

Program for the Symposium on the
Mechanics of Slender Structures

MoSS 2008

July 23 – 25, 2008

Hosted by

University of Maryland Baltimore County, U.S.A.

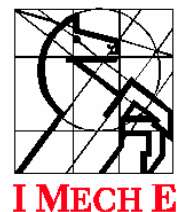


In collaboration with



Technical Committee on Vibration and Sound

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Welcome

This program contains abstracts of presentations for the Symposium on the Mechanics of Slender Structures (MoSS) 2008 held at the University of Maryland, Baltimore County (UMBC) in USA from 23rd to 25th July, 2008. The symposium has been organized in collaboration with the Stress and Vibration Group of the Institute of Physics and the Technical Committee on Vibration and Sound of the American Society of Mechanical Engineers. It follows a seminar on “Ropes, Cables and Chains: Theory and Applications” held in Northampton in 2004 and the MoSS Symposium 2006.

The Organizing Committee welcomes all attending the MoSS 2008 Symposium and hopes that the attendees will find the technical program both interesting and challenging.

Applications of slender structures include terrestrial, marine, and space systems. Moving elastic elements such as ropes, cables, belts, and tethers are pivotal components of many engineering systems. Their lengths often vary when the system is in operation. The applications include vertical transportation installations and, more recently, space tether propulsion systems. Traction drive elevator installations employ ropes and belts of variable length as a means of suspension, and also for the compensation of tensile forces over the traction sheave. In cranes and mine hoists, cables and ropes are subject to length variation in order to carry payloads. Tethers experiencing extension and retraction are important components of offshore and marine installations, as well as being proposed for a variety of different space vehicle propulsion systems based on different applications of momentum exchange and electrodynamic interactions with planetary magnetic fields. Furthermore, cables and slender rods are used extensively in civil engineering; in cable-supported bridges, guyed masts, and long-span roofs of buildings and stadia. Suspended cables are also applied as electricity transmission lines. Chain drives and chain saws are used in various power transmission systems. Moving conveyor belts are essential components in various material handling installations. Other structures such as pipelines, lightning masts, flexible robots, medical needles, and DNA molecules also fall into this category.

The behavior of slender structural elements plays a significant role in the performance of the host structure and a holistic approach is needed in the analysis and design of the entire system. This conference brings together international experts in various fields, including dynamics and vibration, fluid-structure interaction, vibration control, structural mechanics, electrodynamics, kinematics and robotics, structural health monitoring, materials science, and applied mathematics, to discuss the current state of research as well as rising trends and direction for future research in the area of mechanics of slender structures. The event is aimed at improving the understanding of the behavior of slender structures and their interactions with such environments as fluid flows, magnetic fields, and control systems. The methods for the suppression of adverse dynamic responses of slender structures will also be addressed. The presentations at the conference cover analytical, numerical, and experimental research in various applications of slender structures.

The Organizing Committee would like to thank the authors for their hard work and high quality contributions, and the members of the Scientific Committee for their time and effort in reviewing the papers. The Organizing Committee also wishes to thank the invited and keynote speakers for their participation. Finally, the organizers gratefully acknowledge the support from the UMBC administrators, especially Drs. Panos Charalambides, Shlomo Carmi, and Warren DeVries, for their support to host the conference at UMBC; they would also like to thank Ms. Cindy Lutz and several students for their help with the planning of the conference.



Weidong Zhu
Co-Chair and Host
Baltimore, USA

July 2008



Stefan Kaczmarczyk
Co-Chair
Northampton, UK

Tuesday, July 22

18:30 - 20:30 Welcome Buffet Dinner with a Free Bar at the Holiday Inn BWI

Welcome Remarks by Warren DeVries, Dean, College of Engineering and Information Technology, University of Maryland, Baltimore County (UMBC)

Wednesday, July 23

8:00 and 8:30

Holiday Inn BWI Shuttle Will Leave the Hotel for UMBC at 8:00 and 8:30

08:30 – 11:00

PUP Atrium

Registration

09:00 – 09:20

PUP 105

Introduction: Weidong Zhu

Opening Remarks

C. Dan Mote, Jr., President, University of Maryland, College Park

09:20 – 10:10

PUP 105

Chair: Noel Perkins

Keynote Lecture 1: Dynamics of Cylinders, Plates and Shells in Contact with Axial Flow: a Review and Some New Developments

Michael Païdoussis, McGill University (Canada)

Abstract. Some of the principal applications of these systems in engineering applications or in nature are mentioned first, to motivate this talk, ranging from nuclear engineering to snoring and aircraft engines, from oil exploration to swimming fish and ocean mining. The linear dynamics of pipes conveying fluid with various end conditions is then recalled, as a paradigm in the dynamics of all such systems, followed by a review of the similarities in both mathematical and physical terms with the dynamics of cylindrical shells, cylinders and plates subjected to axial flow. The post-critical dynamical behaviour of pipes conveying fluid and differences in nonlinear behaviour of pipes, shells, cylinders and plates are discussed next, focusing on some new work. A characteristic of this new work is the close synergy between theory and experiment. As a result, a number of paradoxes have been resolved, and new insights gained into the nonlinear dynamics of these systems. E.g., in one case (shell with supported ends conveying fluid) the system had been observed to lose stability by flutter, whereas theory and energy considerations suggested it should do so via static divergence; in other cases discrepancies in dynamical behaviour as predicted by linear and nonlinear theory have been clarified, more specifically with regard to post-divergence flutter of shells conveying fluid and cylinders in axial flow. Some interesting dynamical behaviour is illustrated along the way, involving strongly subcritical loss of stability, and quasiperiodic and chaotic oscillations.

10:10 – 10:30

PUP 105

Vortex-Excited Vibrations in Bundled Conductors of Overhead Transmission Lines

Peter Hagedorn, Technische Universität Darmstadt (Germany)

Abstract. It is well known that vortex-excited vibrations are very common in overhead transmission lines. They are not very obvious, since the amplitudes are small; they may however lead to conductor fatigue in extreme cases. For single conductor lines this type of vibrations is usually damped using dampers of the Stockbridge type or similar devices. The phenomena are well understood and there are good mathematical models taking into account all the relevant parameters, which are successfully used in the design phase in order to achieve a properly damped overhead line. In the transmission of high power at a very high voltage level the situation is however different since bundled conductors are often used. A conductor bundle consists of a number of individual conductors, all at the same electric potential, which are kept at certain distances from each other by means of 'spacers'. Often these spacers are designed in a non-rigid form

	<p>as spacer-dampers. The vortex excited vibrations are then damped via the spacer-dampers and possibly additional dampers of the Stockbridge type. The mathematical modeling of the problem is however far more involved than in the single conductor case, both due to the structural modeling and also due to additional aerodynamic effects, since the flows around the individual conductors forming a bundle influence each other. The paper is devoted to some aspects of the mathematical-mechanical modeling of this problem and to the use of the model in designing a safe transmission line of the bundled conductor type.</p>
<p>10:30 – 10:50 PUP Atrium</p>	<p>Coffee Break</p>
<p>10:50 – 11:10 PUP 105 Chair: Peter Hagedorn</p>	<p>Reduced-Order Model for VIVs of Slender Risers</p> <p>Marko Keber, and Marian Wiercigroch University of Aberdeen (UK)</p> <p>Abstract. In this paper we investigate the dynamics of slender vertical risers experiencing vortex-induced vibration from the sea currents. Initially, a uniform configuration of the flow was considered. A semi-empirical model based on the Van der Pol equation was utilised to describe the effects of vortex-shedding on the structure, while the riser was modelled as a straight pipe with an internal flow and an external tensile force applied at its top. The critical condition of lock-in was assumed, with the shedding frequency set to be equal to one of the structure's natural frequencies, resulting in the resonant motion. Consequently, the system was transferred to modal space, where the analysis was carried out. The reduced-order model obtained in this way proved to be computationally very efficient, while it still contained the main characteristics of motion. Next, a weak structural nonlinearity was added to the same system to investigate the differences in behaviour. The same linear modal spaces were used as the basis, which allowed for comparisons with the previous model. However, this time each individual nonlinear normal mode included coupling terms between several linear modal planes. A convergence study showed that only a small number of linear modes retained in the analysis sufficed for the response to be adequately described in the time domain, but their influence on the overall dynamics was substantial. It was observed that the structural nonlinearity caused stiffening in the response, which resulted in a change of the natural frequency as well as the amplitude of oscillation for the coupled system.</p>
<p>11:10 – 11:30 PUP 105</p>	<p>Role of Geometrically Evolving Mechanics in Vortex-Induced Vibrations</p> <p>Robert F. Zueck, Naval Facilities Engineering Service Center (USA)</p> <p>Abstract. Vortex-Induced Vibrations (VIV) are large meta-stable motions transverse to fluid flow in slender bluff-bodied structures. Assuming a simple linear representation of the structure, classical efforts for VIV study focus largely on the complexity of the fluid field. In contrast, the effort summarized in this paper focuses on the nonlinear three-dimensional geometrically-evolving mechanics of the slender structure as an important mechanism for initiation and characterization of VIV. Simulated VIV of a rigid cylinder, which is supported in the cross flow direction by two tensioned strings, are presented for two different simple loadings: 1) a singular initial structural velocity impulse and 2) a coupled harmonically-varying fluid velocity vector.</p>
<p>11:30 – 11:50 PUP 105</p>	<p>Control of Slender Structures - A Survey</p> <p>Amir Lotfi, and Christopher D. Rahn Pennsylvania State University (USA)</p> <p>Abstract. Slender structures can often be succinctly modeled by a set of partial differential equations (PDEs) and boundary conditions. Discretization of this elegant formulation and application of a black box controls approach can result in unnecessarily complex control algorithms that are difficult to implement and devoid of physical basis and insights. Additionally, these controllers may cause spillover stabilities in the unmodeled modes. Using a PDE model-based approach, however, overcomes these limitations and can often result in a simple and physically motivated control law. This approach is challenging, however, because the analysis is often complex and the control laws may not be implementable. In this paper, we review PDE-based control algorithms for slender structures. Feedforward controllers shape the input based on the PDE model to ensure setpoint regulation without residual vibration. Iterative/repetitive controllers force the</p>

	<p>PDE system out-put to track a periodic motion by learning the response and updating the control input for the current period based on previous periods. Adaptive controllers stabilize the response of slender structures without requiring exact knowledge of the system parameters. Backstepping controllers compensate for actuator dynamics while maintaining stability of the PDE model. Examples and experimental results from the authors' previous research are highlighted.</p>
<p>11:50 – 12:10 PUP 105</p>	<p>Exact Parametric Instability Regions of Second-Order Distributed Structural Systems with Periodically Varying Parameters</p> <p>¹Weidong Zhu, and ²Nengan Zheng ¹University of Maryland, Baltimore County, and ²A.O. Smith Electrical Products Company (USA)</p> <p>Abstract. Parametric instabilities in distributed structural systems are often analyzed by applying Floquet theory to their spatially discretized models, and the results obtained may not accurately represent the behavior of the distributed systems. A novel method using the fixed point theory is developed to determine the exact parametric instability regions of several second-order distributed structural systems with periodically varying parameters. The method is based on the non-dispersive wave behavior of the distributed systems. The methodology is demonstrated on several examples, including a translating string with a constant length and a sinusoidally varying velocity, a translating string with a sinusoidally varying length, a stationary string with one or two sinusoidally moving boundaries, and a translating string with a periodically varying tension. The parametric instabilities of these systems are characterized by bounded displacements, unboundedly growing vibratory energies, and formation of shock waves. The period-1 instability regions in a parameter plane are obtained analytically using the new wave method. A general formulation for calculating the period-i ($i > 1$) instability regions is presented. The basins of attraction for period-1 attracting fixed points are obtained analytically and a physical explanation of shock wave instabilities is provided.</p>
<p>12:10 – 13:10</p>	<p>Buffet Lunch at the Skylight Room, UMBC</p>
<p>13:10 – 13:30 PUP 105 Chair: Chris Rahn</p>	<p>On Computing Internal Resonances and Damping Rates for Some Slender Mechanical Structures</p> <p>Wim T. van Horssen, Delft University of Technology (The Netherlands)</p> <p>Abstract. In this paper two mathematical problems in the analysis of vibrations of slender, continuous structures will be addressed. The first problem involves the difficulties when an infinite series (or a Fourier series) is truncated to a finite series to describe the solution of the problem. The main questions then are whether the truncation method can be applied or not, and when it is applicable: how many oscillation modes should be included in the finite series to obtain an accurate approximation of the solution on a sufficiently long time-scale. This problem will be illustrated with, and will be solved for an initial-boundary value problem for a linear equation describing an axially moving stretched beam for which the axial velocity is assumed to be time-varying. The second problem involves the mathematical difficulties when the complex-valued eigenvalues (and so, the eigenfrequencies and damping rates) have to be approximated. These eigenvalues usually have to satisfy a transcendental equation with one (or more) small parameter(s). The asymptotics for small or large eigenvalues is usually different. For the horizontal vibrations of a vertical beam with a tuned mass damper at the top it will be indicated how these mathematical problems can be solved.</p>
<p>13:30 – 14:20 PUP 105</p>	<p>Keynote Lecture 2: The Slender Mechanics of DNA and its Many Roles in Biology</p> <p>Noel Perkins, University of Michigan (USA)</p> <p>Abstract. DNA is arguably one of the most slender “structures” in existence. At the molecular level, this long-chain biopolymer has a contour length that is seven orders of magnitude greater than its diameter and it must achieve an organized, ten thousand-fold compaction merely to ‘fit’ within the micron-sized dimensions of the cell nucleus. In nature, this amazing molecule is subject to considerable bending and twisting, often through the actions of numerous proteins. At these length scales, the energetic cost of bending and twisting (strain energy) is significant in that it may rival or even exceed the available thermal energy. Thus, understanding the functioning of DNA in the cell naturally requires a fundamental knowledge of how the molecule becomes bent and twisted. We will open this talk by reviewing the basic chemistry, length scales, and functions of DNA in the cell. We will learn that major DNA functions (e.g., compaction in forming chromatin, gene transcription, replication and repair) are intricately linked to DNA ‘structure’. By structure, we refer to the topology and</p>

	<p>energetics of the molecule and on multiple length scales. Following this introduction, we shall explore the structure of the molecule by first introducing a mechanics-based ‘rod’ model for the nonlinear, two-axis bending and torsion of the DNA double helix. A computational form of this model will then be used to examine canonical deformations of the molecule including DNA supercoils and loops. One example will focus on the twisting of the molecule into interwound supercoils known as plectonems. A second example will include the looping of the molecule by regulatory proteins. In particular, we shall predict the DNA loops for wild-type and mutated forms of the so-called lactose-repressor protein from the bacterium <i>E. coli</i>. We will close by critically comparing these predictions to the experimental evidence now available in the literature.</p>
<p>14:20 – 14:40 PUP 105</p>	<p>Magnetically-Induced Buckling of Conducting Wires and Instabilities of Electrodynamic Space Tethers Gert van der Heijden, University College London (UK)</p> <p>Abstract. We study the effect of a magnetic field on the behaviour of a conducting slender elastic structure, motivated by stability problems of electrodynamic space tethers. Both statical (buckling) and dynamical (whirling) instability are considered and we also compute post-buckling configurations. The theory used is the geometrically exact Cosserat rod theory. In the statics case this theory leads to a system of ordinary differential equations that is found to be completely integrable if the rod is transversely isotropic, i.e., if the principal bending stiffnesses are equal. Remarkably, unlike in the non-magnetic case, adding the effect of extensibility of the wire to the model destroys integrability, leading to a multiplicity of localized solutions and spatial chaos.</p> <p>We consider two types of boundary conditions: the traditional welded boundary conditions (reasonable for a tether with relatively large attached end masses) and a novel set of boundary conditions that give rise to exact helical post-buckling solutions, allowing for a complete analytical solution of the post-buckling behaviour. Magnetically-induced buckling in the welded case is found to be described by a surprisingly degenerate bifurcation. Our results are relevant for current designs of electrodynamic space tethers and potentially for future applications in nano- and molecular wires.</p>
<p>14:40-15:00 PUP Atrium</p>	<p>Coffee Break</p>
<p>15:00 – 15:50 PUP 105 Chair: Lawrie Virgin</p>	<p>Keynote Lecture 3: Modeling of Slender Structural Members: An Asymptotic Approach to the Modeling of Composite Beams, Plates, and Shells Dewey Hodges, Georgia Institute of Technology (USA)</p> <p>Abstract. An asymptotic approach to the modeling of composite beams, plates and shells is presented. The method is based on rigorous dimensional reduction from geometrically nonlinear three-dimensional (3-D) elasticity theory using the Variational Asymptotic Method (VAM). The presentation will outline the basics of the methodology and illustrate it for composite beams and plates, starting with a 3-D intrinsic formulation of the kinematics for beams. The resulting composite beam models based on VAM are presented, along with features and capabilities of a 2-D finite element code (VABS) built around VAM. Numerical examples are presented that show the accuracy of recovered stresses to be comparable to that of 3-D finite element modeling, but at a significantly lower computational cost. The beam modeling is illustrated and applied in a variety of ways, including aeroelastic analysis of HALE aircraft, optimization of rotor blade crosssections, and elastic stability of arches. Future work involving the dynamics of beams is outlined. A 3-D intrinsic formulation for plates is then presented, and composite plate modeling by the VAM is described. The transformation of the theory to a Reissner-like model enables one to use this theory in standard plate finite element codes. Moreover, the method provides closed-form recovering relations for through-the-thickness distributions of stress and strain that are very close to the 3-D elasticity solutions for moderately thick, laminated plates, as demonstrated by numerical examples. Extension to shells is accomplished in a similar manner. Future work involving the dynamics of shells is outlined.</p>

<p>15:50 – 16:10 PUP 105</p>	<p>Analog Equation Method for Coupled Axial and Transverse Vibration of Automotive Belts</p> <p>¹Petru Razvan Scurtu, ¹Mike Clark, and ²Jean W. Zu ¹Litens Automotive Group, and ²University of Toronto (Canada)</p> <p>Abstract. The existent studies on vibrations of automotive belt drives moving belts mainly consider nonlinear effect of the transversal vibration of the belt under transversal excitation without taking in account the coupling effect between the transversal and longitudinal vibrations under longitudinal excitation. In this paper, a nonlinear model is built for a tensioned belt periodically excited longitudinally at one end with known amplitude and frequency and with the other end clamped. This model allows for coupling between periodic longitudinal excitation and transversal vibration.</p> <p>The nonlinear system is solved using the Analog Equation Method developed by John T. Katsikadelis. The two coupled nonlinear hyperbolic differential equations of the system are reduced to two uncoupled linear equations pertaining to the axial and transverse deformation of a substitute beam with unit axial and bending stiffness, respectively. The reduced equations are under fictitious time dependent load distributions with the same boundary and initial conditions.</p> <p>It is found that the transversal vibration appears as a stable and predictable beating phenomenon due to internal resonance from the periodic energy transfer between the longitudinal excitation and the transversal vibration, manifested as a standing wave. The theoretical results are in good agreement with the experimental results obtained for the transversal wave amplitude envelope. Further simulations predict the vibration amplitude and its time variation for different belt tensions, stiffness, excitation displacements, excitation forces amplitudes and frequencies. The transversal vibration amplitude shows strong dependency on initial transversal displacement at the excitation point.</p>
<p>16:10 – 16:30 PUP 105</p>	<p>On the Vibration of Helically Wrapped Webs</p> <p>¹Ernesto Lopez, ²James Masters, and ¹Sinan Müftü ¹Northeastern University, and ²CD-adapco (USA)</p> <p>Abstract. Free vibration analysis of a thin tensioned web, wrapped around a cylindrical guide in a helical manner was studied. The weak form of the equation of motion was obtained by the finite element method and the eigenvalue problem was solved numerically. The effects of parameters such as web tension guide-radius, wrap, and helix angles, web-width, and the lengths of the non-wrapped sections of the web were investigated. For non-helically wrapped webs the free edges cause a frequency clustering of the lateral-modes about the dominant longitudinal-mode. The frequency clustering diminishes when helical wrap is introduced. Eigenmodes with same mode-numbers were observed in symmetric and anti-symmetric fashion about the center of the web, for configurations with equally long unwrapped sections. Among the other parameters the web's width, tension and helix angle have the strongest effects on the natural frequencies.</p>
<p>16:45</p>	<p>UMBC Bus Will Pick Up Guests at 16:45, Leave First for the Holiday Inn BWI, and Arrive at the Harbor Cruises at 17:40</p>
<p>19:00-22:00</p>	<p>Buffet Dinner Cruise with a Free Bar, with Boarding at 18:30</p>
<p>22:00</p>	<p>UMBC Bus Will Pick Up Guests, and Drop Them Off at the Holiday Inn BWI at 22:30</p>

Thursday, July 24

8:00 and 8:30	Holiday Inn BWI Shuttle Will Leave the Hotel for UMBC at 8:00 and 8:30
08:30 – 11:00 PUP Atrium	Registration
09:00 – 9:50 PUP 105 Chair: Marian Wiercigroch	<p>Keynote Lecture 4: Mechanics of Loops and Arches Lawrie Virgin, Duke University (USA)</p> <p>Abstract. This talk will focus on the deflection and dynamic behavior of very slender structures. For such systems gravity provides a natural loading device, and buckling is a typically encountered feature. Three distinct systems will be considered. First, a looping arch constructed from a material with a softening spring characteristic is examined. The phenomenon of interest is the sub-critical pitchfork bifurcation. An approximate energy analysis is followed by a more detailed approach. Second, a pinched loop is described in which the ends of a clamped-clamped beam are brought together, and orientation of the loop is shown to have a strong effect on subsequent behavior. Finally, a deep arch is subject to end rotation such that snap-through buckling occurs. All of these systems are described analytically in terms of the elastica, and experimental verification is conducted.</p>
9:50 – 10:10 PUP 105	<p>Analysis of Heavy Vertical Cantilever Oscillations ¹Sophia T. Santillan, and ²Lawrence N. Virgin ¹United States Naval Academy, and ²Duke University (USA)</p> <p>Abstract. The free vibration of a vertically-oriented, thin, prismatic cantilever is influenced by weight. That is, the natural frequencies are affected by the application of a linearly varying axial load. A practical example of this occurs in the analysis of marine risers in which gravity and buoyancy effects must be included. A beam with an “upward” orientation, i.e., with the free end above the clamped end, will experience a destiffening effect, up to the point of self-weight buckling (at zero effective stiffness). A beam in a “downward” orientation will be stiffened by the weight of the beam. Here, a shooting method is used to find small-amplitude vibration frequencies for the cantilever with varying weights in the two orientations, and experimental results agree well with the numerical values. The effect of gravity may also be studied by placing a mass at the free end of the beam. The weight of the beam is then negligible and an analytical solution for the frequency as a function of end mass is found. Experimental methods verify the result that an increase in end mass decreases the frequency of the upright beam and increases that of the hanging cantilever. In addition, large-amplitude, in-plane beam vibration of the heavy vertical cantilever is investigated using numerical, finite difference simulations applied to the dynamic elastica model. The governing nonlinear boundary value problem is described in terms of the arclength, and the beam is treated as inextensible. Because the elastica equations do not limit the amplitude of motion, they can be used to accurately describe motion with a large range of deflection sizes. The system is discretized along the arclength, and second-order-accurate finite difference formulas are used to generate time series of large-amplitude motion of an upright cantilever. An numerical backbone curve is generated and compared with perturbation method results in the literature where the self-weight of the beam is neglected. The method is also used to characterize large-amplitude first-mode vibration of the cantilever with nonzero self-weight.</p>

<p>10:10 – 10:30 PUP 105</p>	<p>Generating Equilibrium Conformations of Slender Elastic Structures Using the Euler-Poincare Equation Gregory S. Chirikjian, Johns Hopkins University (USA)</p> <p>Abstract. Three kinds of slender elastic structures are surveyed in this paper: (1) elastic-filament models of double stranded DNA loops with a length in the range from 50-350 base pairs that has ends constrained in position and orientation; (2) snakelike robot arms in which an artificial "backbone curve" of minimal variation is used to describe the overall geometry subject to the constraint that the "hand" reach the desired location; (3) active cannulas in which concentric hyper-elastic tubes of different initial shapes are twisted and translated relative to each other, thereby resulting in time-varying equilibria. In all of these problems the equilibrium conformations (i.e., the minimal energy shape) subject to constraints is obtained in a coordinate-free way by using the Euler-Poincare Equation applied to the Lie groups $SO(3)$ and $SE(3)$.</p>
<p>10:30 – 10:50 PUP Atrium</p>	<p style="text-align: center;">Coffee Break</p>
<p>10:50 – 11:10 PUP 105 Chair: Richard Chaplin</p>	<p>Detection of Damage in Slender Structures Using Changes in Natural Frequencies ¹Weidong Zhu, ¹Benjamin Emory, and ²Guangyao Xu ¹University of Maryland, Baltimore County, and ²Eigen (USA)</p> <p>Abstract. A recently developed iterative algorithm is used to accurately detect the locations and extent of damage in slender structures, whose lengths are much larger than their cross-sectional dimensions, using only changes in their first several natural frequencies. The method combines a multiple-parameter perturbation method and the generalized inverse method. While the system equations can be severely underdetermined, the iteration eventually converges to a solution that closely represents the desired solution in most cases. When the iteration does not converge to a solution that closely represents the desired solution, a measurement enrichment method is developed to augment the system equations, and methods to handle ill-conditioned system equations are developed when some of the system equations are almost linearly dependent. The methodology is demonstrated on several slender structures, including beams, lightning masts, and elevator cables. Experimental results are shown to validate the theoretical predictions.</p>
<p>11:10 – 11:30 PUP 105</p>	<p>The Use of Baseline Measurements for Improved Damage Detection Using Damage Location Vectors ¹Khaled F. Mostafa, and ²Mustafa H. Arafa ¹University of Akron (USA), and ²American University in Cairo (Egypt)</p> <p>Abstract. This paper is concerned with investigating, both theoretically and experimentally, vibration-based damage detection using damage locations vectors while attempting to achieve an enhanced sensitivity through comparisons with baseline measurements of an initially damaged structure. The method is first studied theoretically on a space truss using simulated damage to illustrate its capability. The method is then improved to handle randomly assigned initial damage that is not predicted by the FEM. The improved method is finally tested experimentally on cantilever beams and was effective in identifying damage that would otherwise be concealed within an initially damaged structure.</p>
<p>11:30 – 11:50 PUP 105</p>	<p>Life Prediction of Serpentine Accessory Belt Drive Systems: Theory and Experiment ¹S. Karunendiran, ²J.W Zu, and ¹M.Clark ¹Litens Automotive Group, and ²University of Toronto (Canada)</p> <p>Abstract. The onset of catastrophic belt failure occurs in accessory drive system when the rubber cracks / or internal cords loose their resilience and become brittle. This limits the performance of automotive front-end accessory serpentine belt drive. A new fatigue life model for predicting accessory belt lives subjected to various loading is developed in this study. The stress-life approach is employed to create the belt life equation where serpentine belt rib stresses are used as the damage parameter. The multi axial state of stress in the belt</p>

	<p>rib tip is related to an equivalent uniaxial stress by employing the Sines method and the total mean stresses are derived using the individual mean and the fluctuating stresses as in Sines method.</p> <p>To simulate the stress state between the V-ribbed belt / pulley, two-dimensional and three dimensional finite element models were built in order to study the stress distribution in the ribs of the belt. The results obtained from the finite element (FE) belt model correlates well with the measured strain results which therefore validates the FE belt model and the stresses due to belt pre-tension, power transmission, bending and radial compression are computed using the correlated finite element model. FE run time is long for each individual stress prediction mainly due to the model size. In order to speed up the calculation process, several discrete stress cases were first computed and for real load values the intermediate values were obtained via a curve fit routines to the computed values. From the results produced by the belt durability machine, the fatigue index, b, and the fatigue strength coefficient, σ_f, are estimated empirically for the serpentine belt. The validity of belt fatigue model is illustrated via experimental results.</p>
<p>11:50 – 12:10 PUP 105</p>	<p>Fluid-Structure Interaction Phenomena in Automotive Piping Systems</p> <p>Jan Herrmann, and Lothar Gaul University of Stuttgart (Germany)</p> <p>Abstract. Hydraulic piping systems such as fluid-filled break or fuel pipes in automotive applications undergo strong acoustic excitation due to pressure pulsations of pump and valve operation. In order to obtain a complete and reliable understanding of the vibration and fluid-structure interaction phenomena in spatial piping systems, a test rig is presented, consisting of a dynamic pressure source and a fluid-filled break pipe with an attached target structure. With the proposed experimental setup, it is possible to quantify the acoustic sound transmission and to examine the dynamic behavior by transfer functions. The experimental results are compared with finite element simulations employing efficient model order reduction techniques for the fluid-structure coupled system. This research focuses on the optimal mounting position of the fluid-filled break pipe in order to minimize the structure-borne sound induced on the target structure. Besides, the target structure is replaced by implementing an impedance boundary condition in the reduced simulation model in order to avoid full modeling of large automotive target structures.</p>
<p>12:10 – 13:10</p>	<p>Buffet Lunch at the Skylight Room, UMBC</p>
<p>13:10 – 13:30 PUP 105 Chair: Robert Zueck</p>	<p>Flow Separation of a Smooth Circular Cylinder in the Critical Reynolds Number Regime</p> <p>Arash Raeesi, Shaohong Chen, and David S-K Ting University of Windsor (Canada)</p> <p>Abstract. The spatial structure of flow separation around a circular cylinder in cross-flow has been investigated based on surface pressure collected along the span for Reynolds numbers from 1.14×10^5 to 5.85×10^5, covering sub-critical, single-bubble and two-bubble regimes. Separation angles and their spanwise correlations were deduced from the measured surface pressure. Results indicate the possibility of co-existence of different flow regimes along the cylinder span, at both the lower and upper limits of the single-bubble regime. This seems to confirm that the flow around a circular cylinder in the critical Reynolds number regime is truly three dimensional.</p>
<p>13:30 – 14:20 PUP 105</p>	<p>Keynote Lecture 5: Active Tendon Control of Cable Structures at ULB: Theory and Experiments</p> <p>André Preumont, Mohamed EI Ouni, and Arnaud Deraemaeker Université Libre de Bruxelles (Belgium)</p> <p>Abstract. The paper describes the research work conducted at ULB over the past 10 years on the tendon control of cable structures, with applications to cable-stayed bridges and large space structures. The control strategy uses an active tendon which combines a collocated sensor/actuator pair consisting of a force sensor and a displacement actuator. The first part of the paper develops the theory; it is shown that the control strategy has the following advantages: (1) It does not rely on a model of the structure, and is very robust; (2) The performances are very easy to predict from the knowledge of the natural frequencies of the structure with the active cables attached (open-loop poles) and with the active cables removed (open-loop zeros). The second part compares the theoretical results with experimental ones</p>

	obtained on laboratory scale models representative of a space truss and a cable-stayed bridge; the correlation between theory and experiment is excellent. Finally, the paper describes a large scale demonstrator of a cable-stayed bridge built in the framework of the EU-funded project ACE.
14:20 – 14:40 PUP 105	<p>Multibody Systems with Large Deformation Beams</p> <p>Yingjie Lu, Dapeng Zhu, Jiali Tang, Zhihua Zhao, and Gexue Ren Tsinghua University (China)</p> <p>Abstract. This paper studies the modeling and solving of multibody systems with both rigid bodies and flexible beams or cables. The flexible cable or beam is modeled by employing large deformation beam formulations available from literatures and are coupled to rigid bodies by enforcing algebraic constraints. The resulting differential algebraic equations are solved with the Gear’s BDF method in the index 3 form. The singularity in the formulation of large deformation beam is avoided by swapping between two sets of Euler angles. The length varying, winding cable and cable-spool contacting/sliding are addressed Several heuristic examples on cable-spool interactions are given and an application involving the dynamics and control of the cable suspended pointing mechanism and the Stewart platform for vibration reduction in the feed support system of a large radio telescope is introduced.</p>
14:40 – 15:00 PUP Atrium	Coffee Break
15:00 – 15:50 PUP 105 Chair: Wim van Horssen	<p>Keynote Lecture 6: Slender Structures: From Snake-like Robots to DNA Molecules</p> <p>Gregory S. Chirikjian, Johns Hopkins University (USA)</p> <p>Abstract. In this talk the mathematical modeling of numerous slender structures from engineering and biology will be reviewed. This includes snake-like (hyper-redundant) robots that can maneuver through complex environments, semi-flexible polymer chains such as DNA, and flexible steerable needles for minimally invasive surgical applications. Common modeling tools are used for all of these problems. These involve the use of methods from group theory, differential geometry, and probability and statistics.</p>
15:50 – 16:10 PUP 105	<p>Bending and Modeling of Channel Section Beam</p> <p>Yucheng Liu, and Michael L Day University of Louisville (USA)</p> <p>Abstract. This paper studies the bending resistances of thin-walled channel section beam in different bending modes. Numerical equations are derived to predict the bending resistances and such resistances are applied to develop simplified models for the channel section beam. The developed simplified models are compared to the detailed models and validated through a series of crashworthiness analyses.</p>
16:10 – 16:30 PUP 105	<p>Parametric Study on Axial Crushing of Thin-Walled Beams with Box Section</p> <p>Yucheng Liu, University of Louisville (USA)</p> <p>Abstract. In this paper, the dynamic crushing behaviors of steel beams with box cross sections are investigated. Systematic parametric studies were performed in order to study the effect of material properties, including strain hardening ratio and strain rate effect, length of the beam, and initial impact velocity on the crushing behaviors of the steel beams. A series of numerical models were constructed with various sets of parameters and used for numerical analyses. Maximum crushing force, mean force, and specific energy absorption (SEA) were recorded after analyses and compared to reveal the influences of the parameters. Empirical equations were also developed based on the analyses results to predict the effects of the initial impact velocity on the peak crushing forces of steel beams with box sections.</p>

<p>16:30 – 16:50</p> <p>PUP 105</p>	<p>Harmonic Modeling of Piezoelectric Thin-Film Micro-actuators</p> <p>¹Oliver J. Myers, ²M. Anjanappa, and ³Carl Freidhoff ¹Mississippi State University, ²University of Maryland, Baltimore County, and ³Northrop Grumman Corporation (USA)</p> <p>Abstract. As Microelectromechanical Systems (MEMS) become more practical and useful, there exists a need to properly characterize and model the harmonic behavior of these devices. Piezoelectric materials are commonly used for micro-actuation in MEMS devices. This paper deals with the development of numerical harmonic models of piezoelectrically actuated planar capacitor and interdigitated diaphragms. Two and three-dimensional planar capacitor samples were modelled as unimorph diaphragms with sandwiched piezoelectric material.. The harmonic frequencies were calculated numerically and agree with predicted values and deformations. Two-dimensional axis-symmetric interdigitated models were also developed. The models were able to closely predict the first two harmonics; conservatively predict the third through sixth harmonics and predict the estimated values of center deflection using plate theory. Harmonic frequency and deflection simulations would need to be correlated by conducting further iterative harmonic simulations and experiments.</p>
<p>17:00</p>	<p>Holiday Inn BWI Shuttle Will Pick Up Guests and Leave for the Hotel</p>
<p>18:30 – 20:30</p>	<p>Conference Buffet Dinner with a Free Bar at the Holiday Inn BWI</p>

Friday, July 25

8:00 and 8:30	Holiday Inn BWI Shuttle Will Leave the Hotel for UMBC at 8:00 and 8:30
08:30 – 11:00 PUP Atrium	Registration
09:00 – 09:50 PUP 105 Chair: Weidong Zhu	<p>Keynote Lecture 7: Development of Coated Steel Belts for Elevator Applications Randy K. Roberts, Otis Elevator Company (USA)</p> <p>Abstract. The Otis Elevator Company has developed a revolutionary new component to replace the traditional round steel ropes used in conventional elevators. The coated steel belt (CBS) technology involves encapsulating steel cords in a high abrasion resistant polyurethane jacket to form a thin belt which can be bent around smaller sheaves than normal round steel ropes. This technology has been applied in Otis' unique Gen2 elevator system. This paper will present some of the technical design challenges associated with the CSB development and the testing and analysis that was performed to ensure component robustness.</p>
09:50 – 10:10 PUP 105	<p>Level Setting of Elevator Seismic Detector Based on Rope Dynamics Seiji Watanabe, Kazunari Mori, and Tsunehiro Higashinaka Mitsubishi Electric Corporation (Japan)</p> <p>Abstract. A seismic-resistant design for elevator systems is important for maintaining vertical transportation. When an earthquake activates the seismic detector, elevators switch their service to "earthquake emergency operation" and, as such, prevent any trouble. Because the detector levels are related to both the building and elevator motion, those transient responses are evaluated numerically. In this paper, the detector levels are introduced after evaluating lateral rope vibration. New earthquake emergency operations for long-period ground motion is also presented, which can estimate lateral rope vibration simultaneously.</p>
10:10 – 10:30 PUP 105	<p>The Evolution of Elevator Rope Test Apparatus Rory Smith, and Chi Phan ThyssenKrupp Elevator Corporation (USA)</p> <p>Abstract. Most test apparatus for elevator ropes in use today does not subject the rope to the same conditions that the rope experiences in use. As a consequence, the results do not accurately predict rope performance in real world applications. Starting in 2001, we have been developing new types of elevator rope testing equipment. This has been an evolutionary process and the most recent machine, built in 2008, is quite different from the first machine built in 2001. The goal of these developments was to achieve accelerated testing that more accurately represented reality. The designs of the various machines are explained along with their advantages and disadvantages.</p>
10:30 – 10:50 PUP Atrium	Coffee Break

<p>10:50 – 11:40 PUP 105 Chair: Stefan Kaczmarczyk</p>	<p>Keynote Lecture 8: Interactive Fatigue in Wire Rope Application Richard Chaplin, University of Reading (UK)</p> <p>Abstract. Two technically challenging applications – deep mine hoisting and deepwater offshore mooring – are reviewed in terms of the mechanics of rope response driven by challenges of increasing depth of operation. In both cases, practical and economic solutions lead to a need to understand and quantify interactions between different modes of fatigue loading (simplistically: bending, tension and torsion) which are traditionally segregated in laboratory testing. It is shown that, to assure reliable operation, first a thorough understanding of the mechanics is essential, but also a quantitative measure of the interactions between different modes of imposed loading is required. Some results are presented showing the dramatic effect of such interactions, and an explanation of some these effects is also advanced with supporting experimental data.</p>
<p>11:40-12:00 PUP 105</p>	<p>An Accurate Spatial Discretization Method for Calculating the Dynamic Response of Elevator Cable-Car Systems Hui Ren, and Weidong Zhu University of Maryland, Baltimore County (USA)</p> <p>Abstract. The assumed modes method has often been used to calculate the dynamic response of a distributed structural system with at least one complicated natural boundary condition, and the trial functions used satisfy only the geometric boundary conditions of the system. The resulting solution can converge to the true solution in the L_2 sense, but not uniformly, and the responses at the boundaries, where the natural boundary conditions are not satisfied, cannot be calculated accurately. In this work, a new spatial discretization method is developed to resolve the above problem. The solution is expanded in such a form that all the boundary conditions are satisfied. The methodology is applied to elevator cable-car systems, where the responses of the cars need to be calculated accurately. In particular, the longitudinal vibration of an elevator system, consisting of a hoist cable, a hitch spring and damper, and a car, is analyzed. It is shown that while the assumed modes method for the cable can accurately estimate the energy of the system due to the convergence of the solution in the L_2 sense, it cannot accurately calculate the displacement at any point of the system due to the slow convergence of the solution and the fact that the trial functions do not satisfy the natural boundary condition at the lower end of the cable. On the other end, the two approaches using the new method can yield consistent and accurate results for both the displacement and the energy of the system.</p>
<p>12:00-13:00</p>	<p>Buffet Lunch at the Skylight Room, UMBC</p>
<p>13:00-13:20 PUP 105 Chair: Sinan Müftü</p>	<p>Dynamic Response of Elevator Compensating Ropes in Buildings under Wind Loading ¹S. Kaczmarczyk, ²R. Iwankiewicz, and ³Y. Terumichi ¹University of Northampton (UK), ²Hamburg University of Technology (Germany), and ³Sophia University (Japan)</p> <p>Abstract. High-rise buildings often suffer from severe vibrations induced by strong winds. The low-frequency sway of the structure can excite elevator compensating ropes installed in tall buildings. The danger arises when the building is excited near its natural frequency. If one of the natural frequencies of the compensating ropes coincides simultaneously with the natural frequency of the building transient resonance and large displacements of the ropes occur. This paper focuses on the analysis of relevant models of the building – compensating rope system to predict its dynamic response. In order to demonstrate the dynamic behaviour of the system the excitation mechanism is first represented by a harmonic process and the results of computer simulations are analyzed. However, the excitation due to the wind action is usually a wide band stochastic process and the state vector is governed by stochastic equations. Therefore, the differential equations governing the second-order statistical moments of the state vector are developed and presented.</p>

<p>13:20-13:40 PUP 105</p>	<p>The Simulation Model of the Vertical Dynamics and Control of an Elevator System</p> <p>¹Xabier Arrasate, ¹José M. Abete, and ²Stefan Kaczmarczyk ¹Mondragon Unibertsitatea (Spain), and ²University of Northampton (UK)</p> <p>Abstract. A non-stationary distributed model of the vibration of an elevator system that accommodates the following aspects has been developed: machine and drive dynamics, the longitudinal response of the rope-car-counterweight system, the coupling effects across the traction sheave and the response to excitation sources such as the torque ripple. Hamilton's principle is applied to derive a set of partial differential equations that describes the dynamic behaviour of the mechanical part. These equations are discretized by expanding the longitudinal displacements in terms of the modal shapes to obtain a set of ordinary differential equations. The discrete model is then solved numerically in MATLAB-Simulink. Parameters of actual lift installations are used in the simulations to analyse the response of the system. Experimental tests are carried out in order to identify the system characteristics and to validate the simulation model.</p>
<p>13:40-14:00 PUP 105</p>	<p>Coupled Longitudinal-Transverse Vibration of Flexible Elevator Rope</p> <p>Peng Zhang, Changming Zhu, and Liangjuan Zhang Shanghai Jiao Tong University (China)</p> <p>Abstract. To evaluate the coupled longitudinal-transverse vibration of moving flexible elevator rope, a theoretical unilateral suspension system of elevator is modeled as a taut translating rope with a load attached at its low end. A set of coupled longitudinal-transverse vibration governing equations is derived with Hamilton principle and the boundary conditions are obtained according to this theoretical model. The Galerkin's method is used to discretize the governing equations and then they can be solved with numerical methods. Then, an experimental setup of flexible lifting system is developed to evaluate the reliability of the theoretical equations. From the calculation and test results, the complex longitudinal and transverse vibrations of flexible lifting rope are revealed and the characteristics of these vibrations are analyzed.</p>
<p>14:00-14:20 PUP 105</p>	<p>Finite Element Modelling and Static Stress Analysis of Axial Loaded Wire Ropes</p> <p>C. Erdem Imrak, Said Bedir, and Eren Kayaoğlu Istanbul Technical University (Turkey)</p> <p>Abstract. Wire strands and rope are most commonly used in applications that require a combination of tensile loading and relatively low bending rigidity, such as in lifting devices like cranes. Analysis of the state of stress and strain of the wire ropes is fundamental in assessing mechanical strength. Different approaches are used to design a model for axial force and bending moment. In this study, the static stresses in the individual wires of complex wire rope are determined for loaded state. In the analyses of wire rope stresses, the Love, Phillip's and Costello's theories are used. A finite element model is constructed and the numerical solution using this model is found and the results are presented. In order to show the stress distribution in the individual wires, stress and deformation along the wire rope is analyzed in an illustrative example of wire rope. The finite element analysis results showed excellent agreement with the analytical theory and the experimental results.</p>
<p>14:20 – 14:40 PUP 105</p>	<p>Study on the Effect of External Damper on Suppressing Cable Vibration by Energy-Based Method</p> <p>N. Darivandi, S. Cheng, and F. Ghrib University of Windsor (Canada)</p> <p>Abstract. An energy-based method is developed to evaluate the damping property of a cable-damper system. The overall structural damping of the system is evaluated by introducing the concept of kinetic energy decay ratio. By applying a derived conversion method, design charts are developed which link the overall damping of a cable-damper system to the structural damping in an equivalent cable. Numerical examples are presented to demonstrate the validity and accuracy of the proposed method.</p>

<p>14:40-15:00 PUP Atrium</p>	<p>Coffee Break</p>
<p>15:00 – 15:20 PUP 105 Chair: Erdem Imrak</p>	<p>Finite Element Modeling and Stress Analysis on Guide Rails During Safety Gear Operation</p> <p>C. Erdem Imrak, Said Bedir, and Eren Kayaoğlu Istanbul Technical University (Turkey)</p> <p>Abstract. Guide Rails, as a slender element of elevator systems, are affected during movement of the car and safety gear operation by two different kinds of stresses bending and buckling. During safety gear operation is being exposed to high stresses and brake accelerations. In this study, in order to investigate stresses, deflections and deformations, the guide rail and instantaneous type safety gear are modeled. The stress analyses are performed for different loading cases and different rail support distances. The results from conventional calculation, finite element analysis and experimental set up are compared.</p>
<p>15:20-15:40 PUP 105</p>	<p>Vibration Analysis of the Lifting Units Drive System in Cable Cranes</p> <p>Christian Vorwerk, University of Stuttgart (Germany)</p> <p>Abstract. Transportation performance of cable cranes is dependent to a non-negligible degree on the drive system and the control conception. Vibration examinations and model simulations are increasingly employed to analyze and optimize existent drive systems. Commissioned by ThyssenKrupp Fördertechnik GmbH in St. Ingbert, Germany, the Institute of Mechanical Handling and Logistics (IFT) from the University of Stuttgart conducted an experimental vibration analysis on cable crane hoist drives with a view to finding basic engineering layout parameters for future drive conceptions. With the aid of an experimental determination of the natural frequencies of crane components, a conclusive data base for an engineering approach to future drive conceptions was generated. Vibration impact emergence can, thereby, be minimized as early as during the planning stages of a new crane construction through an adequate drive component precision adjustment according to vibration excitations and natural frequencies which emerge in the steel structure under practical operation conditions.</p>
<p>15:40-16:00 PUP 105</p>	<p>Nonlinear Vibrations of Cantilever Beams</p> <p>Juan Carlos Jáuregui-Correa, and Oscar Manuel González-Brambila CIATEQ, A.C. (Mexico)</p> <p>Abstract. Aerodynamic structures, and modern machinery are designed with slender elements. These elements must have a very high stiffness-weight ratio. Furthermore, speed requirements increase constantly, creating exciting forces at higher frequencies. It is the case of gas turbine fans, where the long blades are design as cantilever elements with a very thin cross section. These elements combine the slender design with high speed excitation. Traditional vibration analysis is unable to predict its dynamic behavior, because it only considers elastic deformations. But when the beam is very thin, the linear elastic theory is no longer applicable. Therefore, the best way of predicting the dynamic behavior of slender beams is through a nonlinear model. Numerical solution shows a typical harmonic distortion pattern. It is due to the fact that, in a simple case, the mathematical formulation is similar to a Duffing's equation. In this work we present the solution for a single degree beam element. We analyze the effects of the nonlinear parameters and a method for its calculation.</p>
<p>16:00-16:05 PUP Atrium</p>	<p>Break</p>

<p>16:05-16:55</p> <p>PUP 105</p> <p>Chair: Rory Smith</p>	<p>Closing Lecture: The Story of the Space Elevator</p> <p>Ben Shelef, Chief Executive Officer, Spaceward Foundation, USA</p> <p>Abstract. The Space Elevator is probably the most daring space access proposal on the drawing boards today. First proposed as a thought experiment in 1960, the Space Elevator has since evolved into a concrete and practical engineering challenge for the 21st century. This presentation by the Spaceward Foundation is a light-technical talk that covers the history, basic concept, and future prospects of the Space Elevator. The presentation is given by Ben Shelef, a co-founder of the Spaceward Foundation and a member of the Space Elevator community. An aerospace engineer by day, he dons the mask and cape of Space Elevator crusader by night, and engages in daring escapades such as running the \$4,000,000 Space Elevator competitions and giving talks like this one. For more information, see http://www.spaceward.org.</p>
<p>17:10</p>	<p>Holiday Inn BWI Shuttle Will Pick Up Guests and Leave for the Hotel</p>