Nonlinear Systems Sessions

Monday, January 30 – Thursday, February 2, 2012

ORGANIZED BY: The Nonlinear Systems Focus Group

Session 2	Nonlinear Structural Dynamics –The Fundamentals Tutorial
Session 9	Application of Nonlinearities: Aerospace Structures
Session 16	Application of Nonlinearities: Vibration Reduction
Session 23	Nonlinear Dynamics: Testing
Session 30	Nonlinear Dynamics: Simulation
Session 37	Nonlinear Dynamics: Identification
Session 44	Nonlinear Dynamics: Localization

The vast majority of real engineering structures behave nonlinearly. Therefore, in order to go *From the Laboratory to the Real World* it is necessary to include nonlinear effects in all the steps of the engineering design: in the experimental analysis tools (so that the nonlinear parameters can be correctly ***identified***) and in the mathematical and numerical models of the structure (in order to run accurate ***simulations***). In so doing it will be possible to create a model representative of the reality which (once ***validated***) can be used for better predictions. The nonlinear sessions will address theoretical and numerical aspects of nonlinear dynamics (covering rigorous theoretical formulations and robust computational algorithms) as well as experimental techniques and analysis methods. There will be one session dedicated to nonlinearity in aerospace structures and two invited speakers from the aerospace industry (DLR and AgustaWestland) will present their experience of nonlinearities in the *Real World*. Finally, one session will discuss an interesting shift in paradigm: nonlinearities are not always bad and need to be avoided, but instead they can be exploited for vibration mitigation. Because nonlinearity and its impact on the dynamics of mechanical systems might still be obscure for many conference participants, the nonlinear sessions will be kicked off by a tutorial on nonlinear oscillations given by Prof. Doug Adams (Purdue University).

Nonlinear Structural Dynamics - The Fundamentals Tutorial

Monday, January 30, 2012 • Session 2

ORGANIZED BY: The Nonlinear Systems Focus Group
PRESENTED BY: **D.E. Adams**, Purdue University

Nonlinear behaviors abound in structural systems and are challenging to identify and predict. Natural frequencies, damping levels, mode shapes, and amplitudes of response can all change unexpectedly and suddenly when nonlinear behaviors arise. How can we model and predict these kinds of behaviors? How can we design tests to observe such behavior? How do we adapt the tools of modal analysis to address engineering challenges posed by nonlinear structural dynamic behavior? This tutorial uses case studies to introduce tools and methods that can be used to address nonlinear dynamic behavior in vibration modeling and testing. Case studies are drawn from a wide range of aerospace and automotive applications involving advanced materials, components, and joints. Physical demonstrations are used to reinforce theoretical concepts and questions/discussion are encouraged.

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Experimental Dynamics Substructuring Sessions

Monday, January 30 – Wednesday, February 1, 2012

ORGANIZED BY: The Experimental Dynamics Substructuring Focus Group

Session 3 Experimental Dynamic Substructures I
Session 10 Experimental Dynamic Substructures II
Session 17 Experimental Substructures Focus Group Test Bed - Ampair 600 Wind Turbine System
Session 24 Substructure Methods I
Session 38 Substructure Methods II

Substructuring is a general paradigm in engineering dynamics where a complicated system is analyzed by considering the dynamic interactions between subcomponents. In numerical simulations, substructuring allows one to reduce the complexity of parts of the system in order to construct a computationally efficient model of the assembled system. A subcomponent model can also be derived experimentally, allowing one to predict the dynamic behavior of an assembly by combining experimentally and/or analytically derived models. This can be advantageous for subcomponents that are expensive or difficult to model analytically. Substructuring can also be used to couple numerical simulation with real-time testing of components. Such approaches are known as hardware-the-loop or hybrid testing.

Whether experimental or numerical, all substructuring approaches have a common basis, namely the equilibrium of the substructures under the action of the applied and interface forces and the compatibility of displacements at the interfaces of the subcomponents. Experimental substructuring requires special care in the way the measurements are obtained and processed in order to assure that measurement inaccuracies and noise do not invalidate the results. In numerical approaches the fundamental quest is the efficient computation of reduced order models describing the substructure's dynamic motion. For hardware-in-the-loop applications difficulties include the fast computation of the numerical components and the proper sensing and actuation of the hardware component. Recent advances in experimental techniques, sensor/actuator technologies, novel numerical methods and parallel computing have rekindled interest in substructuring in recent years leading to new insights and improved experimental and analytical techniques.

At IMAC-XXX two sessions are devoted to experimental substructuring, including a tutorial on some of the latest methodologies as well as a historical account. Two sessions will cover the latest development in numerical methods for substructuring. In a fifth session results of an international benchmark for experimental substructuring on a small wind turbine will be presented.

Note that on Tuesday, Jan. 31 at 12:00 PM, the Experimental Dynamics Substructuring Focus Group will meet to organize sessions, tutorials and panel discussions for the next IMAC conference and to coordinate efforts on the benchmark system. All interested persons are welcome.

Tutorial on Experimental Dynamic Substructuring Using the Transmission Simulator Method

Monday, January 30, 2012 • Session 3

ORGANIZED BY: The Experimental Dynamics Substructuring Focus Group
PRESENTED BY: **R.L. Mayes**, Sandia National Laboratories

Although analytical substructures have been used successfully for years, practical experimental substructures have been limited to special cases until recently. Many of the historical practical applications were based on a single point attachment. Since substructures have to be connected, theoretically, in both translation and rotation degrees of freedom, measurement translation responses and forces around the single point attachment could be used to estimate the rotational responses and moments. For multiple attachment points, often the rotations and moments have been neglected entirely. In addition, often the effect of the joint stiffness and damping is neglected. The translation simulator approach developed by Allen and Mayes captures the interface forces and motions through a fixture called the transmission simulator, overcoming the historical difficulties. The experimental free modes of the experimental substructure mounted to the transmission simulator and the finite element model of the transmission simulator are used to couple the experimental substructure to another substructure and subtract the transmission simulator. This captures the effects of the joint stiffness and damping. The experimental method and mathematics will be explained with examples. The tutorial assumes a basic understanding of the linear multi-degree of freedom equations of motion and the modal approximation.

*Sandia is a multi-program laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under Contract DE-AC04-94AL85000.

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Civil Structures Testing Sessions

Monday, January 30 – Thursday, February 2, 2012

ORGANIZED BY: The SEM Civil Structures Testing Technical Division

The Civil Structures Testing TD serves as a primary focal point within the SEM umbrella for technical activities devoted to civil structures testing, monitoring and assessment. Please note that the TD holds its annual meeting during IMAC (IMAC-XXX: Tuesday, January 31, 2012, 12:00 PM). Four special sessions and a Civil TD programmed session track devoted to large civil structures span the full IMAC-XXX conference schedule. Special sessions of interest to civil attendees are scheduled during the first three days of the conference.

Session 6 & 13	Human Loading on Civil Structures I & II: Monday morning and afternoon
Session 20	Vibration Control of Civil Structures: Tuesday morning
Session 27	Bridge Dynamics: Tuesday afternoon
Session 34	Experimental Techniques and Modeling for Civil Structures: Wednesday morning
Session 41	System Identification for Civil Structures: Wednesday afternoon
Session 47	Method and Technologies for Bridge Monitoring: Thursday morning
Session 48	Damage Detection for Civil Structures: Thursday morning
Session 54	Vibration Control Method and Approaches for Civil Structures: Thursday afternoon
Session 55	Modal Testing of Civil Structures: Thursday afternoon

Other sessions of interest to civil structures attendees include:

Session 21	Tutorial on Sensors and Instrumentation I, II, III: Tuesday morning, Tuesday afternoon, Wednesday morning
Session 33	Wind Turbine Sensing and Health Monitoring: Wednesday morning
Session 31	Operational Modal Analysis: Wednesday morning
Session 43	Damage Detection I: Thursday morning
Session 50	Damage Detection II: Thursday morning

A number of technical sessions devoted to new methods, non-linear dynamics, wind turbine dynamics and monitoring are also dispersed through the conference and many additional civil oriented papers can be found in other general conference sessions. The Civil TD welcomes all attendees to enjoy a very full and diverse IMAC-XXX Technical Program organized in multi-disciplinary style unique to IMAC and SEM.

Basics of Modal Analysis for the New/Young Engineer

Monday, January 30, 2012 • Sessions 7 & 14

DEVELOPED BY: **C.D. Van Karsen**, Michigan Technological University
INSTRUCTORS: **J.R. Blough**, **J.P. De Clerck**, **C.D. Van Karsen**, Michigan Technological University;
SPONSORED BY: The SEM/IMAC Modal Analysis and Dynamic Systems Technical Division

The field of Modal Analysis continues to evolve and mature. In order to allow new or young engineers in the modal field to extract meaningful information from paper presentations at the IMAC Conference, a program has been developed to familiarize the new/young engineer with some of the very basic material related to modal analysis. Held on the first day of the conference, *Basics of Modal Analysis* is geared towards those individuals who have very limited or no experience in the modal field or need a refresher on some of the basic modal nomenclature. The material is centered on the topics of single degree of freedom theory, multiple degree of freedom theory, measurements and linear algebra. The intent is to familiarize the new/young modal engineer with the nomenclature and basic techniques involved in modal analysis; the most basic fundamental equations will be explained in an overview sense rather than developed from a theoretical standpoint. These tutorial sessions should not be considered a training seminar but rather an overview of basic definitions that are inherent in most of the presentations at the conference. By attending these sessions, the new or young engineer should be able to better appreciate and comprehend more of the material that is presented in the technical paper presentations.

NEW THIS YEAR

The *Basics of Modal Analysis for the New/Young Engineer* will be expanded at IMAC-XXX. During the conference Exposition several of the IMAC vendors will be conducting demonstrations of the topics that are covered during the lecture portion of this program. The demonstrations will take place in the Technology Center area of the conference Exposition. Topics will include Impact Testing, Shaker Testing, Modal Parameter Estimation, and Basic Signal Processing.

Course Notes: To purchase a set of notes, see the registration form, or at the conference go to the Conference Registration Desk. For more information contact SEM: (203) 790-6373 • reg@sem1.com.

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Tutorial Guideline VDI 3830: Damping of Materials and Members

Monday, January 30, 2012 • Session 8

ORGANIZED *and*
PRESENTED BY: **L. Gaul**, University of Stuttgart

The guideline VDI 3830 consists of the following parts:

Part 1: Classification and Survey

Part 2: Damping of Solids
1. Physical phenomena
2. Linear models
3. Nonlinear models

Part 3: Damping of Assemblies
1. From the material to the homogeneous member
2. Laminated members
3. Damping in joints
4. Damping due to fluids
5. Damping by squeezing
6. Assemblies

Part 4: Models for Damped Structures
1. Basic model
2. Structures with finite number of degrees of freedom
3. Calculation of viscoelastic components using the boundary element method

Part 5: Experimental Techniques for the Determination of Damping Characteristics
1. Remarks on experimental techniques
2. Experimental techniques and possible instrumentation
3. Special experimental techniques for determining damping characteristics under aggrieved conditions
4. Experimental Modal Analysis (EMA)
5. Experimental techniques for the damping measurement of subsoil

The guideline starts off with the notion of damping and the causes of damping before dealing with different modelling approaches for the linear and nonlinear behaviour of solids. Linear viscoelastic materials are discussed in great detail. They are followed by the damping of assemblies, relevant to the user, by its mathematical characterisation and its relation to material damping. Models for damped structures are discussed next, and the application of the Finite Element Method (FEM) and the Boundary Element Method (BEM) is explained. Finally, as statements on damping rely on experiments, Part 5 describes established experimental techniques, possible instrumentation for the determination of damping characteristics.

Sensors and Instrumentation Tutorials

Tuesday, January 31 – Thursday, February 2, 2012

ORGANIZED BY: **G.C. Foss**, Boeing Test & Evaluation Northwest; **E.T. Wee Sit**, SVcommunity.com
SPONSORED BY: The SEM Sensors and Instrumentation Technical Division

Session 21 Tutorial on Sensors and Instrumentation I
Session 28 Tutorial on Sensors and Instrumentation II
Session 35 Tutorial on Sensors and Instrumentation III
Session 42 Tutorial on Sensors and Instrumentation IV
Session 49 Tutorial on Sensors and Instrumentation V

Credit for much of the progress in the field of modal analysis over the last twenty-five years is owed to substantial advancements in sensors, electronics and computing platforms. Many of those involved in modal analysis and testing have personal and professional interests in the associated equipment and sensors. The SEM Sensors and Instrumentation Technical Division was reorganized at IMAC 25 to address this interest.

Achieving accurate test results depends on an adequate knowledge of the test equipment; its selection, use, and limitations. This series of tutorials, presented by a distinguished group of experts, is meant to offer IMAC attendees an opportunity to learn more about their test instrumentation, and explore the application of emerging technologies such as wireless communication and energy harvesting.

The tutorials are oral presentation only, but some of the material will be posted to the SEM website at a later date.

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Info-gap Analysis and Design of Structures: A Tutorial

Monday, January 30, 2012 • Session 12

ORGANIZED BY: **S. Cogan,** University of Franche-Comte; **L. Horta,** NASA Langley Research Center
SPONSORED BY: The SEM Model Validation & Uncertainty Quantification Technical Division
PRESENTED BY: **Y. Ben-Haim**, Technion-Israel Institute of Technology

The analysis and design of structures is often accompanied by severe uncertainty in material properties, geometry, loads, and operational conditions. In this tutorial we explore several aspects of this problem from the perspective of info-gap decision theory.

We begin with an example of updating a dynamic model from measurements, when the structure of the model is uncertain. We formulate the info-gap robustness and discuss its two basic properties: zeroing and trade-off. Zeroing is the property that the estimated fidelity between model and measurement has no robustness to uncertainty in the model structure. The trade off property is that poorer fidelity has greater robustness to model uncertainty.

We then consider the probabilistic design of a structure when the relevant probability distributions are imperfectly known. We are particularly interested in severe uncertainty in the pdfs such as uncertain fat tails or uncertain mixtures of populations. In addition to the zeroing and trade off properties we also illustrate the potential for reversal of preference between design alternatives, depending on the designer's performance requirements.

Finally, we discuss the relation between optimizing and satisficing, and demonstrate how the robustness function is used in determining the degree of performance-sub-optimality that is required in order to manage the ambient uncertainty.

Bayesian and Markov Chain Monte Carlo Methods Session

Tuesday, January 31, 2012 • Session 25

ORGANIZED BY: **R. Barthorpe**, University of Sheffield
SPONSORED BY: The SEM Model Validation and Uncertainty Quantification Technical Division

This session will provide an overview of Bayesian and Markov Chain Monte Carlo (MCMC) methods and their application to engineering problems. The Bayesian paradigm is of great interest to the engineering community as it provides a principled framework for handling uncertainties in complex systems. The Markov Chain Monte Carlo method is, in turn, a useful tool for practical implementation of the Bayesian paradigm. The session will commence with a tutorial talk by a distinguished expert in field of Bayesian and MCMC methods for Reliability and Risk Analysis, Prof. Nozer Singpurwalla. Various notions central to these methods will be introduced, beginning with quantifying uncertainty via probability and the various interpretations of probability, and progressing to the introduction of Bayes' law and the statistical notion of a likelihood. This will be followed by a discussion of the notion of predictive distributions, model failure rates and predictive failure rates that are central to reliability and risk analyses. The tutorial part of the session will close with a discussion of decision making under uncertainty with a focus towards engineering design and a discussion of the Markov Chain Monte Carlo method and its usefulness for implementing the Bayesian paradigm. The presentataions that follow the tutorial will discuss various extensions and applications of the methods introduced, ranging from questions surrounding sampling techniques and uncertainty quantification to applications in damage location and system identification. The session should prove to be of interest to all engineers and researchers whose work involves dealing with issues of uncertainty, and will appeal to both the Bayesian novice and those with experience in this exciting field.

The Bayesian Paradigm for Quantifying Uncertainty and The Markov Chain Monte Carlo Method Tutorial

Tuesday, January 31, 2012 • Session 25

ORGANIZED BY: **R. Barthorpe**, University of Sheffield
SPONSORED BY: The SEM Model Validation and Uncertainty Quantification Technical Division
PRESENTED BY: **N.D. Singpurwalla,** George Washington University

In this tutorial talk, I will introduce the notion of quantifying uncertainty via probability, the various interpretations of probability, and the rules of probability for ensuring coherence. I will then discuss the law of total probability and Bayes' law. The law of total probability gives birth to the notion of a probability model (like a Gaussian or a Weibull) and Bayes' Law gives birth to the statistical notion of a likelihood. This will be followed by a discussion of the notion of predictive distributions, model failure rates and the predictive failure rates, notions central to reliability and risk analyses. The tutorial part of the talk will close with a discussion of decision making under uncertainty with a focus towards engineering design. The tutorial itself will close with a discussion of the Markov Chain Monte Carlo method and its usefulness for implementing the Bayesian paradigm. The material for the tutorial will be abstracted from the speaker's book on "Reliability and Risk: A Bayesian Perspective," Wiley UK (2006), under revision.

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Wind Turbine Dynamics Sessions

Tuesday, January 31 – Wednesday, February 1, 2012

ORGANIZED BY: **S. Chauhan**, Brüel & Kjær Sound and Vibration Measurement A/S; **D.T. Griffith**, Sandia National Laboratories

Session 26 Wind Turbine Analytical-Experimental Methods
Session 33 Wind Turbine Sensing and Health Monitoring
Session 40 Wind Turbine Modal Analysis and Identification Techniques

Governments around the world have set ambitious goals of meeting 20% of energy requirements by 2020 through renewable energy sources including wind energy. This not only requires significant increase in the number of installed wind turbines, but also design and development of high MW capacity (5MW and more) turbines. Further, it is essential that the turbines work efficiently and optimally throughout their intended life cycle. These challenges, including the growing size and complexity of the wind turbine structure, necessitate the need for designers to better understand and characterize the dynamics of the wind turbine.

Dynamic characterization based on experimentation has proved to be of considerable value in the field of mechanical engineering structures (including automotive and aerospace structures) and has also found great relevance in the civil infrastructure domain. In the case of wind turbines, this is a necessary task from the point of view of design optimization as well as validation and verification of aeroelastic design codes and development of robust control systems. It is thus imperative to validate and improve these codes by substantiating them with experimental findings. This is expected to reap benefits in terms of improved performance and reliability of the various wind turbine components, including blades, using improved design codes that make modelling and simulation based design more useful. Finally, the role of measurements, aimed at quantifying wind turbine dynamics, becomes further highlighted from the point of view of structural health monitoring, given that more and more machines are being installed on offshore and remote locations.

Having underlined the importance of dynamic characterization in wind turbine design, it is also important to understand that despite well-established techniques (Experimental and Operational Modal Analysis) for dynamic characterization of structures, their application to wind turbines is not straight forward due to the complexities involved on account of considerable aeroelastic interaction and time-varying nature of wind turbines, when in operation. No wonder these issues and challenges have attracted the research community world over. At IMAC XXX, sessions covering various aspects of wind turbine dynamic characterization and associated research areas, have been organized. These sessions showcase research activities with regards to application of modal analysis to wind turbines, preparing and updating numerical models, instrumentation and sensing on wind turbine blades and structural health monitoring as applied to wind turbines.

Acoustic Fluid-Structure Interaction of Cars and Ships Tutorial

To be programmed

ORGANIZED BY: **L. Gaul**, University of Stuttgart

Acoustic fluid-structure interaction is a common issue in automotive applications. An example is the pressure-induced structure-borne sound of piping and exhaust systems. Efficient model order reduction and substructuring techniques accelerate the finite element analysis and enable the vibro-acoustic optimization of such complex systems with acoustic fluid-structure interaction. This tutorial reviews the application of the Craig-Bampton and Rubin method to fluid-structure coupled systems and presents two automotive applications. First, a fluid-filled brake-pipe system is assembled by substructures according to the Craig-Bampton method. Fluid and structural partitions are fully coupled in order to capture the interaction between the pipe shell and the heavy fluid inside the pipe. Second, a rear muffler with an air-borne excitation is analyzed. Here, the Rubin and the Craig-Bampton method are used to separately compute the uncoupled component modes of both the acoustic and structural domain. These modes are the used to compute a reduced model which incorporates full acoustic-structure coupling. For both applications, transfer functions are computed and compared to the results of dynamic measurement.

The Vibro-acoustic behaviour of ship-like structures is noticeably influenced by the surrounding water and thus represents a multifield problem. In this tutorial, fast boundary element methods are applied for the semi-infinite fluid domain. As an advantage, the Sommerfeld radiation condition is satisfied in an exact way and only the boundary, i.e. the ship hull, has to be discretized. To overcome the draw-back of fully populated matrices, fast boundary element methods are applied. The focus is on the comparison of the multipole method with hierarchical matrices, which are set up by adaptive cross approximation. In both cases, a half-space fundamental solution is used to incorporate the water surface, which is treated as pressure-free. The structural domain is decretized with finite element method. A binary interface to the commercial finite element package AYSYS is used to import the mass and stiffness matrices. The coupled problems are formulated as Schur complements, which are solved by a combination of iterative and direct solvers. Depending on the applied fast boundary element method, different strategies arise for the preconditioning and the overall solution. The applicability of these approaches is demonstrated using a realistic model problem.