CAV Review '15–'16

CENTER FOR ACOUSTICS & VIBRATION

CAV Update

Spring workshop dates set

The CAV's annual workshop will be held at the Penn State Nittany Lion Inn 3—4 May. This year the workshop will have a format similar to that of previous years with the event lasting for two full days. During each technical group's presentation there will be a few minutes to highlight special areas of interests. As in the past laboratory tours will be given to familiarize attendees with some CAV facilities. Tuesday evening we will host a student poster session and reception. It will be held in Café Laura. The program will bring a mix of presentations from technical group leaders, international liaisons, and several corporate sponsors. Graduate students and their advisors are available for discussions concerning their research. While formal presentations are organized to allow for the exchange of technical information, we lengthened the allotted time for breaks to offer ample opportunities for informal discussions.

Student poster session held during workshop

The student poster competition will be held at our Tuesday evening social in Café Laura, between 6 and 9 pm. Our corporate sponsors, government guests, and international liaisons will be asked to cast votes for the best posters, and we will award prizes for 1st, 2nd, and 3rd places ($200, $150, and $100).

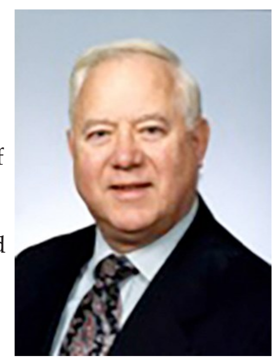
Last year's winners were tied for first place, Saad Ahmed and Housain Shekhani, and Phil Feurtado took third place.

CAV seminars archived online

Remember that CAV members may now access our previous lunchtime seminar series online. Videos of the presentations from Fall 2009 to present may be viewed. This is a service to our members only, so please contact us for the site location.

Temperature Resistant Spray-on Piezoelectric Transducers for Materials Characterization with Ultrasonic-Guided Waves

By Cliff J. Lissenden and Bernhard R. Tittmann



Material Degradation

Many advanced reactor concepts require the materials to resist various stresses in harsh environments over long service durations. Thus, at some point material degradation (e.g., creep, fatigue, embrittlement) will commence, and its progression, if unchecked, could eventually lead to failure. While degradation processes evolve differently based on material, loading, and conditions, they invariably start at the microstructure level and then progress to the macroscale, and ultimately to fracture. Since shutdowns for inspections are extremely costly, it is preferred to implement online condition monitoring to keep the plant operating until maintenance is necessary. The interaction of ultrasonic guided waves with damage make them very useful for condition monitoring, as will be described below. The requirements of the online condition monitoring system investigated herein are (i) resistance to elevated temperature and (ii) ability to detect incipient damage.

Objectives

The Nuclear Energy Enabling Technologies (NEET) program develops crosscutting technologies that directly support the Office of Nuclear Energy's development of advanced reactor concepts and fuel cycle technologies. The Advanced Sensors and Instrumentation (ASI) subprogram develops the scientific basis for sensors and supporting infrastructure technology that address technology gaps relating to measurements at existing and advanced nuclear power plants. One of the five objectives of the ASI subprogram is to "identify and conduct research into monitoring and control technologies, including human factors, to achieve control of new nuclear energy processes, and new methodologies for monitoring to achieve high reliability and availability." This article describes results of a Nuclear Energy University Program (NEUP)-sponsored blue-sky project (11-3046) to investigate spray-on piezoelectric transducers for online condition monitoring in high-temperature environments. The condition monitoring is based on ultrasonic-guided waves.

Materials

Ultrasonic transduction is traditionally achieved using piezoelectric ceramic materials, which convert an alternating voltage into a mechanical disturbance that propagates into and through the material to be monitored or vice versa. Traditional ultrasonic transducers use lead zirconate titanate (commonly known as PZT) as the active material because of its high coupling parameter (d_{33}), but its Curie temperature (T_c) limits its usage at elevated temperatures. There are piezoceramics that provide better temperature resistance, but typically at a cost of having a lower coupling coefficient. Bismuth titanate ($Bi_4Ti_3O_{12}$, or BT for short) and lithium niobate ($LiNbO_3$, or LN for short) are good examples and their relevant properties are compared with PZT in Table 1. The sol-gel technique makes processing of composites quite straightforward, as described in the subsequent section. In this research

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Corporate Members & International Liaisons

Corporate Members & Representatives

Bechtel Marine Propulsion Corp. —Eric Salesky (PA), Steve Dunn (NY)
Boeing—Paul Brent
Bose—Ray Wakeland
Bridgestone Americas—Paul Zakelj
Carrier—Lee Tetu
Fisher Valves and Instruments— Shawn Anderson
Gulfstream—Kristopher Lynch
ITT—Mark Downing
KCF—Jacob Loverich
Lord Corporation—Mark Negro
Martin Guitar—Josh Parker
Moog, Inc— Chris Layer
Newport News Shipbuilding—Kevin Smith
Pratt & Whitney— Richard Labelle
United Launch Alliance—Ed Heyd
Volvo - Hongan Xu

International Liaisons and Representatives

ISVR (UK) - Paul White
DLR (Germany) - Lars Enghardt
CIRA (Italy) - Antonio Concilio
INSA de Lyon—Etienne Parizet
KAIST—Jeong-Guin Ih
KU-Leuven—Wim Desmet
Hong Kong Polytechnic University—Li Cheng

CAV Welcomes New Corporate Members

The CAV is pleased to welcome three new corporate members, 3M Science, The Babcock & Wilcox Company and Bristol Compressors to the group.

3M Science. Applied to Life.™ Those words embody the spirit of our enterprise. 3M harnesses the power of science to make the world safer, more efficient and more prosperous. We use science to solve impossible challenges with our customers, and to stretch toward our vision of advancing every company, enhancing every home and improving every life. To learn more about 3M please visit www.3M.com; Ron Gerdes is the company's liaison with the CAV.

Babcock & Wilcox (B&W) is a global leader in energy and environmental technologies and services for the power and industrial markets. Headquartered in the USA, B&W has operations, subsidiaries and joint ventures worldwide. Within B&W, the Technology Group supports engineering technology, research & development, and new product development & planning. Vibrations testing and analysis is a core expertise in the Technology Group, and supports the performance of our entire range of products. We pride ourselves on continually maintaining the state of the art in detection and characterization of vibration sources to efficiently solve complex problems, both in the research lab and in the field. Expertise in the area of vibrations testing and analysis includes flow-induced vibrations, acoustics, rotating equipment, and structural vibrations. To learn more about B&W please visit www.babcock.com. Suzana Rufener is the liaison to the CAV.

Bristol Compressors designs and manufactures hermetic compressors for residential and light commercial air conditioning, heat pump and refrigeration applications. It is one of the largest compressor manufacturers in the world and is the only one that can claim "Made in the U.S.A" The company is committed to environmentally conscious, energy-efficient products and offers a variety of ozone-friendly refrigerant compressors. Bristol operations are headquartered in Bristol, Virginia and are fully integrated, with world-class machining capabilities. To learn more about Bristol Compressors please visit www.bristolcompressor.com. David Halbrooks is the liaison to the CAV.

CAV Members Receive Honors and Awards

Erika Arrojado received Second Place in the Shreyer's Honors College ROAR Competition

Whitney Coyle received the 2015 Kenneth T. Simowitz Memorial Citation

Philip A. Feurtado received the Leo Beranek Student Medal for Excellence in the Study of Noise Control which was awarded by the Institute of Noise Control Engineering USA; won the student paper competition at InterNoise 2015; and received the 2015 Skudrzyk Award from the Graduate Program in Acoustics

Scott Hromisin received a SMART scholarship from the Department of Defense

Richard C. Marboe was approved as Senior Vice President-elect for the Technical Events and Content Sector of the American Society of Mechanical Engineers.

S. Ahmed, **Zoubeida Ounaies and Mary Frecker** received the Best Paper Award in Mechanics and Material Systems at the Adaptive Structures and Material Systems Branch of the ASME Aerospace Division

Yashwanth Tummala, Aimy Wissa, **Mary Frecker** and James Hubbard received the Best Paper Award in Structures and Structural Dynamics at the Adaptive Structures and Material Systems Branch of the ASME Aerospace Division

Mary Frecker, Professor of Mechanical Engineering & biomedical Engineering promoted to Associate Department head for Graduate Programs Mechanical & Nuclear Engineering at Penn State

Trevor Jerome received second place in the student poster session of the ASA meeting in Pittsburgh

Martin Lawless received the 2015 Kenneth T. Simowitz Memorial Citation

Richard Metzger has been presented with a copy of the NIST Speaker Recognition Training Part 2 and Test for his work in speaker recognition

Jennifer Miksis-Olds received the Presidential Early Career Award in Science and Engineering.

Matthew Neal received the Robert Bradford Newman Student Medal for Merit in Architectural Acoustics for his Master's thesis; 2016

Stephen Nichols received the 2015 Kenneth T. Simowitz Memorial Citation

Zoubeida Ounaies was promoted to Fellow of ASME

Kenji Uchino was the Chief Guest Speaker at 34th Annual Convocation, Sri Sathya Sai Inst. of Higher Learning, gave the Convocation Address and received the International Ceramic Award at the Global Academy of Ceramics

Paper titled "Design and Analysis of A Supersonic Jet Noise Reduction Concept" coauthored with Anthony Pilon (Lockheed Martin), **Russell Powers, Dennis McLaughlin, and Philip Morris** (all PSU) was selected as the overall winner of the 2015 LM Aeronautics Best Technical Paper Competition

Steve A.E. Miller, NASA Langley Acoustics and a CAV grad, received the NASA Early Career Achievement Medal

Mike Doty (MS '98, Ph.D. "02) and a CAV grad, was promoted to Acoustics Branch chief at NASA Langley Research Center

Continued from page 1

PZT/ BT and BT/LN composites were investigated for service temperatures up to ~400°C (e.g., for a number of light water reactor components) and ~850°C (e.g., intermediate heat exchanger for the next generation very high temperature reactor), respectively.

Table 1. Properties of some piezoelectric ceramics

Material	T_c(°C)	d_{33}(pC/N)
PZT	340	125-340
$Bi_4Ti_3O_{12}$	685	5-20
$LiNbO_3$	1200	6

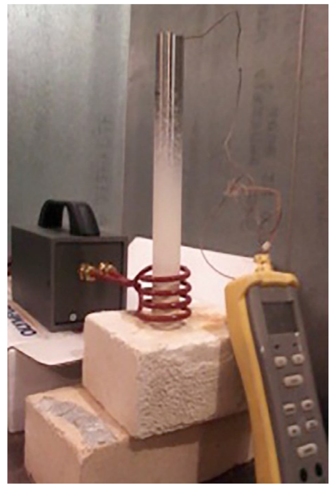

Figure 1. PZT/BT coating sprayed on a stainless steel pipe and ready to densify with an induction heater.

Figure 2. Laser ablated 4-element PZT/BT comb transducer

Transducer Processing

The processing of transducers to send and receive ultrasonic-guided waves has multiple steps. The following steps can be used in the laboratory or modified for field implementation.

1. Create a sol-gel solution consisting of the first constituent (e.g., PZT) and dope it with the second constituent (e.g., BT) to form the composite (e.g., PZT/ BT). Mix the solution with an ultrasonic horn.
2. Air-spray the mixture at low pressure onto the selected sample. Once dried, a single spray coating is roughly 20 microns thick. Spraying can be done on flat or curved surfaces; a pipe example is shown in Figure 1.
3. Drive out the organic compounds by heating the sample. This pyrolization process reduces the volume so care is taken to minimize microcracking.
4. Repeat the spray and pyrolization steps to achieve the desired coating thickness.
5. Partially densify the multilayer coating with an induction heating system, again taking care to minimize microcracking.
6. Deposit the electrode (e.g., gold or platinum) on the coating. Due to the porosity of the coating and elevated operating temperatures, electrode material selection and the deposition method are critical. Sputter coating and brush application of the same material can have completely different results.
7. Pattern the electrode to enable control of actuation and reception of specific preferred guided wave modes, as described in the ultrasonic-guided wave section below. Figure 2 shows a multi-element comb transducer on a pipe.
8. Attach a lead wire to the electrode to serve as ground as long as it is electrically conductive.
9. Build a dam around the transducer to enable an oil bath to eliminate arcing when a large voltage is applied to the electrode. Pole the transducer by applying a large voltage at elevated temperatures.
10. Deposit a layer of Sauereisen to protect the transducer.

Functionality

The temperature-dependence of the signal strength of a PZT/BT transducer sprayed on the end of a roughly 25-mm-long cylindrical rod was tested in a tube furnace. The transducer was pulsed to send a longitudinal wave that reflected off the back wall and was received in pulse-echo mode. The normalized peak-to-peak amplitude is plotted as a function of temperature in Figure 3. Signal degradation starts at 475°C and a detectable signal was received until 690°C. Analogous results are shown in Figure 4 for a BT/LN transducer, for which signal degradation began at 700°C and a detectable signal was received until 1000°C. A limited number of mechanical fatigue tests were conducted, and no coating degradation was observed. Thermal aging tests demonstrated the importance of electrode material selection and deposition method in that electrode atoms can migrate through the porosity of the piezoceramic coating causing short circuit or they can chemically react with elements in the coating nullifying its piezoelectric nature.

Ultrasonic-Guided Waves

Ultrasonic-guided waves can propagate long distances between transmitter and receiver, provide volumetric coverage of inaccessible material, and offer good sensitivity to damage. Energy loss is small compared to bulk waves because the boundaries of the structure (e.g., a plate or pipe) guide the energy in specific directions. However, the existence of multiple modes at a given frequency and the fact the wave speed depends on the excitation frequency must be taken into account. A comb transducer has multiple elements at a fixed spacing, and because the fixed spacing dictates the preferred wavelength generated, the comb transducer provides a means of wave mode control via the fundamental relationship, $c_p = \lambda f$; where λ is the wavelength, f is the excitation frequency, and cp is the phase velocity of the preferred mode. By knowing the phase velocity dispersion curves and the desired excitation frequency, the wavelength is computed; hence, the element spacing is known. The dispersion curves for a stainless steel pipe are shown in Figure 5 along with the activation line for a comb transducer having element spacing λ. A comb transducer for a pipe has a sequence of rings with fixed spacing λ, as shown in Figure 2. This PZT/BT comb transducer was processed using the aforementioned 10-step procedure, where the patterning (Step 7) was performed by laser ablation to remove electrode material (i.e., transform a continuous electrode into five rings). The signal in Figure 6 was actuated and received by PZT/BT comb transducers.

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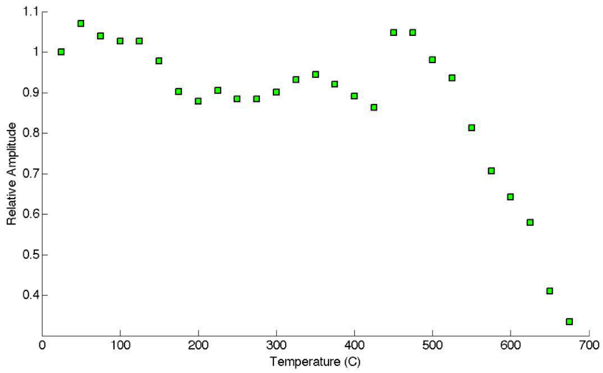


Figure 3. Normalized peak-to-peak amplitude as a function of temperature for PZT/BT transducer.

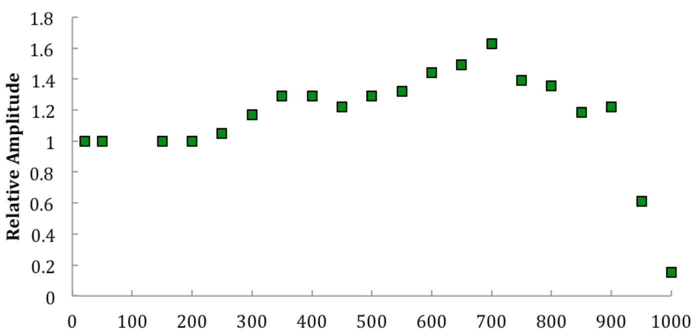


Figure 4. Normalized peak-to-peak amplitude as a function of temperature for BT/LN transducer.

Ultrasonic-Guided Waves

Ultrasonic-guided waves can propagate long distances between transmitter and receiver, provide volumetric coverage of inaccessible material, and offer good sensitivity to damage. Energy loss is small compared to bulk waves because the boundaries of the structure (e.g., a plate or pipe) guide the energy in specific directions. However, the existence of multiple modes at a given frequency and the fact the wave speed depends on the excitation frequency must be taken into account. A comb transducer has multiple elements at a fixed spacing, and because the fixed spacing dictates the preferred wavelength generated, the comb transducer provides a means of wave mode control via the fundamental relationship, $c_p = \lambda f$; where λ is the wavelength, f is the excitation frequency, and cp is the phase velocity of the preferred mode. By knowing the phase velocity dispersion curves and the desired excitation frequency, the wavelength is computed; hence, the element spacing is known. The dispersion curves for a stainless steel pipe are shown in Figure 5 along with the activation line for a comb transducer having element spacing λ. A comb transducer for a pipe has a sequence of rings with fixed spacing λ, as shown in Figure 2. This PZT/BT comb transducer was processed using the aforementioned 10-step procedure, where the patterning (Step 7) was performed by laser ablation to remove electrode material (i.e., transform a continuous electrode into five rings). The signal in Figure 6 was actuated and received by PZT/BT comb transducers. A comb transducer can also be created by brush painting electrode stripes, although the edges are less uniform.

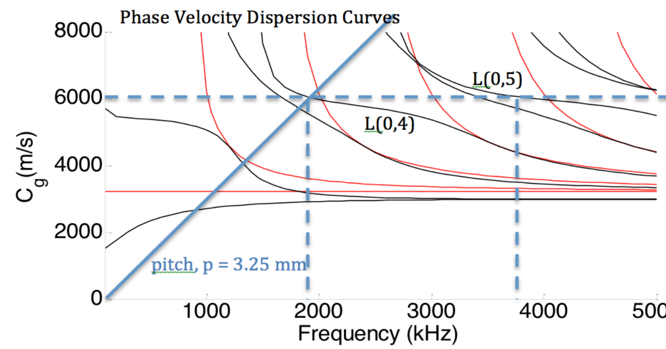


Figure 5. Phase velocity dispersion curves for axisymmetric modes of a stainless steel pipe (25.4-mm diameter, 2.1-mm wall thickness); black lines indicate longitudinal modes and red lines indicate torsional modes. The activation line for a comb transducer is shown for L(0,4) mode, which generate L(0,5) mode second harmonic.

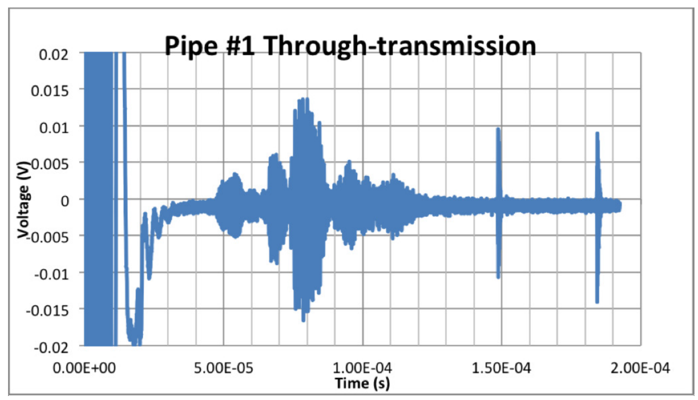


Figure 6. Stainless steel pipe with two PZT/BT comb transducers with four 1.6-mm -wide elements that generates axisymmetric L(0,n) modes when excited at 1.83 MHz

Incipient Damage Characterization

Nonlinear ultrasonics are sensitive to the effects of microstructural features such as dislocation density, persistent slip bands, precipitates, and voids. This sensitivity is due to the small distortion of the wave caused by the lattice anharmonicity. The distortion is measurable in terms of higher harmonics in the frequency spectrum, thus the term nonlinear ultrasonics is used because the interrogation signal is at a different frequency than the excitation frequency. Nonlinear ultrasonic-guided waves are more demanding to analyze bulk waves because the higher harmonic must lie on a dispersion curve, it must be phase matched with the primary mode, and there must be power flux transferred to it. If these so-called internal resonance conditions are met, then the higher harmonic will have an amplitude that increases as it propagates, thus it is said to be cumulative. Nonlinear-guided waves combine the advantages of large propagation distances, volumetric coverage, single-sided access, and coverage of inaccessible material with sensitivity to microstructural changes indicative of incipient damage. However, it remains to be shown that spray-on PZT/BT and BT/LN transducers can actuate guided wave modes that generate detectable higher harmonics. If so, then it should be possible to characterize incipient damage in-situ, thereby enabling condition-based remaining life estimates.

CAV student theses 2015

We continue to update our Penn State CAV student thesis database, available at: www.cav.psu.edu/thesislist.aspx Most of the theses are available as PDF downloads. Here is a list of our 2015 MS and PhD CAV graduates:

PhD:

Camin, Henry: *Coherent broadband sonar signal processing with the environmentally corrected matched filter*

Denes, Samuel: *Ocean environmental effects on walrus communication*

Ding, Ma: *Holography for nonlinear imaging and metamaterial characterization*

Guo, Feng: *Acoustic tweezers : manipulating micro-objects with the power of sound*

Lee, Abe: *Fluid-structure interaction of large amplitude structure vibrations and moderately high reynolds number turbulent flows*

Lurie, Michael: *The prediction of unsteady aerodynamic loading in high aspect ratio wall bounded jets*

Mei, Lei: *Novel piezoelectric composite systems for biomedical and industry applications*

Myers, Leighton: *Investigation of the flow-field of two parallel round jets impinging normal to a flat surface*

Olson, Derek: *High-frequency acoustic scattering from rough elastic surfaces*

Powers, Russell: *Experimental investigation of the noise reduction of supersonic exhaust jets with fluidic inserts*

Shaw, Matthew: *Predicting vibratory stresses from aero-acoustic loads*

MS:

Bondoux, Alexandre: *Modeling, design and testing of a multi-cell periodic fluidic flexible matrix composite device*

Corle, Ethan: *Optimization of active flap deployment for efficient in-plane rotor noise reduction*

Haidar, Ahmad: *Comprehensive model and experimental validation of passive vibration suppression for supercritical rotary machines*

Hildebrandt, Timothy: *Like-envelope recombination: a technique for recombining dependent intrinsic mode functions*

Hromisin, Scott: *Laser doppler velocimetry measurements of a scale model supersonic exhaust jet impinging on a ground plane*

Irwin, Jeffrey: *An acoustic foundation for a fully-coupled aeroelastic and aeroacoustic phonation model using OpenFOAM*

Jain, Abhishek: *Trailing edge noise prediction using the non-linear disturbance equations*

Kearney, Jennifer: *An analysis of the dynamic response of suspension footbridges measured against human comfort criteria*

Ledford, Kenneth: *Practical sprayed-on transducer composites for high temperature applications*

Neal, Matthew: *Investigating the sense of listener envelopment in concert halls using third-order Ambisonic reproduction over a loudspeaker array and a hybrid room acoustics simulation method*

Petersen, Erik: *Absorption and dispersion predictions of noise from en-route subsonic and supersonic aircraft*

Rufo, Joseph: *From chip-in-a-lab to lab-on-a-chip: the development of a prototype for acousto-fluidic nanoparticle separation*

Suo, Qiuling: *The implementation of a time domain impedance boundary condition*

Yu, Tianliang: *Vibration reduction of sandwich composites via 3-D manufactured acoustic metamaterial cores*

50 Years of Acoustics Education

During the past academic year the Graduate Program in Acoustics has celebrated 50 years of acoustics education at Penn State. Founded in 1965, the Acoustics Program is the largest program of its kind in the United States offering the Master of Science, Master of Engineering and the only educational institution that offers a Ph.D. in Acoustics. A celebratory event was held in conjunction with the May 2015 meeting of the Acoustical Society of America in Pittsburgh, PA. It was wonderful to catch up with so many alums of the Acoustics Program at the Pittsburgh event. This event and a brief history of the 50 years of the Acoustics Program were documented in an article appearing in the Fall 2015 issue of the magazine Acoustics Today, and it is available online for free at acousticstoday.org .

While everyone is taking the time to look back on what all has been accomplished over the years, for example, over 200 Ph.D. degrees and over 400 Masters degrees completed in Acoustics, the Program looks forward to continued growth. For example, in the upcoming 2016-2017 academic year, the Acoustics Program is offering for the first time a Master of Science (M.S.) 1-year option.

This option is a research-focused masters degree consisting primarily of coursework. This degree does require a research-based scholarly paper, but it does not involve the level of research required for a traditional thesis. This 1-year M.S. degree option is completed within one calendar year and requires students to take a slightly heavier course load (13 credits during the Fall and Spring semesters and 4 credits during the Summer term). Students in the 1-year resident M.S. program are expected to pay their own tuition and living expenses, as they don't receive assistantships. But they are able to return to the workforce much more quickly than for students in the traditional 2-year M.S. option which requires a thesis.

Technical Research Group Highlights

Acoustics Characterization of Materials
Bernhard Tittmann, Group Leader
brt4@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. A major thrust is in the research and development of sensors for harsh environments, including high temperature (up to 1000C) and nuclear irradiation (Nuclear Reactors).

Our group has been fortunate to receive major funding from DOE for ATR-NSUF tests in the MIT Nuclear Reactor of 6 different piezoelectric sensors for possible use in harsh environments. The results of these test are currently being evaluated but preliminary findings show that 4 of the sensors survived the irradiation for a period of 18 months after which the program came to an end.

The group has also been fortunate to receive rare and expensive piezoelectric wafers from Bechtel Bettis for phased array design, construction and testing for high temperature, high pressure.

One of the students graduating last year received the coveted ESM Fenlon Award for the outstanding senior capstone thesis.

Our recent graduate Dr. Matt Guers has a permanent position at the PSU Applied Research Laboratory where he is doing outstanding work for Prof. Hambric. He is also a part-time instructor in the ESM Department.

Projects and Students:
Title: Ultrasonic Phased Array Design, Construction and Testing
Sponsor: Bettis Atomic Power Laboratory
PI: B. Tittmann
Students: Brian Reinhardt (EMS; Ph.D. Candidate), Andrew Suprock (EMS; MS)

Title: Enhancement of Spray-on Transducer Technology for Field Deployment
Sponsor: Electric Power Research Institute
PI: B. Tittmann
Students: Janet Xu (Acoustics; MS); Chunying Wang (EMS MS)

Title: DOE Creep Specimens at High Temperature
Sponsor: Battelle - Pacific Northwest National Laboratory
Co-PIs: C. Lissenden, B. Tittmann
Students: Leland Tien (EMS; MS), Connor Smith (EMS BS)

Adaptive Structures and Noise Control
George Lesieutre, Group Leader
gal4@engr.psu.edu

The mission of the Adaptive Structures and Noise Control Technical Group is to pursue strategies for reducing vibration and noise in engineering systems. This involves the development of active materials and devices, accurate modeling approaches, passive control methods, discrete and distributed sensors and actuators as well as placement strategies, structural integration methods, 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 adaptive structures.

Title: Placement of Circular Force Generators for Vibration Cancellation
Sponsor: Sikorsky
Summary: Relatively new devices, "circular force generators" can be used to cancel hub forces and moments in helicopters, typically at N/rev. We seek optimal approaches to placement of such devices, along with heuristic insight into the best approaches.
Student: Brad Sottile, Ph.D. expected (with R.G. Melton)

Title: A Two-Material Topology Optimization Method for the Design of Spacecraft Structures under Thermo-Mechanical Loads
Sponsor: AFOSR
Summary: Passive spacecraft thermal control systems could be lighter and simpler than the electrically-driven systems that are in wide use today. Thermal control of a two-dimensional sandwich panel could be achieved by forcing contact at internal interfaces via differential thermal expansion. Ongoing research addresses thermo-mechanical topology optimization of a two-material sandwich panel core to achieve a broad range of effective thermal conductivity, as well as associated advances in 3-D printing.
Collaborators: Dr. Mary Frecker (ME), Dr. Jim Adair (MatSci)
Student: Tianliang Yu, Ph.D. December 2017 (expected)

Title: Piezoelectric Actuators for Synthetic Jets
Sponsor: Boeing
Summary: Synthetic jet devices are attractive for active flow control because they do not require a pressurized air source. Instead, they cyclically ingest and expel air with zero net mass flow. High-performance ferroelectric materials can effectively drive synthetic jets; however, which materials and what associated optimal actuator geometries yield the best performance are unknown.
Collaborators: Dr. Tom Shrout (MatSci)
Student: Tianliang Yu, Ph.D. December 2017 (expected)

Title: Dynamic Tensegrity for Deployable Structures
Sponsor: PSU
Summary: Tensegrity structures offer the potential of very high packing efficiency for launch to space, but are relatively soft in the classical deployed configuration. Higher stiffness should be possible with strut-to-strut load transfer, requiring dynamic cable actuation and higher joint fixity.
Student: Yaan Kildiz, Ph.D. December 2018 (expected)

Title: Deployable Solar Arrays for Cubesats
Sponsor: PSU
Summary: High power, compact solar arrays are needed to enable ever more ambitious Cubesat missions. These are initially stowed and must withstand high vibratory and acoustic launch loads. Finite-thickness panels require novel, structurally integrated current-carrying hinges.
Student: Amey Chaudhari, M.S. expected August 2016

Projects completed in 2015 and graduated students

Title: Vibration Reduction of Sandwich Composites via 3-D Manufactured Acoustic Metamaterial Cores
Summary: Composite sandwich panels provide excellent stiffness- and strength-to-weight, often at the expense of vibro-acoustic response and especially in the presence of tensile loads. Metamaterial core configuration that provide high effective vibration reduc-

tion in key frequency regions were designed, fabricated using 3-D manufacturing, and experimentally characterized.
Student: Tianliang Yu, M.S., Aerospace Engineering, August 2015

Professor Mary Frecker and her students are pursuing a number of projects related to active structures

Title: Multi-field responsive origami structures: advancing the emerging frontier of active compliant mechanisms. https://wikispaces.psu.edu/display/NEO/Welcome
Sponsor: NSF & AFOSR
Summary: The objective is to develop methods to design origami structures that actively fold from an initially flat sheet to complex three-dimensional shapes in response to multiple fields
(e.g., electric, thermal, magnetic). These multi-field responsive origami shapes are being developed through collaboration with a visual artist. The artistically inspired shapes provide targets for designing novel active compliant mechanisms, which along with predictive multi-scale modeling and multi-physics simulations, guide the development of new active materials. A design optimization framework is being developed to integrate the modeling, design and active materials efforts and enable system trade studies from the nano to the macro scale. A video featuring this work was recently produced by NBC Learn as part of their Science of Innovation series: http://www.nbclearn.com/innovation/cuecard/105467.
Collaborators: Dr. Zoubeida Ounaies (ME), Dr. Paris von Lockette (ME), Dr. Tim Simpson (ME & IE), Prof. Rebecca Strzelec (Visual Art), Dr. Jyh-Ming Lien (George Mason University)
Students: Landen Bowen, Ph.D. expected August 2016, Kara Springsteen, B.S. expected May 2017, Elaine Sung, B.S. May 2016, Wei Zhang, Ph.D. expected May 2018, Brad Hanks, Ph.D. expected May 2019.

Title: Spatially Distributed Compliant Passive Elements for Aerodynamic Structural Tailoring
Sponsor: AFOSR
Summary: The objectives are to develop methods to design spatially distributed passive 3D compliant elements and to develop the associated models to predict the dynamic coupling between those elements. The compliant elements are being structurally integrated to create an appropriate spatially distributed wing stiffness. The modeling efforts include an analytical spar structural model and a numerical compliant element design and optimization model. Validation and verification are being performed by applying the techniques developed to an avian-scale ornithopter test platform in both Bench top and flight testing.
Collaborators: Dr. James Hubbard (Univ. of Maryland)
Students: Joseph Calogero, Ph.D. expected May 2017.

Dr. Kenji Uchino and his students are working on the following projects.

Title: Burst mode high power piezoelectric characterization
Sponsor: Office of Naval Research
PI: Kenji Uchino
Student: Husain N. Shekhani (EE PhD, expected)

Title: Crystallographic orientation dependence of piezoelectric losses
Sponsor: Office of Naval Research
PI: Kenji Uchino
Student: Minkyu Choi (MatSE PhD expected)

Title: Partial electrode configuration for measuring piezoelectric losses under various constraints
Sponsor: Office of Naval Research
PI: Kenji Uchino
Student: Maryam Majzoubi (EE PhD expected)

Title: DC bias field and stress effects on piezoelectric losses
Sponsor: Office of Naval Research
PI: Kenji Uchino
Student: Anushka Bansal (MatSE PhD expected)

Dr. Reginald Hamilton and his student are working on the following project.

Title: High Damping NiTi-Based Shape Memory Alloys
Sponsor: National Science Foundation
PI: Reginald F. Hamilton
Students: Asheesh Lanba (Ph.D. August 2015)

Chris Rahn's Mechatronics Lab group is working on several vibration-related projects. First, with support from the National Science Foundation ASSIST Engineering Research Center, Chris and graduate student Xiaokun Ma are developing energy harvesters for the low frequency and sporadic excitation associated with human movement. They developed a new compliant mechanism harvester that ensures optimal strain distribution in a piezoelectric unimorph. Experimental tests conducted this year with large base excitation demonstrate significantly higher power production than traditional proof mass cantilever harvesters. Chris is also collaborating with Ed Smith in Aerospace Engineering to develop fluidlastic damping and vibration absorption treatments for stiff aerospace structures. Graduate student Matt Krott, with funding from the National Science Foundation, is conducting theoretical and experiment work on tailboom damping augmentation. Finally, the Army is supporting Tahzib Safwat in the development of electroactive polymer actuators for battlefield robotic applications.

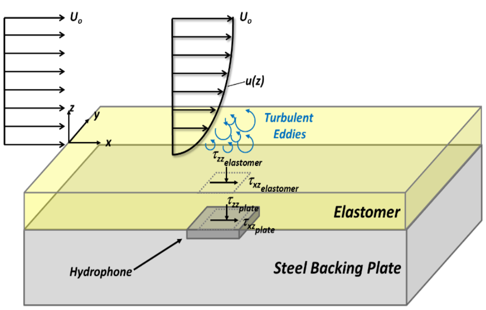
Flow-Induced Noise

Mike Jonson —Group Leader
mxj6@arl.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 ongoing work of the members of the Flow Induced Noise Technical Group is presented below:

Title: Design of an experiment to measure unsteady shear stress and wall pressure transmitted through an elastomer in a turbulent boundary layer
Sponsor: Office of Naval Research
Student: Cory Smith
Advisors: D. E. Capone, T. A. Brungart, and W. K. Bonness
Summary:
A flat plate that is exposed to a turbulent boundary layer (TBL) experiences unsteady velocity fluctuations which result in fluctuating wall pressures and shear stresses on the surface of the plate. There is an interest in understanding how fluctuating shear stresses and normal pressures generated on the surface of an elastomer layer exposed to a TBL in water are transmitted through the layer onto a rigid backing plate. Analytical models exist which predict these shear stress and normal pressure spectra on the surface of the elastomer as well as those transmitted through the elastomer. The design of a novel experiment is proposed which will utilize Surface Stress Sensitive Films (S3F) to measure the fluctuating shear stress and hydro-

phones to measure fluctuating normal pressure at the elastomer-plate interface. These experimental measurements would then be compared to models of unsteady shear and unsteady pressure spectrums within a TBL for purposes of model validation. This work will present the design of an experiment to measure the unsteady pressure and unsteady shear at the elastomer-plate interface and the methodology for comparing the measured results to the analytical model predictions.



Title: Noise from Pulsating Supercavities and Its Control
Sponsor: Office of Naval Research
PI(s): Drs. Timothy A. Brungart and Jules W. Lindau
Student: Grant M. Skidmore, Ph.D. in Aerospace Engineering, May 2016
Summary: The noise radiated by pulsating supercavities has been explored experimentally in a water tunnel facility, computationally using 3D finite volume computational fluid dynamics (CFD) and analytically. The noise was found to be single frequency and monopole in nature with a spectrum level given by the level of the cavity interior pressure and attenuation due to spherical spreading from the interface. The radiated noise levels from pulsating supercavities were found to be at least 35 dB higher in level than those from comparable re-entrant jet and twin vortex supercavities. Extensive investigations were performed into suppressing pulsation noise by modulating (i.e., adding a sinusoidal component to) the gas ventilation rate in order to shift the supercavity resonance frequency away from the interface excitation frequency. This technique, which has its roots in parametric oscillators, causes pulsating supercavities to transition to another (twin vortex) closure regime over a wide range of modulation frequencies, typically within 0.25 seconds of modulation initiation. Accompanying the transition from pulsation to twin vortex closure is a reduction in the radiated noise, to the continuum at the pulsation frequency, oftentimes 35 dB or more. Other modulation frequencies do not suppress pulsation but are effective at changing the supercavity pulsation frequency.

Title: Compressor Acoustic Diagnostics and Noise Control
Sponsor: Bristol Compressors
PI(s): Drs. Timothy A. Brungart and Steven A. Hambric
Student(s): Seeking Acoustics Ph.D. Student for Spring 2019 Graduation
Summary: This effort is just getting underway.

Title: High Power Carbon Nanotube Thermophone Development
Sponsor: Joint Non-lethal Weapons Directorate
PI(s): Drs. Timothy A. Brungart and Benjamin S. Beck
Student: James J. Chatterley, Ph.D. in Acoustics expected December 2018
Summary: The summary has not yet been cleared by the sponsor.

Project: Glottal jet aerodynamics
Sponsor: NIH
PI: Michael Krane (ARL PSU)
Collaborators: Lucy Zhang (Rensselaer Polytechnic Inst.), Timothy Wei (Univ. Nebraska-Lincoln), Daryush Mehta (Massachusetts General Hospital), Robert Hillman (Massachusetts General Hospital), Sid Khosla (Univ. of Cincinnati Med. School)
Students: Michael McPhail (PSU Bioengineering), Jubiao Yang (RPI Mechanical Engineering)

In 2015, project was renewed for 5 more years. Has been running continuously since 2002.

Propagation and Radiation

Victor Sparrow, Group Leader
vws1@psu.edu

The mission of the Propagation and Radiation Technical Group is to develop a new understanding of how sound is generated and propagated in realistic environments, to translate this understanding into techniques for making decisions about the use and control of sound, and for making inferences about sources and the environment, and to apply this understanding to the design of devices and systems. Understanding the perception of sound by individuals and estimating noise impacts on people are two of the primary applications of the research.

In the 2015-2016 academic year Penn State has continued to participate in the FAA Center of Excellence in Alternative Jet Fuels and the Environment. Called ASCENT for Aviation Sustainability CENter, Dr. Vic Sparrow is continuing to work on multiple FAA ASCENT projects as well as serving as the overall ASCENT Lead Investigator at Penn State. Some of the ongoing research has focused on the understanding and overcoming the limitations of current FAA noise tools, particularly in improving the propagation modeling using updated atmospheric absorption and atmospheric profiles models. Further work has centered on improving our understanding of the limitations of metrics for sonic booms, and the sensitivity of those metrics due to atmospheric turbulence distortions.

Dr. Sparrow is also participating in a new NASA project this year, SonicBAT, which focuses on the effects of atmospheric turbulence on low-boom sonic booms. The lead for this project is Wyle, and Penn State is a subcontractor on the effort. Penn State is developing a new propagation code that includes the effects of atmospheric turbulence in addition to nonlinearity and loss mechanisms. On the topic of sonic booms, Dr. Sparrow was co-organizer of the 2nd International Sonic Boom Forum, held July 1-3, 2015 in Lyon, France, and the proceedings of that meeting are now available through the AIP Press of the American Institute of Physics.

Dr. Michelle Vigeant is an Assistant Professor of Acoustics and Architectural Engineering, and her research group, the Sound Perception and Room Acoustics Laboratory (SPRAL) is continuing to expand. She is currently pursuing research in three areas: (1) concert hall acoustics, (2) the emotional response to acoustics stimuli, and (3) aircraft noise and cardiovascular disease. She currently has four students working on projects related to concert hall acoustics, two of which are supported by NSF, with specific topics of: (a) developing a metric to predict listener envelopment, the sense of being immersed in the sound field; (b) developing a metric to predict the perception of overall acoustic quality in concert halls; (c) evaluating the proposed metric of bass ratio to predict warmth in halls; and (d) investigating methods to predict binaural room impulse responses from spherical microphone array measurements. She currently has two students working on projects predicting the emotional response to acoustics stimuli using neuroimaging, specifically using functional magnetic resonance imaging (fMRI). One student is using fMRI to predict the response of reward regions to room acoustics stimuli with varying levels of reverberation time. The second student's project is in collaboration with Dr. Pamela Cole, professor of psychology at PSU and project PI, which is supported by NIH. The purpose of the project is to evaluate the developmental effects on children who are exposed to hearing angry conversations. For the final topic of aircraft noise and cardiovascular disease, she has recently completed a project in collaboration with Dr. Sparrow and two other PSU researchers, funded through PSU's Clinical and Translational Science Institute (CTSI), to pilot predicting environmental noise around the Philadelphia International Airport using a commercially-available noise modeling program. New funding from the NIH is very likely to be awarded in Summer 2016 on a project that will be in collaboration with researchers at Boston University.

The most recent student graduates from the Propagation and Radiation Group include Mr. Matthew Neal (M.S.) and Mr. Erik Petersen (M.S.).

Current Graduate Students:

Mansi Biwalkar, Ph.D. expected Summer 2018
Thesis topic: Validation and extension of noise tools using existing airport noise data
Sponsor: FAA
Advisor: V. Sparrow

David Dick, Ph.D. expected Fall 2016
Thesis topic: Listener envelopment in concert halls through listening tests and spherical microphone array measurements
Sponsor: NSF
Advisor: M. Vigeant

William Doebler, Ph.D. expected Summer 2019
Thesis topic: Removing turbulence from sonic boom ground measurements
Sponsor: FAA
Advisor: V. Sparrow

Beom Soo Kim, Ph.D. expected Fall 2016
Thesis topic: Low frequency noise of aircraft noise transmission from outdoors to indoors
Sponsor: FAA
Advisor: V. Sparrow

Martin Lawless, Ph.D. expected Spring 2018
Thesis topic: Emotional response to room acoustics stimuli using functional neuroimaging
Sponsor: Penn State College of Engineering
Advisor: M. Vigeant

Amanda Lind, M.S. Spring 2011, Ph.D. expected Fall 2016
Thesis topic: Diffraction effects for predicting the impact of low-boom sonic booms around buildings
Sponsor: FAA
Advisor: V. Sparrow

Peter Moriarty, M.S. expected Summer 2017
Thesis topic: Children's neural processing of the emotional environment: angry voices
Sponsor: NIH
Advisor: M. Vigeant

Matthew Neal, Ph.D. expected Fall 2018
Thesis topic: Predicting perceived acoustical quality of concert halls using a combination of room acoustics metrics
Sponsor: NSF
Advisor: M. Vigeant

Nick Ortega, Ph.D. expected Fall 2020
Thesis topic: Calculating binaural room impulse responses from spherical microphone arrays using spherical harmonics
Sponsor: Penn State College of Engineering
Advisor: M. Vigeant

Joshua Palmer, M.S. expected Summer 2016
Thesis topic: Variability in noise metrics due to the effects of atmospheric turbulence on sonic boom signatures
Sponsor: FAA
Advisor: V. Sparrow

Rachel Romond, Ph.D. expected Summer 2016
Thesis topic: Including meteorological reanalysis for atmospheric models for subsonic aircraft noise prediction
Sponsor: FAA
Advisor: V. Sparrow

Kristina Sorensen, Ph.D. expected Fall 2020
Thesis topic: Study of the perception of warmth in concert halls and correlation with room acoustics metrics
Sponsor: Penn State College of Engineering
Advisor: M. Vigeant

Trevor Stout, Ph.D. expected Summer 2018
Thesis topic: KZK predictions of sonic booms propagating through atmospheric turbulence in three dimensions
Sponsor: Wyle/NASA
Advisor: V. Sparrow

Rotorcraft Acoustics and Dynamics
Ed Smith, Group Leader
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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 three NRTC Vertical Lift Research Centers of Excellence (VLRCOE) in the country. In summer of 2011, our Center was successfully renewed for another 5 years. As part of our new program, we started 12 new research projects. We are grateful to our industry partners at LORD Corp., Timken, Goodrich (now UTAS), Bell, and Sikorsky for their support of our proposal. New projects include: airfoil design methods for unsteady flow (Prof. Maughmer), rotor hub flow physics for drag reduction (Prof. Schmitz), Icing physics, modeling, and detection (Dr. Palacios, Prof. Brentner, Dr. Kinzel), autonomous multi-lift systems (Profs. Horn and Langelaan), nanotailored composites for improved toughness and durability (Profs. Bakis and Adair), aeroelastically tailored wing extensions and winglets for large Civil Tiltrotors (Profs. Smith and Maughmer), control redundancy on compound rotorcraft for performance, handling qualities, and survivability (Profs. Horn, Brentner, and Gandhi), physics of active rotors for performance and acoustics (Profs. Schmitz, Maughmer, and Brentner), comprehensive analysis of gearbox loss of lubrication (Prof. Kunz and Drs. Saribay and Bill), health monitoring for joints in composite structures (Profs. Lissenden and Rose), advanced response types/ cueing systems for naval operations (Prof. Horn), and autonomous shipboard take-off and landing (Prof. Langelaan). We recently prepared and submitted a major new proposal that would fund the Center for the 2016-2021 time period. We have a suite of proposed projects in the vibration and noise control area, in addition to others in various areas related to rotorcraft technology needs. This Center currently supports more than 50 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 noise signatures is a high priority. We have experienced particular growth in programs focused on structural health monitoring, pneumatic ice protection systems, and naval-oriented flight dynamics/controls. Acoustics and dynamics issues associated with 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; advanced flight controls and vehicle dynamics simulation, interactional source noise, acoustical scattering of rotor noise, gearbox noise, active and passive 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) has proven to be a versatile and heavily used facility. Additionally, experimental testing has also been recently conducted for new compact energy harvesters, tiltrotor whirl flutter wind tunnel models, rotor hub-flow visualizations, and new rotor system dampers. Our annual Rotorcraft Technology Short Course will be offered for the 49th consecutive year on August 8-12. Topics in the comprehensive course include rotorcraft aerodynamics, dynamics, acoustics, composite structures, flight controls and propulsion.

Projects and Graduate Students:

Title: Flutter Stability of Rotors with Fluidlastic Pitch Links
Sponsor: LORD Corp.
PIs: Ed Smith, Chris Rahn
Student: Shawn Treacy (PhD candidate)

Title: Tailboom Vibration Control via F2MC Devices
Sponsor: NSF.
PIs: Ed Smith, Chris Rahn
Student: Kentaro Miura (PhD 2016), Matt Krott (PhD Candidate)

Title: High Fidelity CFD Analysis and Validation of Rotorcraft Gear Box Aerodynamics
Sponsor: NASA
PI: Rob Kunz
Students: Sean MacIntyre (PhD 2015), Qingtao Yu (PhD Candidate)

Title: Wind Turbine Ice Protection Coating Performance Evaluation
Sponsor: GE Global Research
PI: Jose Palacios

Title: Experimental Measurement of Ice Crystal Dynamics
Sponsor: NASA
PI: Jose Palacios
Student: Sihong Yan (MS 2015, PhD candidate)

Title: Helicopter Icing Physics, Modeling and Detection
Sponsor: NRTC VLRCOE Program
PIs: Jose Palacios, Ken Brentner, Michael Kinzel
Students: Yiquian Han (PhD 2015), Baofeng Chen (PhD 2015), David Hanson (PhD candidate)

Title: Centrifugally Powered Pneumatic De-icing for Helicopter Rotors
Sponsor: NASA
PIs: Jose Palacios, Doug Wolfe
Student: Matthew Drury (MS 2016)

Title: Acoustic Capability for NDARC
Sponsor: NRTC VLRCOE Program
PI: Ken Brentner
Student: Kalki Sharma (MS candidate)

Title: Civil Certification Noise Prediction Tools
Sponsor: Bell Helicopter TEXTRON
PI: Ken Brentner
Student: Abhishek Jain (PhD Candidate)

Title: Fundamental Physics of Active Rotor Concepts for Acoustics and Performance Enhancement
Sponsor: NRTC VLRCOE
PIs: Ken Brentner, Mark Maughmer, Sven Schmitz
Students: Ethan Corle (PhD Candidate), Tenzin Choephel (PhD Candidate), Tianxiao Yang (PhD Candidate), Kevin Ferguson (PhD Candidate)

Title: Rotorcraft Airfoil Design for Unsteady Aerodynamics
Sponsor: NRTC VLRCOE
PI: Mark Maughmer
Student: Bernardo Vieira (PhD Candidate)

Title: Tailored Wing Extensions and Winglets for Large Civil Tiltrotors
Sponsor: NRTC VLRCOE
PIs: Ed Smith, Mark Maughmer
Students: Willie Costa (MS 2015), Sandilya Kambampati (PhD candidate), Taylor Hoover (MS 2015), Julia Cole (PhD Candidate)

Title: Control Redundancy to Enhance Rotorcraft Performance, Handling Qualities, and Survivability
Sponsor: NRTC VRCOE
PIs: Joe Horn, Ken Brentner
Students: Adam Thorsen (MS 2014, PhD Candidate), Greg Walsh (MS Candidate)

Title: Acoustic Capability for NDARC
Sponsor: NRTC VRCOE
PI: Ken Brentner
Student: Kalki Sharma (MS Candidate)

Title: Advanced Response Types and Cueing Systems for Naval Operations
Sponsor: NRTC VRCOE
PI: Joe Horn
Student: Albert Zheng (MS Candidate)

Title: Autonomous Multi-lift Systems
Sponsor: NRTC VRCOE
PIs: Joe Horn, Jack Langelaan
Students: ZuQun Li (MS 2015), Jacob Enciu (Postdoc)

Title: Rotorcraft Noise Abatement Operating Conditions Modeling
Sponsor: FAA
PI: Ken Brentner
Students: Yaowei Li (MS Candidate), Willca Villafana (MS Candidate),

Title: Flight Test Measurement of Airwake Disturbances for Validation of Virtual Dynamic Interface Simulations
Sponsor: Office of Naval Research
PI: Joe Horn
Student: Sylvie Shafer (MS Candidate)

Title: Pilot-in-the-Loop CFD Method Development
Sponsor: Office of Naval Research
PI: Joe Horn
Student: Ilker Oruc (PhD Candidate)

Title: Autonomous Control Modes for Shipboard Landing in High Sea States
Sponsor: Office of Naval Research
PI: Joe Horn
Student: Junfeng Yang (PhD Candidate)

Title: Fundamental Physics of Rotor Hub Flows Towards Reduction of Helicopter Parasite Drag
Sponsor: NRTC VLRCOE
PIs: Sven Schmitz, Steve Willits
Student: David Reich (PhD Candidate)

Title: Placement of Circular Force Generators for Vibration Cancellation
Sponsor: Sikorsky Aircraft
PI: George Lesieutre
Student: Brad Sottile, (Ph.D. candidate)

Technical Group Research Highlights

Title: Efficiency, Dynamics, and Noise Characteristics of Pericyclic Transmissions
Sponsors: NASA, Vertical Lift Consortium
PI: Ed Smith, Bob Bill,
Students: Tanmay Mathur, (Ph.D. candidate), Zach Cameron (MS Candidate)

Title: Passive Tailboom Damping with Fluidic Flexible Matrix Composite Tubes
Sponsor: (I'm an NSF Fellow so technically there isn't one)
PI: Ed Smith, Chris Rahn
Student: Matt Krott (Ph.D. Candidate)

Title: Ultra-Reliable Helicopter Design
Sponsor: Army Aviation Technical Directorate (AATD)
PI: Jeff Banks/Sam Evans/Lorri Bennett (ARL) Teamed with AVX Aircraft Company and General Electric
Student: Leland Renoff (Aero Undergrad, former USMC, 6 years as CH-53 Crewmember)

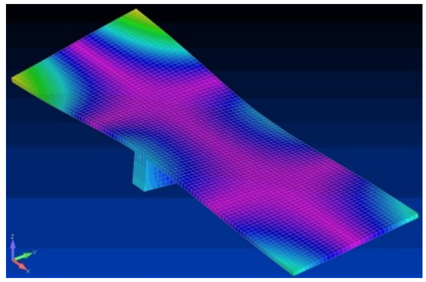
Structural Vibration and Acoustics

Steve Hambric, Group Leader
sah19@psu.edu

The Structural Vibration and Acoustics Technical Group investigates vibration in structures and its interaction with acoustic media. The group develops novel methods to analyze, measure, and control structural vibrations and radiated noise.

In 2015-2016 the group members investigated a wide range of topics, as shown below. We are particularly excited about a new topic we are collaborating with Sandia on: joint stiffness and damping. Trevor Jerome, a PhD student in Acoustics, will spend this summer working with Dr. Matt Brake at the Nonlinear Mechanics and Dynamics (NOMAD) institute at SANDIA National Labs. Matt coordinates an international consortium on joint friction, stiffness, and damping, and we look forward to this collaboration.

Trevor has been modeling and measuring the effects of joint dynamics on bolted structures. Two L-shaped plates have been tested with free boundary conditions, and bolted together. The nonlinear effects of bolt preload and vibration amplitude on joint stiffness and damping are being investigated. Reduced-order linearized methods for simulating these effects will be developed for FE models.



Projects and Graduate Students:

Title: Adaptive Acoustic Metamaterials
Sponsor: NAVSEA 073
PIs: Ben Beck
Student: Aaron Stearns (PhD Mechanical Engineering)

Title: CNT Turnkey Thermophone
Sponsor: Joint Non-Lethal Weapons Directorate
PIs: Ben Beck, Tim Brungart

Title: Materials Development Future Naval Capabilities (FNC)
Sponsor: ONR
PIs: Ben Beck, Dean Capone

Title: High performance structural-acoustics computing
Sponsor: ONR
PIs: Dean Capone, Rob Campbell, John Fahnline

Title: Large journal bearing modeling and measurements
Sponsor: NAVSEA PMS 397
PI: Rob Campbell

Title: Fluid-Structure Interaction Simulations of a Wind Turbine with Consideration of Atmospheric Boundary Layer Turbulence
Sponsor: DoE
PIs: Rob Campbell (part of interdisciplinary PSU team)
Student: Javier Motta-Mena (MS – Mechanical Engineering)

Title: Fluid Structure Interaction Modeling of Blood Clot Migration and Entrapment in the Inferior Vena Cava
Sponsor: ARL Walker Fellowship
PIs: Rob Campbell, Brent Craven
Student: Ken Aycock (PhD – Biomedical Engineering)

Title: Performance Optimization of an Intake Port Shape Design for an Internal Combustion Engine
Sponsor: Self-funded
PIs: Rob Campbell, Justin Watson
Student: Michael Donnelly (MS – Mechanical Engineering)

Title: Force Reconstruction using Force Gauges and Modal Analysis
Sponsor: ARL Walker Fellowship
PIs: Tyler Dare
Student: Wesley Axtell (MS – Acoustics)

Title: Accelerated fatigue characterization of composites
Sponsor: NAVSEA 073R
PI: Steve Hambric and Rob Campbell
Student: Chester Kupchella (MS, Acoustics)

Title: Nonlinear structural joint dynamics
Sponsor: Pratt and Whitney and US Navy
PIs: Steve Hambric, Micah Shepherd
Student: Trevor Jerome (Ph.D., Acoustics)

Title: Ohio Replacement Program Propulsor
Sponsor: NAVSEA 073R
PI: Steve Hambric

Title: Large chiller noise and vibration
Sponsor: UTC Building and Information Systems
PIs: Steve Hambric, Tim Brungart
Student: Stephen Wells (Ph.D., Acoustics)

Title: Small reciprocating compressor noise and vibration
Sponsor: Bristol Compressors
PIs: Steve Hambric, Tim Brungart
Student: TBD (Ph.D., Acoustics)

Title: Acoustic Scattering from Elastic cylindrical shells reinforced by internal circular plates- 3D solution
Sponsor: NUWC, Newport RI
PI: Sabih Hayek and J.E.Boisvert

Title: Acoustic cell separation
Sponsor: NIH, NSF
PI: Tony Jun Huang
Students: Peng Li and Yuchao Chen (Ph.D., ESM)

Technical Group Research Highlights

Title: Acoustic and Vibrational Analysis of an Acoustic Guitar
Sponsor: Self-funded
PI: Dan Russell
Student: Corey Taylor (MEng – Acoustics)

Title: Vibrational Analysis of Foam-Filled Tennis Rackets for Reduction of Vibration at the Wrist
Sponsor: Self-funded
PI: Dan Russell
Student: Kritika Vayur (MEng – Acoustics)

Title: Acoustic and Vibrational Analysis of Golf Club Drivers
Sponsor: Nike Golf
PI: Dan Russell
Student: Peter Kerrian (MS – Acoustics)

Title: Quiet Structure Design Using Embedded Acoustic Black Holes
Sponsor: ARL Walker Fellowship
PI: Steve Conlon
Students: Phil Feurtado (Ph.D., Acoustics), Angelina Conti (B.S -Honors Aerospace Engineering)

Title: Wireless sensing technologies
Sponsor: NAVSEA PMS 397
PI: Steve Conlon

Title: Improved Advanced Hybrid Propulsor
Sponsor: NAVSEA PMS 450
PI: Steve Conlon

Title: Assessment of Bolted-joint Structures
Sponsor: NAVSEA
PI: Steve Hambric
Student: Trevor Jerome

Title: Acoustic cell separation
Sponsor: NIH, NSF
PI: Tony Jun Huang
Students: Mengxi Wu and Shujie Yang

Systems and Structures Health Management

Group Leaders
***Karl Reichard** -kmr5@psu.edu*
***Cliff Lissenden** – Lissenden@psu.edu*

The mission of the Systems and Structures Health Management Technical Group is to develop new methodologies and technologies to manage the life cycle of systems and structures. This includes the full range of material state awareness, health and usage monitoring, and condition based maintenance, to support both autonomic and conventional operations with logistics informed by reliable useful life prediction. The underlying goal of the group is to maximize safety, minimize life cycle cost and increase capability. Key areas being investigated include: senor systems, signal processing, pattern recognition, reasoning techniques, and modeling of damage progression to failure.

The group leaders Lissenden and Reichard are part of a Department of Energy NEUP integrated research project to research and develop robotic inspection systems for dry cask storage of used nuclear fuel. Some of the canisters that confine the spent fuel are in environments that could be conducive to stress corrosion cracking. However, access to the canister is very limited by the shielding overpack structure, and in addition the harsh environment includes elevated temperature and radiation. Hence, robotic systems are required to deliver sensors to inspect for cracks, determine surface composition (are salts present?), measure temperature and radiation. Laser induced breakdown spectroscopy (LIBS) delivered by an optical fiber was selected to detect the presence of chloride bearing salts on the surface of the stainless steel canister. While shear-horizontal ultrasonic guided waves were chosen to inspect for cracks in the vicinity of welds using noncontact electromagnetic acoustic transducers (EMATs). A schematic of the nondestructive inspection method is shown in Fig. 1. A photo of the optical fiber delivery of a laser pulse and a preliminary LIBS result are shown in Fig. 2. EMAT and LIBS measurements will be made robotically, with the robotic inspection system entering the cask through an exhaust vent and unfolding a delivery arm on the lid of the canister. As shown in Fig. 3 sensor cars will be deployed from the arm by a tether. Final demonstration of the robotic inspection systems is planned for the fourth quarter of 2017.

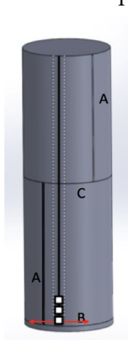
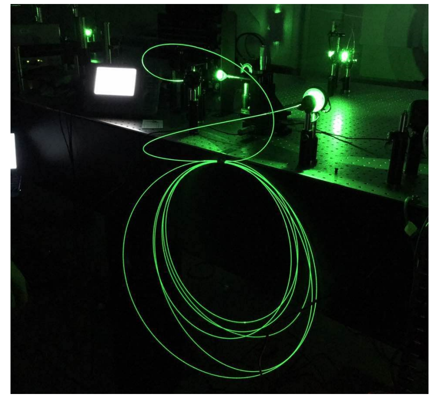


***Fig. 1**. Schematic of robotic inspection system using an EMAT to send a shear-horizontal wave along the bottom weld (B) of a canister for used nuclear fuel. Axial welds (A) and the circumferential weld (C) will also be inspected.*



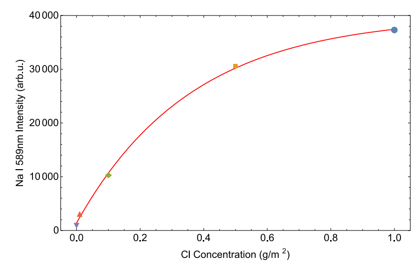


***Fig. 2**. Optical fiber delivery of laser pulse over 10 m for LIBS measurement of sodium from breakdown of synthetic sea salt on stainless steel. Intensity of sodium increases with the concentration of chloride on the surface.*

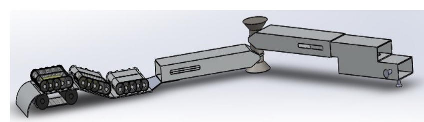


***Fig. 3**. Conceptual sketch of delivery arm and deployable cars that deliver sensors through the ventilation system of the storage cask.*

Projects and Graduate Students:

Title: Multi-Sensor Inspection and Robotic Systems for Dry Storage Casks
Sponsor: DOE NEUP IRP
PIs: Cliff Lissenden, Arthur Motta, Igor Jovanovic, Sean Brennan, Karl Reichard, Travis Knight, John Popovics
Students: Hwanjeong Cho (PhD – Engineering Science and Mechanics), Sungho Choi (Post Doc - Engineering Science and Mechanics)

Title: Higher Harmonic Ultrasonic Guided Waves for Structural Integrity Assessment of Infrastructure
Sponsor: NSF
PI: Cliff Lissenden
Student: Gloria Choi (PhD –Engineering Science and Mechanics)

Technical Group Research Highlights

Title: Health Monitoring Methods for Joints in Rotorcraft Composite Structures
Sponsor: National Rotorcraft Technology Center (Army, Navy, NASA)
PIs: Cliff Lissenden and Joe Rose
Student: Baiyang Ren (Post Doc - Engineering Science and Mechanics)

Title: High-temperature Sensor Technology in Support of In-situ Monitoring of Creep Specimens
Sponsor: Pacific Northwest National Lab
PIs: Cliff Lissenden and Bernie Tittmann
Student: Andy Suprock (PhD – Engineering Science and Mechanics)

Title: Submarine CBM+ Implementation
Sponsor: U.S. Navy
PIs: Jeffery Banks, Mitchell Lebold
Student: Michael Roemer (MS – Mechanical Engineering)

Title: Early Entry Fuel Delivery System
Sponsor: U.S. Army
PIs: Karl Reichard, Eddie Crow
Student: Jason Reiter (MS – Aerospace Engineering)

Title: CBM+ for Submarines
Sponsor: U.S. Navy
PIs: Jeffery Banks, Mitchell Lebold
Student: Michael Roemer (MS – Mechanical Engineering)

Title: Hydroturbine Design
Sponsor: Department of energy
PIs: Arnold Fontaine, Todd Palmer, Jeffery Banks
Student: Corey Hunt (MS – Mechanical Engineering)

Graduates:

Vamshi Chillara, Ph.D. in Engineering Science and Mechanics, August 2015, Towards improved NDE and SHM methodologies incorporating nonlinear structural features, NSF, Cliff Lissenden

Baiyang Ren, Ph.D. in Engineering Science and Mechanics, August 2015, Phased array transducers for structural health monitoring of aircraft structures using ultrasonic guided waves, NRTC, Cliff Lissnden

Underwater Acoustics and Instrumentation

Amanda Hanford, Group Leader
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One of the missions of he Underwater Acoustics and Instrumentation Technical Group is to conduct basic and applied research related to the propagation of sound in the ocean and the systems, natural and manmade, that generate and receive sound underwater. The group also conducts applied research characterizing the performance of underwater acoustic systems, design and development of in air and in water transducers and application of advanced signal processing techniques.

In 2015, our group continued many Oceanography studies using acoustic data to determine physical properties of the ocean environment. One of them consisted of an atsea experiment that took place off the coast of La Spezia, Italy. Acoustic data was collected by PSU using the cardioid aperture of

The ONR Five Octave Research Array (FORA). Successful raw hydrophone data was collected in the interest of estimating the effectiveness of continuous active sonar (CAS) processing in the shallow water littoral environment.

Our group is also active in other novel technical areas for applications in under water environments such as acoustic metamaterials.

The following is a current list of other projects and graduate students in our section.

Projects and Graduate Students:

Title: Ambient Noise
Sponsor: ONR
PIs: Dave Bradley
Student: Stephen Nichols

Title: Scattering Rock Outcrops
Sponsor: ONR
PIs: Derek Olson

Title: Whale Density Estimates
Sponsor: ONR
PIs: Jennifer Miksis-Olds
Student: Julia Vernon

Title: Bottom Backscatter
Sponsor: ONR
PIs: Charles Holland

Title: FORA Support and Clutter Statistics
Sponsor: ONR
PIs: Chad Smith

Title: Sediment Mapping
Sponsor: ONR
PIs: Charles Holland

Title: Infrasound Array Performance
Sponsor: DTRA
PIs: Tom Gabrielson

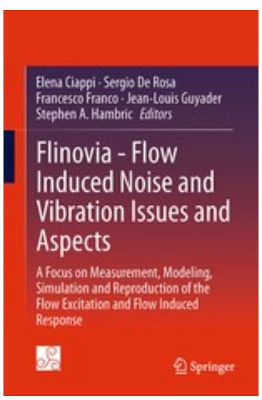
Title: Ocean Acoustic Reverberation Modeling
Sponsor: ONR
PI: Charles Holland

Technical Group Research Highlights

Special CAV sponsored Symposium on Flow Induced Noise and Vibration – Issues and Aspects (FLINOVIA II), 27-28 April 2017

Instead of the short course which usually follows CAV workshops, next year Steve Hambric and Amanda Hanford, along with an international consortium, will organize the second two-day symposium on flow induced noise and vibration (Flinovia II). The CAV workshop will be held 25-26 April 2017, and Flinovia II will immediately follow.

The first Flinovia was held in Rome, Italy in November 2013, and hosted by The University of Rome and the Italian Research Institute for Naval Architecture and Marine Engineering (INSEAN). The proceedings are available in a book published by Springer: (http://www.springer.com/us/book/9783319097121), and feature articles by 15 invited authors.

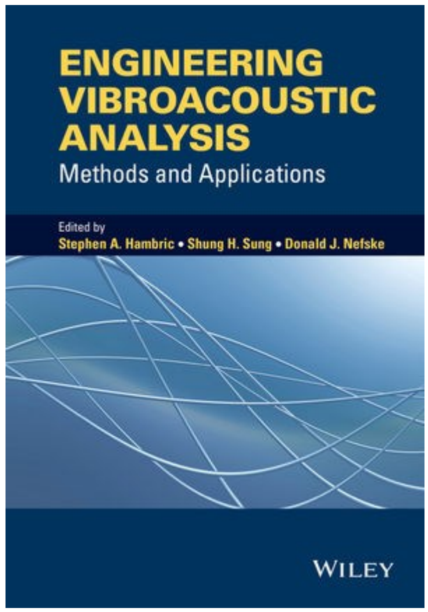


Flinovia II will feature talks by invited authors from around the world on simulating and measuring flow-induced vibration and noise mechanisms. All CAV members are welcome to attend the symposium free of charge. The agenda will be developed later this year, and made available to CAV members.

Other organizers include Sergio De Rosa and Franco Francesco from Naples University, Elena Ciappi of INSEAN, Jean-Louis Guyader from INSA de Lyon (a CAV international liaison), and Randolph Leung from Hong Kong Polytechnic (another CAV international liaison).

CAV members co-author book

Steve Hambric, John Fahnline, and Micah Shepherd wrote and co-wrote chapters in the new book: *"Engineering Vibroacoustic Analysis – Methods and Applications,"* recently published by Wiley. The book was co-edited by Hambric, and his colleagues (formerly from General Motors) Don Nefske and Sue Sung.



The book describes analytical methods (based primarily on classical modal synthesis), the Finite Element Method (FEM), Boundary Element Method (BEM), Statistical Energy Analysis (SEA), Energy Finite Element Analysis (EFEA), Hybrid Methods (FEM-SEA and Transfer Path Analysis), and Wave-Based Methods. The book also includes procedures for designing noise and vibration control treatments, optimizing structures for reduced vibration and noise, and estimating the uncertainties in analysis results. Written by several well-known authors, each chapter includes theoretical formulations, along with practical applications to actual structural-acoustic systems. Readers will learn how to use vibroacoustic analysis methods in product design and development; how to perform transient, frequency (deterministic and random), and statistical vibroacoustic analyses; and how to choose appropriate structural and acoustic computational methods for their applications. The book can be used as a general reference for practicing engineers, or as a text for a technical short course or graduate course.

CAV Information

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MARK YOUR CALENDARS

CAV Workshop 2017

Tuesday — Wednesday
25 — 26 April
Nittany Lion Inn

Flinovia II is scheduled for 27 — 28 April