



CAV Review '09-'10

CENTER FOR ACOUSTICS & VIBRATION

CAV Update

We're pleased to announce some new initiatives at the CAV.

Government Liaisons

First, we have added liaisons from the US Government to our membership, including members of the US Navy and NASA (with more on the way). We hope that our corporate sponsors, faculty, and students will benefit from interacting with various US Government agencies.

New website

Second, we have updated and renamed our website. Please visit us at www.cav.psu.edu. You'll find a new detailed list of all of our technical groups and members there, and we're working on a database of our key labs and facilities that we plan to post later this year.

Videostreamed lunch seminars

Finally, we have begun holding many of our CAV technical group lunch seminars in the Graduate Program in Acoustics classroom, using their distance learning videostreaming software from Adobe Acrobat Connect Pro Meeting. This means that our corporate sponsors and government and international liaisons may now participate in our seminars, many of which feature outside speakers from industry, government labs, and other universities. To attend, simply go to: <http://distanceed.acs.psu.edu/cav/> during one of our seminars. We are currently working to make available archives of past seminars, which we hope to post on our new web site.

PENNSTATE



The screenshot shows the CAV website homepage. At the top, there is a navigation bar with the Penn State logo, the text 'Center for Acoustics and Vibration', and a search box. Below the navigation bar is a 'Quick Links' section with a dropdown menu. To the right is an 'Overview' section with text about the center's research and three missions. Further right are two small portraits with names: George Lesieutre and Steve Hambric. Below the overview is a 'News and Upcoming Events' section with several announcements.

CAV Members Receive Awards

Dr. Dennis McLaughlin of the Aerospace Engineering Department will receive the 2010 AIAA Aeroacoustics Award at the 16th AIAA/CEAS Aeroacoustics Conference 7-9 June 2010 in Stockholm, Sweden. The citation reads:

For pioneering contributions in experimental aeroacoustics, particularly measurements of noise generated by large-scale structures in supersonic jets, and for leadership in aerospace engineering education.

Dr. Patricia Watts, Program Director of the FAA Centers of Excellence, presented Dean Anthony Atchley with a Certificate of Recognition from the Federal Aviation Administration for his work in the PARTNER Center of Excellence at Penn State. Dean Atchley was one of the founding principal investigators of PARTNER, Partnership for AiR Transportation Noise and Emissions Reduction, www.partner.aero. The presentation was made at the Annual Awards Luncheon for the Graduate Program in Acoustics on April 7, 2010.

Dr. Ed Smith was a co-recipient of the 2009 ASME Dynamic Systems and Control Division (DSCD) Rudolf Kalman Best Paper Award for the paper "Multi-Harmonic Adaptive Vibration Control of Misaligned Driveline via Active Magnetic Bearings." The award is given annually for the paper judged to be the best from those published in the JDSMC during the past year.

Dr. George Lesieutre was elected to the Board of Directors of the American Institute of Aeronautics and Astronautics (AIAA). AIAA is the world's largest technical society dedicated to the global aerospace profession. With more than 35,000 individual members worldwide, and 90 corporate members, AIAA brings together industry, academia, and government to advance engineering and science in aviation, space, and defense.

Congratulations to Dennis, Anthony, Ed, and George!

CAV Workshop May 3 & 4, 2010

The Center for Acoustics and Vibration's annual workshop will be held at the Penn Stater Conference Center. On Monday, following the formal presentations, we will offer several laboratory tours to familiarize attendees with some CAV facilities. George and Annie Lesieutre will host a picnic for all participants on Monday evening. As in the past, the program will mix presentations from technical group leaders, international liaisons, several corporate sponsors, and new government liaisons. Graduate students and their advisors will be available for discussions concerning their research. While formal presentations are organized to allow for the exchange of technical information, there will be ample opportunity for informal discussion during the breaks, meals and on Tuesday afternoon following the wrap-up luncheon.

CAV Members Receive Honors and Awards

Terry Johnson, graduate student in aerospace engineering: Won first place in the best student paper competition at the Society of Photographic Instrumentation Engineers' (SPIE) Smart Structures and Materials and Non-destructive Evaluation and Health Monitoring Conference.

Johnson's paper, "Modeling and Experimental Validation of a Bistable Mechanism for Chord Extension Morphing," was co-authored by Mary Frecker, professor of mechanical engineering, and Farhan Gandhi, professor of aerospace engineering.

The competition had 51 entries.

Corporate Members and International Liaisons

Corporate Members & Representatives

ATA Engineering – Mike Yang
Bettis Atomic Power Lab – Eric Shook
Copeland Corporation – Macinissa Mezache
Electric Boat – Albert Kirwan
Emerson Process & Management – Al Fagerlund
General Electric Global Research Center – Huangang Luo
Lockheed Martin/KAPL – Kristin Cody
Northrop Grumman Shipbuilding – Kevin Smith
United Launch Alliance – Ed Heyd
United Technologies Research Center – Jeff Mendoza
Westinghouse Electric Company – Larry Corr
Dresser-Rand – Zheji Liu
Applied Physical Sciences Corp. – Marty Pollack

International Liaisons and Representatives

ISVR (UK) - Michael Brennen
DLR (Germany) - Robert Meyer
CIRA (Italy) - Antonio Concilio
INSA de Lyon – Goran Pavic

CAV Welcomes New Corporate Sponsors

The CAV is pleased to announce three new corporate sponsors for 2009-2010.

- General Electric Global Research Center - corporate liaison, Dr. Huangeng Luo

GE Global Research (GEGR) is one of the world's largest and most diversified industrial research organizations, providing innovative technology for all of GE's business. Global Research has been the cornerstone of GE technology for more than 100 years, and is now focused on developing breakthrough innovations in areas such as molecular imaging and diagnostics, energy conversion, nanotechnology, advanced propulsion and security technologies. GE Global Research is headquartered in Niskayuna, NY, and has facilities in Bangalore, India, Shanghai, China, and Munich, Germany. For any industrial lab, technical diversity is key.

GE's diverse set of four businesses naturally creates the most diverse industrial lab in the world. From aircraft engines to power generation to our financial businesses and even our television network and movie studios, GE Global Research leverages technology across industries and across scientific disciplines. GEGR employs more than 2,800 (more than 1,000 PhDs) with over \$500 million R&D funding in 2008. GEGR's mission is to be the growth engine for GE. GEGR strives to drive new technology breakthroughs, introduce this technology into the product pipeline and leverage it to fuel growth for GE's businesses.

The Structural Mechanics and Dynamics Lab performs advanced development and design in the area of structural dynamics and structural mechanics of mechanical systems such as rotating machinery, medical imaging equipment, process equipment and mechanical manipulators.

- Northrop Grumman Shipbuilding - corporate liaison, Kevin Smith

For more than a century, Northrop Grumman Shipbuilding (NGSB) has been designing, building, overhauling and repairing a wide variety of ships for the U.S. Navy, the U.S. Coast Guard and world navies. Today, NGSB builds more ships, in more ship types/classes, than any other U.S. naval shipbuilder. Northrop Grumman Shipbuilding, a newly-formed sector of Northrop Grumman Corporation is made up of the former Northrop Grumman Ship Systems and Northrop Grumman Newport News shipbuilding sectors, and with nearly 40,000 employees, is the largest industrial employer in Virginia, and the largest private employer in Mississippi and Louisiana.

NGSB is the nation's sole industrial designer, builder and refueler of nuclear-powered aircraft carriers and one of only two companies capable of designing and building nuclear powered submarines. NGSB is one of the leading providers of major surface warships such as destroyers, cruisers, high endurance cutters, and amphibious assault and transport ships. NGSB supports a variety of naval and commercial vessels with maintenance, repair & complex overhaul. Annual revenues are approximately \$5.6 billion, with a backlog of more than \$20.5 billion. Finally, with expertise in container construction and nuclear material handling, NGSB provides services to energy, petrochemical and government customers.

Welcome New Corporate Sponsor—Cont.

- ATA Engineering – corporate liaison, Dr. Mike Yang

ATA Engineering, Inc. (ATA) provides innovative solutions through test- and analysis-driven design by focusing on the engineering needs of manufacturers in addressing their cost, quality, and time-to-market challenges for mechanical and aerospace systems.

ATA uses testing and analysis coupled with computer-aided engineering and mechanical engineering software to solve problems in the aerospace, biomedical, automotive, and consumer products industries. ATA engineers are experts in applying advanced mechanical engineering software to design and engineering testing and analysis of mechanical structures including structural dynamics and structural analysis. They also conduct training in mechanical engineering software, structural dynamics, structural analysis, thermal analysis, modal analysis, modal test (modal survey), model correlation, durability, and vibro-acoustics.

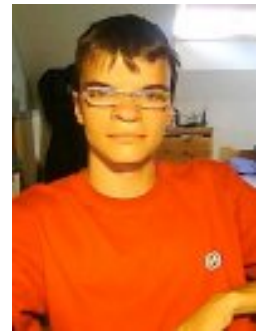
Recent projects in the fields of vibration and acoustics include vibro-acoustic modeling of the Ares I and Orion vehicles, the development of an acoustic holography system that significantly reduces the number of microphones required to measure jet noise, dynamic analysis and test of hybrid engines for mass-transit buses, shock and impact analysis of consumer electronics, and dynamic testing of monorail transportation systems.

Welcome New International Liaisons

The CAV is also pleased to welcome a new International Liaison – the Institute National des Sciences Appliquées de Lyon (INSA de Lyon). We look forward to interacting with Dr. Jean Louis Guyader, director of the Vibration and Acoustics Lab, and Dr. Daniel Guyomar, director of the Electrical Generation Lab. You can learn more about the Vibration and Acoustics Lab at:

http://lva.insa-lyon.fr/en/index_en.html

This summer, we are pleased to welcome Roch Scherrer, an MS student from INSA de Lyon, who will be working with Dr. Hambric in the CAV Reverberation Room, Anechoic Room, and Transmission Loss Facility.



Featured Research

Wind Turbine Noise

Dennis McLaughlin and other Aerospace Engineering faculty members have recently begun conducting research on wind turbine noise. A small wind turbine system, rated at 3.5 kW, is located in the Penn State Center for Sustainability, directed by David Riley. A larger 7 m diameter rotor rated at 10 kW should be operational shortly. Having two different size wind turbines at different heights and with different power delivery systems provides an opportunity to test many components of advanced designs of wind turbines. The most obvious contribution can be made in further developing small scale systems for remote small population, or agricultural or industrial applications. A more important contribution can be made addressing the behavior of large systems at model scale. One major goal will be to develop a methodology for scaling the results of experiments from small scale to large scale applications. These experiments will address aerodynamics issues as well as those involving aeroacoustics. This methodology will interact with partner activities in analytical/computational aerodynamic and aeroacoustic research that will also be a major part of the overall Penn State program.



Featured Research

Phononic Crystals

The turbulent structure of the oncoming wind under different meteorological conditions are important considerations in the aforementioned aeroacoustic studies but also are important to aeroelastic studies that will be integral to advanced composites development work. Using the model facilities to investigate the aerodynamic, aeroacoustic and aeroelastic phenomena requires a great deal of expert engineering. The flow over turbine blades is not Reynolds number independent in the speed ranges of interest of wind turbines. This is further complicated when transition to turbulent boundary layers is important to the physical issue under study. Researchers in Aerospace Engineering at Penn State have considerable experience developing methodologies to handle imperfections in simple scaling.

An array of ball cup anemometers can measure the spatial and temporal variations in the wind environment simultaneously with those instruments measuring the performance of the wind turbine. RPM is conveniently measured from the output of any of the 3 phases of the AC generator. Torque is most easily calculated from measured power delivered from the generator to the controller. With these measurements, the overall quasi-steady aerodynamic performance of the turbine can be estimated. If more detailed information about the wind turbine flow is important, an array of hot film or flush mounted pressure sensors would be appropriate. These sensors require small electronic drive circuitry as well as A/D conversion and telemetry to the instrumentation data acquisition system.

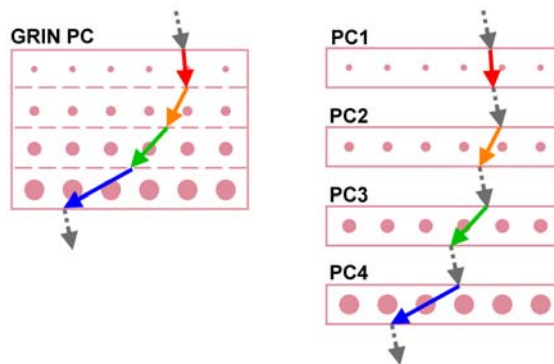
Experiments on the noise produced by wind turbines are as difficult as those that characterize the overall aerodynamic performance. A phased microphone array will be required to obtain enough detail of the noise to perform a serious aeroacoustic analysis. Such a system will require a fairly involved on-site calibration system to establish the correct phase relationships of the microphones. In addition, the computer acquisition systems will have appropriate synchronizing signals should more than one A/D system be used.

In summary, Penn State University is willing to consider working with different groups of wind turbine manufacturers or researchers. Inquires can be sent to Prof. Dennis McLaughlin (dkm2@psu.edu) or Prof. George Lesieutre (gal4@enr.psu.edu) both of the Department of Aerospace Engineering, Penn State.

Phononic Crystals and Acoustic Bandgaps and Mirages

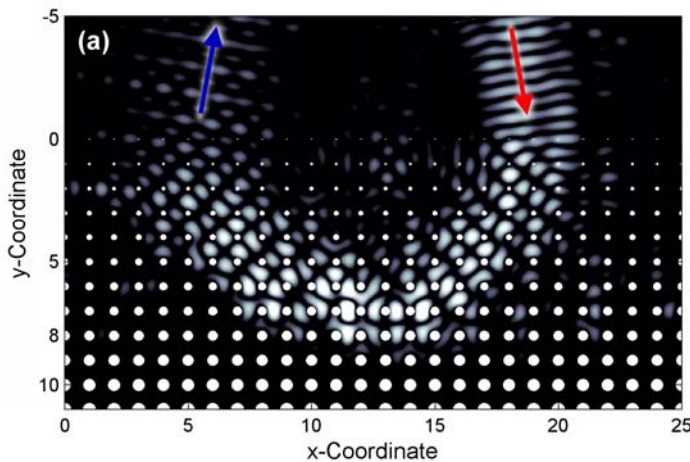
Sz-Chin Steven Lin, a PhD candidate in the Engineering Science and Mechanics Department, and his advisor, Dr. Tony Jun Huang, are studying how to use arrays of structural discontinuities to block or change the direction of sound propagation over specific bands of frequencies. Periodically distributed structures called phononic crystals (PCs) have attracted much attention because of their ability to manipulate the propagation of acoustic waves. By varying constitutive parameters of the PCs, one can achieve phononic bandgaps where the propagation of acoustic waves is forbidden. This principle has been used to engineer acoustic waveguides by introducing straight- or bent-line defects to PCs. In a different approach, one can employ the anisotropic properties of PCs to redirect acoustic beams in the conducting bands, thus enabling new applications such as negative refraction and self-collimation.

Recently, the "acoustic mirage" effect, continuous bending of acoustic waves along an arch-shaped trajectory, has been demonstrated using a concept called gradient-index (GRIN) PCs. Originated from gradient-index optics, a GRIN PC is an engineered PC with a gradual variation of the constitutive parameters (e.g., filling ratios, material properties, or inclusion geometry). As illustrated below, a two-dimensional (2D) GRIN PC of one-dimensional (1D) gradient is a discretized medium that can be thought of as a composite of multiple single-layer PCs of different filling ratios. When an acoustic beam propagates through a 2D GRIN PC, it encounters redirection at every virtual interface between layers, resulting in consecutive reorientations of the acoustic beam inside the structure. Thus, by gradually modulating the constitutive parameters of a GRIN PC, one may create an arc-shaped trajectory for acoustic wave propagation.



Featured Research Phononic Chrystals—Cont.

The acoustic mirage effect has been numerically demonstrated in a 2D GRIN PC composed of 25×12 layers of steel cylinders arranged in a square lattice and embedded in Epoxy by a finite-difference time-domain (FDTD) method. The radius of each row of cylinders increases linearly with the row number (along the y -direction) per the following relation: $r_y = \sigma(y+1)a$, where $\sigma = 2.08\%$ and a is the lattice spacing. A tilted line source with a width of $4a$ was placed in the epoxy region ($y < 0$). As shown below, the GRIN PC was exposed to an acoustic beam with an incident angle of 10° at reduced frequency $\Omega = 0.79$. The acoustic beam bends slightly toward the direction of the gradient upon entering the GRIN PC. The beam then steadily refracts toward the negative x -direction, redirecting back to the epoxy/GRIN PC interface with a lateral shift of $13.75a$. While traveling within the GRIN PC structure, the beam exhibits little spread with distance; however, as the beam approaches the epoxy/GRIN PC interface, the width of the output beam widens marginally due to multiple reflections near the interface. This superbending effect, caused by a refractive-index gradient, shares the same physical principle as an optical mirage. The methodology described in this work can be implemented in acoustic devices such as on-chip waveguides, filters, and multiplexers.



Graduate Program in Acoustics Update

Sparrow named interim Chair

In January 2010 Victor W. Sparrow, Professor of Acoustics, was named as Interim Chair of the Graduate Program in Acoustics by Dean David N. Wormley, College of Engineering. Dr. Sparrow will serve until a permanent Acoustics Program chair is in place. He will continue teaching, advising students, and working on research while serving in this administrative role. Dr. Sparrow has been with the Acoustics Program since 1990, and he can be contacted at vws1@psu.edu.

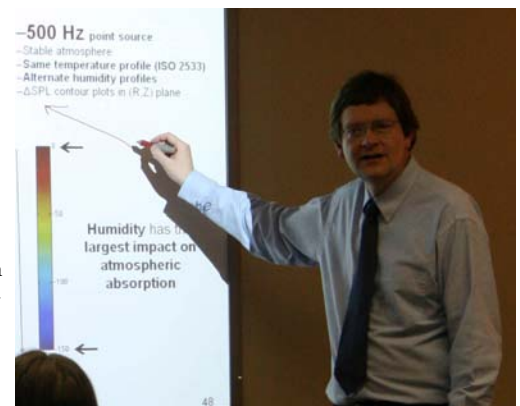
Another recent change has been an administrative realignment of the Graduate Program in Acoustics with the Department of Aerospace Engineering. There are a number of administrative and budgetary support services that will now be provided by Aerospace Engineering, and the Acoustics Program is appreciative of this assistance. In this realignment, it should be emphasized that the Graduate Program in Acoustics remains a separate inter-college graduate degree program offering the specific degrees of Master of Engineering in Acoustics, Master of Science in Acoustics, and Doctor of Philosophy in Acoustics.

There have also been a number of recent staff changes in the Graduate Program in Acoustics. Longtime Graduate Secretary Carolyn Smith retired at the end of December 2009, and a search was conducted for a new Graduate Secretary. Center for Acoustics and Vibration members will be pleased to know that Mrs. Karen J. Thal, former CAV Communications Coordinator, took over the Graduate Secretary position from Carolyn Smith. Karen Thal has been supporting the Acoustics Program in her new role since February 2010. We have very pleased to have Karen take on this important position. She can be contacted at kjt3@psu.edu.

Another departure from the Acoustics Program has been long time Program Coordinator

Karen Brooks. Karen was offered and accepted a substantial promotion to the Penn State Graduate School as assistant to the Associate Dean of the Graduate School. Karen Brooks did an amazing job working with students and running the Acoustics Distance Education Program. We wish Karen good luck in her new position, and a search for a new Program Coordinator is getting underway.

Meanwhile the Acoustics Distance Education Program is doing well, and a full schedule of courses is being offered. In Fall 2010 courses available at a distance will include fundamentals of acoustics, digital signal processing, acoustic data measurement and analysis, outdoor sound propagation, and aerodynamically induced noise. For more information go to www.acs.psu.edu and click on "Distance Ed."



Technical Research Group Highlights

Featured Research—Cont.

Acoustics Students measure football game noise

Members of the Acoustics program measured the noise levels at two Penn State football games during Fall 2009. The measurements were featured in various Penn State web publications, along with this Spring's College of Engineering magazine. The magazine article is reproduced below, courtesy of the Penn State College of Engineering and Curtis Chan, reporter. An article, presented at this year's NoiseCon 2010 conference in Baltimore, was also written, and will be available shortly on INCE-USA's electronic publications website: www.incedl.org. Thanks to exposure through the Acoustical Society of America's World Wide Press Room, the work has been highlighted recently in an article in the Philadelphia Inquirer:

<http://www.philly.com/philly/sports/colleges/91574784.html>

and in a WTAJ-TV interview:

http://wearecentralpa.com/fulltext/?nxd_id=168095&watch=1

Acoustics faculty and students braved the soggy weather to measure crowd noise during this past season's Penn State-Iowa football game. Andrew Barnard, a senior research assistant with the Applied Research Laboratory and a Ph.D. candidate, said the Department of Intercollegiate Athletics wanted a better understanding of how crowd noise works in Beaver Stadium.

The team placed sound meters on each goal post, on each side of the 10-yard and 50-yard lines, on top of the press box, and on top of the south end of the luxury suites. Not surprisingly, the engineers found that crowd noise was loudest when the opposing team was on offense. Barnard said the maximum noise level was 110 decibels for brief moments in the game, which is similar to the level experienced in front of a speaker at a loud rock concert. When Penn State was on offense, the noise level peaked at 75 decibels, which is closer to the level of everyday conversation.

The team conducted a similar test in 2007 in a game against Ohio State. It repeated the test later this past season during the Nov. 7 game against the Buckeyes.



Technical Group Research Highlights

Active Structures

George Lesieutre – Group Leader
g-Lesieutre@psu.edu

The mission of the Active Structures and Noise Control Technical Group is to pursue strategies for reducing vibration and noise in engineering systems. This involves the development of accurate modeling approaches, passive control methods, discrete and distributed sensors and actuators as well as placement strategies, fast and stable adaptive control algorithms, and experiments to evaluate real-world performance. In complex mechanical/acoustical systems with multiple sensing and source/actuator locations, significant challenges remain.

Professor George Lesieutre and his students are pursuing a number of projects in vibration control and active structures. Working with Prof. Frecker's group, they just completed a research project in morphing aircraft structures for the Air Force Office of Scientific Research (AFOSR), and a more general extension of the work is being continued by the National Science Foundation. The National Rotorcraft Technology Center (NRTC) supports a project that involves the active deployment of small trailing-edge devices to improve rotor performance. The Lord Corporation sponsors a program to improve the dynamic behavior of helicopter lag dampers. Finally, NASA supports a research effort that aims to damp vibrations of integrally-bladed turbomachinery rotors using piezoelectric materials.

Title: High-Strength High-Strain Structures Using Ceramic Cellular Contact-Aided Compliant Mechanisms (C3M)

Sponsor: NSF

Summary: Cellular Contact-Aided Compliant Mechanisms (C3M) are cellular structures with novel integrated contact mechanisms that provide stress relief. C3M are capable of very large strains compared to their bulk material constituents, and, due to the stress relief, are capable of even greater strains than their non-contact cellular counterparts. Originally developed by Drs. Frecker and Lesieutre for the skin of morphing aircraft vehicles, C3M have the potential to be used in many applications requiring large strain. In this project we are developing integrated design and fabrication methods for high-strength high-strain ceramic C3M. Ceramic materials are of interest because of their high strength particularly at the mesoscale, with over 2 GPa bend strength, and potential high temperature capability. Bulk ceramic materials also have high strength, but low strain at failure, perhaps 0.2 – 1.0 percent, depending on the size. In contrast, ceramic C3M are capable of ultimate strains of 11 to 13

Active Structures – Cont.

percent, an order of magnitude higher than the ultimate strain of the bulk material. This project brings together expertise in materials, fabrication, modeling, and design.

Collaborators: Dr. Mary Frecker (ME), Dr. Jim Adair (MatSci)

Student: Vipul Mehta

Ph.D. expected: August 2010 (“Design, Analysis, And Applications Of Cellular Contact-Aided Compliant Mechanisms”)

Title: Actuation of Miniature Trailing Edge Effectors (MiTEs) for Rotorcraft Applications

Sponsor: NASA / Army Vertical Lift Research Center of Excellence (VLRCE)

Summary: Focus on actuation of MiTEs using piezoelectric devices. Address the use of MiTEs for stall alleviation, flight control, and vibration reduction. Consider steady and unsteady aerodynamics, wind-tunnel experiments and CFD analysis, actuation, rotor performance.

Collaborators: Dr. Mark Maughmer, Dr. Farhan Gandhi

Student: Michael Thiel

Ph.D. expected: December 2010

Title: Reduction of High-Cycle Fatigue in Integrally Bladed Rotors through Piezoelectric Vibration Damping and Control

Sponsor: NASA Glenn Research Center

Summary: A robust vibration damping system for integrally bladed rotors can dramatically reduce high-cycle fatigue in turbomachinery. Such a system can be implemented using piezoelectric materials in both passive and active roles. Current research focuses on passive and semi-active vibration control methods and modeling using an assumed-modes method. As more advanced models are developed, they will be used to evaluate more realistic blade geometry and patch placement. More advanced response reduction concepts will also be considered, such as hybrid harvesting-switching and shunt tuning approaches. Finally, these models will be used to optimize the ability of these damping systems to reduce high cycle fatigue and extend blade life.

Student: Jeff Kauffman

Ph.D. expected: August 2011

Title: Lag Dampers with Frequency-Variable Properties

Sponsor: Lord Corporation

Summary: Develop concepts for lag dampers that provide damping adequate to stabilize ground and air resonance, while reducing loads when not needed for stability. Evaluate the concepts and pursue the most promising in design-build experiments.

Active Structures – Cont.

Collaborator: Dr. Edward Smith (Aerospace)

Student: Conor Marr

Ph.D. expected: August 2011

Title: Embedded Inertial Dampers for Control of Transient Rotor Loads During Resonance Crossing

Sponsor: Fellowship

Summary: Variable-speed rotors are of interest for the potential to improve efficiency over a range of flight conditions. Changing rotor speed increases the likelihood of resonance interactions and undesirable response transients. Embedded inertial dampers are being explored as a way to minimize load excursions during such transients.

Collaborator: Dr. Edward Smith (Aerospace)

Student: Joseph Shenglan Wang

M.S. expected: May 2010

Professor Chris Rahn and his students in the Mechatronics Research Laboratory are pursuing a number of projects in vibration control and active structures. Working with Prof. Srinivas Tadi-gadapa in Electrical Engineering, they are building Nano Air Vehicles for the Air Force Office of Scientific Research (AFOSR). In collaboration with Prof. Chuck Bakis in Engineering Science and Mechanics, the MRL team has recently been awarded a National Science Foundation (NSF) grant to study biologically inspired structures. The National Rotorcraft Technology Center (NRTC) supports a project on rotor loads control led by Prof. Ed Smith. Finally, Prof. Qiming Zhang in Electrical Engineering is working with MRL to develop electroactive polymer actuators for a Braille Display funded by the National Institutes of Health (NIH).

Title: High Performance Piezoelectric Actuators and Wings for Nano Air Vehicles

Sponsor: AFOSR

Summary: In this project, we use newly developed MEMS process based on Inductively Coupled Plasma Reactive Ion Etching (ICP-RIE), for PZT and high performance single crystal PMN/PZN-PT piezoelectric wafers to fabricate novel, high performance actuators and NAV airframes. The NAV airframe is composed entirely of active piezoelectric material that has been micro-machined and electroded to provide multiple wings with the desired flap and twist rotations. Integral sensors (e.g. load cells, accelerometers, gyros) and mechanisms (e.g. grippers) could also be monolithically machined into the airframe to provide all the sensing and actuation needs of the NAV. This unique and promising concept is enabled by the research in actuator and wing modeling, design, and fabrication.

Collaborators: Dr. Srinivas Tadi-gadapa (EE)

Students: Hareesh Kommepalli, Mark Zhang, and Kiron Mateti

Ph.D. May 2010, M.S. August 2010

Technical Group Research Highlights

Active Structures – Cont.

Title: Braille Display Using EAP

Sponsor: NIH

Summary: Even after many decades of effort, progress in the development of refreshable Braille displays for the blind and visually-impaired is very limited. One key problem is the lack of small volume, robust, and low cost actuators that can generate large motion with small size under electric signals. The goal of this work is to design and develop electroactive polymer Braille actuators with high reliability and reproducibility, optimized performance, compact size, and low cost.

Collaborators: Dr. Qiming Zhang (EE)

Students: Paul Diglio and Thomas Levard

M.S. expected 8/10 and 12/10

Title: EFRI-BSBA: Learning from Plants -- Biologically-Inspired Multi-Functional Adaptive Structural Systems

Sponsor: NSF

Summary: The overall goal of this research is to create a transformative multifunctional adaptive structure concept through investigating the unique and desirable characteristics of plants; including nastic (rapid plant motions) actuation with large force and stroke and self-sensing/reconfiguration/healing. More specifically, we are developing and investigating new bio-actuation/bio-sensing ideas building upon innovations inspired by the mechanical, chemical, and electrical properties of plant cells. This effort will create a paradigm shift of the fundamental knowledge required in developing future generations of adaptive structural systems.

Collaborators: Dr. Charles Bakis (ESM)

Student: Bin Zhu

Ph.D. expected August 2014

Structural Vibration and Acoustics

Stephen A. Hambric, Group Leader
sah19@psu.edu

The mission of the Structural Vibration and Acoustics Technical Group is to better understand the mechanisms of vibration generation and propagation in structures and the interaction of structural vibrations with acoustic media, and to develop novel methodologies for the analysis, measurement, and control of structural vibrations and radiated noise.

We've had some interesting guest speakers at our lunch seminars this year, including Steve Porter, of Head Acoustics, who demonstrated Head's Visor Array system for beamforming of acoustical sources to us last Fall. Steve also worked with us during our Beaver Stadium football game noise measurements described elsewhere in this newsletter. We were also visited this Spring by Dr. Raj Singh of Ohio State, who presented his research on the root causes of side-band tones in rotating machinery.

Structural Vibration and Acoustics – Cont.

Our group has worked on several interesting projects this year, including:

- Simulating the effects of bearing types on gearbox noise transmission, for NASA
- Measuring the impedances of operating fluid film bearings
- Simulating and measuring the interesting behavior of phononic structures (see the feature article elsewhere in this newsletter)
- Measuring the sound intensity in reverberant environments, for the US Navy
- Measuring the sound transmission through joints between honeycomb sandwich panel spacecraft structures for United Launch Alliance (a CAV corporate sponsor)
- Monitoring the structural health of rotorcraft structures using structural intensity, for AATD (see detailed description below).

Here's a list of our projects for 2009-2010.

Highlighted Project: Intensity Based Structural Health Monitoring

Sponsor: U.S. Army Aviation and Missile Research, Development and Engineering Center, Aviation Applied Technology Directorate
PI: S.C. Conlon

CO-PIs: E.C. Smith, J.C. Banks

Students: Fabio Semperlotti (PhD – Aerospace), David Santorelli (MS – ME), Peter Romano (MS pending, Aerospace), Walter Schmidt (MS, Aerospace)

In this work the application of an active Structural Intensity (SI) approach to the problem of airframe damage detection and localization was explored and enhanced techniques developed. The types of damage focused on in the investigation related to critical metallic structure fatigue areas on current Army rotorcraft. SI is a measure of the active vibrational energy flow through a structure and is a vector quantity characterized by both its magnitude and direction. Previous studies have identified potential damage detection sensitivity enhancements offered by SI over traditional vibration based metrics. Key results from the investigation include both linear and non-linear SI implementations. Instrumented test structures were designed and assembled for modeling and sensor / algorithm development and validation. The developed method's ability to detect structural damage was experimentally validated and its structural damage detection and localization capabilities quantified.

Structural Vibration and Acoustics – Cont.

Title: Measurements of distributed dynamic impedance of fluid film bearings

Sponsors: ARL and E&F

PIs: Steve Hambric and Karl Reichard

Student: Harrison Gyurko (Ph.D. candidate)

Title: Effects of high vibration levels on propeller hydrodynamic performance

Sponsor: NAVSEA 073R

PI: Steve Hambric

Student: Marc Reese (M.S. candidate)

Title: Structure-borne sound through rolling element and fluid film 'wave' bearings

Sponsor: NASA

PIs: Ed Smith and Steve Hambric

Student: Micah Shepherd (Ph.D. candidate)

Title: Acoustics of Shaftless Propulsors

Sponsor: DARPA and US Navy

PI: Steve Hambric

Title: Acoustics of Submerged Actuators

Sponsor: ONR

PIs: Dean Capone and Steve Hambric

Title: Commercial Nuclear Reactor Flow-Induced Vibration and Fatigue Failure

Sponsor: Nuclear Regulatory Commission

PI: Steve Hambric

Acoustics Characterization of Materials

Bernhard R. Tittmann, Group Leader

btr14@psu.edu

The mission of the Acoustics Characterization of Materials group is to develop a **new** understanding of how various types of waves, i.e., ultrasonic x-ray, thermal, optical, electromagnetic, acoustic, etc., interact with advanced materials; to translate this understanding into techniques for monitoring and controlling industrial processes; and to apply these techniques to the development of materials processes.

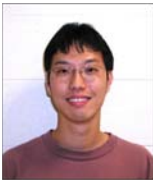


Brian Reinhardt

Brian Reinhardt, engineering science and mechanics masters student, was awarded the 2010 Student Travel Reimbursement of the American Society for Nondestructive Testing (ASNT). As a winner of this award, Brian (btr5016@psu.edu) received free registration to the ASNT Research Symposium and Spring Conference in Williamsburg, VA, from March 22-26, 2010. Brian presented the paper "Fatigue Characterization Using Nonlinear Harmonic Generation" at the Conference.

Technical Group Research Highlights

Acoustics Characterization of Materials – Cont



Hyeong-Sick Ju

in Acoustics whose work has appeared in written proceedings of major conferences, who has participated in invited special exhibits or poster sessions, or who has presented invited papers at technical meetings. Hyeong-Sick's article

"Recent Advances in Scanning Acoustic Microscopy for Adhesion Evaluation of Thin Films" which he co-authored with Dr. Bernhard R. Tittmann was published in the *Journal of the Korean Society for Nondestructive Testing* in 2009. In addition, he presented the paper "Quantitative Acoustic Model for Adhesion Evaluation of PMMA/Silicon Film Structures" which he co-authored with Dr. Tittmann at the 36th Annual Review of Progress in Quantitative Nondestructive Evaluation, held in Kingston, Rhode Island, July 26-31, 2009. Hyeong-Sick died unexpectedly in January 2010.

Kate Boudreau successfully defended her masters thesis, "A Comparison of Speed of Sound and Acoustic Nonlinearity Parameters as Biofuel Characterization Techniques," and plans to graduate in May. Kate (kbb151@psu.edu) has accepted an internship at the Idaho National Laboratory for Summer 2010.



Kate Boudreau



João Marcos Salvi Sakamoto

João Marcos Salvi Sakamoto, a doctoral candidate in electronic engineering at Aeronautics Institute of Technology, São José dos Campos - SP, Brazil, did research in acoustics, ultrasound and non-destructive evaluation of materials with the group for six months in 2009 as fulfillment of his doctorate "sandwich." Based on this research, João

has written a paper, "Directivity Measurements in Aluminum Using a Laser Ultrasonics System" with Dr. Bernhard R. Tittmann which has been accepted for a poster presentation at the 2nd International Symposium on Laser Ultrasonics to be held in Bordeaux, France, in July 2010.

Manton "Matt" Guers, doctoral candidate in engineering science and mechanics, completed the Graduate School Teaching Certificate. To achieve this, Matt (mjg244@psu.edu)



Manton Guers

Acoustics Characterization of Materials – Cont.

attended the Schreyer New Instructor Orientation, completed the Schreyer Institute Course in College Teaching and Higher Education (HI ED 546) and made several contributions to teaching E MCH 440 (Nondestructive Evaluation). In addition to teaching all the laboratory experiments, he took initiative to revise established experiments and developed new experiments for the course. Matt also has accepted an internship at the Idaho National Laboratory for Summer 2010.

Flow-Induced Noise

Dean Capone – Group Leader
dec5@psu.edu

The mission of the Flow-Induced Noise Group of the Center for Acoustics and Vibration is the understanding and control of acoustic noise and structural vibration induced by fluid flow. A summary of the accomplishments of the members of the Flow-Induced Noise Technical Group is presented below.

Dr. Stephen Hambric continues to consult for the NRC on flow-induced vibration and fatigue failure problems in U.S. commercial nuclear power plants.

Dr. Bill Bonness completed his Ph.D. research titled, "Low Wavenumber Turbulent Boundary Layer (TBL) Wall-Pressure and Wall Shear Stress Measurements from Vibration Data on a Cylinder in Pipe Flow," in Summer 2009. Dr. Bonness has one journal article accepted for *The Journal of Sound and Vibration* based upon the work and is working on a second one.

Dr. Dean Capone and Dr. Bill Bonness have started two new graduate students in flow-induced noise. Ms. Alexandria Salton is investigating the use of rings of sensors (likely accelerometers) for non-intrusively determining the acoustic pressure inside a water filled piping system. Mr. Neal Evans, following on the work of Dr. Bill Bonness, will be examining the effect of roughness on the low wavenumber portion of a turbulent boundary layer. The work will use the facilities developed by Dr. Bonness during his Ph.D work.

Dr. Timothy A. Brungart, Senior Research Associate, ARL Penn State and Dr. Michael S. Howe, Professor of Theoretical Mechanics, Boston University, recently completed a 3 year University/Laboratory Initiative (ULI) sponsored by the Office of Naval Research. The ULI was established to increase the number of engineers and scientists in Navy laboratories and University Affiliated Research Centers (UARC) that conduct research and development of undersea weaponry.

Flow-Induced Noise – Cont.

This specific ULI consisted of a laboratory mentor (Brungart), an academic advisor (Howe) and a student (Alia W. Foley) whose Ph.D. thesis focused on the self noise of supercavitating vehicles. Dr. Foley graduated in May 2009 from Boston University and accepted a position at Naval Undersea Warfare Center in Newport, RI.

Drs. Dennis McLaughlin and Phil Morris continue their work in supersonic jet noise. The work is developing analytical / computational noise generation models, enhanced understanding and methods (and validation) of scaling of small-scale and moderate-scale jet noise experimental data to full size, fully operating turbojet engines. Additionally, they will be evaluating several of the most promising methods of noise reduction for the new generation engines.

Propagation and Radiation

Victor Sparrow – Group Leader
vws1@psu.edu

The Propagation and Radiation Group had a wonderful year in 2009. The federal government continues its support of the Propagation and Radiation Group in the form of sponsored research, either directly or through subcontracts. We are very grateful for this support.

NASA Langley Research Center continues its sonic boom modeling efforts, and this support has been funding 3 of our graduate research assistants. Some of this funding has been through subcontracts, with Wyle, Arlington, VA acting as the prime. And through Penn State's work with the FAA/NASA/Transport-Canada PARTNER Center of Excellence (www.partner.aero), an additional 3 graduate research assistants are supported. The Penn State Graduate Program in Acoustics is a founding member of PARTNER (Partnership for Air Transportation Noise and Emissions Reduction), led by MIT. For information on either the NASA sonic boom modeling work or the PARTNER work, please contact Vic Sparrow.

We are pleased to welcome two new graduate research assistants this year, and both are from France. Alexandre Jolibois comes to us as a Ph.D. student from the French Building Research Center (CSTB) (Paris and Ecoles des Ponts Tech), and he is working on the design of improved noise barriers for high-speed train applications.

He is co-advised by Vic Sparrow, Denis Duhamel (University of Paris Est, UR Navier, Ecole des Ponts), and Jerome Defrance (French building research center, CSTB). In addition, Kieran Poulain comes to us as a M.S. student from Ecole Centrale de Lille.

Technical Group Research Highlights

Propagation and Radiation – Cont.

Kieran's research is to understand the propagation of en-route aircraft noise (high altitude cruise noise), and this work is funded by the FAA. It is wonderful to have these students working with the Propagation and Radiation Group.

We also sadly report a tragedy in April 2010 that directly impacts the Propagation and Radiation Group. Prof. Nadine Barrie Smith, of the Department of Bioengineering and the Graduate Program in Acoustics, passed away at home due to an accident. Dr. Smith was very active in the CAV, as well as many other laboratories and institutes at Penn State. She made many important contributions in therapeutic ultrasound, particularly in the areas of hyperthermia treatments for prostate cancer and for trans-dermal drug delivery of insulin for diabetics. Her friendliness, collegiality, and enthusiasm for acoustics and ultrasound will be greatly missed by us all.

Graduate Students:

Joyce Rosenbaum, Ph.D. expected summer 2010

Thesis topic: Advanced acoustic propagation models for predicting aviation noise.

Sponsor: FAA/U.S. Dept. of Transportation Volpe Center

Advisor: A. Atchley

Kimberly Lefkowitz, Ph.D. expected summer 2010

Thesis topic: Ray/radiosity methods for the propagation of sonic booms in urban canyons

Sponsor: NASA

Advisor: V. Sparrow

Sang Cho, Ph.D. expected summer 2010

Thesis topic: Sonic boom diffraction around buildings and hybrid model implementations

Sponsor: NASA

Advisor: V. Sparrow

Brian Tuttle, Ph.D. expected fall 2010

Thesis topic: Nonlinear acoustic streaming in conical thermoacoustic devices

Sponsor: Office of Naval Research

Advisor: V. Sparrow

Denise Miller, Ph.D. expected summer 2010

Thesis topic: Human reaction to low-amplitude sonic boom: indoor versus outdoor responses

Sponsor: National Science Foundation and FAA

Advisor: V. Sparrow

Beom Soo Kim, Ph.D. expected spring 2011

Thesis topic: Sonic boom transmission from outdoors to indoors

Sponsor: NASA/Wyle and FAA

Advisor: V. Sparrow

Propagation and Radiation – Cont.

Amanda Lind, M.S. expected summer 2010

Thesis topic: Terrain reflection and post-boom noise for low-boom sonic booms

Sponsor: FAA

Advisor: V. Sparrow

Kieran Poulain, M.S. expected summer 2011

Thesis topic: Atmospheric profile effects on the propagation of aircraft en-route noise

Sponsor: FAA

Advisor: V. Sparrow

Alexandre Jolibois, Ph.D. expected summer 2012

Thesis topic: Optimization of high-speed rail noise barriers using a boundary element approach

Sponsor: Graduate Program in Acoustics and French building research center (CSTB)

Advisors: V. Sparrow, D. Duhamel, J. Defrance

Machinery Prognostics and Condition Monitoring

Karl Reichard – Group Leader

kmr5@psu.edu

The Machinery Prognostics and Condition Monitoring Technical Group is focused on methodologies and technologies for accurate and reliable assessment of equipment condition and predicting remaining useful life in machinery. Below are descriptions of one current and one recently completed project.

Wind Turbine Health Monitoring

Researchers from the Applied Research Laboratory and the Aerospace Engineering Department are working with the Penn State Center for Sustainability (CfS) to demonstrate health monitoring concepts on a CfS wind turbine at Penn State. The CfS wind turbine is a Southwest Windpower Whisper 500 with two blades and a peak capacity of three kilowatts of power.



Figure 1
Penn State
Whisper 500
wind
turbine

Brenton Forshey, a graduate student in Aerospace Engineering, is working to implement health monitor on the turbine blades and the electrical generator. The wind turbine is cur-

Machinery Prognostics – Cont.

rently instrumented with voltage and current sensors to each of the generator's three output phases and an accelerometer on the mast supporting the turbine nacelle. Additional sensors monitor the meteorological conditions at the site and the energy storage system.



Figure 2 Prototype composite wind turbine blade – a 3-axis accelerometer will be mounted inside each blade monitoring unsteady loads

Another group of students is designing and building new composite blades for the wind turbine. Each blade will contain an embedded accelerometer to monitor blade vibrations and to characterize unsteady wind loads on the blades. The accelerometer mounted on the wind turbine tower measures the unsteady forces transmitted from the blades to the rest of the structure.

Blade and gearbox failures are two of the most critical failures in full-scale commercial wind turbines. Studies suggest that gearbox faults are initiated by unsteady loads on the generator shaft bearings. One goal of the present measurements is to characterize the unsteady loads on the wind turbine, and to hopefully show that those unsteady loads can also be detected in the electrical output of the generator. Additional drive train testing will be conducted on the ARL mechanical diagnostic test bed using load conditions measured on the wind turbine.

Other participants in the project include Dr. Karl Reichard, Dr. Susan Stewart, Mr. Mark Turner, and Mr. Nate Lasut from ARL, and Dr. Dennis McLaughlin from the Department of Aerospace Engineering.

US Army HEMTT Demonstration Vehicle

ARL Penn State recently completed installation of several advanced technologies on a US Army HEMTT truck. The truck was loaned to ARL by the Project Management Office for Heavy Tactical Vehicles at the US Army Tank Automotive Command (TACOM) and was recently returned to TACOM to serve as a technology demonstration platform.

Technical Group Research Highlights

Machinery Prognostics – Cont.

The ARL project was lead by Brian Murphy and Mark Brought with individual technology development efforts lead by contributors from ARL and the PSU College of Engineering.

The technology demonstrations on the HEMTT vehicle included installation of sensors and computing infrastructure for monitoring and in-vehicle display of critical system health parameters, a pulse power starting system, a hydraulically driven auxiliary power generation system, and a low-cost collision warning system.



Figure 3 US Army HEMTT A2 technology demonstration vehicle

The on-platform system for health monitoring and diagnostics integrated information from existing vehicle data sources and new sensors. The existing vehicle data sources used in the health monitoring implementation are listed below:

- Existing Vehicle Computer System (VCS)
- Open data sources: J1939, J1708
- Proprietary data sources such as diagnostic messages and operational parameters

Several new sensors were also added to the truck to monitor engine oil level and condition, fuel filter condition, transmission oil level, tire pressure, coolant level, brake wear, and hydraulic reservoir oil level. Condition monitoring was also applied to power system components:

- Alternator - Voltage, current, temperature
- Battery - V, I, T, State of Charge, State of Health
- Ultracap - V, I, T, SOC

The power system components were part of the development and demonstration of a new Primary Power Management System (PPMS) for the vehicle. The PPMS uses an ultracapacitor to provide starting power for the vehicle and replaces the traditional starting lighting and ignition batteries with appropriately sized deep-cycle batteries. This will eliminate one of the most common causes of shortened battery life in vehicles -

Machinery Prognostics – Cont.

deep cycling of vehicle starting batteries when they are used to power vehicle electrical loads when the engine is off, since starting batteries are typically not designed to be repeatedly fully discharged and recharged.

A key component of the health monitoring system demonstration was the development and integration of a set of common graphical user interfaces for displaying the health and status of critical platform systems. These graphical interfaces, examples of which are shown in Figure 4 and Figure 5, can be customized for other platforms by substituting the desired vehicle-specific graphics and editing an underlying configuration file.



Figure 4 Top-level display showing 3-D representation of platform with color-coded alert and alarm messages,



Figure 5 System schematic with critical health and status information

One more capability developed and demonstrated on the HEMTT platform was a low-cost collision avoidance system designed to provide a warning to the driver if they follow too closely to another vehicle during convoy operations. The system uses commercial off-the shelf parts and consists of a GPS, a MEMS accelerometer, a processor card and an 802.11 wireless network connection. The on-platform system monitors the GPS information and acceleration

Machinery Prognostics – Cont.

characteristics of the platform and shares that information with other vehicles in the convoy. Each vehicle compares its own speed and dynamic driving conditions to the speed and dynamics of the vehicle in front of it (shared via the 802.11 wireless network connection). The system determines whether there is sufficient stopping distance to the vehicle in front and

alerts the driver if he or she is following too closely.



Figure 6 Collision avoidance warning system

The system was tested at the Penn State Larson Transportation Institute Test Track and in multi-vehicle convoys at the US Army Yuma Proving Ground with simulated emergency stops. Future work with the system will include determination of required stopping distances based on measurements of vehicle acceleration and deceleration characteristics, system health, and classification of current road conditions. The same sensor packaged used in the collision warning system is also being used to monitor road-induced wear on vehicles for several other projects.

Structural Health Monitoring

Dr. Cliff Lissendon from the PSU Engineering Science and Mechanics Department is engaged in several structural health monitoring projects. As part of NASA's Aircraft Aging and Durability program, Cliff is studying how ultrasonic guided waves interact with defects and how their propagation depends on the elastic properties of the materials. The goal is to use guided ultrasonic waves to measure and monitor structural integrity in bonded joints. Preliminary results show the dependence of the conversion of Lamb waves to interface waves on dispersion curves and the layered structure of the materials.

Technical Group Research Highlights

Machinery Prognostics – Cont.

In other projects, Dr. Lissendon is developing phased arrays of piezoelectric transducers for detecting delamination in composite materials. The phased sensor array allows correction of skewing in the ultrasonic energy normally caused by anisotropic laminates, providing better sensitivity and localization of the defects. This work was funded by the Air Force Office of Scientific Research.

With support from the Ben Franklin Institute

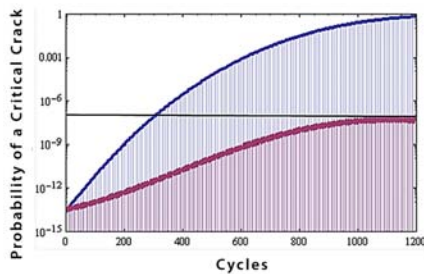


Figure 7 Probabilities of critical crack formation (blue line) and critical crack detection (red line) by SHM system.

through the Penn State Center of Excellence in Structural Health Monitoring, Dr. Lissendon is working to develop an ultrasonic guided wave SHM system for characterizing fatigue crack size at a hot spot in a built-up plate structure. Four piezoelectric wafer active sensors (PWAS) are located around a hole in the structure. One PWAS sends a toneburst signal that is received by the other three PWAS. Cycling through all four PWAS in this manner gives 12 signals associated with different guided wave paths. Because of the presence of multiple modes and reflections the signals are fairly complex. The PWAS have detected a crack less than 2 mm long. Accurate detection of crack size enables better fatigue crack growth modeling and calculation of the probability that a crack exceeds a critical size at which maintenance is required, as shown in the figure above.

Rotorcraft Acoustics and Dynamics

Ed Smith, Group Leader
ecs5@psu.edu

The Penn State's CAV Rotorcraft Acoustics and Dynamics Group continues to be at the core of our Vertical Lift Research Center. Penn State is home to one of only two Vertical Lift Research Centers of Excellence (VLRCOE) in the country. This Center currently supports nearly 60 full-time graduate students and involves more than 25 Penn State faculty members in a wide range of technologies supporting rotary-wing aircraft.

Seeking cost and weight efficient solutions to lower interior noise and vibration levels, and reduced exterior noises signatures is a high priority. We have experienced particular growth in programs focused on structural health monitoring, and ultrasonic ice protection systems. These areas have "increased the frequency range of interest" amongst our CAV Group members. Acoustics and dynamics issues associated with ducted fan air vehicles, active rotor systems, and variable speed compound rotorcraft are driving many of our technical objectives. Our various research projects are presently supported by the US Army, US Navy, NASA, and the industry sector (including large airframe manufacturers, sub-system vendors, and numerous small high-technology companies). Emphasis areas include; interactional source noise, acoustical scattering of rotor noise, ducted fan noise, gearbox noise, actively controlled and morphing rotors, active airframe vibration control, crashworthy and impact resistant structures, anti-icing systems, variable speed rotors, structural health monitoring, and rotor loads monitoring. Several new facilities have recently been brought online. The Adverse Environment Rotor Test Stand (rotor icing chamber), 3 separate Ducted Rotor Testbeds, a crash testing sled, and a new robotically controlled filament winder are now fully operational.

CAV Information

Dr. George A. Lesieure,
 Director (Acting)
 Penn State University
 233 Hammond Building
 University Park, PA 16802
 Tel: 814-865-2569
 Fax: 814-865-5965
 Email: gal4@psu.edu

Dr. Steve Hambric
 Associate Director
 ARL/Penn State
 PO Box 30
 State College, PA 16804
 Tel: 814- 863-3030
 cell: 814- 404-0653
 email: sah19@arl.psu.edu

Kelley Williams
 Communication Coordinator
 Penn State University
 157 Hammond Building
 University Park, PA 16802
 Tel: 814-863-1673
 Fax: 814-863-7777
 Email: kak253@psu.edu