CAV Review '17-'18

CENTER FOR ACOUSTICS & VIBRATION

CAV Spring Workshop

The CAV's annual workshop will be held at the Penn State Nittany Lion Inn 24—25 April, 2018. 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. This year it will be held in The Faculty Staff Club at The Nittany Lion Inn. 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 The Faculty Staff Club at The Nittany Lion Inn, 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 first place Stephen Wells, second place Saad Ahmed and third place Phil Feurtado.

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.

The Departure of an Outstanding Leader for the Center for Acoustics & Vibration...

Associate Dean of Research and Graduate Programs
College of Engineering

Dr. George Lesieutre, Director of the Penn State Center for Acoustics and Vibration (CAV), has transitioned to a full-time position as Associate Dean of Research and Graduate Programs in the College of Engineering. Having served as CAV Director since 2009, this is an appropriate time to pass the torch to Dr. Steve Hambric, Research Professor at ARL/Penn State and Professor of Acoustics, who will now lead the CAV as Director. Steve, who has served as Associate Director of the CAV since 2009, will be assisted by Dr. Cliff Lissenden, who becomes the new Associate Director. Cliff is a Professor of Engineering Science and Mechanics, and has co-directed the CAV's Systems and Structures Health Management technical group with Dr. Karl Reichard since 2012.

Since its inception, the faculty and students affiliated with the CAV have worked: (1) to strengthen basic and applied research in related engineering areas; (2) to provide a base for technology transfer to industry; and (3) to foster graduate education in acoustics and vibration. Since 2009, under George and Steve's leadership, the CAV has evolved to better serve its corporate and academic members. In this period, the CAV created new membership tiers for both small and large companies, expanded our stable of international liaisons, and increased the number of corporate sponsors from 12 to 20. The CAV introduced several new technical interest groups (while sunsetting others) and promoted dynamic new group leaders. The format of the annual spring workshop evolved to include a student poster reception, timely panel sessions, and a one-day short course. We now also provide a searchable thesis database as well as links to faculty research papers, and webcast technical seminars right to the desks of our corporate members.

In his new position, George will continue advising the CAV as a liaison to the Dean's office. We thank George for his many years of dedication and service to the CAV!

Steve and Cliff look forward to continuing to expand the CAV's connections and impact with our growing list of corporate sponsors and government and international liaisons.

Director, CAV

Associate Director, CAV

Corporate Members & International Liaisons

Corporate Members & Representatives
American Acoustical Products—Emanuele Bianchini
Avery Dennison—Henry Milliman
3M Science –Ron Gerdes
Babcock & Wilcox—Suzana Rufener
Bechtel Marine Propulsion Corp. —Eric Salesky (PA), Steve Dunn (NY)
Boeing— Brent Paul
Bose—Ray Wakeland
Bridgestone Americas—Yousof Azizi
Bristol Compressors—David Gilliam
Corning—William Fisher
Carrier—Lee Tetu
EBCO—Peijun Xu
Fisher Valves & Instruments—Shawn Anderson
Gulfstream - Kristopher Lynch
Harman—Donald Butts, Kevin Hague, and Sean Olive
ITT—Mark Downing
Johnson Controls—R. Troy Taylor
Martin Guitar—Josh Parker
Newport News Shipbuilding—Kevin Smith
Pratt & Whitney— Richard Labelle
Praxair— Reh-Lin Chen
Textron Aviation - Gonzalo Mendoza

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GAUS (Canada) - Alain Berry
INSA de Lyon (France)—Etienne Parizet
KAIST (Korea)—Jeong-Guin Ih
KU-Leuven (Belgium)—Wim Desmet
Hong Kong Polytechnic University (Hong Kong)— Li Cheng

CAV Welcomes New Corporate Members

As a global leader with 40+ years of experience as a noise, vibration and harshness (NVH) solutions provider for automotive applications, Avery Dennison continues to develop innovations that drive the industry.

Our resources include a wealth of knowledge on Advanced Constrained Layer Damping Technology, and we have the capability to custom design polymers in order to provide damping solutions tailored to specific temperature ranges and frequencies. Our newest solutions provide opportunities for significant weight reductions and are designed for ease of convertibility and better conformability.

Avery Dennison's **Performance Tapes business** draws on years of materials science engineering and manufacturing expertise to deliver a wide range of specialized tapes tailored to specific industry demands and end-user applications.

Headquartered in Glendale, California, Avery Dennison Corporation employs approximately 30,000 employees in more than 50 countries. Reported sales in 2017 were $6.6 billion. Learn more at **www.averydennison.com**. Henry Milliman is the company's liaison.

As a global supplier of engineered elastomeric components, Ebco hs been serving OEMs in the commercial vehicle, agricultural, construction, turf care, defense, and power generation industries for more than 65 years.

In addition to our products, Ebco provides customers a variety of technical services to reduce the time and costs associated with moving a product from prototype to the production line, including:

- CAD Modeling
- Virtual Analysis
  - MBD
  - FEA
- Material Testing
  - DMA
  - TGA
  - FTIR
- Physical Testing
  - Static
  - Dynamic
  - Destructive
  - Life Cycle
- Material Selection and Custom Compounding
- Data Acquisition

Peijun Xu is the company's Liaison.

Please tell others about joining CAV and your experience.

Thank you!

CAV Members Receive Honors and Awards

Manasi Biwalkar received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Daniel C. Brown received the 2018 Kenneth T. Simowitz Memorial Award from the Graduate Program in Acoustics.

William J. Doebler received the 2018 Kenneth T. Simowitz Memorial Award from the Graduate Program in Acoustics.

Zhendong Huang received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Trevor W. Jerome received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Martin S. Lawless received the 2018 Kenneth T. Simowitz Memorial Award from the Graduate Program in Acoustics.

Matthew T. Neal received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Matthew Neal received the Acoustical Society of America, Best Student Paper Award in Architectural Acoustics at ASA, New Orleans, LA.

Nicholas Ortega received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Rachel Romond received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Trevor Stout received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Trevor Stout received an Outstanding Paper by a Young Presenter in Noise Control Award at Acoustics '17 Boston.

Stephen Wells received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Janet Xu received the 2018 Kenneth T. Simowitz Memorial Citation from the Graduate Program in Acoustics.

Sparrow appointed to professorship

Dr. Victor Sparrow, professor and director of the Graduate Program in Acoustics, Penn State, has been named the United Technologies Corporation Professor of Acoustics.

Sparrow was one of nine faculty members in the College of Engineering at Penn State who were appointed to professorships in 2017. All were selected following a recommendation from the Harold and Inge Marcus Dean of Engineering, Justin Schwartz, for their outstanding teaching and research initiatives. "We are extremely grateful to those who fund these professorships and chairs, which are critical to furthering scholarly excellence in areas of instruction and research," said Schwartz. "Not only do they benefit our students, they also enrich our research enterprise, connect us with industry, contribute to the prosperity of the Commonwealth and raise our profile."

The United Technologies Corporation Professorship in Acoustics is awarded to a full-time faculty member in the College of Engineering with the academic rank of professor, who has excelled in teaching and research in the area of acoustics. It provides the resources necessary to continue and further the scholar's contributions to teaching, research, and public service activities that enhance the field of acoustics.

Upon hearing of this professorship, Dr. Sparrow exclaimed, "Wow! I am very humbled by this honor. I am most pleased that we will be able to put the endowment funds provided by United Technologies Corporation to work for the betterment of the Acoustics Program and to support our graduate students. We thank UTC, again, for their support of Acoustics at Penn State."

"Our college is fortunate to have outstanding faculty members at all stages of their careers," said Anthony Atchley, senior associate dean of engineering. "While there are many more faculty members deserving of recognition than we have ways to do so, we are happy to be able to acknowledge these nine faculty members who have distinguished themselves."

For additional information regarding the other eight faculty members, see http://news.psu.edu/story/495320/2017/11/21/

Rahn receives Myklestad Award from ASA

Associate Dean Christopher Rahn for Innovation and Professor of Mechanical Engineering has received the Myklestad Award from the Acoustical Society of America.

Congratulations Chris!

Congratulations to everyone on their outstanding accomplishments!

CAV 2017 Graduate Student Theses

Here are this year's CAV graduate student PhD and MS theses. Most of them are available in PDF format through Penn State's library system. We have archived all of our student theses in a CAV database on our website (see the 'CAV bookshelf' page). Just search for the student's name or thesis title and you will be taken to a link of the thesis abstract and, if available, a downloadable PDF file.

PhD

Brown, Daniel, Acoustics, *Modeling and measurement of spatial coherence for normal incidence seafloor scattering*

Cho, Hwanjeong, Engineering Science and Mechanics, *Towards robust SHM and NDE of plate-like structures using nonlinear guided wave features*

Choi, Gloria, Engineering Science and Mechanics, *Towards a robust characterization of material damage evolution via linear and nonlinear ultrasonic guided wave features*

Dick, David, Acoustics, *A new metric to predict listener envelopment based on spherical microphone array measurements and higher order ambisonic reproductions*

Feurtado, Philip, Acoustics, *Quiet structure design using acoustics black holes*

Kerrian, Peter, Acoustics, *Developments in acoustic metamaterials for acoustic ground* cloaks

Lind, Amanda, Acoustics, *Auralizing impulsive sounds outdoors among buildings*

Ma, Xiaokun, Mechanical Engineering, *Dynamics and control of energy harvesting devices*

Mao, Zhangming, Engineering Science and Mechanics, *Acoustophoresis and fluid dynamics in surface acoustic wave-based acoustofluidics*

Nama, Nitesh, Engineering Science and Mechanics, *Microacoustofluidics: an arbitrary lagrangian-eulerian framework*

Nichols, Stephen, Acoustics, *Properties of low frequency underwater ambient noise in the ocean sound channel*

Reich, David, Aerospace Engineering, *Experimental investigation of a helicopter rotor hub flow*

Swaminathan, Anand, Acoustics, *Experimental investigation of dynamic stabilization of the Rayleigh-benard instability by acceleration modulation*

MS

Biwalkar, Manasi, Acoustics, *Single event comparisons of predicted and measured sound at Vancouver international airport*

Doebler, William, Acoustics, *The minimum number of ground measurements required for narrow sonic boom metric 90% confidence intervals*

Hunt, Corey, Mechanical Engineering, *An investigation of strain measurement via embedded fiber bragg grating strain gauges for condition monitoring in additively manufactured hydroturbines*

Kinzie, Andrew, Acoustics, *Acoustic characterization of PSU recording studio above and below the Schroeder frequency*

Koh, Veronica, Acoustics, *Design improvements of an underwater low frequency projector based on clarinet acoustics*

Kupchella, Chester, Acoustics, *Quantifying the uniaxial high cycle fatigue life of laminated composites with a resonant beam test*

Moriarty, Peter, Acoustics, *The acoustics of emotion: creation and characterization of an emotional speech database*

Notarangelo, Claudio, Acoustics, *The prediction of vibratory stresses in wall-bounded jets due to unsteady aeroacoustic loading*

Palmer, Joshua, Acoustics, *Quantifying sonic boom metric variability*

Papavizas, Nicholas, Mechanical Engineering, *Modeling dynamic instability of off-highway mining dump trucks*

Patterson, Kevin, Acoustics, *Acoustic fault detection in tactical flow meters*

Pradeep Kumar, Arjun, Mechanical Engineering, *Efficient computation of frequency response of multi-degree of freedom non-linear vibrational system*

Roemer, Michael, Mechanical Engineering, *Fuzzy Logic, Neural networks and statistical classifiers for the detection and classification of control valve blockages*

Shankar, Arjun, Acoustics, *High power evaluation of textured piezoelectric ceramics for SONAR projectors*

Sundaresan, Niranjana, Engineering Design, *Design & fabrication of non-linear bistable vibration electromagnetic harvesters*

Vernon, Julia, Acoustics, *Fin whale distribution in the Indian and equatorial Pacific Oceans in support of passive acoustic density estimation*

Xu, Janet, Acoustics, *Practical ultrasonic transducers for high-temperature applications using bismuth titanate and ceramabind 830*

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PLEASE MARK YOUR CALENDARS

CAV WORKSHOP 2019

Tuesday — Wednesday

7-8 May

Nittany Lion Inn

Technical Research Group Highlights

Acoustic Materials and Metamaterials

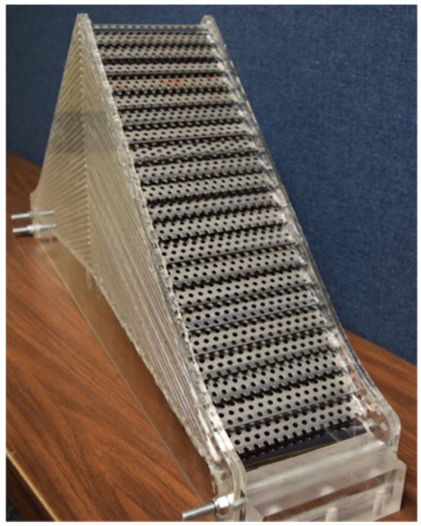
Amanda Hanford, Group Leader
ald227@psu.edu

This year, the newly reformatted technical group has a new name to better reflect the active research and interest of the PSU CAV community. The Acoustic Materials and Metamaterials technical group performs research in many areas involving the interaction between acoustics and materials. Not only can materials be used for acoustics and structural performance but acoustics can be used to evaluate material performance. Advances in traditional and additive manufacturing technologies can provide for unique acoustic and structural advantages. The underlying goal of this group is to continue to advance acoustic materials to evaluate new applications for acoustic and vibration control. The group also has an expanded focus to include work in acoustic metamaterials. Acoustic metamaterials are engineered materials that are designed to control, direct, and manipulate sound waves.

Research topics of the newly reorganized group include:

- Material characterization
- Manufacturing techniques for novel materials
- Acoustic cloaking
- Metamaterial inverse design
- Active metamaterials
- Structural vibration control through novel materials

Peter Kerrian recently graduated with his PhD in Acoustics, researching developments in acoustic metamaterials for acoustic ground cloaks. Peter's work encompassed many aspects of acoustic materials and metamaterials ranging from non-destructive acoustic excitation techniques for material characterization to designing, building and testing anisotropic materials for use in an acoustic ground cloak. Peter's work this year focused experimentally demonstrating the anisotropic behavior of a metamaterial comprised of a solid inclusion unit cell in water as well as the effectiveness of an underwater acoustic ground cloak shown in the picture below.



Projects and Graduate Students:

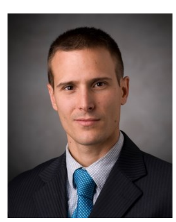
Title: Adaptive Acoustic Metamaterials
Sponsor: NAVSEA 073
PIs: Ben Beck and Rob Campbell
Student: Aaron Stearns (PhD Mechanical Engineering)

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

Title: Acoustic Defect Detection in Powder Bed Fusion Additive Manufacturing
Sponsor: Applied Research Laboratory
PIs: Ted Reutzel and Robert Smith

Adaptive Structures and Noise Control

Jose Palacios, Group Leader
jlp324@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.

Assistant Prof. Jose Palacios and his students are pursuing a number of projects in vibration control and adaptive structures fields. Dr. Palacios' group is also active on the field of aircraft icing and impinging jets, currently working on the following: 1) The Effects of Tip Leakage on Jet Engine Partially Melted Ice Crystal Ice Accretion (NASA Fellowship); 2) Ice Adhesion Strength Modeling and Verification of Controlled Surface Roughness Erosion Resistant Coatings (Vertical Lift Research Center of Excellence Task); 3) Engine Icing Ice Accretion Modeling; 4) Dual Impinging Hot/Cold Jet Outwash Modeling and Experimental Verification; 5) Modeling and Experimental Verification of the Effects of Erosion Resistance Tapes for Wind Turbines (3M).

The following are projects related to adaptive structures being conducted by Palacios' group:

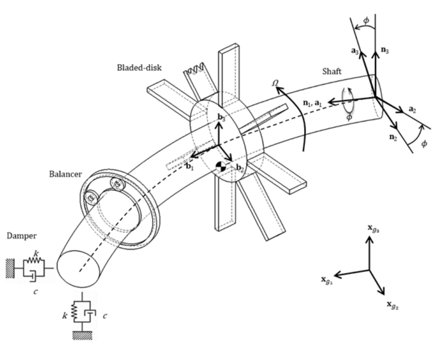
Title: Supercritical Tail Rotor Shaft Passive Balancing Bearing Modeling, Design and Testing.
Sponsor: LORD Corp.
Summary: Passive balancing devices for rotary systems consist of masses that are free to move in concentric guides about a shaft axis. At supercritical shaft speeds, the balancing masses automatically assume positions that counter any imbalance due to uneven mass distribution in the system. The problem is highly nonlinear and requires comprehensive modeling to achieve satisfactory prediction of the balancing behavior. A test rig was fabricated to test the performance of a passive balancing device on a supercritical shaft and to validate a comprehensive model. The model includes balancing mass collisions and balancing mass interaction with the balancer track through friction. Experimentally, the passive balancing device on average reduced shaft transverse vibrations by 62% at steady-state. Models available in the literature predicted

Technical Research Group Highlights

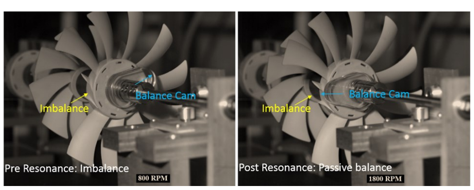
vibration amplitudes to within 68% of the experimental values. The new balancing model improved the accuracy of predicting shaft vibration amplitudes by a factor of 3.9 when compared to published models (18% vs. 68%). This suggests that friction and mass collisions cannot be ignored in passive balancer modeling. In addition, novel partition approaches are being investigated to further reduce imbalance while preventing negative effects in pre-resonance regions.

PI: Palacios

Student: Ahmad Haidar, Ph.D. Candidate. Expected Graduation August 2018.



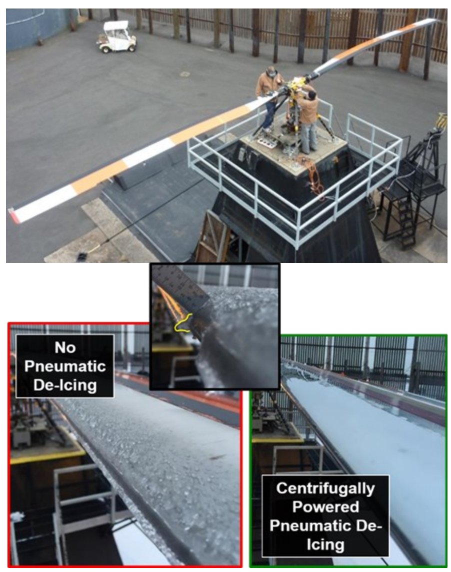
Schematic of degrees of freedom assumed for modeling of passive balancing



Example of passive balancing post 1st resonance of the system

Title: Modeling and Experimental Verification of a Low-Power Pneumatic Ice Protections System for Fixed-Wing UAS
Sponsor: Airforce, Invercon LLC.
Summary: A novel low power, low weight, erosion resistant, pneumatic actuators combined with a bi-stable latch is modeled and experimentally evaluated. The system has been demonstrated in a full-scale helicopter rotor blade using centrifugal pumping to inflate and deflate the rotor leading edge. The configuration uses a metallic leading edge cap rather than neoprene as it is used by other pneumatic systems. The small deformation on the metallic cap create sufficient transverse shear stresses to debond accreted ice. For fixed-wing UAVs, due to the lack of centrifugal forces to remove the ice, and since aerodynamic forces could prevent the ice from dislodging from the wing of the UAS despite being fully debonded, bi-stable latches are introduced. The bi-stable latches release during the inflation process providing a transient non-symmetric input to the leading edge cap, assisting with the removal of the debonded ice. The configuration is being tested in the PSU icing wind tunnel and it will be testing in a full-scale Predator UAV wing at the NASA Icing Research Tunnel in the Fall of 2018.
PI: Palacios

Student: Carter Forry, Expected M.S. graduation May 2019.



Full-scale rotor blade used for testing of the centrifugally powered pneumatic de-icing configuration and sample results of ice protection using semi-passive centrifugally powered pneumatic de-icing

Mary Frecker – Member
mxf36@engr.psu.edu

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

Title: Endoscopic Flexible Pancreatic Tumor Ablation System with Reduced Force Effector and Specialized Ablation Zone
Sponsor: National Institutes of Health, with Actuated Medical Inc.
Summary: We are developing specially shaped deployable probe tips for radio frequency ablation of pancreatic cancer.
PIs: Frecker (PSU), Snook (AMI)
Student: Brad Hanks, Fariha Azhar

Title: Design of multifield responsive material systems
Summary: We are developing finite element modeling and systematic design optimization methods for active materials that respond to multiple applied fields such as electric and magnetic.
PIs: Frecker, Ounaies
Student: Wei Zhang

Title: Design for additive manufacturing (DFAM) of cellular contact aided compliant mechanisms (C3M) for energy absorption
Summary: Energy absorbing C3M are expected to be useful for applications such as vehicle armor. We are developing a DFAM approach including finite element modeling of structural during impact and thermal response during fabrication.
PIs: Frecker
Students: Jivtesh Khurana, Brad Hanks

Kenji Uchino – Member kenjiuchino@psu.edu

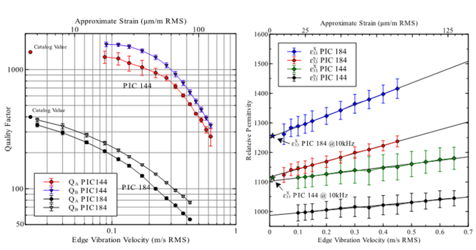
Prof. Uchino has been awarded as the 2018 -2019 prestigious IEEE Ultrasonic, Ferroelectrics and Frequency Control Society Distinguished Lecturer. Kenji Uchino continues his work in 1) high power piezoelectric materials and their characterization, including mechanical losses; 2) piezoelectric energy harvesting; and 3) piezoelectric motors and transformers. An example of one of his on-going research projects is highlighted below.

Title: Loss Mechanisms in Piezoelectric Single Crystals and Ceramics
Sponsor: Office of Naval Research

Technical Research Group Highlights

Summary: This program is composed of three aspects: (1) Loss Phenomenology: Phenomenological formulation in piezoelectric losses (i.e., dielectric, elastic and piezoelectric losses for intensive and extensive parameters) are considered comprehensively, including new equivalent circuit proposals. Microscopic loss mechanisms are investigated in piezoelectric single crystals and ceramics with respect to the domain dynamics. We conduct the loss measurement on various polarization direction. From the crystal orientation dependence of loss factors, we explain the contributions of different domain wall motions to these dielectric, elastic and piezoelectric losses. (2) Characterization Methodology: In addition to the conventional admittance/impedance spectrum analysis, we complete the Burst Mode analytical technique aiming at the future IEEE Standard method. In order to facilitate to measure various loss tensor components, we also propose a new piezo-sample configuration (i.e., partial electrode patterns) for measuring intensive and extensive losses experimentally. (3) Materials: The loss mechanism difference are explored, in particular, in the conventional PZT's, relaxor:$PbTiO_3$ ferroelectrics and lead-free materials, with a particular focus on ionic species and dopants, in terms of the internal bias field generated in hard piezoelectric materials, aiming at development of high energy density materials. DC external bias electric field and stress dependence of losses is another important target of research from a practical application viewpoint.

Six research topics were conducted in FY2017:



(a) Change in quality factors and (b) change in dielectric permittivity with vibration velocity for PIC 144 (Hard PZT) and PIC 184 (Soft PZT)

(1) Based on a phenomenological approach, a new equivalent circuit with integrating three losses (dielectric tanδ', elastic tanϕ' and piezoelectric tanθ') is introduced for practical analysis of the loss & Q_m values, which provides the optimum (i.e., highest efficiency) operation frequency for piezoelectric transducers.

(2) Polarization cutting-angle dependence of piezoelectricity & losses in $Pb(Zr,Ti)O_3$ and analysis are conducted, in addition to crystallographic orientation dependence of losses in $Pb(Mg_{1/3}Nb_{2/3})O_3$-$PbTiO_3$ single crystals.

(3) Detailed formula of the force factor/voltage factor are derived for the Burst Mode method, and measurements are conducted on various samples without rising temperature. The dielectric constant is planned to measured even at the resonance frequency.

(4) Partial Electrode sample configuration is proposed for measuring both s_{11}^E and s_{11}^D in a piezo-ceramic plate, which expands the measuring capability even on un-electroded samples.

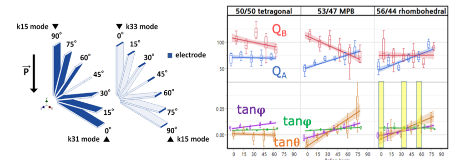
(5) From loss characterization in Pb-free piezoelectric ceramics, Mn-doped Bi-perovskite has very stable high power behavior compared to other Pb-free and Pb-based ceramics. The reason will be explained in terms of the internal bias field generation and high thermal conductivity.

(6) DC bias stress and electric field effects on the dielectric, elastic and piezoelectric losses are modeled for a k31 plate PZT sample in order to clarify the domain dynamic contribution, and the experimental verification is conducted.

PI: Uchino

Students: Minkyu Choi (MatSE Ph.D.), Hossein Daneshpajooh (EE Ph.D.), Yuxuan Zhang (EE Ph.D.), Anushka Bansal (MatSE MS), Maryam Majzoubi (EE MS)

Organization: International Center for Actuators and Transducers, The Pennsylvania State University.



Piezoelectric losses according to polarization direction for various PZT compositions

George Lesieutre – Member gal4@psu.edu

Prof. George Lesieutre and his students are pursuing a number of projects in vibration control and adaptive structures.

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.

Student: Tianliang Yu, Ph.D. December 2018 (expected).

Title: Cable-Actuated Tensegrity for Deployable Structures

Sponsor: PSU / external Fellowship

Summary: Tensegrity structures offer the potential of very high packing efficiency, but are relatively soft in the classical deployed configuration. Higher stiffness is possible with strut-to-strut load transfer. Dynamic cable actuation enables deployment and makes higher stiffness possible.

Student: Yaan Kildiz, Ph.D. August 2018 (expected).

Title: Articulated Tensegrity Structures for Space Applications

Sponsor: PSU Fellowship

Summary: Spacecraft having extended configurations must be stowed for launch compactly, with final stiffness adequate to maintain shape and stability under dynamic disturbances. Tensegrity structures are of interest for their potential to provide novel deployable structures (booms, arrays) for space applications,

Technical Research Group Highlights

as well as articulated structures that can be reconfigured and adjusted during mission operation. Research issues include tendon actuation; metrology, precision and control; and reachable shape states.

Student: Kaila Roffman, M.S. May 2019 (expected)

Chris Rhan – Member
cdrahn@engr.psu.edu

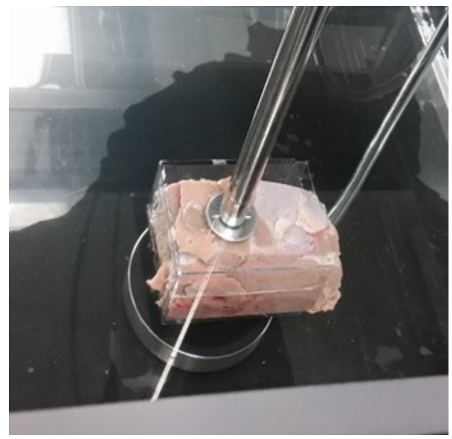
Title: Wearable piezoelectric polymer energy harvesters and wearable energy harvesting and storage system modeling
Sponsor: NSF ASSIST ERC
Student: Tahzib Safwat
Summary: Energy harvested from the body can be used to power wearable devices and sensors for applications such as biomedical (i.e. health-monitoring), and also minimizes or eliminates the need for user intervention (i.e. charging, changing batteries). Kinetic energy from breathing provides a continuous source or power and can be harvested ergonomically via textile-integrated piezoelectric polymer energy harvesters. Piezoelectric materials can convert mechanical stress to electrical energy, or vice versa. A special interdigitated electrode pattern is being applied to a multilayer PVDF copolymer (P(VDF-TrFE)) harvester to increase the efficiency and robustness of the device. Power management is also a critical issue in a wearable energy harvesting system. Using publicly available human activity and travel data, the wearable energy harvesting system (which includes multiple energy harvesters, their respective electronics, and a supercapacitor for energy storage) is being modeled by combining statistical and physics-based approaches to size components.
PIs: Chris Rahn, Zoubeida Ounaies

Biomedical Acoustics –NEW GROUP!
Julianna Simon, Group Leader,
jcsimon@psu.edu

The mission of the Biomedical Acoustics group is to understand and apply acoustics towards improving human health. The group joined CAV in Fall of 2017. Currently, the group consists of 10 faculty members and approximately 20 students. Research interests include advanced image processing, ultrasound imaging and therapeutics, photoacoustic imaging, shear wave elastography, drug delivery, and more! Some highlights for 2017-2018 include the new collaboration between Drs. Meghan Vidt (Biomedical Engineering) and Julianna Simon (Acoustics).

Funded Projects and Students:
Title: Focused ultrasound histotripsy as a novel therapeutic approach to tendon injury: an assessment of structure and mechanical properties
Sponsor: Penn State College of Engineering Multidisciplinary Seed Grant Program
PI: M. Vidt, **Co-PI:** J. Simon
Summary: Rotator cuff tears are a leading cause of shoulder pain but conventional treatments such as surgery or dry needling have mixed failure rates ranging from 15-90%. Developments in focused ultrasound histotripsy demonstrate promise for noninvasively causing microdamage to stimulate tendon healing. The objectives of this pilot project are: 1) identify the effect of histotripsy on tendon microdamage compared to dry needling in *ex vivo* rat supraspinatus tendon; and 2) determine tendon mechanical properties following histotripsy and dry needling exposure, and develop a finite element model to evaluate parameters and perform predictive analyses. Long-term this approach will be clinically transferred, where it has the potential to revolutionize the standard of care for rotator cuff tear patients.

Students: Molly Smallcomb (PhD student, Acoustics), Bailey Klein, Sizhe Kuang (Undergraduate students Biomedical Engineering), and Sujata Khandare (PhD student, Biomedical Engineering)



Practice using the high intensity focused ultrasound (HIFU) transducer on liver as we work towards treating tendons

Flow Induced Noise
Michael Jonson, Group Leader, mxj6@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: Radiated Sound from a Crossflow Turbine with Pitching Hydrofoils
Sponsor: ARPA-E
Advisors: Michael Jonson and Joseph Horn
Summary: The Ocean Renewable Power Company (ORPC) has been developing power-generating turbines for a few

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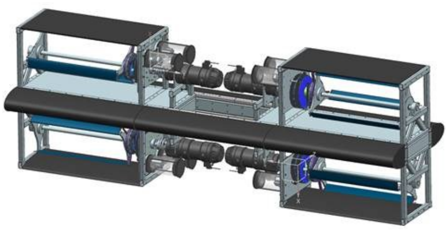
years. These crossflow turbines have a non-pitching foil geometry that generate power regardless of the tide flow direction. The direction of rotation remains the same because the foils contain a prescribed cambered airfoil with a rounded leading edge and a sharp trailing edge. To smooth out the torque generated by the flow, the turbine foils are skewed along the span. Two-dimensional analysis has shown that turbine performance can be improved by oscillating the foils during each rotation. Furthermore, applying the mechanisms of airborne cyclocopters to a crossflow turbine to produce lift and drag have shown that such hydro-crossflow rotors could be used to self-deploy with the turbine acting as a propulsor.



A single turbine Rapid Prototype Device (RPD) is designed and manufactured. The main objectives of the RPD are to ascertain the performance of a submerged single turbine so testing knowledge can be put into more complex underwater systems. To expedite fabrication and testing, the RPD has components that are operated in air and water. Ideally the whole system would be operated submerged but the required waterproof motor could not be acquired in the short term. The RPD uses a barge with the motor and 90 degree gearhead mounted on top. The axis of the turbine is oriented vertically and submerged below the barge. This configuration allows for any thrust to be oriented in the horizontal plane. Radiated sound power from such a device is unknown and may have environmental impact on marine mammals and fish. Since the RPD hydrodynamic testing was performed in a reverberant tank, little effort was required to place hydrophones within the tank and make acoustic measurements at the same time. For lower frequencies below where sufficient modal overlap occurs, the sound was estimated using a six degree-of-freedom load cell through a dipole transfer function. For the higher frequency noise, standard reverberant tank processing was used. The radiated sound spectra from the RPD straight pitching foils was then scaled up to full scale and compared to field measurements of a conventional ORPC cross flow turbine.

Student: Margalit Goldschmidt

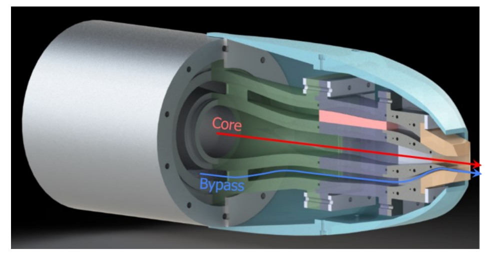
Title: Design and Development of a Dual Flow Supersonic Jet Aeroacoustics Facility Upgrade

Sponsor: Naval Air Warfare Center - Aircraft Division - Naval Air Station, Patuxent River,

Summary: Multi-stream, variable-cycle turbofan engines with low-aspect ratio rectangular exhaust nozzle profiles are in consideration for future tactical aircraft. Such engine architectures aim to combine the benefits of airframe-integrated nozzles with the capability to operate between high-thrust or high-efficiency depending on the demands of the flight profile. However the exhaust from these engines generates noise levels in excess of excess of 140 dB in the vicinity of the aircraft. Studies have shown an increase in hearing loss among shipboard personnel on the flight decks of aircraft carriers due to the continued exposure to such dangerously high noise levels. The capabilities of the High Speed Jet Aeroacoustics Facility have been upgraded to support small-scale experiments simulating the dual flow supersonic rectangular exhausts proposed for advanced concept military tactical aircraft. The bypass ratio for such dual flow exhausts may be as high as 35%. Experiments will be performed at Mach numbers, simulated total temperatures, and bypass ratios expected of full-scale aircraft exhaust. The primary objective of this study will be to characterize the far-field acoustics of generic dual stream, rectangular, supersonic jets in various configurations with comparisons to equivalent single stream rectangular and circular jets operating at the same thrust and mass flow rates. A secondary objective of this study will be to measure mean jet exhaust velocities and perform shadowgraph flow visualization. These data serve to characterize the flow fields and will be used to assist in the interpretation of the acoustic measurements as well as provide an experimental database to validate expected future RANS computational fluid dynamic simulations.

PI: Dennis K. McLaughlin

Student: Scott Hromisin, Ph.D. Candidate. Expected Graduation August 2019.



CAD rendering of generic dual flow rectangular jet model configuration with the bypass stream exhausting underneath the core flow

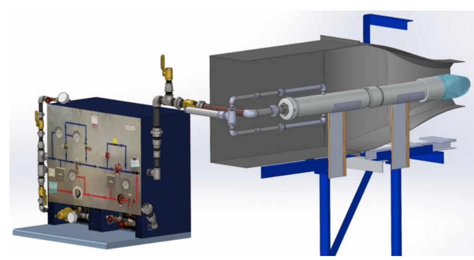


Figure. CAD model of dual flow model installed in Penn State High Speed Jet Aeroacoustics Facility with source and control piping shown

NASA University Leadership Initiative

Penn State is a member of a multi-university research team led by researchers from the University of Tennessee (UT), Knoxville Tickle College of Engineering, that was selected by NASA to explore transformative system-level aviation innovations as part of NASA Aeronautics' University Leadership Initiative (ULI). Under the ULI, the project team will aim to demonstrate a viable ultra-efficient aerodynamic wing-design concept that could be incorporated into

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commercial aircraft and contribute to a 70 percent reduction in aircraft fuel and energy consumption. This research will support NASA's main aviation research goals under its Ultra-Efficient Commercial Vehicles strategic thrust. Achieving the fuel/energy consumption goals with the SNLF concept will be performed in three phases — Technology Development, Technology Integration and Technology Demonstration — with associated, investigator-driven research tasks. Penn State will be responsible for four of the team's 10 tasks for which two involve structural vibration and noise:

Aeroelastic Behavior and Flutter Mitigation of Multi-element Wings (Researchers Robert Campbell and Michael Jonson: Student Auriane Bottai)

Aeroacoustic Predictions at Low-speed Flight Conditions (Researcher Kenneth Brentner: student starting in fall)

Project: Glottal jet aerodynamics
Sponsor: NIH
PI: Michael Krane (ARL PSU)
Collaborators: Michael McPhail (Mayo Clinic-Scottsdale), 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)
Summary: Project uses a combination of reduced-order modeling, aeroacoustic-aeroelastic computer simulation, and physical model measurements to address current open questions regarding the physics of human phonation, and to translate these findings into improved clinical measures. Current focus is on energy utilization and voice efficiency. This program, which began in 2002, has been renewed through 2020.
Students:

Michael McPhail (PhD Bioengineering, PSU 2016): now employed by Mayo Clinic-Scottsdale

Jubiao Yang (PhD Mechanical Engineering, Rensselaer Polytechnic Inst. 2016): now employed by Goldman-Sachs

Feimi Yu (PhD Mechanical Engineering, Rensselaer Polytechnic Inst.)

Gage Walters (PhD Mechanical Engineering, PSU)

Dylan Rogers (BS Mechanical Engineering, UNL)

Hunter Ringenberg (BS Mechanical Engineering, UNL)

Recent news:
Conference presentations:

Zhang, L., Yu, F., Krane, M., "Power Flow in Phonation," 70th Annual Meeting of the American Physical Society (Division of Fluid Dynamics), Denver, CO, Nov. 19-21, 2017.

Krane, M., Walters, G., McPhail, M., "Correlation of phonatory behavior with vocal fold structure, observed in a physical model," 70th Annual Meeting of the American Physical Society (Division of Fluid Dynamics), Denver, CO, Nov. 19-21, 2017.

Ringenberg, H. Rogers, D., Wei, N., Krane, M., Wei, T. ,"Simultaneous temporally resolved DPIV and pressure measurements of symmetric oscillations in a scaled-up vocal fold model," 70th Annual Meeting of the American Physical Society (Division of Fluid Dynamics), Denver, CO, Nov. 19-21, 2017.

Rogers, D., Wei, N., Ringenberg, H., Krane, M., Wei, T. ,"Examining diseased states in a scaled-up vocal fold model using simultaneous temporally resolved DPIV and pressure measurements," 70th Annual Meeting of the American Physical Society (Division of Fluid Dynamics), Denver, CO, Nov. 19-21, 2017.

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 2017-2018 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 for atmospheric profiles models. Further work has centered on improving our understanding of the limitations of metrics for sonic booms and to develop methods to potentially certify future civilian supersonic aircraft. Such certification methods might include signal processing to remove the effects of atmospheric turbulence from measured sonic boom signatures.

Dr. Sparrow is also participating in the 3rd year continuation of a NASA project, SonicBAT, which focuses on the effects of atmospheric turbulence on low-boom sonic booms. The lead for this project is KBRwyle, and Penn State is a subcon-

Technical Research Group Highlights

tractor 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 co-organized four special technical sessions on sonic boom at the upcoming June 2017 joint meeting of the Acoustical Society of America and the European Acoustics Association in Boston, MA, known as Acoustic'17.

Dr. Michelle Vigeant is an Assistant Professor of Acoustics and Architectural Engineering who leads the Sound Perception and Room Acoustics Laboratory (SPRAL), her research group, which currently consists of 4 Ph.D. students. She had three students graduate in 2017 (1 doctoral and 2 masters students. She is currently pursuing research in three areas: (1) concert hall acoustics, (2) the neurological response to acoustics stimuli, and (3) aircraft noise. She currently has two students, Matthew Neal and Fernando del Solar, working on projects related to concert hall acoustics.

- Neal is working on developing a metric to predict the perception of overall acoustic quality in concert halls. The stimuli for this study will be taken from the large database of concert hall measurements obtained in summer and fall 2017 at 15 American and 6 European halls. The spatial impulse responses measured will be convolved with short anechoic musical excerpts for use in subjective studies to investigate the relationships between different room acoustic attributes, e.g. reverberance and envelopment, and overall preference.
- del Solar is investigating the smallest detectable difference of early decay time (EDT), which is a measure of the time it takes for the initial sound level to decrease 10 dB. This metric has been shown to work well as a predictor for the perception of reverberance, but more research is needed to determine the smallest change in EDT that is audible.

In the second topic area of neurological response to acoustics stimuli, she currently has one student, Martin Lawless, who has just finished his doctoral dissertation in this area. Lawless used neuroimaging specifically the method of functional magnetic resonance imaging (fMRI) to quantify human response to different room acoustics stimuli. For example, the goal of his final study was to examine the differences in activations in the auditory cortex due to different amounts of reverberation, which have varying amounts of incoherent acoustic information.

For aircraft noise, Dr. Vigeant is working in collaboration with Dr. Sparrow on two projects. For the first project, which is funded through the FAA, her graduate student Nick Ortega is studying human response to a special type of sonic booms that are produced when aircraft fly slightly above the speed of sound around Mach 1.1 to 1.5 – known as Mach cut-off. Ortega used recordings of Mach cut-off flyovers from NASA to conduct a subjective study to identify a set of perceptual attributes associated with this type of noise. He is currently working on a follow-up study wherein participants will rate this set of attributes along with annoyance as a next step towards identifying a possible metric to quantify public acceptability of this type of aircraft noise. For the second project, Drs. Vigeant and Sparrow continue to work on a NIH-funded project in collaboration with Boston University researchers in the School of Public Health. The project aims to examine the effects of both road and rail traffic on cardiovascular disease, where Penn State's contribution to the project is historical noise modeling of regions around several U.S. airports.

The current graduate students working in from the Propagation and Radiation Group include …

Current Graduate Students:

William Doebler, Ph.D. expected Summer 2020
Thesis topic: Improved sonic boom models for lateral cutoff and over the top booms
Sponsor: NASA
Advisor: V. Sparrow

Zhendong Huang, Ph.D. expected Summer 2019
Thesis topic: Corrected three-dimensional ray theory for the prediction of Mach cut-off sonic boom
Sponsor: FAA
Advisor: V. Sparrow

Beom Soo Kim, Ph.D. expected Fall 2018
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

Matthew Neal, Ph.D. expected Summer 2019
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: The effects of Mach cut-off sonic booms on annoyance
Sponsor: FAA
Advisor: M. Vigeant

Harshal Patankar, Ph.D. expected Fall 2021
Thesis topic: Uncertainty and validation for aircraft noise propagation predictions
Sponsor: FAA
Advisor: V. Sparrow

Rachel Romond, Ph.D. expected Fall 2019
Thesis topic: Including meteorological reanalysis for atmospheric models to improve subsonic aircraft noise prediction
Sponsor: FAA
Advisor: V. Sparrow

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

Nathan Tipton, M.S. expected Summer 2019
Thesis topic: Improved sound mapping tools using ArcGIS
Sponsor: U.S. National Park Service
Advisor: V. Sparrow and P. Newman

Janet Xu, Ph.D. expected Summer 2023
Thesis topic: Group processing of sonic boom waveforms to remove atmospheric turbulence
Sponsor: FAA
Advisor: V. Sparrow

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 three NRTC Vertical Lift Research Centers of Excellence (VLRCOE) in the country. In summer of 2016, our Center was successfully renewed for another 5 years. As part of our new program, we started 14 new research projects. We are grateful to our industry partners at LORD Corp., Bell, and Sikorsky for their support of our proposal. New projects include: Fundamental Investigations into Future Low-Drag Single-/ and Co-axial Rotor Hub Systems (Prof. Schmitz et al), Advanced Transition and Turbulence Modeling for Rotorcraft CFD Applications (Prof. Coder et al), Nonlinear Laser Ultrasonics for Reduced Variability in Additive Manufacturing Parts (Profs. Lissenden and Reutzel), Ice Adhesion Strength Modeling and Mitigation Via Low Surface Roughness Erosion Resistant Coatings for Rotor Blades (Profs. Palacios and Wolfe), Seamless Manufacturing of Hybrid-Material Turbines for High Temperature Rotorcraft Propulsion System by Field Assisted Sintering (Profs. Singh and Yamamoto), Fidelity Requirements for Ship Airwake Modeling in Dynamic Interface Simulations (Prof. Horn et al, High Airspeed Carriage of External Loads (Profs. Horn, Langelaan, et al), Load Alleviation Control Design Using High Order Dynamic Models (Prof. Horn et al), Slung Load State and Parameter Estimation for Autonomous Multi-lift Systems (Profs. Langelaan and Horn), Fundamental Aeroacoustics of Coaxial Helicopter Rotors (Profs. Brentner and Lee), Enhanced Damping for High-Speed Rigid Rotors via Tailored Hybrid Nanocomposites and Flexible Fluidic Matrix Composite Blade Dampers (Profs. Smith, Rahn, and Bakis), Experimental and Computational Analysis of Thermal and Dynamic Performance of Hybrid Gears Under Normal and Loss-of-Lubrication Operation (Prof. McIntyre et al), Experimental Validation, Noise and Dynamic Analysis and Variable Speed Attributes of High Power Density Pericyclic Transmission (Prof. Smith et al), and Active Clutch Engagement Control and Maneuver-Assisted Shifting for Two-Speed Rotorcraft Transmissions (Prof. DeSmidt et al). 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 we have a suite of research tasks, 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. 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 50th consecutive year on August 6-10. Topics in the comprehensive course include rotorcraft aerodynamics, dynamics, acoustics, composite structures, flight controls and propulsion.

https://rotary-wing.outreach.psu.edu/

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 2017)

Title: Improved Passive Balancing of Shafts via Numerical Analysis and Experimental Verification
Sponsor: LORD Corp. PI: Jose Palacios
Student: Ahmad Haidar (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: Acoustic Capability for NDARC
Sponsor: NRTC VLRCOE Program
PI: Ken Brentner
Student: Kalki Sharma (MS 2017)

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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 2016), Tianxiao Yang (PhD 2016)

Title: High Fidelity CFD Analysis and Validation of Rotorcraft Gear Box Aerodynamics
Sponsor: NASA
PIs: Rob Kunz
Students: Sean MacIntyre (PhD 2015), Qingtao Yu (PhD 2016)

Title: Experimental Measurement of Ice Crystal Dynamics
Sponsor: NASA
PI: Jose Palacios
Student: Sihong Yan (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 2017)

Title: Centrifugally Powered Pneumatic Deicing for Helicopter Rotors
Sponsor: NASA
PIs: Jose Palacios, Doug Wolfe
Students: Matthew Drury (MS 2016)

Title: Rotorcraft Airfoil Design for Unsteady Aerodynamics
Sponsor: NRTC VLRCOE
PI: Mark Maughmer
Student: Bernardo Vieira (PhD 2017)

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 2016), Taylor Hoover (MS 2015), Julia Cole (PhD 2017)

Title: Advanced Response Types and Cueing Systems for Naval Operations
Sponsor: NRTC VRCOE
PI: Joe Horn
Student: Albert Zheng (MS 2016)

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

Title: Rotorcraft Noise Abatement Operating Conditions Modeling and Procedures Development
Sponsor: FAA
PI: Ken Brentner
Students: Yaowei Li (MS 2016), Willca Villafana (MS 2016)

Title: Pilot-in-the-Loop CFD Method Development
Sponsor: Office of Naval Research
PI: Joe Horn
Student: Ilker Oruc (PhD 2017)

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 2017)

Title: Placement of Circular Force Generators for Vibration Cancellation
Sponsor: Sikorsky Aircraft
PI: George Lesieutre
Students: Brad Sottile, (Ph.D. candidate), Keerti Prakash (MS 2017, PhD candidate)

Title: Computational and Experimental Investigation of Interactional Aerodynamics Relevant to Rotor Hub and Empennage Flows
Sponsors: Vertical Lift Consortium
PIs: Schmitz, Coder, Foster + GA TECH

Title: Design Tool for Gearbox Loss-of-Lubrication Performance
Sponsor: Vertical Lift Consortium
PIs: Kunz, McIntyre

Title: DURIP - Computing/Simulation High-Performance Computing System for Real Time Analysis of Rotorcraft Aeromechanics
Sponsor: ONR
PIs: Schmitz and Brentner

Title: 1D-patterned Nanocomposites Structured Using Oscillating Magnetic Fields
Sponsor: ONR
PI: Yamamoto

Title: Bearing Loads Analysis for Pericyclic Transmissions
Sponsor: NASA Glenn
Student: Zach Cameron (MS 2017)

Structural Vibration and Acoustics

S.A. 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

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analyze, measure, and control structural vibrations and radiated noise.

In 2017-2018 the group members investigated a wide range of topics, as shown below.

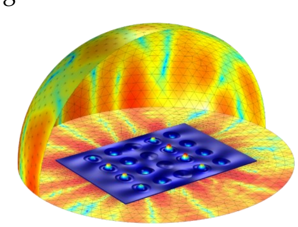
Title: Vibration and Noise Control Using Embedded Acoustic Black Holes

Sponsor: Dept. of Aerospace Engineering & Vertical Lift Research Center of Excellence

Principal Investigators: Ed Smith and Steve Conlon

Students: Yu Xiong (Ph.D., Aerospace Eng.), Robert Veltre (B.S –Honors Aerospace Engineering), Milton Rahman (B.S. Aerospace Engineering)

Summary: The Acoustic Black Hole (ABH) is a novel passive vibration control technique. This work strives to improve the low frequency performance of ABH structural systems. Structural-acoustic simulations of driven plates incorporating discrete tuning masses (within the ABH cells' center) indicate that the first ABH mode frequency can be adjusted. The optimal amount of tuning mass allows the cut-on frequency of the ABH cell to be tuned to the critical frequency of the plate. This ABH tuning results in high structural losses and significant radiation decoupling, hence less sound radiated. Varied distributed tuning masses further extend the radiation decoupling region and can result an enhanced effective bandwidth. The effect of discrete tuning masses on transmission loss problem is being explored using these FE models.



Sound and vibration of a flat rectangular plate with a 4x5 array of ABHs. Tuning masses are used to adjust the ABH cuton frequencies.

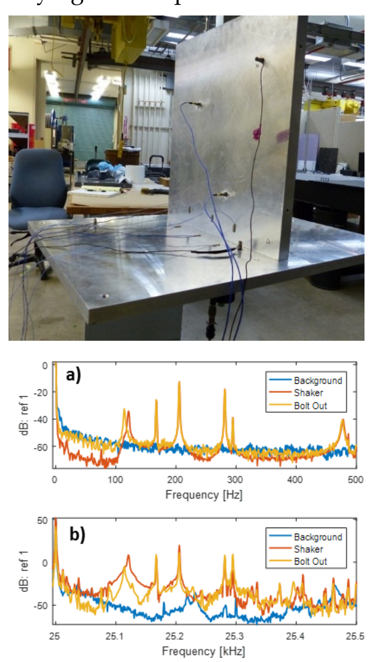
Title: Evaluation of Bolt Torque Levels using Nonlinear Wave Modulation Spectroscopy

Sponsor: Walker Graduate Assistantship Program

Principal investigators: Dr. Dean Capone, Dr. Manton Guers

Student: Carter Neblett (M.S. Acoustics)

Summary: The goal of this work was to examine torque levels of a bolted joint using nonlinear wave modulation spectroscopy with impact excitation. A photograph of the test structure is shown below. An ultrasonic shaker was used to supply the probing signal near the bolt location and an impact hammer was used to excite the natural vibration modes of the structure. Some of these modes produced significant displacements at the bolts leading to nonlinear sidebands around the ultrasonic probing frequency. The example below shows the modal excitation and the corresponding nonlinear sideband content around the probing signal frequency. Both discrete sideband peaks and broadband sideband levels were examined to determine a damage metric related to varying bolt torque levels.



Left - Experimental Setup; Right - (a) Modal excitation due to impact excitation; (b) Corresponding sidebands around the probing signal frequency

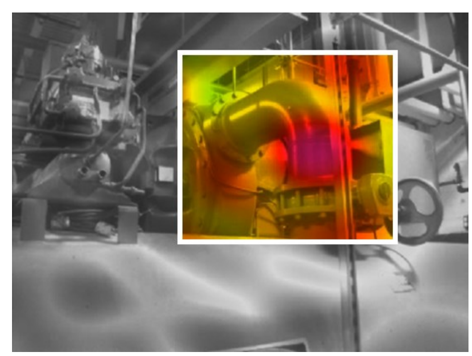
Title: Large chiller noise and vibration

Sponsor: UTC Building and Information Systems (Carrier)

Principal Investigators: Steve Hambric, Tim Brungart

Student: Stephen Wells (Ph.D., Acoustics)

Summary: Noise and vibration was measured on a 1600-ton capacity water-cooled industrial chiller that is comprised of a centrifugal compressor mounted on top of an evaporator in a side-by-side condenser/evaporator system. An evaluation of the chiller components with an acoustic camera indicates that the dominant radiation mechanism of these tones results from the coupling of the compressor-induced tones with the low order shell modes of the compressor discharge pipe, which is comprised of a horizontal section attached to the compressor discharge, a 90-degree elbow, and a vertical section connected to the condenser. The structural modes of interest are above the coincidence frequencies of the condenser shell and compressor discharge pipe structures, respectively, resulting in efficient sound radiation. A hybrid experimental/Finite Element/Statistical Energy Analysis model is being constructed to simulate the chiller vibration and sound.



Title: Nonlinear structural joint dynamics

Sponsor: NAVSEA 073R

Principal Investigators: Micah Shepherd, Steve Hambric

Student: Trevor Jerome (Ph.D., Acoustics)

Summary: The dynamics of structural joints, despite much research, remain poorly understood. A rigorous treatment of two plates with a bolted L-joint is underway, including ultrasonic scanning of the contact pressures on the faying surface, non-contact acoustic excitation of the structure and analysis of the non-linearities in the response time histories, and eventually simplified finite element modeling of the joint stiffness and damping.

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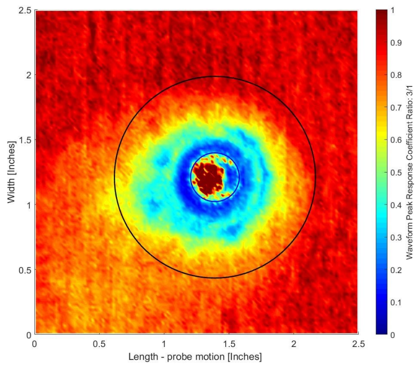


Bolted joint faying surface reflection coefficient. Blue indicates small reflections (and transmission through the joint), whereas red indicates strong reflection and weak joint contact away from the bolt

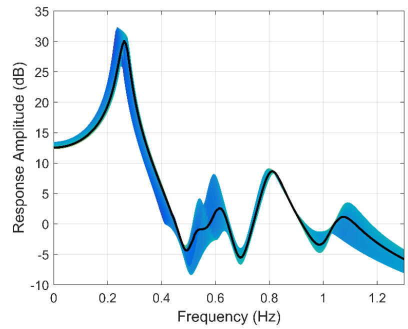
Title: Uncertainty quantification in flow-induced vibro-acoustic simulations

Sponsor: NAVSEA 073R

Principal Investigators: Andy Wixom, Sheri Martinelli

Student: Gage Walters (Ph.D., Mechanical Engineering)

Summary: There are many uncertainties in an analysis of the vibration and radiated sound from a flow-excited structure. The largest uncertainties are typically in the flow excitation model (turbulent boundary layer flow, ingested turbulence), but there are also uncertainties in structural properties, particularly in the damping of built up structures. Monte Carlo assessments of these uncertainties is not computationally tractable due to the large number of uncertain variables and analyses required. Generalized Polynomial Chaos (GPC) methods, however, can be used to dramatically reduce the number of computational analyses required to map the probability distributions of structural vibration and radiated sound. GPC and other methods are being pursued for a plate excited by turbulent boundary layer flow.



Probability distribution of structural response amplitude

Title: Small reciprocating compressor noise and vibration

Sponsor: Bristol Compressors

Principal Investigators: Tim Brungart, Steve Hambric

Student: John Cunsolo (MS - Acoustics)

Summary: The noise radiated by small reciprocating compressors is dominated by a wide distribution of tonal harmonics. The harmonics are amplified by the structural resonances of the cylindrical housing, particularly near the coincidence and ring frequencies. Experimental modal analyses are used to measure the modal distribution, and combined with radiated sound/force transfer functions to identify strongly radiating modes. Internal structural design changes are being evaluated to reduce the transmission of the source tones into the housing, and therefore reduce radiated noise.

A Bristol compressor in ARL/Penn State's hemi-anechoic chamber

Title: Power transmission metrics and applications in the design of quiet structures

Sponsor: ARL Walker Assistantship

Principal investigators: Dr. Kyle Myers (ARL), Dr. Robert Campbell (ARL)

Student: Jonathon Young (Ph.D, Mechanical Engineering)

Summary: Connected structures subject to applied dynamic loads transfer vibrational energy through their connecting junctions. Identifying the dominant paths of transmission and characterizing the power flow through those paths is important for designing a quiet structure. This work focuses on transmitted power flow assuming known mechanical connections between structures, with an emphasis on connections with fully coupled degrees of freedom characterized by an impedance matrix. This requires numerical modeling via finite elements as well as validation with experimental measurements. By identifying the dominant paths of transmission and structural modes that effectively transmit energy, power flow between structures can be better understood, and can inform design changes to the system to create quieter structures.

Title: High performance structural-acoustics computing

Sponsor: ONR

Principal Investigators: Rob Campbell, John Fahnline, Dean Capone

Summary: Recent demonstrations of a time-domain equivalent source technique have shown significant computational performance benefits, due primarily to the sparsity of the acoustic coupling coefficients in the linear system of equations. Another benefit of the time domain equivalent source technique is the ability to predict acoustic radiation from an underlying system that undergoes a nonlinear response due to, for example, large amplitude vibrations.

Title: Optimization of Acoustic Black Hole Design for improved Structural Acoustics

Sponsor: ARL Walker Fellowship

Principal Investigator: Micah Shepherd

Student: Cameron McCormick (PhD - Acoustics)

Summary: Arrays of Acoustic Black Holes (ABHs) have the potential to significantly reduce structural vibration and radiated sound. However, the optimal hole profiles, sizes, damping, and spacing are difficult to determine. An automated global optimization procedure and high performance parallel computing methods are applied to vibroacoustic problems to demonstrate the optimal design of ABHs.

Title: Structural Integrity of Naval Materials under Alternating and Extreme Loads
Sponsor: NAVSEA 073R
Principal Investigators: Matt Guers and Steve Conlon
Student: Connor McCluskey (Ph.D., Acoustics)
Summary: Marine structures are subjected to a wide range of alternating loads during their lifetimes. Alternating loads can cause fatigue cracking and in some cases failure. Structural damage can be accelerated by infrequently occurring extreme loads. However, the statistics of these extreme loads are not well understood. Water tunnel flow-induced vibration test data are analyzed to quantify the distribution and amplitudes of the extreme loads and their potential effects on naval structural materials.

Title: Aeroelastic Behavior and Flutter Mitigation of Multi-Element Wings
Sponsor: NASA
Principal Investigators: Rob Campbell, Mike Jonson
Student: Auriane Bottai (PhD – Aerospace Engineering)
Title: Experimental and Computational Analysis of Thermal and Dynamic Performance of Hybrid Gears under Normal and Loss-of-Lubrication Operation
Sponsor: U.S. Army, U.S. Navy and NASA (via PSU VLRCOE award)
Principal Investigators: Sean McIntyre and Rob Campbell
Student: Sean Gauntt (PhD – Mechanical Engineering)

Title: Integrated Shafting and Propulsor Demonstration
Sponsor: NAVSEA 073
Principal Investigators: Steve Conlon / Kevin Koudela

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

Title: Columbia Class Submarine Propulsor design
Sponsor: NAVSEA 073R
Principal Investigators: Steve Hambric and Bill Straka

Title: Journal bearing modeling and measurements
Sponsor: NAVSEA
Principal Investigators: Bill Straka, Steve Hambric, Rob Campbell

Title: ONR Materials Future Naval Capabilities (FNC)
Sponsor: Office of Naval Research (ONR)
Principal investigators: Dean Capone and Thomas Donnellan

Title: Acoustic Material Additive Manufacturing
Sponsor: ONR DURIP
Principal Investigators: Benjamin Beck and Thomas Juska

Systems and Structures Health Management Technical Group
Group Leaders
Karl Reichard, kmr5@psu.edu
Cliff Lissenden, Lissenden@psu.edu

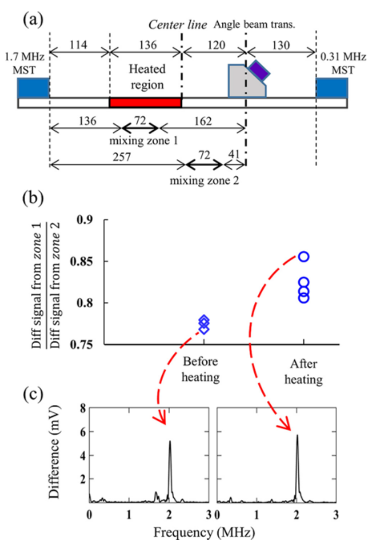
The mission of the Systems and Structures Health Management Technical Group is to develop new methodologies and technologies to manage the life cycle of systems and structures. This includes the full range of material state awareness, health and usage monitoring, and condition-based maintenance, to support 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: sensor systems, signal processing, pattern recognition, reasoning techniques, and modeling of damage progression to failure.

Title: Multi-sensor inspection and robotic systems for dry storage casks
Sponsor: DOE Nuclear Energy University Programs
PIs: Cliff Lissenden, Karl Reichard, Sean Brennan, Arthur Motta, Igor Jovanovic, John Popovics, Travis Knight
Students: Hwanjeong Cho, Sungho Choi, Bobby Leary, Ian Van Sant, Jen Brackens, Xuan Xiao, Samuel Le Barre
Summary: The DOE Nuclear Energy University Programs sponsored a Penn State-led Integrated Research Project with 7 faculty investigators (led by Cliff Lissenden). The team developed the multi-sensor PRINSE (proactive robotic inspection of nuclear storage enclosures) system for robotic inspection of dry storage casks. This capability is critical to managing the extended storage of spent nuclear fuel due to the lack of a disposal repository. Chloride-induced stress corrosion cracking is perceived to be the most probable degradation mode for the stainless steel canisters. The PRINSE system operates in the ventilation system of the cask and senses the environment (temperature and radiation), uses a laser induced breakdown spectroscopy (LIBS) system to characterize chloride concentration on the surface of the canister, and electromagnetic acoustic transducers (EMATs) to detect cracks. One EMAT actuates ultrasonic guided waves that interact with any existing cracks within about 35 cm of the EMAT and the other EMAT receives the echo. Thus, the EMATs provide 100% coverage of the canister even only about 50% of the surface is accessible to sensor train. The PRINSE system was tested on mockups and a HI-STORM 100 system fabricated by Holtec International.

Title: Higher harmonic ultrasonic guided waves for structural integrity assessment of infrastructure
Sponsor: National Science Foundation
PIs: Cliff Lissenden
Students: Mostafa Hasanian

Technical Research Group Highlights

Summay: Ultrasonic waves interact in nonlinear materials, and their interaction can be used to detect material degradation at an early stage. Here, the interaction of two counter-propagating shear horizontal (SH) waves at frequencies f_a = 1.7 MHz and f_b = 0.3 MHz generate the S0 Lamb wave mode at the sum frequency $f_a + f_b$ = 2 MHz in an aluminum plate. At this frequency the S0 Lamb wave has a large out-of-plane displacement at the surface that can be measured by an angle beam transducer, an air-coupled transducer, or a laser interferometer. The wave interaction is quite sensitive to the material microstructure. The example shows that thermal aging increases the amplitude of the S0 Lamb wave generated by the two SH waves. The full details are given in: Hasanian and Lissenden, 2017, J. Appl. Phys. 122:084901.



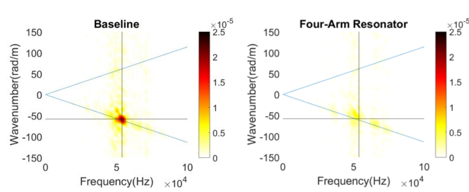
Title: Engineering a giant metamaterial: a band-stop seismic/blast filter to shield critical civil infrastructure

Sponsor: Penn State College of Engineering

PIs: Parisa Shokouhi and Cliff Lissenden

Students: Chris Hakada and Alexis Gawelko

Summary: Profs Shokouhi and Lissenden received a seed grant from the College of Engineering to study the use of a metamaterial to forbid earthquake ground motion that can be destructive to civil infrastructure. The approach is to add resonators at sub-wavelength spacing to the surface of the half-space. As a preliminary step, finite element simulations and experiments were conducted on an aluminum plate. Since others have shown that rod-like resonators prevent propagation of the A0 Lamb mode (having out-of-plane displacements at the surface), it seemed reasonable that beam-like resonators would block S0 Lamb mode wave propagation (having in-plane displacements). But this is not the case. To understand why, consider the boundary conditions. The Mindlin BCs are intended to decouple shear-vertical and longitudinal waves. The BCs #1 $T_{yz} = T_{xz} = u_z = 0$ permit only in-plane wave motion, while the BCs #2 $T_{zz} = u_x = u_y = 0$ permit only out-of-plane wave motion. The BCs #1 can be reasonably well satisfied by rod-like resonators and thus block low frequency A0 mode propagation, but the BCs #2 are not satisfied by beam-like resonators thus the beam-like resonators do not block low frequency S0 mode propagation. Four-arm resonators were found to replicate BCs #2 and successfully blocked low frequency S0 mode propagation.



Title: Nonlinear acoustic/ultrasonic monitoring of distributed damage in concrete

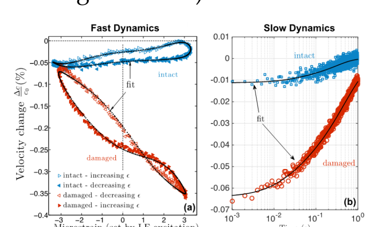
PI: Parisa Shokouhi

Student: Jiang Jin

In several independent projects, nonlinear acoustic/ultrasonic testing was used to monitor progressive microcracking in cementitious materials. Volumetric microcracking is one of the early signs of distress in cementitious materials. Excessive mechanical stress, chemical attacks (e.g., carbonation) and environmental effects (e.g., freeze-thaw cycles) initiate microscopic cracks. The microcracks will widen over time, coalesce and develop into larger cracks with the progress of damage. Visible macro-cracks indicate severe damage that often cannot be easily mitigated. Detection of damage at the early stages of development is essential for designing optimal preventive and rehabilitation programs for concrete structures. Nonlinear acoustics-based nondestructive testing techniques have shown great promise in diagnosis of micro-scale cracks.

In one study, we used impact-based nonlinear acoustic spectroscopy to monitor the progressive damage due to freezing and thawing cycles. The advantage of impact-based nonlinear acoustic techniques lies in their simplicity and field transportability. In one study, we compared the results from multi-impact nonlinear ring-down spectroscopy where several impacts of increasing intensities are applied, to those from single impact testing where only one impact of large intensity is applied. Alternative signal processing techniques are proposed for the analysis of single-impact experiments using full-curve reverberation signal fitting and Hilbert Huang Transform (HHT). The differences between multi-impact and single-impact testing results were reported and discussed taking into account conditioning and slow dynamics effects. While being simpler, our proposed single-impact testing and data analysis yield results compatible with those from multi-impact testing.

In another study, the nonlinear acoustic responses of stress-damaged concrete samples were compared. Dynamic Acousto-Elastic Testing (DAET) with a coda wave probe was used to infer the nonlinearity of each sample. While showing very similar wave velocities and elastic moduli, the two samples clearly differ in terms of their nonlinear acoustic response. The damaged sample shows a much larger velocity change due to a low-frequency strain perturbation (fast dynamics in the figure below) and much slower rate of recovery (slow dynamics in the figure below).



Technical Research Group Highlights

Title: Area Acoustic and Electromagnetic Emissions Monitoring

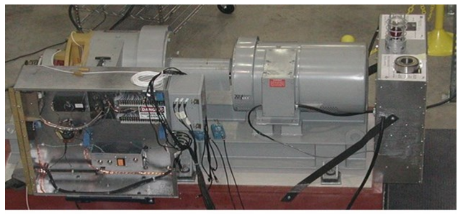
Sponsor: Electric Power Research Institute

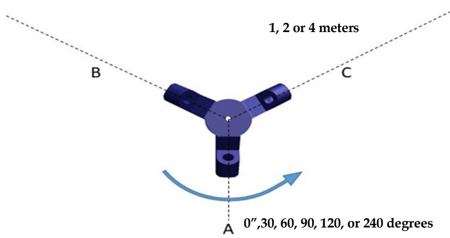
PI: Karl Reichard

Comprehensive monitoring of power plant equipment can be difficult, costly, and in some cases impractical when using sensors that are embedded or placed in direct contact with actual systems or equipment to be monitored, particularly in a large powerplant environment. This can require equipment modifications, and the purchase, installation, and maintenance of numerous sensors. Conventional techniques typically monitor basic performance parameters, such as current and voltage, to ensure that they stay within their nominal range. A potentially more cost-effective approach is to develop a non-invasive, area-wide monitoring system that, from a distance, can collect signals emitted from a variety of electrical and mechanical equipment and perform data analysis that can reveal potential anomalies or provide an early indication of developing malfunctions.

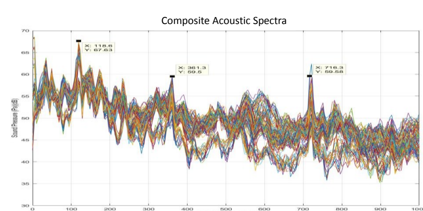
This project is focused on collecting a combination of radiated and conducted acoustic and electromagnetic (AEM) from motors and generators and developing algorithms capable of detecting faults and isolating the associated piece of equipment. These emissions can increase or show a significant pattern variation in the presence of a malfunction or degrading condition. Ambient sensors can detect these signals and collect the data for further processing and analysis.

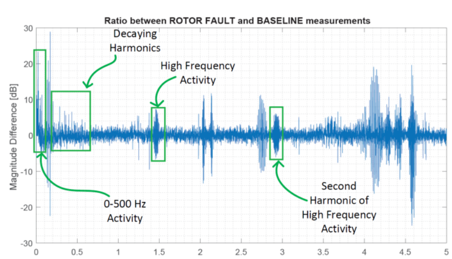
AEM data were collected for various health conditions on a Rockwell Automation/Kato Engineering synchronous motor/generator combination which was specially modified to allow inducing multiple different types of faults. Data were collected with 3 microphones (labeled A, B, and C below) in a equilateral triangular array as shown below. Data were collected for 6 different angles of rotation of the entire array – 0°, 30°, 60°, 90°, 120°, and 240° and three different distances from the motor/generator set – 1, 2, and 4 meters to test the ability to isolate the source of the acoustic fault signal.





The figure below shows composite spectra from all three microphones, in each rotation, at each measurement distance for a rotator winding fault. The measurements show that the spectra are consistent. The second figure shows the ratio of the measured electromagnet spectrum relative to the baseline, no-fault case. The plot shows areas of difference that are unique to the rotor winding fault. The next step is to show the ability to determine the relative direction of the faulty machine and combine the acoustic measurements with the measured electromagnetic spectra.



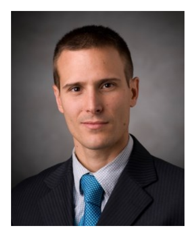


CAV Group Changes

We are evolving some of our CAV groups to reflect changing technologies, as well as exciting new expertise emerging at Penn State. Julianna Simon, Assistant Professor of Acoustics, has started a group devoted to advancing research in Biomedical Acoustics, and ultrasound in particular. After Bernie Tittmann's retirement, Amanda Hanford, Assistant Research Professor at ARL/Penn state, has taken over the Acoustic materials group, but with a new focus on the emerging topic of Metamaterials. We have therefore renamed that group 'Acoustic Materials and Metamaterials'. Finally, with George Lesieutre 'retiring' from the CAV (but not Penn State, see the CAV Leadership article above) we are pleased to welcome Dr. Jose Palacios, Assistant Professor of Aerospace Engineering, as the new leader of the Adaptive Structures and Noise Control Group.

Dr. Julianna Simon, Biomedical Acoustics, Group Leader

Dr. Amanda Hanford, Acoustic Materials and Metamaterials, Group Leader



Dr. Jose Palacios, Adaptive Structures and Noise Control, Group Leader

Classes and Books

ACOUSTICS CLASSES OFFERED

Fall 2017
ACS 501—Elements of Acoustic and Vibration
ACS 502—Elements of Waves in Fluids
ACS 597.001—Applications of Aeroacoustics and Vibrations
ACS 597.002— Outdoor Sound Propagation

Spring 2018
ACS 505—Experimental Techniques in Acoustics
ACS 514—Electroacoustic Transducers
ACS 515—Acoustics in Fluid Media
ACS 590—Colloquium
ACS 597.001—Advanced Signal Analysis for Acoustics and Vibrations
ACS 597.002—Spatial Sound and 3D Audio
ACS 597.003—Advanced Transducers and Acoustic Systems Modeling

CAV Faculty Books

We have compiled books written and edited by CAV faculty members below. The books are also listed on our CAV website under 'CAV bookshelf'.

Books

Atchley, A., Sparrow, V., Keolian, R., (Eds.), *Innovations in Nonlinear Acoustics: 17th Intl. Symposium on Nonlinear Acoustics*, AIP Conf. Proc. Vol. 838, American Institute of Physics Publishing, Melville, NY, 2006.

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Uchino, K., *Ferroelectric Devices & Piezoelectric Actuators*, DEStech Pub., Lancaster, PA, 2016.