Volume 1, Issue 1 December 2008

PENNSTATE

Structural Health Monitoring

About the Center of Excellence in Structural Health Monitoring

Ben Franklin Technology PArtners
Central and Northern Pennsylvania

The center was founded in 2007 with initial funding from the Ben Franklin Technology Partners.

Vision:

Bring designers and owners of platforms that benefit from structural health monitoring (SHM) technology together with researchers and developers of SHM systems. Grow the Center by building relationships that lead to fruitful multidisciplinary collaborations between industry, academia, and government.

Mission:

Advance the state-of-the-art in SHM to improve public safety, reduce maintenance costs, improve readiness, and foster a paradigm shift in design by leveraging and fostering collaborative R&D efforts between academia, industry, and government entities. Provide a means for transferring technology to member companies, agencies, and institutions.

Objectives:

- Spur the research and development of new SHM technologies
- Transfer SHM technologies to member companies to give them a competitive advantage
- Make PA a hotspot for structural health monitoring, creating a new high tech job market that will provide jobs for residents and draw people and SHM industries to PA
- Train students to provide an outstanding workforce pool in SHM technology areas

Penn State participants are from throughout the College of Engineering and the Applied Research Lab.

For more information on becoming a member contact Cliff Lissenden (*lissenden@psu.edu*) or Ed Smith (*ecs5@engr.psu.edu*).

Inside this edition

Upcoming Events

- Spring Meeting, Penn Stater, April 22–23, 2009
- SHM Short Course, Penn State, June 9–11, 2009
- SPIE Smart Structures/NDE, Health Monitoring of Structural and Biological Systems, San Diego, CA, March 8–12, 2009
- International Workshop on SHM, Stanford, CA, September 9–11, 2009

ESM Engineering Science and Mechanics
IMPACT
SIEMENS
GE Sensing & Inspection Technologies
AAI
Sikorsky A United Technologies Company

Structural Health Monitoring

From the Director

These are exciting times in the field of structural health monitoring. There is so much potential and so many challenges that provide many opportunities. As our Center continues its steady growth, we are better suited to meet the challenges. Examples of SHM initiatives are given below.

The Naval Aviation Materials, Manufacturing, & Maintenance Workshop: Accelerating Technology Insertion sponsored by NAVAIR addressed the two important and interrelated topics that affect the Navy's ability to sustain long-term operations and prosecute the global war on terrorism: reducing the cost of maintenance, repair, and manufacturing; and accelerating the rate of technology insertion. Technology is needed to achieve material state awareness and state of health determination technologies need to be developed. A summary of the workshop was published in Advanced Materials & Processes (W.E. Frasier, August 2008, pp. 43-46).

The NATO RTO Applied Vehicle Technology panel sponsored a symposium on *Ensured Military Platform Availability* (AVT-157) in Montreal. The focus was on airframe and aero and marine propulsion system failure mechanisms and enabling a higher level of understanding of spare parts provisioning and greater insight into the forecast of maintenance actions. This knowledge enables higher overall system readiness with less operation and support costs and ensures platform availability with fewer surprises in fielding systems. www.rta.nato.int

The Air Force Office of Scientific Research has issued a *Discovery Challenge Thrust* for prognosis of aircraft and space devices, components and systems. The Air Force strongly needs prognosis capability in their aircraft and space platforms. Pervasive prognosis capability is needed at all levels of complexity, from material level through device and component levels up to the system level. Proposals from multidisciplinary teams will be accepted for this broad agency announcement from 2008–2010.

The first *International Conference on Prognostics and Health Monitoring* was held in Denver in October 2008. A competition to predict remaining life of an unspecified component using data driven techniques was conducted. Also, a panel session on prognostics and health monitoring education was held. The conference site is www.phmconf.org.

The *Aerospace Industry Steering Committee for SHM* is creating a guideline and recommendations on how to use structural health management for various aircraft platforms, in order to improve operability and optimize maintenance plans where structures are concerned, considering their regulatory aspects. A standards guidebook for SHM of commercial aircraft is being prepared with the help of SAE.

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Meetings

The Center hosted its 2008 fall meeting at the Nittany Lion Inn on November 3–4.

The meeting got off to a great start with **Mr. John B. Johns**, the Assistant Deputy Under Secretary of Defense for Maintenance, giving the opening address on structural health monitoring within the context of the military sector. Mr. Johns' remarks centered around a quote from ADM Mike Mullen, Chief of Naval Operations, "The challenges we face today are not altogether for today. They are for the future, for our children and for their children. We owe these future generations nothing less than our best effort to plan well, of course, but also to execute smartly those things we plan." The current environment for military maintenance is very complex: wartime usage of assets (e.g. rotorcraft and humvees) is 2-6 times the peacetime usage rate, these assets must operate in a wide range of harsh conditions, damage rates are significantly increased, replacement material costs are exorbitant, logistics are difficult, and the supplementary budgets so critical for current maintenance actions are likely to be significantly reduced. Furthermore, program managers have an operations view (system performance bias) and maintenance is very typically a secondary concern. Yet a third of the fleet is operating near, or past, its design limits. Our Center fits into the data-to-management maintenance spectrum by facilitating partnerships between government, industry, and academia. The spectrum includes: data, data analysis for reliability centered maintenance, condition based maintenance, and enterprise health management. As we move from data to enterprise health management in the spectrum, both the benefit (cost savings, readiness, and safety) and the sophistication (diagnostics, prognostics, and logistics) increase. Tying back to the welcome comments from Dean Atchley, technology development needs to be related to a clear benefit or value. Partnerships are required to move forward.

Dr. Eric Lindgren, Technical Advisor for the Air Force Research Laboratory Nondestructive Evaluation Branch, opened the second day of the meeting with a description of the challenges and opportunities for SHM of aerospace structures. Dr. Lindgren linked his presentation to **Mark Derriso's** (AFRL Air Vehicles Directorate) given at the Spring 2008 meeting, and emphasized on-board sensing capabilities and validation. A strong statistical foundation is necessary to determine the probability of detection for SHM applications. The many challenges are wonderful opportunities for research and development, as the payoff is high.

Dr. Shuang Jin, from the Turner-Fairbank Highway Research Center, Federal Highway Administration, discussed structural health monitoring of bridge structures. Dr. Jin's presentation emphasized the use of nonlinear dynamics simulation and chaos theory analysis.

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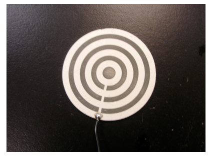
Annular Array Sensor Design

Sponsor: CoE SHM
Investigators: Jaya Prakash Koduru** juk205@psu.edu **and
***Joseph L. Rose** jlresm@engr.psu.edu*



A design procedure for ultrasonic sensors has been demonstrated for two rigorous trial applications; i) reduction of false alarms due to surface water and ii) detection of disbond in an adhesive joint. Rather than using conventional piezoelectric disk transducers, innovative annular array transducers that function like comb transducers are developed based on the mechanics of plate wave propagation. The procedure relies upon both phase velocity and group velocity dispersion curves as well as the wave structure, which depends on both wave mode and frequency. Consider first an aluminum plate with a surface corrosion defect. Eight annular array transducers designed and manufactured from PVDF (polymer) film and Cu electrodes were mounted in a circle around the corrosion hot spot. Excitation of the appropriate mode and frequency enabled tomography to detect corrosion in the presence of surface water, while other excitation frequencies or conventional disk transducers falsely identified water to be corrosion as shown in Fig. 1.

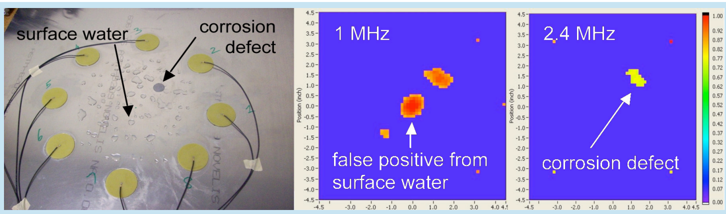


Figure 1. Aluminum plate with surface water, 6% deep corrosion defect, and annular array transducers. Tomograms are shown to the right.

A disbond in epoxy bonding two aluminum plates face to face was detected by designing and manufacturing PZT (ceramic) transducers having annular Ag electrodes. The key to the transducer design is to select a wave mode and frequency that is sensitive to defects in the epoxy adhesive. The phase velocity dispersion curves, group velocity dispersion curves, and an optimal wave structure are shown in Fig. 2. The results from active monitoring in the through-transmission mode are shown in Fig. 3 for both a good epoxy region and a disbonded epoxy region. A more detailed description of these project results is available to Center members at *www.esm.psu.edu/shm.*

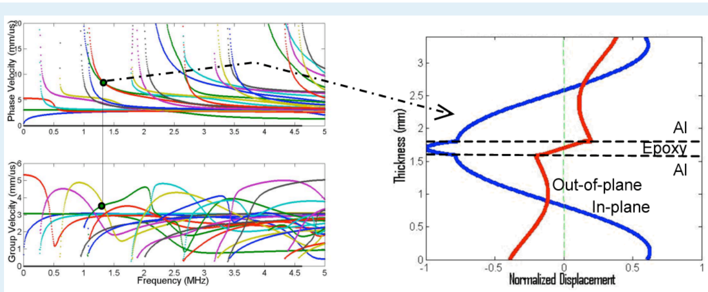


Figure 2. Dispersion curves for epoxy-based Al plates and wave structure for high order mode at 1.2 MHz.

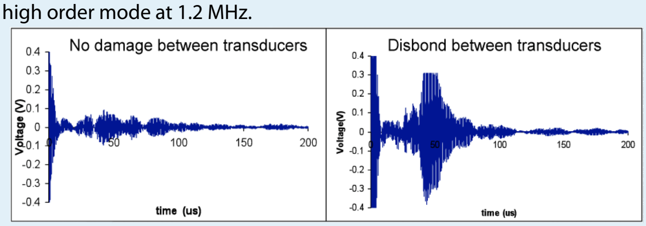


Figure 3. Received signals from annular array with 1.2 MHz excitation.

Origin of Randomness

Sponsor: Siemens
Joseph Cusumano** jpc3@psu.edu **and
***Francesco Costanzo** fxc8@psu.edu*

What is the origin of the randomness observed in damage processes, and what limitations does it place on SHM technologies? Engineering Science & Mechanics professors Joseph Cusumano and Francesco Costanzo are carrying out research aimed at answering these questions. The research is sponsored by Siemens as their membership project for the Ben Franklin CoE in SHM. Computationally efficient models that capture the coupling between damage field variables and continuum scale vibrations are used to simulate damage evolution all the way to failure. The massively parallel implementations use simulations started from many thousands of different random damage initial conditions to demonstrate how small initial microstructural uncertainties give rise to probability distributions of failure in space and time (see Fig. 1). Numerical experiments similar to these will eventually be used to study how uncertainty propagates from the smallest scales through the data collection and analysis processes required for SHM, including the collection of vibration data, the generation of feature vectors, and remaining life prediction. By linking damage physics to the intrinsic unpredictability of damage evolution, this project will improve our fundamental understanding of the limits to health state monitoring

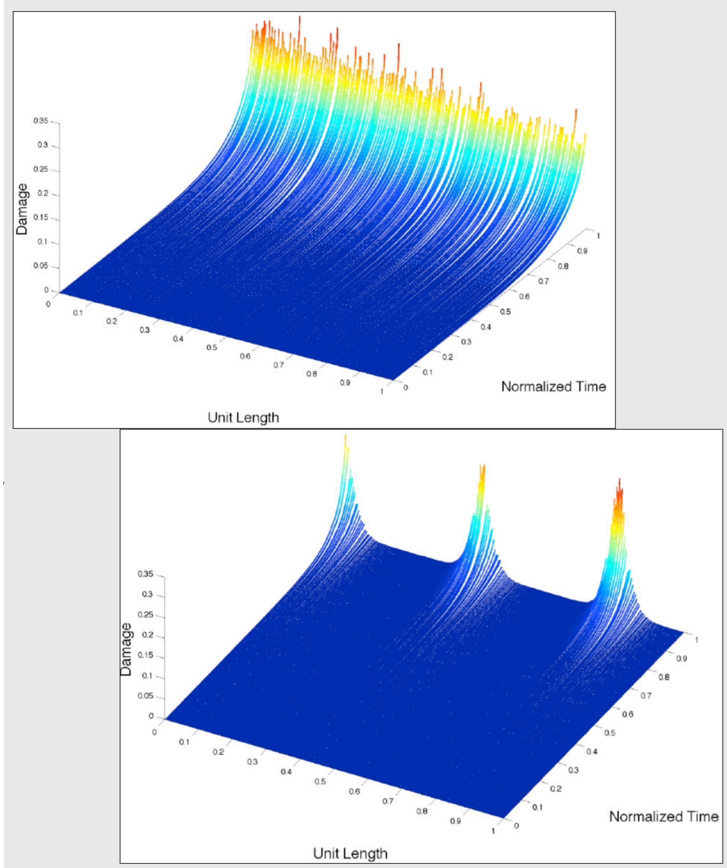


Figure 1. Plots of average space-time damage evolution in a thin steel bar, obtained by simulation using a coupled-field model. The bar is fixed at at x=0 and has a cyclic traction at x=1. (left) Very low frequency forcing, similar to that for a fatigue test: in this case, the intensity of damage evolution is nearly uniformly distributed, and so the failure locations are spread out, with a moderate increase in likelihood of failure near the clamped end. (right) Forcing near the third natural frequency: here, the damage evolution rates are highest in distinct "hot spots" related to the mode shape of the response, and so the most probable failure locations are clustered in three small areas. Both plots represent the ensemble average of many simulations carried out with different random initial damage fields.

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Student Spotlight

Jaya Prakash Koduru is a PhD candidate in Engineering Science and Mechanics. His work on the design of sensors for ultrasonic guided wave tomography, directed by his advisor **Prof. Joseph Rose,** has been supported by the Center. Jaya received his Bachelor of Technology in Civil Engineering from the Indian Institute of Technology Guwahati, one of the premier engineering institutes of India. He focused his bachelor's research on computational mechanics in which he developed parallel finite element software for fluid transport problems. He received a Master of Science in Engineering Mechanics degree from Penn State in 2007. The title of his Master's thesis is, "Wireless guided wave tomographic imaging" in which he demonstrated a low power wireless system hardware and software for in-situ structural health monitoring. His current research interests include theoretical and experimental studies of guided wave phased array transducers for structural health monitoring.

Fabio Semperlotti is a Ph.D. student in Aerospace Engineering working at the Vertical Lift Research Center of Excellence (VLRCOE) at Penn State. Now a US Permanent Resident, Fabio is originally from Rome, Italy. He earned a M.S. degree in Aerospace Engineering in 2000 and a M.S. in Astronautic Engineering in 2002 from the University of Rome "La Sapienza".

In 2001 Fabio was one of the recipients of the "Leonardo" Scholarship program funded by the European Community in order to promote international research activities. Under this program, he spent a six months period at the European Space Agency (ESA-ESTEC), in the Netherlands, working on the development of an active vibration control algorithm for large space flexible structures.

From 2000-2006, he worked as a structural engineer in different European industries. He was mainly involved with the design of space propulsion systems. In 2006 Fabio joined the doctoral program in Aerospace Engineering at Penn State. Together with his advisors, **Dr. Edward Smith** and **Dr. Kon-Well Wang**, he carried on SHM research funded by the Center for Rotorcraft Innovation (CRI).

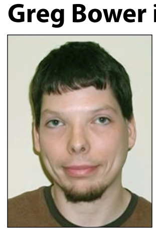
During the past three years he has been working on the development of a damage detection technique for the localization of fatigue cracks in helicopter blades. His research mainly focused on the use of nonlinear dynamic based algorithms able to sense the cracked structure and to localize the defect using an active network of piezoelectric transducers. The approach has been formulated and experimentally validated for isotropic slender structures proving the feasibility of damage localization via nonlinear dynamics. Fabio is currently working on extending the theoretical formulation to a wider variety of structural components. His work has recently been presented at American Helicopter Society Workshops and Conferences.

Short Course

From July 8–10 2008 we conducted a 3-day short course on structural health monitoring. The course was led by six Penn State faculty (Joseph Rose, Karl Reichard, Martin Trethewey, Charles Bakis, Francesco Costanzo, and Cliff Lissenden) and included classroom as well as laboratory components. 15 people external to Penn State attended the course. The course objectives were that students would be able to: 1) describe and compare various types of diagnostics for SHM applications, 2) select a viable SHM methodology for a given application based on available technology, 3) apply the mechanics of guided waves for SHM applications to detect structural defects, and 4) analyze vibration data from a complex system and use it to predict remaining fatigue life. Course topics include: SHM overview, SHM framework, material behavior, composite materials, damage mechanics, fatigue life prediction, mechanical testing, ultrasonic guided wave theory and experiments, dynamical systems and vibrations, diagnostics, prognostics, signal analysis, data fusion, classification, system design and implementation. Student feedback was very positive and we plan to offer the course again, June 9–11, 2009.

Recently Fabio started supporting an SHM project funded by the Aviation Applied Technology Directorate (AATD), and led by **Dr. Stephen Conlon** from the Applied Research Laboratory (ARL). Under this program, Fabio conducts numerical and experimental investigations aiming to further develop and implement Structural Intensity based damage detection techniques.

Fabio is on track to receive his PhD Degree in May 2009 and is looking forward to beginning a career involving research work.



Greg Bower is a PhD student in the Electrical Engineering department. His research interests include control systems, power conversion, and health monitoring. He completed his Masters degree in the Electrical Engineering program at Penn State in 2005 focusing on system identification using input-output relationships. He spent two summers working as a Space Scholar for the Air Force Research Laboratories Space Vehicle Directorate in Albuquerque, NM working on the topic of system identification. His PhD research topic is on prognostics and health management of electronics focusing on dc-dc converters. His research aims to implement diagnostics on a dc-dc converter to ascertain health of the system and to be able to predict remaining life of the converter. He also works as a research assistant at ARL with **Dr. Karl Reichard**, working on the problem of electronic packaging prognostics. Outside of work, Greg enjoys backpacking, biking, motorcycling, building somewhat useful electronic circuits, and spending time with his wife and daughter.

Technology Evaluation on Characterization of the Air Void System in Concrete

Sponsor: Pennsylvania Department of Transportation
Investigators: Maria Lopez mmlopez@engr.psu.edu, ***Cliff Lissenden, Bernhard Tittmann, Joseph Rose, Shelly Stoffels, Angel Palomino***

In addition to winter conditions in Pennsylvania, deficient material quality, among other factors, can severely affect the durability of concrete pavements, thus diminishing their service life.

A common and well-proven quality control measure has been the determination of air content in fresh concrete (using ASTM standard test methods such as ASTM C231, C173 and C138). More reliable indicators of future performance can be obtained from hardened concrete by analyzing the air void system, in particular the air content, spacing factor and specific surface (ASTM C457. The need for obtaining these parameters at the fresh state of concrete, thus significantly improving the quality control of concrete pavements at an early stage, has moved researchers to investigate technologies that can characterize the air void system.

A recently completed project by the Pennsylvania Department of Transportation (PennDOT) evaluated the effectiveness of a commercially available device (Air Void Analyzer) to characterize the distribution of air voids in fresh concrete. This device was found not ready for field-based applications.

The objective of this project is to evaluate current technologies that have the capability of characterizing the air void system in concrete within the first several hours of placement. This objective will be met by conducting a review of current research developments at universities, research centers, and industry facilities that have the potential for characterizing concrete air void system parameters such as air content, spacing factors and surface areas and assessing their feasibility. This evaluation will specifically focus on technologies that have the potential of being implemented in the field.

Intensity Based Structural Health Monitoring

Sponsor: US Army Aviation Applied Technology Directorate
Investigators: Steve Conlon, Jeff Banks, and Ed Smith

The focus of the research is on the implementation of Structural Intensity (SI) sensing for SHM and assessment. The fundamental mechanisms of structural intensity (or vibrational energy flow) are being investigated computationally and experimentally as they relate to the development of structural damage and its detectability in aviation platform structures. In house computational software is used to post process structural vibration responses from finite element analyses to determine a structure's complete structural intensity state for given types of loading. The contribution of various vibrational wave types to the overall flow of energy are studied and their sensitivities to simulated damage evaluated. The types of representative damage include cracks, delaminations, and other general mass/stiffness changes. Finite element modeling requirements are being examined to establish model applicability and accuracy requirements for use in SHM system design optimization. Test beds will also be developed to correlate and validate the SHM technology developments.

Probabilistic Fatigue Life Prediction

Starting Jan. '09

Sponsor: CoE SHM
Investigator: Cliff Lissenden lissenden@psu.edu

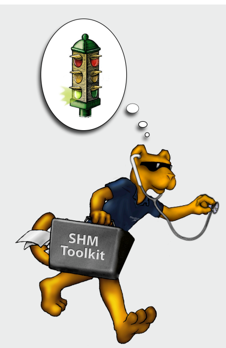
Great strides have been made recently to use guided wave ultrasonic technology (GWUT) for damage detection in structural materials, especially in the area of tomographic imaging and phased arrays. An array of sensors can be clustered around a hot spot and through-transmission GWUT used to detect fatigue crack growth, loss of material due to corrosion, or interply delamination. Likewise, a closely packed array of sensors can be phased by time delays in order to form and steer a beam of ultrasonic energy, as structural radar. The pulse-echo mode is used for defect detection from a phased array.

The hierarchical diagnostic ladder for structural health monitoring (SHM) is: detect, locate, classify, and size. Some research has been conducted to size damage for a limited number of SHM applications, but the defect sizing potential of GWUT is largely unrealized. This is a critical step in the development of GWUT for SHM because defect size must be input to prognostic models in order to determine the severity of the defect and provide information for making maintenance decisions. GWUT without sizing is cast into the role of a screening technique that indicates when an inspection is necessary, which while very useful, is less than its potential.

If characterization of the current material/structure/system state is a necessary first step toward condition based maintenance, then a prognostic model is the second step, and estimating the confidence level in model predictions is the third step.

Consider, for example, fatigue crack growth in metals. The well-known Paris law (and its many derivatives) provides a way to extrapolate the current state forward in time given the loading parameters and material parameters. Furthermore, if the critical crack size is known then the remaining life can be predicted Recasting the Paris law into a probabilistic framework enables determination of confidence levels on predicted future crack sizes.

There has been a recent explosion in the literature on probabilistic fatigue crack growth. The objective of this project is to develop quantitative GWUT that can, in turn, be input autonomously to a prognostic model to predict future defect (fatigue crack) size given loading and environmental conditions. Furthermore, the prognostic model will be probabilistic and provide an estimate of the confidence level for the prediction. Thus, this new project has strong ties to the center funded project of Prof. Rose and of Profs. Cusumano and Costanzo.



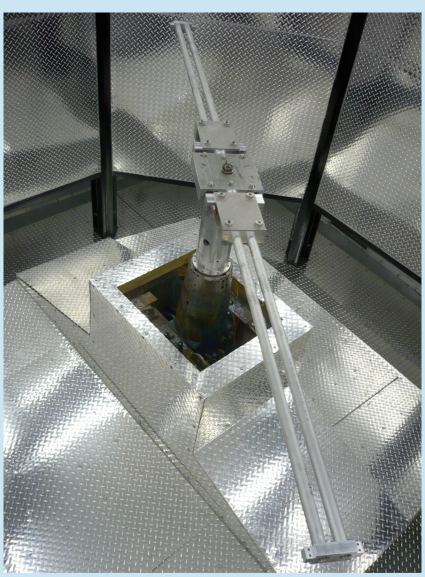
C-130 hercules

Structural Health Monitoring

Health Monitoring of Composite Structures Using Guided Waves

Sponsor: Air Force Office of Scientific Research
Investigators: Joseph Rose *jlresm@engr.psu.edu* ***and***
Cliff Lissenden *lissenden@psu.edu*

Ultrasonic guided waves for health monitoring of aircraft composite structures are being researched. While a number of researchers have studied the use of Lamb-like guided waves for damage detection in composite plates, we as a community lack the understanding of wave mechanics in complex composite structures necessary to fully exploit their potential. This project researches the sensitivity of guided waves to defects, system reliability, penetration power, and visualization of defects; and then will develop an effective health monitoring system. A theoretically based approach, making use of analytical and finite element models that are verified by experimental results will be followed. The focusing and steering of ultrasonic energy over long distances from a phased array of sensors is expected to be one of the primary contributions of this research. Another major contribution will be on sensor design; to exploit sensor shape, size, array utilization, frequency and frequency bandwidth, and excitation mode of normal beam or shear. This will improve sensitivity to certain defects, resolution, and penetration power, narrow the phase velocity spectrum and reduce side lobes, and provide an ability to get onto a preferred portion of the phase velocity dispersion curve. A point source excitation model will be developed to study such new sensor designs. There is a solid foundation for ultrasonic beam steering in isotropic plates, but energy skew in anisotropic plates makes it more difficult. Once damage is detected it must be clearly visualized in order to locate, classify, and size it. Ultrasonic tomography has recently been used with great success to visualize various types of damage. But in complex stiffened structures it may be more effective to employ discontinuity locus maps in addition to tomography. The impact of the work will be improved mission readiness of the fleet, reduction in maintenance costs, and safer aircraft.



Inside the new rotor spin chamber at Penn State's Vertical Lift Research Center. The chamber has environmental controls that enable creation of icing conditions. The rotor has a 4.5 ft radius. The airfoil cover and waterproof fairing is removed. Durability of SHM instrumentation can be studied. This lab was toured during our FA08 meeting.

Meetings

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Dr. Michael Yu, from the Naval Air Systems Command, discussed the procedures and opportunities associated with the SBIR programs supported by the Navy.

Academic presenters included: **Doug Adams** (Purdue) on barriers and solutions for the application of SHM technology, **Ed Smith** (AERSP) on advances in rotor system SHM, **Ghassan Chehab** (CEE) on pavement monitoring, **Karl Reichard** (ARL) on prognostics, **Joe Rose** (ESM) on annular array design for guided wave tomography, **Bernie Tittmann** (ESM) on SHM of underground concrete water pipes, **Fei Yan** (ESM) phased arrays for plate-like structures, **Chris Wassel** and **Brian Zentis** (Penn State Behrend) on RFID technology

Industry presenters included: **Jim Cycon** (Sikorsky) on incorporating SHM into the helicopter design process, **Carl Palmer** (Impact) on prognostic sensor programs, **Dan Xiang** (Intelligent Automation) on sensor development for SHM, **Jacob Loverich** (KCF) on helicopter rotor assembly loading monitoring.

At previous meetings the keynote speakers included:

Spring 2008

Ignacio Perez, Office of Naval Research, Asset Health Management of Naval System

Mark Derriso, Air Force Research Laboratory Air Vehicles Directorate, Structural Health Management Challenges and Applications

Jerome Lynch, University of Michigan, Carbon Nanotube Sensing Skins for Structural Health Monitoring

Fall 2007

James Blackshire, Air Force Research Laboratory Nondestructive Evaluation Branch, Structural Health Monitoring: a Material State Perspective

Elliott Cramer, NASA Langley Research Center, Results of On-Orbit Testing of an Extra Vehicular Infrared Camera Inspection System

John Berry, US Army Aviation and Missile RDEC, Army Aviation CBM Vision and Progress

Spring 2007

Fu-Kuo Chang, Stanford University, Promises and Challenges in SHM

Aditi Chattopadhyay, Arizona State University, Air Force SHM MURI Project

Richard Ross, NASA Langley Research Center, Improving the Safety of Current and Future Aircraft Through Integrated Health Monitoring

Our next meeting is scheduled for April 22–23, 2009 at the Penn Stater Conference Center.

Ultrasonic Guided Wave Integrity Analysis Tool for Well Casing

Starting Jan. '09

Sponsor: Gas Storage Technology Consortium
Investigators: Cliff J. Lissenden and Joseph L. Rose

Underground natural gas storage requires wells for access. The steel well casing is in a harsh environment and is susceptible to corrosion and cracking, which compromise its structural integrity. To ensure the safety of the public and the environment, and to protect the investment in the storage facility, it is necessary to monitor the integrity of these mechanical systems. Magnetic flux leakage (MFL) probes are used to diagnose the mechanical integrity of well casings. This technology is well suited for damage detection but not classification and sizing of defects.

Guided wave ultrasonic technology (GWUT) is emerging as an excellent way to inspect over long distances from a single point and has applications in the oil, gas, and power generation industries. One of the first commercial applications has been long range guided wave inspection of unpiggable pipeline sections such as cased crossings and compressor stations. Improvements to these systems continue to enhance performance and expand areas of use. Through the proper application of theoretical wave mechanics, numerical modeling, and physically-based experimentation, guided waves can be optimized by selecting the modes and frequencies with the ideal dispersion characteristics and wave structures for a particular task.

A synergistic approach would combine the advantages of MFL with those of GWUT and, in the process, overcome many of the disadvantages of the two traditionally independent methodologies. The result would be a more decisive, robust, and information-rich inspection system for detecting and sizing corrosion that neither of the individual technologies is capable of on their own. The strengths and weaknesses of MFL and GWUT for detection and sizing of corrosion anomalies will guide modeling and sensor development for integrity analysis of well casing.

Since MFL tools exist, the focus of this work is GWUT. A multi-sensor down-hole fixture is envisioned that transmits and receives axial guided waves as well as circumferential guided waves in order to detect, locate, classify, and size defects that reduce the mechanical integrity of the casing. The objective of the project is to design an optimal sensory tool for sizing corrosion and crack defects in steel casing. Here, optimal refers to defect sensitivity, reliability, cost, and ease of use. The design will leverage findings regarding axial guided waves from a previous GSTC-funded project, as well as ongoing research and development of circumferential guided wave methodology.

The methods proposed herein include analytical modeling, numerical simulations, sensor and equipment design, laboratory experiments, and field studies. The unique aspect of the project is that it is fundamentally driven by theoretical considerations. Study of guided wave propagation and interaction with defects will enable optimal design of sensors, fixtures, data acquisition, signal processing, and pattern recognition algorithms.

From the Director

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According to *Flight International* (Ranson, "Down on downtime: airframers under pressure to develop predictive maintenance systems", 09/16/08), SHM technologies have enabled airlines to reduce flight delays and cancellations due to maintenance problems. Improving SHM technologies are increasing expectations for preventative maintenance capabilities to reduce aircraft downtime and simplify maintenance logistics. Airframers are improving SHM products to ensure that aircraft operate at their full revenue potential. In the future, operators hope to use SHM to tailor maintenance by aircraft serial number. Specific efforts by Boeing, Airbus, Bombardier, and Embraer use SHM to increase reliability and reduce costs. Also in Flight International, *Turner* ("Europe works to develop built-in structural sensors" 09/16/08) describes the Structural Monitoring with Advanced Integrated Sensor Technology funded by the European Union. Candidate monitoring technologies being researched and evaluated are: fiber optic Bragg gratings, coatings, environmental degradation sensors, microwave antennas, ultrasonics, comparative vacuum measurement, acoustic emissions, and eddy current systems. These and several other SHM related articles are linked to the Center's website (www.esm.psu.edu/shm) under Sources/ Commercial airframe SHM news items.

National Institute of Standards and Technology (NIST) has identified advanced sensing technologies for infrastructure (roads, highways, bridges, and water systems) as a critical national need. The technology innovation program (TIP) has solicited proposals for sensing systems for measurement of explicit infrastructure performance characteristics such as fatigue, corrosion, stress, usage, damage, etc. (www.nist.gov/tip/) Likewise, the *Federal Highway Administration* (FHWA) issued a solicitation for a smart pavement monitoring system.

E MCH 597B Structural Health Monitoring: the Engineering Science and Mechanics department is offering a new graduate level course on structural health monitoring in the Spring 2009 semester. Our aging AERSP/ME/CE infrastructure is a huge maintenance and safety concern. This course addresses technology development to meet these needs.

Our next center meeting is scheduled for April 22–23, 2009 at the Penn Stater Conference Center. We look forward to seeing you then and working with you to create innovative solutions for the challenging needs of today and tomorrow.

Cliff J. Lissenden

Members

Sikorsky Aircraft Corporation is a world leader in the design, manufacture and service of military and commercial helicopters; fixed-wing aircraft; and spare parts; in maintenance, repair and overhaul services for helicopters and fixed-wing aircraft; and civil helicopter operations. Sikorsky helicopters are used by all five branches of the United States armed forces, along with military services and commercial operators in 40 nations. Our well known rotary wing products include the BLACK HAWK, SEAHAWK, H-53 and Schweitzer light helicopters. Our fixed wing aircraft include Schweitzer reconnaissance airplanes as well as the PZL Mielec Sky Truck and Dromader airplanes. Sikorsky Aerospace Services provides full-spectrum service solutions to fixed and rotary wing, commercial and military customers worldwide. SAS comprehensive support is designed to minimize operator downtime, improve ease of use, and reduce cost of ownership. From newly engineered logistics programs to industry-recognized maintenance, repair and overhaul services and parts requisition, Sikorsky Aerospace Services keeps you flying.

Intelligent Automation, Inc. (IAI) is a woman owned firm founded in 1987. Headquartered in Rockville, Maryland and with over 100 researchers and technical staff, IAI has maintained its character as a diverse R&D "think tank." Our current areas of research, applications, and products focus on distributed intelligent systems, networks, signal processing, controls, robotics, artificial intelligence, communications, health monitoring, electro-mechanical systems, forensics, and educational & training technology. Key application areas include defense, transportation, law enforcement, space, communications, and training. IAI has twice been honored with the prestigious "Tibbetts Award" from the Small Business Administration and the Small Business Technology Council for excellence in technology research and commercialization.

Impact Technologies, LLC is a engineering services and product development firm that deploys solutions to monitor systems, autonomously analyze data, estimate health, and predict future capability. Impact has existing products and continued new developments in the areas of structural health management, smart sensing devices, advanced vibration detection software, oil quality monitoring, electronic component test and prognostics, actuation component fault detection, adaptive control algorithms, and a range of design, maintenance planning, and logistics tools. The broad range of these offerings and customized solution approach has assisted many DoD and industrial users to optimize the utilization of their aircraft, shipboard, ground vehicle, and land-based equipment assets with realizable cost benefit, safety enhancements, and readiness/availability improvements. Impact Technologies maintains offices in Rochester, New York, State College, Pennsylvania, and Atlanta, Georgia.

In recent news, Impact Technologies, LLC is pleased to announce the acquisition of RLW, Inc., a privately held company located in State College, Pennsylvania and the formation of Impact-RLW Systems. As a new subsidiary of Impact Technologies, Impact-RLW Systems' SXNAP™ family of intelligent sensor products and wireless network technology complements Impact's core competencies in diagnostics, prognostics, and condition-based maintenance software, systems, and enterprise management tool sets.

GE Sensing & Inspection Technologies is part of GE Enterprise Solutions, a $5 billion business helping customers compete and win in a changing global environment by combining the power of GE's unique expertise and intelligent technology to drive customers' productivity and profitability. GE Sensing & Inspection Technologies is a leading innovator in advanced measurement, sensor-based and inspection solutions that deliver accuracy, productivity and safety to its customers. The company designs and manufactures sensing instruments that measure temperature, pressure, moisture, gas and flow rate for demanding customer applications. It also designs, manufactures and services inspection equipment, including radiographic, ultrasonic, remote visual and eddy current, that monitors and tests materials without disassembly, deforming or damaging them. Its products are used in a wide range of industries, including oil and gas, power generation, aerospace, transportation and healthcare. The company has 4,700 employees at more than 40 facilities in 25 countries worldwide.

Siemens Power Generation. Siemens Energy is the world's leading supplier of a complete spectrum of products, services and solutions for the generation, transmission and distribution of power and for the extraction, conversion and transport of oil and gas. It develops and builds fossil fueled power plants and power generating components as well as wind turbines, turbines for use as mechanical drives and compressors for industrial applications. It also offers operations and maintenance and management services for its own technology as well as that of other manufacturers. Instrumentation and control systems, as well as air pollution control technologies, are also part of the portfolio. The company is also a leading supplier of high and medium voltage power delivery equipment, energy management systems, network planning and power system engineering software for regulated and deregulated generation, transmission and distribution markets. Siemens Energy employs approximately 73,000 people world wide, with approximately 12,000 in the U.S.

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