelectric patches, restraining the beam’s axial displacements at its two ends can lead to either softening of stiffening of the beam stiffness, as a function of the voltage supplied to the patches.

However, when those structures behave like a cantilevered beam, or a free-free beam, classical beam theories show that the lateral vibrations of those beams cannot be altered by applying a constant electric voltage to the collocated surface bonded piezoelectric layers or patches. This occurs because the resultant force on each cross section of the beam is always identically zero (due to the fact that axial external forces are not applied on the beam).

It is the aim of the present manuscript, to show that under certain circumstances one can alter also the natural frequencies of a cantilevered piezolaminated beam. The present paper will investigate this phenomenon, and provide a new insight into this topic.

Based on a first order shear deformation theory (FSDT), the three coupled equations of motion of a general piezolaminated composite beam and its corresponding boundary conditions are presented and solved and the natural frequencies and mode-shapes are numerically calculated for a cantilever beam. Then an experimental model was designed and manufactured from glass–epoxy, having a uniform rectangular hollow cross section. Two glass–epoxy plates were glued at the root and tip cross sections and the centers of these plates, namely the centers of the root and tip cross sections, were connected by a 0.6 mm steel wire. The wire is the main element in the phenomenon that will be further on described in the manuscript. Without the wire, the influence on the lateral vibrations by applying a constant voltage to the collocated piezoelectric patches bonded on the cantilevered beam is negligible, in spite of the internal stresses that are induced inside the beam. In parallel, a FE model was constructed using the ANSYS code. Its results are compared with the experimental ones, yielding a good agreement between the two, concerning frequencies of the first bending mode of free vibrations and the buckling voltage.
Modeling and Control of Hysteresis and Creep Behavior of Piezoelectric Macro Fiber Composites Based Bimorph Actuator

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Piezoelectric macro fiber composites (MFCs) which are usually bimorph or monomorph in configuration have been implemented as actuators into many useful applications. However, for the purposes of control system, the inherent nonlinear properties of MFCs such as hysteresis and creep behaviors should be paid special attention. In this paper, the actuation performance of a MFCs based bimorph actuator has been tested and a new approach for modeling the actuator is presented. In order to model the nonlinear hysteresis, creep and linear beam structure, the new method utilizes a ‘generalized Maxwell slip’ (GMS) model of hysteresis, a system of creep which is based on a combination of several first-order systems and a mechanical system. Therefore, this model can be used to characterize the MFCs based bimorph actuator. The properties of the new model have also been studied and experimental results prove the feasibility of this model. Based on the inverse model of the actuator, an open-loop inverse controller is designed and implemented in a real-time control system. The performances of the actuator are tested. With this result, the open-loop controller can not only suppress the hysteresis nonlinearity but also the creep behavior.
Impact Detection on Mechanical Structures and Quantification of the Shock Energy: a Wireless Low-power Approach

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Estimating the location and energy of impacts is of primary importance for assessing the condition of mechanical structures. Measuring the shock characteristics in real time, with a low consumption device is still an opened issue for aircraft and spatial companies. Several approaches have been proposed, some have good accuracy, but most of them need a huge computation and consequently cannot be self-powered. To overcome this drawback, we propose an approach based on the mechanical Poynting vector that measures the power flowing across a surface. For thin plate and bending motion, the Poynting can be measured with piezoelement bonded on the structure to form a closed contour (a rectangle frame for instance). A simple processing of the piezo-frame voltage leads to outgoing (ingoing) power flux and the bending wave energy variation inside the frame. If the energy variation is positive then the impact location took place inside the frame and outside if the variation is negative. Meshing the whole structure with these lightweight piezo-frames will then give the shock location on the structure and the shock energy. The power requirement for the voltage processing and for storing, or sending, the data are extremely low, thus the system can be wireless and self-powered.

The measurement concept and the voltage processing to measure the power flow will be detailed during the presentation. Theoretical and experimental results and isotropic and anisotropic plate will be given.
Nonlinear-Wave Modulation Analysis for Damage Detection in Smart Chiral Sandwich Structures

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This paper demonstrates damage detection in a smart sandwich panel with integrated transducers. The panel is built from a chiral honeycomb and two composite skins. Chiral structures are a subset of auxetic solids exhibiting counterintuitive deformation mechanism and rotative – but not reflective – symmetry. Low-profile sensors and actuators are surface-bonded on the face skin of the panel. Nonlinear acoustics is applied for damage detection. The combined vibro-acoustic interaction of high-frequency ultrasonic wave and low-frequency vibration excitation leads to various nonlinear effects. The paper demonstrates that when structure is damaged, the high-frequency “weak” ultrasonic wave is modulated by the low-frequency “strong” vibration wave. As a result frequency sidebands can be observed around the main acoustic harmonic in the spectrum of the ultrasonic signal. The analysis presented focuses on ultrasonic wave directivity.
Disbond Detection Using an Acousto-Ultrasonic System

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In recent years, many aerospace organizations have introduced new projects in which aircraft structures manufactured with composites are targeting better fuel efficiency as well as reduced maintenance. In addition to the use of composites, manufactures have chosen to use adhesive bonded joints for instead of convectional mechanical fasteners for non primary structures. Unlike mechanical fasteners, adhesive joint integrity is more difficult to assess during the operation of the aircraft. An Inspection of such joints can be done by one of two methods Non Destructive Evaluation (NDE) which is carried out during routine maintenance of the aircraft or Structural Health Monitoring (SHM) which is carried out during the operation of the aircraft. This paper focuses of the evaluation of an Acusto-Ultrasonics (AU) technique in the determination of adhesive failure and compares it to other SHM and NDE systems.

AU, Capacitance Disbond Detection Technique (CDDT) and Surface Mountable Crack Detection System (SMCDS) are among some commercially or soon to be commercially available SHM systems for disbond detection. AU is SHM technique based on the principles of guided wave propagation through the structure’s surface for damage detection. AU utilizes piezoelectric elements and an algorithm to transmit waves that propagate through the structure and interact with damage. To detect damage, the system record wave readings along a path and compares them to a baseline (wave readings that were previously recorded prior to structural damage).

A specialized test was developed to evaluate the effectiveness of the AU system for the detection of adhesive failure. This test involved the development of a coupon in which a composite-to-composite joint was simulated through bonding a boron fiber patch to a carbon fiber substrate. Coupons were designed using Finite Element Analysis (FEA) such that failure within the adhesive bond is achieved under static loading. The adhesive failure (disbond) was achieved by creating a stress concentration point on the patch. The concentration point was introduced by machining two sides of the rectangular patch down to a single point (triangle). Once bonded to the substrate and loaded, the local peel stress within the tip of the patch increased such that it exceeded the shear strength of the adhesive and therefore disbond occurred.
In-Situ Integrity Assessment of a Smart Structure Based on the Local Material Damping

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The potential to embed functional elements into fibre reinforced structures provides a unique possibility for the in-situ monitoring of the structural integrity of critical components. Such integrated monitoring function could be often implemented additionally to the primary active functions of a smart structure by merely extending the control unit software. The accuracy of the damage assessment of the monitoring function depend primary on a proper selection of the measurable damage-dependent parameters. One of such parameters, identified as especially sensitive to different failure modes of fibre reinforced composites, is the local material damping. A practical application of the local material damping as a damage indicator is presented on example of the carbon fibre reinforced composite plate with an implemented actuating/sensing system, developed within the European Centre for Emerging Materials and Processes Dresden (ECEMP) funded by the European Union and the Free State of Saxony.

In the experimental investigations the local material damping properties of intact and impact-damaged carbon fibre reinforced composite plates were determined using the dynamical mechanical analysis technique. The obtained damping values were used for the configuration of the developed parametrical Finite Element. In comprehensive numerical investigations the position and size of the region with changed damping properties due to damage was independently varied in order to simulate the effect of different impact damages. The results of the performed series of numerical modal analyses in form of the modal damping ratios were stored and used in the subsequent data analysis in order to identify the damage symptoms.

Subsequently, novel data-mining algorithms were applied to the obtained sets of modal damping ratios in order to determine the clusters in the symptom space and to inductively build rule-based state classifiers. Finally, the classifiers were tested using standardised validation techniques and implemented as the damage identification procedure in the control unit of the developed smart structure.
Supervisor with Adaptive Observer for Bolt Loosening Diagnosis by Using Smart Washer

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Bolted joints are widely used in mechanical and architectural structures. However, many serious accidents occur because of loosening in bolted joints. The diagnosis of the bolt loosening is able to be achieved by evaluating the variation of tightening axial tension. Conventionally, the inspection method of the loosening bolted joint is generally the measurement of the axial tension of a bolted joint by using ultrasonic waves. These methods require the use of special measurement equipment and the human operation.

In this study, a smart washer was proposed to detect the loosening without human involvement. The smart washer which consists of the flexible cantilever beam enables to detect bolt loosening by using self-sensing and actuation functions of piezoelectric material.

The basic principle of how to detect bolt loosening is to the dynamics characteristics of a smart washer system which varies depending on bolt tightening axial tension.

Previous research had indicated that a correlation was confirmed between the natural frequency of the smart washer and the tightening axial tension from the theoretical and experimental results, and proposed two approaches, one is adopting the system identification algorithm, the other is adopting the supervision system by using multiple observers.

Considering the practical use, the method using system identification has the problems that the fault detection accuracy degrades due to the influence of identification error. On the other hand, the method using a supervision system has the problems that prepared observers are discrete to loosening level, hence, the detection accuracy depends on division number of observers.

A novel method by adopting supervisor with adaptive observer is proposed in this paper. The numerical simulations and the experimentations are performed to verify the possibility of the adaptive observer-based loosening detection. Improvement of bolt loosening detection accuracy is confirmed by comparing the proposed method with the previous method.
Shunted Piezoelectric Damping: Identification of the Electromechanical Parameters and Prediction of the Dissipated Energy

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Shunted piezoelectric elements have been studied since several years as promising devices for vibration damping, and different shunting techniques have been developed. The energy dissipated by all these techniques, expressed in terms of loss factor or damping ratio, depends mainly on two different contributions: the electromechanical coupling and the shunt topology. Therefore, an accurate prediction of the damping has to start from a reliable identification of the generalized coupling coefficient that completely describes the electromechanical coupling. In this study, a robust method for the measurement of this coefficient is proposed, where the influence of the inherent damping of the structure is also considered. This method is based on the analysis of the dynamic response of the structure when the piezoelectric patch is connected to a resonant shunt. The proposed method is applied to different sample structures, and the measured generalized coupling coefficients are used for predicting the values of damping reachable with different shunting techniques (such as the Resonant Shunt or the Synchronized Switching Damping). Vibration tests are then carried out on the same shunted structures and the analytical prediction of the damping is compared with the experimental results. A sensitivity analysis is also performed in order to evaluate the influence of the experimental uncertainties.
Energy Harvesting Using Piezoelectric MEMS Generators with Dual Interdigital Electrode

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Most of the afore presented power generators in MEMS structures are mainly based on silicon substrates, taking advantage of its unsophisticated fabrication process and the easiness to purchase. An alternative choice of substrates would be promising to improve some of the characteristics within the silicon substrates, but our aim is to also keep the complexity of the fabrication down. In this work, we demonstrated power generators based on stainless steel substrates. As an alternative choice, the stainless steel has avoided some of the demerits from silicon, which in other words enhanced the flexibility and strength of the generators. The presence of raising flexibility and strength leads to robustness and better endurance ability from higher levels of strain. As a consequence of the increased strain, the generator is able generate a promoted level of power output efficiency. In our previous work, we have shown that the first prototype of our generator has a maximum open circuit output voltage of 4.24 V\textsubscript{P-P} and a maximum output power of 10.533 W with a 2.903 V\textsubscript{P-P} output voltage at resonant frequency of 213.9 Hz at a 2.9 g acceleration level. The two different modes of a cantilever generator, $d_{31}$ and $d_{33}$, are both presented and discussed in this work. The fabrication process of the proposed generator as well proved the simplicity of the fabrication. The total process takes about the same amount of time or even less time comparing to the fabrication of the silicon based generators.
Energy harvesting for powering wireless sensing electronics is widely pursued in the past few years. To improve the efficiency of energy harvesting in practice, many researchers exploited nonlinearity to address the issue of limited bandwidth of conventional linear energy harvesters. Although wider bandwidth can be obtained in their work, the performance of such nonlinear energy harvesters is sensitive to the extent of nonlinearity and the vibration level in the environment. In this paper, both monostable and bistable nonlinear energy harvesters are experimentally studied. The nonlinearity in the system is introduced by two repulsive magnets. By adjusting the gap between the twin magnets, both monostable and bistable nonlinear configurations and different extent of nonlinearity can be achieved. The harvester with different nonlinear properties is tested under various random excitations. The optimal performance of the nonlinear energy harvester is determined to be near the monostable-to-bistable transition point. Both monostable and bistable configurations are demonstrated significantly advantageous over the conventional linear harvester near this transition point. For the bistable configuration, this finding also helps avoid the difficulty of overcoming the high energy barrier. The results in this work provide useful guidelines for the design of nonlinear energy harvesters.

**Keywords:** energy harvesting; broadband; nonlinearity; monostable configuration; bistable configuration
Adaptive MR-isolation System Based on Piezoelectric Power Harvesting

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To restrict the horizontal displacement of isolation layer of isolated structure with rubber bearings, the passive viscous damper is always used. Due to the damping ratio of the viscous damper is not adjustable, storey drift and acceleration of superstructure may be amplified in some cases. In order to resolve above problem, magnetorheological (MR) damper whose damping force is adjustable is suggested to replace viscous damper. As sensors and industrial control system should be installed, the semi-active MR damper isolation system is too complex to be considered in many structures. Because possessing ability of transfer mechanical energy into electric energy, piezoelectric materials have been used widely to generate electrical energy from ambient vibration in the field of Micro-Electro-Mechanical systems. Recent studies have also shown that, piezoelectric materials can also to be used for harvesting large power in civil engineering. In this paper, one adaptive MR damper isolation system, whose excitation energy generated by adjacent piezoelectric ceramic, is proposed. In above system, the piezoelectric energy harvester can not only absorb seismic energy, but also provide electrical power to MR damper. Larger seismic induce larger electric power, and more electric power may excite more damping force of MR damper. Consequently, the new system has the ability of self adapting. Compared with the semi-active MR damper isolation system, the new system does not need sensor and industrial control system, consequently, has higher reliability. Simple formulas for piezoelectric stack energy harvester are derived. The adaptive MR damper isolation system with piezoelectric power harvesting device is preliminarily designed.
Piezoelectric patch actuators are widely used in the field of intelligent and adaptive structures. They are bonded to or embedded into the host structure. When voltage is applied to the electrodes of the actuator, it is strained and some force is acting on the structure. These forces strongly depend on its properties and are often of interest for evaluating the impact of active devices.

In many cases the impact can be estimated by different methods, like analytical calculations or finite-element models. But small model errors can cause large variances of the results. A more extensive method is to use experimental data from vibration analyses to estimate the actuator impact. Although this method yields an accurate dynamic model, many measurements have to be taken from experiments, which is costly in terms of time.

In this work an alternative method is used to evaluate the actuator impact, which can be used for static and dynamic applications simultaneously. For that a finite-element model of the structure without actuators is used as a general basis for stiffness and modal information. Actuators can be included into the model with the help of Ritz vectors, which is an essential part of this method. Due they contain information about the static deformation of a structure; experimental data can be used to account for the real actuator impact. Thus, the deformation of the host structure under static actuator load is obtained by a visual three dimensional measurement system. The Ritz vector can then be composed from this data for each actuator according to the degrees of freedom of the finite-element model.

The main advantage of this method is that only a few measurements are required to evaluate for the actuator impact. In addition, the computational effort remains low due no experiment based identification is necessary.
Strain monitoring of aeronautical composites with embedded sensors

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Composite materials and structures offer great specific mechanical properties in order to be used in light-weight constructions; their main disadvantage is the difficulty to detect induced damage during their mechanical service. Several structural health monitoring methodologies have been devised the last decades to provide on-line information regarding the type and location of induced damage to the composite that would firstly increase safety of the aircraft structure and secondarily minimize inspection / maintenance intervals.

Typical state-of-the-art damage and sensing techniques use embedded sensors; typical cases are the active piezoelectric, the fibre optical and the acoustic emission sensors. Nevertheless, each SHM technique presents specific advantages and disadvantages. Currently, an essential drawback for their extensive use is the sensor size; it produces artificial defects that downgrade mechanical properties.

In the present work, Fiberoptic Bragg grating sensors were embedded in typical aeronautical composite structures in order to be used as detection system for structural health monitoring purposes. Optical fibers had been embedded in several locations in between the layers of composite material and for various geometrical configurations, including typical tensile coupon and stiffened panel. Data values taken from the FBG system during the experimental tension tests of the composite structures were calculated to axial strain values with the aid of an interrogator. Theoretical axial strain values of the composite patch had been calculated by exploiting a finite element model. Discussion has been made on the correlation between experimental and theoretical results for the verification of sensing sensitivity and accuracy.

A very promising technique for damage monitoring of composites is the polyvinyl-alcohol – carbon nanotubes (PVA-CNT) fiber. They can be spun by injection of carbon nanotubes suspension through an orifice into a co-flowing stream of a coagulating solution. PVA- CNT fibers have small dimensions (d ~ 40 μm), they do not impose geometrical defects on manufactured composites and offer a promise for high mechanical performance.

Exploiting the electrical conductivity of the carbon nanotubes (CNT), they could be used to non-conductive composite materials in order to enhance their monitoring capabilities. The electric resistance change method had been used widely for sensing of the structural health monitoring, by means of identifying internal damage of carbon fiber reinforced (CFRP) laminates that have inherent conductivity.

Sensing of the structural integrity of GFRP composites was made by the in-situ measurements of electrical resistance of the embedded PVA-CNT fiber during mechanical testing. The fibers worked well in a variety of mechanical tests, such as tension and bending. Tensile progressive damage accumulation tests had been also performed to seek simultaneously the electrical response of the PVA-CNT fibers with known level of accumulated damage to the composite.
Study of Fracture and Thermal Properties of Cement-based Nano-structured Materials

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This study aims in developing innovative multi-functional cement-based materials by modifying traditional cement-based mixtures with the introduction of nano-particles (carbon nanotubes – CNTs). Such materials would have improved mechanical properties enabling significant weight-reduction in structures. They would also possess intrinsic multi-functionality offering controllable thermal and other (i.e. electrical) properties in constructions. Properties and degradation mechanisms of cementitious materials occur within multiple length scales. Addition of nano-sized particles is a means to manipulate the structure at the smallest scale in order to tailor the macroscopic properties of cement composites. In this work, among several other physical tests, thermal conductivity, compressive and flexural strengths and fracture toughness were measured as a function of the aspect ratio and volume content of the CNTs. The fracture behavior was evaluated during three-point bending tests with concurrent monitoring of acoustic emission behavior. Apart from the influence of CNTs on different physical properties, acoustic emission monitors the fracture behavior showing the contribution of the nano-phase, as well as its mixing procedure directly on the damage process of the material. Advanced indices, which have been shown sensitive to the cracking mode (i.e. tension or shear) and are related to the frequency and the general shape of the acoustic waveforms recorded after crack propagation incidences, were studied in order to indicate the effect of the nano-reinforcement on the dominant fracture mode and the tortuous path of the crack. The thermal behavior of the nano-structured cementitious materials were compared with the properties of conventional, unreinforced materials using IR thermography. The study concerns both cement paste and cement mortar in order to evaluate the effect of nano-reinforcement in material with different typical size of micro-structure
Impact Damage Detection in Composites Using an Active Nonlinear Acousto-Ultrasonic Piezoceramic Sensor

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The development of effective SHM methods for composite structures receives high attention, as the volume of composite materials used in primary aerospace, transport and energy structures is rapidly increasing. Among the various types of damage which may coexist in a composite structure, early detection and monitoring of foreign body impact damage is desirable, as the latter may easily occur, remain hidden and propagate catastrophically. Non-linear ultrasonic NDE techniques, are newly developed methodologies for which are reported to provide high sensitivity in the detection of small crack damage. However, little work has been reported on the application of non linear ultrasonics for damage detection in composite structures; moreover, the reported techniques are suitable for non destructive inspection, and not for permanent structural health monitoring.

The authors have introduced the concept of the active nonlinear acoustoultrasonic piezoelectric sensor (ANAUPS), using permanently attached piezoelectric wafers as actuators and sensors, which has demonstrated capability to detect delamination and matrix cracks in composites [1,2], through in-situ generation and nonlinear modulation of an acoustoultrasonic carrier wave. Previous experimental measurements using nonlinear ultrasonics methodology based on the usage of the Acoustic Nonlinear Piezoelectric Sensor described above, presented high sensitivity to reveal the delamination debondings and matrix cracks in composite beams even for significantly small damage sizes.

The objective of this paper is to experimentally and analytically investigate the potential of non-linear acousto-ultrasonic modulation method to detect impact damage in composite structures, and to develop and evaluate a novel SHM methodology based on the usage of solely in-situ piezoelectric devices (ANAUPS). Glass/epoxy composite plates and strips are fabricated with [90/0]2S and [90/0/45/-45]S laminate configurations. These specimens are subjected to impact loading, for various low energy levels, to create impact damage in the composite laminate. These specimens are tested using at minimum 3 surface bonded piezoceramic wafers: two piezoceramic actuators exciting the low-frequency nonlinear vibration and the high-frequency carrier wave, respectively, and a piezoceramic sensor picking up the modulated wave signal. Apparent objective of the present work is to investigate the feasibility to detect impact damage developed in composite structures caused for various energy levels, and to quantify the effect of impact energy/damage size and the carrier wave excitation frequency level on the resultant carrier modulation. Comparison with previously obtained frequency spectra of the modulated signal for a single delamination crack, or matrix cracking in the composite will be presented, to demonstrate changes in the sensor signal pattern for each type of damage.

References
Semi-Modal Active Vibration Control of Plates Using Discrete Piezoelectric Modal Filters

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Modal sensors and actuators working in closed loop enable to observe and control independently specific vibration modes, reducing the apparent dynamical complexity of the system and the necessary energy to control them [1,2]. Modal sensors may be obtained by a properly designed weighted sum of the output signals of an array of sensors distributed on the host structure [3,4]. Although several research groups have been interested on techniques for designing and implementing modal filters based on a given array of sensors, the effect of the array topology on the effectiveness of the modal filter has received much less attention [5]. In particular, it is known that some parameters, such as size, shape and location of a sensor, are very important. This work presents a methodology for the design of semi-modal active vibration control of a rectangular plate using modal filters based on arrays of piezoelectric sensors. The topology of the array of piezoelectric sensors bonded to a rectangular plate is numerically optimized to improve the effectiveness and frequency range of a set of modal filters. Using properly located piezoceramic sensors bonded on a rectangular plate, the frequency range of a set of modal filters is enlarged by 25% to 50%. An experimental implementation of the modal filters is carried out in order to validate their performance. It is shown that proper setup of weighting coefficients is an important requirement. Then, a direct velocity feedback control strategy using the modal filter output is considered to evaluate the control input to be applied to the plate. It is shown that a reasonable and adaptive number of vibration modes may be effectively controlled with quite simple processing requirements.

A variable geometry truss (VGT) is a truss structure system having length-adjustable actuated truss members. Adjusting its actuated member lengths, a VGT can change its geometrical as well as mechanical characteristics in accordance with the given task or the change in its mechanical environment. From the viewpoint of a structure system having actuators, the VGT can be said to be as one of the typical examples of “adaptive structure”.

We deal with a VGT having shape memory alloy (SMA) wires as its length-adjustable actuators. Adopting SMA wires as the actuators, it is possible to realize a light-weight and low-cost VGT system without mechanical actuators such as ordinary electric motors. We have been studied so far the kinematics, dynamics, feasibility examination with prototype system and so on of this type of mechanical system. On the basis of the studies, it has been shown that the SMA-wire actuated VGT has various different characteristics from the conventional VGT consisting of rigid length-adjustable actuators. In this study, we discuss issues about the practicality of the SMA-wire actuated VGT.

The application fields of this type of mechanical system are examined from the viewpoint of the dimension of the system. Significantly large and small systems are considered to be promising candidates of the application since mechanical systems having ordinary actuating devices can be impractical in such cases. We study the suitability of the SMA-wire actuated VGT to applications in such dimensions through simulation studies.

In order to realize the VGT as a 3D practical system, the actual design of the nodal points where the truss members are connected is quite important; this can also be said to be as one of the traditional issues in the study of VGT. We propose a design of the nodal points that takes account of the characteristics of the SMA wires. In 3D case, the existence of the so-called nodal offset cannot be avoidable. We also discuss the influence of the nodal offset on the performance of the SMA-wire actuated VGT.
Damage Detection of Wind Turbine Blades

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New generation wind turbines are gaining a leading role in the energy market by becoming larger and being placed at less accessible locations such as offshore sites. One of the key challenges is a reliable Structural Health Monitoring of the blades. Detection of damage at the early stage is a crucial issue as blade failure could have a catastrophic result for the entire wind turbine.

Experimental measurements of Frequency Response Functions FRFs are extracted by using LMS systems and through input/output acquisition techniques, identification of modal shapes is performed.

Intelligent fault diagnosis methods is introduced by adopting novelty detection and applied to the blade structure. The method used is statistical outlier analysis which allows a diagnosis of deviation from normality. Fault diagnosis of wind turbine blades is "grand challenge" due to variable aerodynamic loads, environmental conditions and gravitational loads. It will be shown that vibration dynamic response data combined with novelty approach on all involves an online structural damage method. Outlier analysis is a robust statistical method for low-level damage detection which has not yet widely used in condition monitoring of blades.

The paper puts forward a smart structures approach to SHM for wind turbine blades that combines vibration based methods and novelty detection.
Semi-Active Vibration Control for Magnetorheological Seat Suspension Systems with Shock and Time-Delay

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In particular, Magnetorheological (MR) dampers have found considerable attraction in vibration reduction of bridges, helicopter rotors, truss structures, suspension seats, seismic reduction and vibration isolator, etc. Semi-active control with MR dampers for vehicle seat suspension systems have also been studied by many researchers. Many control strategies such as skyhook, groundhook and hybrid control, H-infinity control and model-following sliding mode control have been evaluated in terms of their applicability in practice. However, in case of results in aforementioned control method cannot be applicable the condition of the shock. It is well known that vehicle seat suspension systems are often disturbed by shock in the road, which may affect the ride comfort. In this paper the control problem is investigated for a class of semi-active seat suspension systems with the shock affect, norm-bounded parameter uncertainties and time-varying input delay. A vertical vibration model of human body, which is described by impulse differential equation is introduced in order to make the modeling of seat suspension systems more precise. By employing a Lyapunov function and exploring the theory of impulse differential equation, the existence conditions of the desired state-feedback controller are derived in terms of linear matrix inequalities (LMIs). The controller is derived by solving the LMIs such that the shock effect of seat suspension systems have been apparent decreased. A design example is presented and the simulation results show that maximum peak acceleration of seat suspension systems can be inhibited and the developed vibration controller has good isolation performance.
SMA actuator for Aerodynamic Load Control on Aircraft Wings

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This paper presents the results of the development of an actuator based on embedded Shape Memory Alloys (SMA) wires, which was developed to work as an aerodynamic load control surface on aircraft wings. The beam-like actuator was made out of a flexible polymer (anionic polyamide-6). The prestrained SMA wires were placed in small channels that go through the actuator. The wires were mechanically gripped at both ends in order to ensure their stability. These channels have the suitable size to keep the wires on their proper place, but also to let a forced airflow go through them. Pressured air was used to cool the wires after heating them by Joule Effect. In order to prevent permanent bending of the actuator, two sets of SMA wires were embedded. One set was located at each side of the neutral axis of the actuator so that bending in two directions is possible.

Fuzzy Logic Control (FLC) was used to control the actuator. This choice was made due to the nonlinear behavior of the SMA wires, besides their hysteresis. The inputs are: the error between the setpoint (desired deflection) and the measured deflection, the time derivative of the setpoint, and the current value of the setpoint. The outputs are: a heating signal that is split to both sides of the actuator, and two signals to the valves that control the airflow through the channels. First, an antagonist set-up was tested, which presented a similar thermo-mechanic behavior to the beam-like actuator, but eliminating the effect of the dynamics of the beam. A bandwidth of 1Hz was achieved. Secondly, the controller was tested on the actuator. Relatively small error was observed for sinusoidal response until 0.6Hz.

Keywords: Shape Memory Alloys, morphing surface control.
Biomolecular detection has become an emerging research field in micro-electro-mechanical system (MEMS) because of its potential applications. Various detection mechanisms, such as surface-plasma-resonance (SPR) and micro-resonator, have been proposed and implemented. To be employed in applications, however, these developments are limited by the complicated read-out circuits and tedious fabrication processes. To overcome these obstacles, a fully integrated biomolecular detection system-on-chip (SOC) is proposed and examined. Utilizing a 0.35μm CMOS Bio-MEMS process step, the microcantilever based biosensor, readout circuits, MCU, and RF transceiver are implemented.

Briefly, the detection of the microcantilever is based on piezoresistors constructed with N+ poly2 layer. On the top of the microcantilever, the Au layer is deposited by post-process to improve the immobilization of the probe DNA. Furthermore, the microcantilever is freed by dry etching in post-process. Because of the surface-stress change induced by DNA hybridization, the microcantilever structure bends and leads to the variation of piezo-resistance. As a consequence, the biomolecular detection can be achieved by extracting the resistance variation using electronic-interface circuits. To examine the developed SoC sensitivity, a 19-mer nucleotide of Hepatitis B Virus (HBV), which is one of the most critical viral infectious diseases in Asia, is used as the target Deoxyribonucleic acid (DNA) in this work. The experimental results show that the developed device can achieve the specific label-free DNA detection over a concentration range from 100pM to 1μM. In addition, the SoC also demonstrates successful detection of HBV DNA from the 1 base-pair mismatching DNA. These results demonstrate the developed DNA sensor is functional for clinical application.

In summary, an integrated wireless biomolecular detection SoC is implemented in a 0.35μm CMOS bio-MEMS process with a die size of 30.4mm² and low-power consumption of 18.6mW. This work is the first time to realize fully integrated biomolecular detection SoC by standardized CMOS processes.
A Polymeric Fiberoptic Metal Sensor for Metal Capable of Profile Detection

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Currently metal detectors operate on three basic technologies: very low frequency (VLF), pulse induction (PI), and beat-frequency oscillation (BFO). Besides, these different types of sensors appear in everyday life as either a walk-through or hand held device. They are commonplace in airports, libraries, prisons, stores and shops. However, these devices share the common disadvantages of not being able to detect the profile of metal object. The purpose of this paper is to present a portable metal detector capable of detecting different shapes and geometry of a metal object using a fiber-optic magnetostriction sensor. This ferromagnetic polymeric metal detector system is small and easy to fabricate. Because it is an optical sensor, it is also resistant to RF interference (which is common in typical electromagnetic type metal detectors).

The detector system utilizes a simple DC magnetic field detection scheme that uses magnetostriction and interferometer to create the metal detection. The basic concept of the metal detection is based on monitoring strain-induced optical path length change in the interferometer stems from the magnetic field induces magnetostrictive effect on the ferromagnetic coating. The magnetostrictive device can produce polarized magnetic fields that have temporal characteristics, similarly generated from walk-through metal detectors system. Metal detection is made possible by disrupting the magnetic flux density present on the magnetostrictive sensor. This paper discusses the magnetic properties of the ferromagnetic polymers. In addition, the measurement of different geometrical metal shapes will also be presented and results will be compared with the actual geometry of the metal objects.
Fabrication of Ternary System Lead-Free Piezoelectric Ceramic Bismuth Sodium Titanate–Bismuth Potassium Titanate-Barium Titanate Ceramics Prepared Using the Combustion Technique

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Recently, lead-free materials with high dielectric and piezoelectric properties have attracted considerable attention to replace the lead containing ferroelectrics. Bi₀.₅Na₀.₅TiO₃ (BNT) is considered as one of promising lead-free piezoelectric materials due to a large remnant polarization (Pᵣ = 38 μC/cm²) at room temperature and a high Curie temperature (Tₑ = 320 °C). However, BNT ceramics is difficult to be poled because of its high coercive field (Eₑ = 73 kV/cm) and high conductivity, causing a difficulty in obtaining desired piezoelectric properties. To solve this problem, Bi₀.₅Na₀.₅TiO₃-based multi-component solid solution systems have been developed [1-4]. It has been found that ceramics with good piezoelectric properties can be obtained by the partial substitution of A-site ions (Bi₀.₅Na₀.₅)²⁺ by Ba²⁺, (Bi₀.₅K₀.₅)²⁺ and others [5-6]. In this work, a ternary system lead-free piezoelectric ceramic bismuth sodium titanate–bismuth potassium titanate-barium titanate was studied. a[0.935(Bi₀.₅Na₀.₅)TiO₃-0.065BaTiO₃]-(1-a)[0.8(Bi₀.₅Na₀.₅)TiO₃-0.2(Bi₀.₅K₀.₅)TiO₃]; BNBK ceramics with 0≤ a≤ 1 were successfully fabricated using the combustion technique. The effect of sintering temperatures (1050-1200 °C) and the changing of proportion of a on the phase formation, microstructure, dielectric properties of perovskite BNBK ceramics were investigated. XRD results of BNBK ceramics with 0≤ a≤ 1 showed the rhombohedral-tetragonal morphotropic phase boundary (MPB). At the same a content, the SEM results showed the average grain size increased with the increase of sintering temperatures. The effect of the a content had no influence on grain sizes. The optimum temperature in all samples obtained from the ceramic sintered at 1150 °C, which showed the maximum density, shrinkage, dielectric constant at Curie temperature, remanent polarization (Pᵣ), coercive field (Eₑ) and high piezoelectric constant (d₃₃). The dielectric constant was related to the density of the sintered ceramic.
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