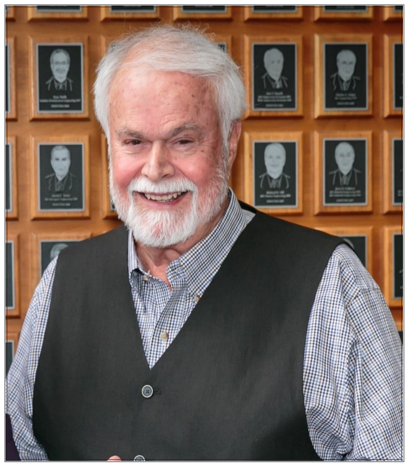
Penn State Center for Acoustics and Vibration

CAV Review '18 - '19

CAV Celebrates 30 Years

Founded by Professor Gary Koopmann, the Penn State Center for Acoustics and Vibration (CAV) has brought together Penn State faculty and students working in all areas of sound and vibration for 30 years. The CAV also shares research and technology with our many corporate and government sponsors, as well as with our several international liaisons. The annual CAV workshop continues to thrive with over 130 participants attending in recent years. The Penn State CAV looks forward to continuing to expand and serve our vibration and sound community for many years to come.

Penn State's Joe Rose retires



During his 45 years of teaching, with 27 of them at Penn State, Dr. Joseph Rose often used storytelling and his own life's lessons in class to help students transition from academia to the "real world." Now, Rose has added a new chapter to his story—retirement. An international leader in the fields of wave mechanics, ultrasound and ultrasonic guided waves, Rose served in the Department of Engineering Science and Mechanics (ESM) since 1992 as the Paul Morrow Professor of Engineering Design and Manufacturing in the College of Engineering.

Rose retires cont on p3.

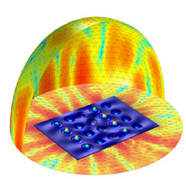
Spring Workshop 7-8 May 2019

The 2019 CAV Technology Transfer Workshop is a two day event held at Penn State attended by our corporate sponsors, international liaisons, US government liaisons, and Penn State CAV faculty and students. The workshop is a mix of technical presentations by faculty, students, corporate sponsors, and international and US government liaisons, along with lab tours and social activities. The workshop also gives our corporate sponsors an opportunity to provide feedback on CAV activities and performance, and to meet our graduate students.

Student Poster Competition

The annual student poster competition will be held at our Tuesday Evening (7 May) social in the Hinz Alumni Center between 6:30 and 8:30 pm. Our corporate sponsors, government guests, and international liaisons will judge the posters. Three $1,000 prizes will be awarded to support travel costs for students presenting their work at upcoming conferences. Last year's winners were Trevor Jerome, Sean Gauntt, and Nicholas Ortega.

Short Course on Acoustic Black Holes



This year's CAV short course will be held on 9 May on the hot topic of Acoustic Black Holes, arrays of damped structural indentations tuned to reduce vibration and sound radiation. Dr. Stephen Conlon, assisted by Dr. Micah Shepherd, have assembled a short course to be taught by an international panel of experts in this field. Please see our website for details.

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. Here's a list of seminars for Fall 2018 – Spring 2019:

Fall 2018			
Dr. Jackie O'Connor	The Pennsylvania State University	10 December 2018	Swirling Flow Instabilities and their Applications to Gas Turbine Engines
Dr. Joe Rose	The Pennsylvania State University	5 December 2018	Avoiding Infrastructure Catastrophic Failure with Ultrasonic Guided Wave Inspection
Dr. Yousof Azizi	Bridgestone	7 November 2018	Automotive Systems Noise and Vibration and Application of Lightweight Sandwich Structures
Dr. Tim Hall	University of Michigan	12 October 2018	Instrumentation for Histotripsy Ultrasound Therapy
Dr. Eric Greenwood	NASA Langley Research Center	9 October 2018	Rotorcraft Aeroacoustic Modeling using Parameter Identification Methods
Dr. John Tague	Office of Naval Research	25 September 2018	The US Navy's Submarine Force: Platforms, Missions, Technology

Spring 2019			
Dr. Stephen Hambric	The Pennsylvania State University	9 January 2019	To Infinity and Beyond: The Amazing Uses of Infinite Structure Mobility Theory
Dr. Stanislav Emelianov	Georgia Tech	20 March 2019	The Smaller the Better - Isn't that Obvious? (Research in Ultrasound)
Dr. Jason Anderson	Naval Surface Warfare Center, Carderock Division	8 April 2019	Airfoil Shape Effects on Force and Sound Response to Incident Turbulent Flows
Dr. Jayant Sirohi	University of Texas at Austin	12 April 2019	Wind Energy Harvesting from Galloping
Kallan Berglund and Cameron McKormick	The Pennsylvania State University	24 April 2019	The River Model of Black Holes and Connections to Acoustic Black Holes

CAV Information

Dr. Stephen A. Hambric

Director
ARL/Penn State
PO Box 30
State College PA 16804
Tel: 814-863-3030
Cell: 814-404-0653
Email: sah19@arl.psu.edu

Dr. Clifford Lissenden

Associate Director
Penn State University
411D EES Building
University Park PA 16802
Tel: 814- 863-5754
email: cjl9@psu.edu

Diane Bierly

Coordinator
302 Earth and Engineering Sciences Building
Tel: 814-863-6491
Email: dkb11@psu.edu

Kelly Driftmier

Workshop and Corporate Sponsor Liaison
225 Penn State Conference Center
Tel: 814-865-9202
Email: kmd5315@psu.edu

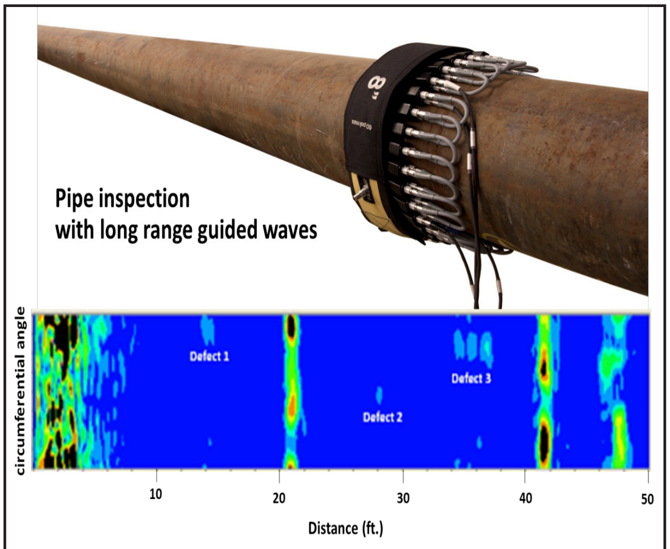
Please Mark Your Calendars

CAV Workshop 2020
Tuesday-Wednesday,
27-28 October 2020
Penn State Hetzel Union Building (HUB)

Rose retires

In his time with the department, Rose was the principal adviser to 40 Ph.D. students and more than 60 master's students. He has been honored by the University for his teaching and research with a 2011 Graduate Faculty Teaching Award, a 2002 Penn State Engineering Alumni Society (PSEAS) Premier Research Award, a 1997 PSEAS Outstanding Research Award and a 1996 Penn State Faculty Scholar Medal for Outstanding Achievement.
Rose has also received numerous industry awards for his innovative work in ultrasonic guided waves for nondestructive evaluation (NDE) and structural health monitoring, including the 2014 Roy Sharpe Prize from The British Institute for Non-destructive Testing (BINT), the 2014 Mentoring Award from the American Society for Nondestructive Testing (ASNT), the 2011 International Society for Optics and Photonics Smart Structures/ NDE Lifetime Achievement Award, the 2006 ASNT Research Council Award for Innovation and the 2003 American Society of Mechanical Engineers (ASME) Nondestructive Evaluation Engineering Division Founders Award. Dr Rose was also honored at the 16th National Congress on Theoretical and Applied mechanics with special sessions and a dinner in 2010.

He earned a Ph.D. in applied mechanics from Drexel University in 1970 and a master's degree in applied mechanics from Drexel Institute of Technology (DIT), now named Drexel University, in 1967. Rose is a fellow of ASNT, ASME, BINT and the Institute of Electrical and Electronics Engineers. He holds 30 patents, has authored five text books and published more than 600 articles on such topics as ultrasonic NDE, wave mechanics, medical ultrasound, adhesive bonding, pipe and tubing inspection, bridge and rail inspection, composite material inspection, ice detection, structural health monitoring, signal processing and pattern recognition. His publication work has received more than 18,000 citations.
At Penn State, Rose taught a class titled Business Opportunities in Engineering, where he alerted students to the many entrepreneurship and intrapreneurship paths to success. One of his most famous quotations for both engineering and business students that he'll be remembered for is "Failure is on the path to success. If you've never failed, it means that you are not doing anything."
Rose will certainly not be sitting still in his retirement. He intends to continue guided wave research and product development as it relates to structural health monitoring, and he also plans to interact with ESM's Prof. Cliff Lissenden and the department's four new ultrasonics faculty members (see accompanying story).



Sample flattened pipe image showing defects and other features.

Penn State's new faculty in ultrasonic wave research

The Department of Engineering Science and Mechanics (ESM) is proud to welcome Andrea Arguelles, Christopher Kube, Jacques Rivière and Parisa Shokouhi as its newest faculty members for the 2018-2019 academic year. All four faculty members conduct research in the Penn State Ultrasonics Lab, which focuses on ultrasonic research with diverse applications in industrial, geophysical and medical fields.

Arguelles also holds an affiliate faculty position with the Penn State Graduate Program in Acoustics. She comes to Penn State from Brimrose Technology Corporation, where she was a lead scientist for nondestructive testing (NDT), developing improved NDT techniques and instrumentation, and cultivating new research programs in NDT. Prior to Brimrose, Arguelles was a research and development engineer at X-Wave Innovations, Inc. She earned a doctorate in mechanical engineering and applied mechanics from the University of Nebraska-Lincoln (UNL) in 2016. Arguelles's research focuses on wave propagation in heterogeneous media with applications in materials and microstructural characterization, nondestructive evaluation (NDE) and biomedical ultrasound.

Kube was most recently a research engineer with Bennett Aerospace, Inc. under contract from the U.S. Army Research Laboratory's (ARL) Weapons and Materials Research Directorate (WMRD). At WMRD, his research focused on ultrasonic NDE and qualification of additively manufactured materials. Prior to WMRD, he was with ARL's Vehicle Technology Directorate, where he served as NDE lead with a focus on developing ultrasonic technology for predicting overall health and remaining useful life of rotorcraft components. Kube, who also holds an affiliate faculty position with the Penn State Graduate Program in Acoustics, received his doctoral degree in mechanical engineering and applied mechanics in 2014 and his master's degree in engineering mechanics in 2011, both from UNL. Kube's research revolves around the study of elastodynamic behavior of heterogeneous media with applications in structural health monitoring, NDE and materials characterization.

Rivière was previously a Marie Skłodowska-Curie Postdoctoral Fellow at Grenoble Alpes University in Grenoble, France. He also holds a courtesy faculty position as an assistant professor in the Penn State Department of Geosciences. He earned a doctorate in 2011 from the University Pierre and Marie Curie in Paris, in 2011. Rivière was a postdoctoral scholar, working on projects funded by the U.S. Department of Energy, the National Science Foundation and Chevron, at the Los Alamos National Laboratory (2012-2015) and the Penn State Department of Geosciences (2015-2016). His main research interests include the use and development of novel ultrasonic tools for material characterization and monitoring of rocks in the context of earthquake physics and geophysical applications, concrete and metals for civil and industrial applications and bone and bone/prosthesis interfaces in the biomedical domain.

Shokouhi joins the department as an associate professor and also holds an affiliate faculty position with the Penn State Graduate Program in Acoustics. Most recently, she was an associate professor in the Penn State Department of Civil Engineering. Shokouhi received her doctoral degree and master's degree in civil engineering from Rutgers University in 2006 and 2003, respectively. Prior to joining Penn State, she was a research group leader at BAM (Federal Institute for Materials Research and Testing) in Berlin, Germany, and a visiting research faculty at Los Alamos National Laboratory. Her research interests involve stress wave propagation in fractured media, nondestructive evaluation (linear and nonlinear ultrasonic testing), structural health monitoring (acoustic emission), machine learning and data analytics and seismic metamaterials.

CAV Helps Corporate Sponsor Solve In-Plant Noise Problem

The Babcock & Wilcox Company, a CAV corporate sponsor, approached the CAV with an interesting noise control problem. A high-amplitude, low-frequency pulsation was emitted by a package boiler under certain operating conditions. Occupants of the facility could feel and hear the pulsation, but the source of the phenomenon was not obvious. Through a CAV consulting visit to the site and small follow-on project, Penn State researchers, led by Tyler Dare, were able to identify the source of the pulsation and recommend mitigation strategies.

In an initial CAV consulting visit, measurements were made at the package boiler facility to quantify noise levels and identify likely noise sources for future testing. The pulsation was found to have a fundamental frequency of 9 Hz with an amplitude of over 120 dB (Z-weighed). Low-order harmonics at 18 and 27 Hz were louder than 100 dB. These high sound pressure levels were an indication that a significant source of acoustic energy is present in the system. Unfortunately, typical sources of boiler noise, including the boiler walls, blower, and duct, were all vibrating with the pulsation, so it was not possible to identify the source using a sound level meter alone.

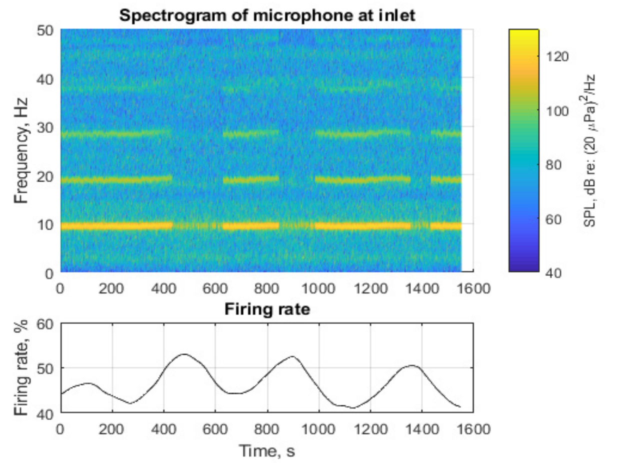


Fig. 1—Spectrogram of acoustic pressure when varying firing rate. Harmonics of the 9 Hz fundamental cut on and off suddenly as the firing rate is increased and decreased.

A small follow-on investigation was conducted to identify the source of the noise and any potential treatments. The noise level at the fresh air intake was recorded as the firing rate was varied over several minutes. As shown in Figure 1, it was found that the fundamental frequency of 9 Hz was always present, even at high firing rates where the pulsation was not perceived by the occupants. At lower firing rates, harmonics cut on abruptly. These results, along with the high levels, were taken as strong indications of a nonlinear acoustic phenomenon. An accelerometer was placed at a series of locations around the boiler. By measuring the transfer function between this roving accelerometer and stationary accelerometers, the operational mode shape of the 9 Hz resonance was identified. As shown in Figure 2, the walls of the furnace vibrating in a breathing-like motion, with exterior surfaces expanding and contracting in-phase. This was taken as an indication that an acoustic resonance was forming inside the furnace, which was propagating throughout the duct system and into the room.

The noise source was identified as a thermoacoustic resonance formed by the furnace-duct system coupling with the flame, where the acoustic pressure wave changes the amount of combustion gas consumed by the flame, which responds with a time-varying heat output, which can in turn reinforce the acoustic pressure wave. One way to eliminate the phenomenon is to de-tune the system by changing the acoustic boundary conditions. After considering several mitigation strategies, a stack damper was added to the outlet flue of the boiler, and the occupants reported that the pulsation was sufficiently reduced. For more details on the study, see the paper published in the Internoise 2018 proceedings: Dare, T., Beck, B., Bonness, W., Rufener, S., and Flynn, T., "Low-Frequency Pulsation from a Package Boiler."

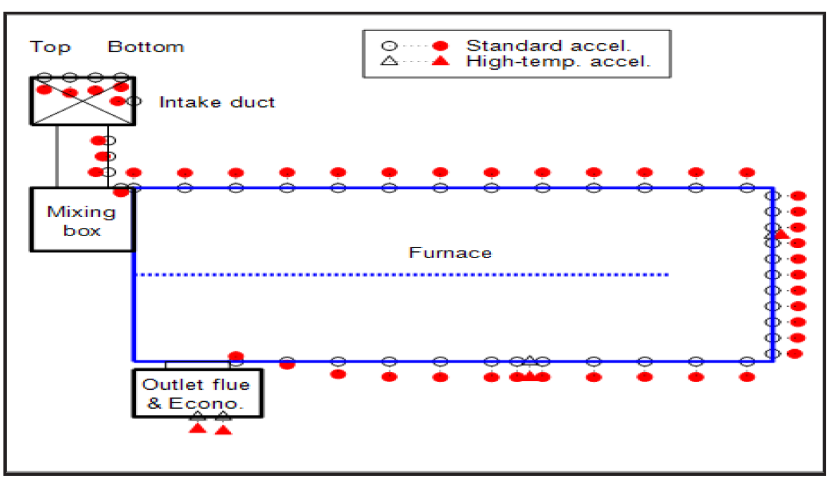


Fig. 2—Operational mode shape of boiler system at 9 Hz. The walls of the furnace all move in-phase as a breathing mode.

Corporate Sponsors
• 3M
• Avery Dennison
• Babcock and Wilcox
• Naval Nuclear Labs (Bettis and Knolls Atomic Power Labs)
• Boeing
• Bridgestone Americas
• Carrier
• Corning
• Ebco
• Fisher Valves and Instruments (Emerson)
• General Dynamics/Electric Boat
• Gulfstream
• Harman
• ITT
• Johnson Controls
• Martin Guitar
• Pratt and Whitney
• Praxair

International Liaisons
• Centro Italiano Ricerche Aerospaziali (CIRA), Italy
• Consortium for Sound and Vibration Research at Hong Kong Polytechnic University, Hong Kong
• Deutsches Zentrum fur Luft und Raumfahrt (DLR), Germany
• Groupe d'Acoustique de L'Universite de Sherbrooke, Canada
• Institute of Sound and Vibration Research (ISVR), United Kingdom
• Noise and Vibration Research Group at Katholieke Universiteit in Leuven(KU-Leuven), Belgium
• Sound and Vibration Lab at the Korean Advanced Institute for Science and Technology (KAIST), South Korea
• Vibration and Acoustics Laboratory at INSA de Lyon, France

Government Liaisons
• Federal Aviation Administration (FAA)
• NASA Langley Research Center (NASA LaRC)
• National Institute of Occupational Safety and Health (NIOSH)
• National Institute of Standards and Technology (NIST)
• Naval Research Lab (NRL)
• Naval Surface Warfare Center, Carderock Division (NSWCCD)
• Sandia National Labs

Vendor Liaisons
• Romax software
• PCB Piezotronics
• wave6 (Dassault)

CAV Members Receive Honors and Awards

Prof. Kenji Uchino has been awarded as the 2018 -2019 prestigious IEEE Ultrasonic, Ferroelectrics and Frequency Control Society Distinguished Lecturer, in which role he gave 80 lectures in the world 30 institutes and conferences. He has also been working as a Mirai-Sendo (Future Leading) Daiwa Securities Chair Professor at Keio University, Japan for providing the summer intensive lecture course on "Global Crisis Technologies".

Chris Rahn, associate dean for innovation and the J. 'Lee' Everett Professor of mechanical engineering, has been awarded the ASME 2018 N.O. Myklestad Award. Rahn and a team of Penn State researchers created a novel technique, called fluidic flexible matrix composites (F2MC), to dampen the vibrations of a helicopter tail boom.

Prof. Reggie Hamilton has been awarded the 2019 Defense Advanced Research Projects Agency (DARPA) Young Faculty Award (YFA). Hamilton's interests are in developing advanced fabrication for tuning shape memory alloy behavior through investigating the underlying physical mechanisms that tune the martensitic transformation and the competing micro-structural and geometrical length scales that control those mechanisms.

Jacqueline O'Connor, assistant professor of mechanical engineering, has been selected by ASME's International Gas Turbine Institute (IGTI) as the 2018 Dilip R. Ballal Early Career Engineer Award winner.

Professor Scott Medina received an NSF CAREER grant.

Molly Smallcomb (PhD candidate in Acoustics) and **Mike Trowbridge** (PhD candidate in Mechanical Engineering) received NSF Graduate Research Fellowships.

Cameron McCormick (PhD candidate) won the Hallberg Foundation award to attend Internoise 2018.

Kostas Papakonstantinou received the National Science Foundation CAREER award, 2018.

CAV Welcomes New Corporate Sponsors:

Regal Beloit Corporation is a leading manufacturer of electric motors, electrical motion controls, power generation and power transmission products serving markets throughout the world. The company is comprised of three business segments: Commercial and Industrial Systems, Climate Solutions and Power Transmission Solutions. Regal is headquartered in Beloit, Wisconsin, and has manufacturing, sales and service facilities throughout the United States, Canada, Latin America, Europe and Asia. Our product brands meet customer requirements in demanding applications used around the globe in heating, ventilation, air conditioning, commercial refrigeration, food processing, pharmaceutical, chemical processing, material handling, medical, oil and gas, construction, manufacturing, power generation, agriculture and mining.

Stanley Black and Decker (SBD) manufactures products to serve the builders, makers, and protectors of the world, including power tools, electronic door security systems, and engineering fastening systems. SBD's brands include:

- Facom
- Lenox
- Lista
- Mac Tools
- Vidmar
- Bostitch
- Proto
- AeroScout
- Stanley
- DeWalt
- Black and Decker
- Craftsman
- Irwin
- Porter Cable

Through technology and innovation, Chevron is executing major capital projects designed to yield decades of energy. Once on line, our newest generation of producers will help fuel the world's growth for years to come. Chevron Energy Technology Company develops and manages technology to help find and produce new oil and gas reserves, enhance recovery in existing fields, and optimize productivity of downstream assets. Chevron Technology Ventures identifies, develops and commercializes emerging technologies that have the potential to transform energy production and use.

ATA Engineering provides test- and analysis-driven design for aerospace, defense, themed entertainment, robotics and controls, consumer products, and industrial and mining equipment. We use advanced computer-aided engineering software to solve problems for our customers and to design, analyze, and test complex, highly engineered structures subject to severe dynamic loads. ATA is the leading independent company in modal and dynamic testing of aerospace structures in the U.S. We have supported testing of military and commercial products in more than six countries across the globe. As an engineering services company, our capabilities include advanced multidisciplinary analysis, design engineering, industrial design, prototype manufacturing, and hardware and software development.

The Otis Elevator Company develops, manufactures and markets elevators, escalators, moving walkways, and related equipment. Based in Farmington, Connecticut, Otis is the world's largest manufacturer of vertical transportation systems, principally focusing on elevators, moving walkways, and escalators. The company pioneered the development of the "safety elevator", invented by Otis in 1852, which used a special mechanism to lock the elevator car in place should the hoisting ropes fail. Otis has installed elevators in some of the world's most famous structures, including the Eiffel Tower, Empire State Building, the original World Trade Center, The Twilight Zone Tower of Terror, Petronas Twin Towers, Burj Khalifa, CN Tower, the Winchester Mystery House, the Hotel del Coronado, the Demarest Building (first electric elevator), the Singing Tower at Bok Tower Gardens, and the Skylon Tower.

Pittsburgh Glass Works, LLC (www.pgwglass.com), a Vitro Glass Company (www.vitro.com), is a leader in the design, production and distribution of automotive glass to high-volume Auto-OEM applications and glass replacement markets worldwide. Employing more than 4,500 people globally, PGW's business comprises engineering development and application of sophisticated automotive glass technologies coupled with glass manufacturing and assembly operations in North America, Europe and Asia.

Bechtel Plant Machinery, Inc.

Quality, Integrity, Excellence

Since 1956, at the direct request of the Navy's Admiral Hyman G. Rickover, our employees have successfully supported our nation's fleet and Sailors in various aspects of the design, development, and continuing support of Naval Nuclear Propulsion equipment—a vital part of our nation's defense. We work with our many partners to deliver and maintain safe, reliable, and cost-effective products that ensure the long-term viability of the Naval Nuclear Propulsion Program (NNPP).

The NNPP comprises the military and civilian personnel who design, build, operate, maintain, and manage the nuclear-powered ships and the many facilities that support the U.S. nuclear-powered naval fleet. The Program has cradle-to-grave responsibility for all naval nuclear propulsion matters, and elements include:

- Research, development, and support laboratories.
- Contractors responsible for designing, procuring, and building propulsion plant equipment.
- Shipyards that build, overhaul, and service the propulsion plants of nuclear-powered vessels.
- Navy support facilities and tenders.
- Nuclear power schools and Naval Reactors training facilities.
- Naval Nuclear Propulsion Program Headquarters and field offices.

CAV 2018 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

Baek, Seung, Acoustics, *Effects of oscillations in the main flow on film cooling at various frequencies and blowing ratios*

Choi, Minkyu, Materials Science and Engineering, *Polarization Orientation Dependence of Piezoelectric Loss and Proposed Crystallographic Characterization Methodology*

Haidar, Ahmad, Aerospace Engineering, *Vibration Control of Shafts via Automatic Passive Balancing*

Hasanian, Mostafa, Enginering Science and Mechanics, *Mutual nonlinear interaction of ultrasonic guided waves in plate with applications for NDE*

Hudson, Robert, Mechanical Engineering, *Vibration of Carbon Nanotubes with Defects and Their Composites : Reduced-Order Model and Damping*

Karun, Ronald, Acoustics, *Design and Testing of a Single Crystal Low Frequency Dual-resonant Shear-Mode Transducer for Sonar Applications*

Krott, Matthew, Mechanical Engineering, *Fluidic Flexible Matrix Composite Vibration Treatments for Helicopter Airframes and Rotor Blades*

Lawless, Martin, Acoustics, *Assessing the auditory and reward responses to room acoustics and music using functional magnetic resonance imaging*

Stout, Trevor, Acoustics, *Simulation of N-wave and shaped supersonic signature turbulent variations*

Wu, Mengxi, Engineering Science and Mechanics, *Acoustofluidic separation technology for advancing health care*

Yang, Tianxiao, Aerospace Engineering, *Study of active rotor control for in-plane rotor noise reduction*

Yildiz, Kaan, Aerospace Engineering, *Cable Actuated Tensegrity Structures for Deployable Space Booms with Enhanced Stiffness*

MS

Cunsolo, John, Acoustics, *Noise transmission from a small hermeteic reciprocating refrigerant compressor*

Doyle, Andrew, Acoustics, *Measurement and analysis of impedance in loudspeakers due to eddy currents*

Gawelko, Alexis, Civil and Environmental Engineering, *Can Meta-Soil Attenuate Seismic Waves?*

Joon, Shams, Energy and Mineral Engineering, *Velocity Model Calibration Using Distributed Acoustic Sensors and Sparse Geophones*

Landge, Ameya, Aerospace Engineering, *Liquid water and flow turbulence characterization of the penn state icing wind tunnel*

Merck, Andrew, Acoustics, *The Development of a Fast Method for the Calculation of Noise from Supersonic Jets*

Miller. Lane, Acoustics, *An Analysis of Acoustic Beam-forming with Sparse Transducer Arrays for Active Control*

Moriarty, Peter, Acoustics, *The Acoustics of Emotion : Creation and Characterization of an Emotional Speech Database*

Neblett, Carter, Acoustics, *Nondestructive Evaluation of Bolt Torque Levels Using Nonlinear Wave Modulation Spectroscopy*

Prakash, Keerti, Aerospace Engineering, *Modeling for polymer/ carbon nanotube nanocomposite to estimate structural damping in a rotocraft blade*

Trivedi, Yaman, Enginering Science and Mechanics, *Field Deployable Guided Wave Transducers for High-Temperature Applications*

Technical Research Group Highlights

Graduate Program in Acoustics News

Sparrow named President of the Acoustical Society of America

Victor W. Sparrow, director of the graduate program in acoustics and United Technologies Corporation Professor of Acoustics, will soon begin a one-year term as president of the Acoustical Society of America (ASA). In spring 2018, he was elected by the ASA members to serve as president-elect.

Sparrow will begin his service as president at the conclusion of the 177th Meeting of ASA in Louisville, Kentucky, on May 17. Sparrow is the seventh person to serve as ASA president while being a faculty member at Penn State; the previous six were David L. Bradley (2011-2012), Anthony Atchley (2005-2006), Richard Stern (2001-2002), Jiri Tichy (1993-1994), John C. Snowdon (1976-1977), and John C. Johnson (1970-1971). Current ASA President Lily Wang (2017-2018), ending her term in May, is a Penn State Graduate Program in Acoustics alumna.

ASA website: acousticalsociety.org

Student Awards

Each year, the program recognizes graduate students for publishing papers at conferences and in journals. Here are this year's award winners.

Simowitz Award and Citation

The Simowitz Award and Citation programs were established as memorials by the family of Kenneth T. Simowitz, a student in the Acoustics Program. Awards recognize superior work in a written article published in a refereed journal or other scholarly work such as a film, patent, editorial or creative work. Citations recognize a special "honorable mention" or similar category for students whose work appears in written proceedings of major conferences, who participate in special exhibits or poster sessions, or who present "invited" papers at technical meetings.

Awards:

Trevor Stout; Anand Swaminathan

Citations:

Thomas Blanford; John Cunsolo; Fernando del Solar Dorrego; Zhendong Huang; Connor McClusky; Cameron McCormick; Peter Moriaty; Matthew Neal; Nicholas Ortega; Harshal Patankar; Andrew Pyzdek; Stephen Wells; Janet Xu

New Acoustics Program Coordinator

Melissa Wandrisco is the new resident student coordinator of the Graduate Program in Acoustics. She can be reached at 814-865-6364 and myw5290@psu.edu

Upcoming Distance Education Classes (SEE PDF WITH COURSE SCHEDULE)

Please contact Kris Popovich to enroll or learn more about our courses.
Kris is at 814-863-6078 and cxp23@psu.edu

Penn State Graduate Program in Acoustics
Fall 2019 Distance Education Courses
August 26 – December 20

ACS 501, Elements of Acoustics and Vibration
Instructor: Dr. Dan Russell
Credits: 3
Prerequisite: Undergraduate physics, differential equations, and complex numbers

---

ACS 502, Elements of Waves in Fluids
Instructor: Dr. Julianna Simon
Credits: 3
Prerequisite: Undergraduate physics and differential equations

---

ACS 597, Signal Analysis for Acoustics and Vibration
Instructor: Dr. Tom Gabrielson
Credits: 3
Prerequisite: Undergraduate physics, differential equations, and complex numbers as well as some familiarity with programming in MatLab or equivalent.

ACS 519, Sound Structure Interaction
Instructor: Dr. Steve Hambric
Credits: 3
Prerequisite: ACS 501 or ACS 597, Elements of Acoustics and Vibration, and ACS 502 or ACS 597, Elements of Waves in Fluids

---

ACS 597, Nonlinear Acoustics
Instructors: Dr. Vic Sparrow
Credits: 3
Prerequisite: ACS 502, Elements of Waves in Fluids or instructor approval

Spring 2020 Distance Education Course Schedule
January 13 – May 8

ACS 514, Electroacoustic Transducers
Instructor: Dr. Tom Gabrielson
Credits: 3
Prerequisite: Undergraduate physics, basic linear circuit theory, differential equations, and complex numbers. Must have working knowledge of required software.

ACS 515, Acoustics in Fluid Waves
Instructor: Dr. Dan Russell
Credits: 3
Prerequisite: ACS 502, Elements of Waves in Fluids or ACS 597B, Introduction to Acoustics and Fluid Media, ACS 598E, Engineering Mathematics I or equivalent, or instructor consent.

ACS 597, Advanced Signal Analysis for Acoustics and Vibration
Instructor: Dr. Karl Reichard
Credits: 3
Prerequisite: ACS 597, Signal Analysis for Acoustics and Vibrations

---

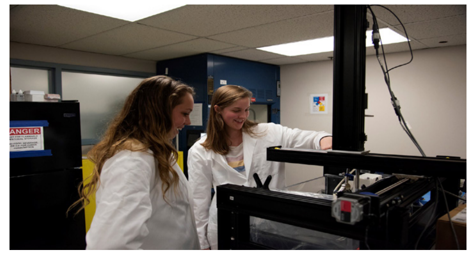
ACS 598, Engineering Mathematics I
Instructor: Dr. Amanda Handford
Credits: 3
Prerequisite: Undergraduate physics, differential equations and complex numbers

---

Biomedical Acoustics

Julianna Simon, Group Leader - jcsimon@psu.edu

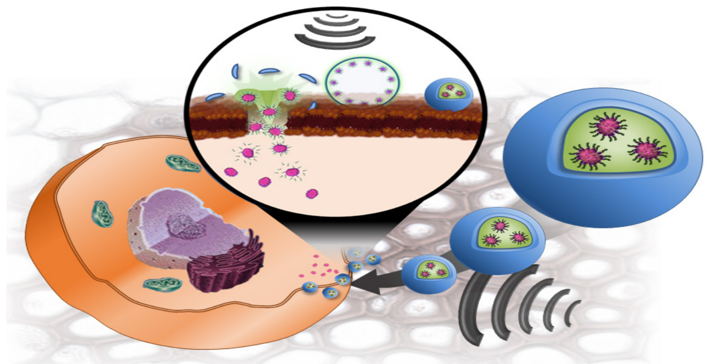
The mission of the Biomedical Acoustics group is to understand and apply acoustics towards improving human health. The group joined CAV in Fall of 2017. Currently, the group consists of 10 faculty members and approximately 20 students. Research interests include advanced image processing, ultrasound imaging and therapeutics, photoacoustic imaging, shear wave elastography, drug delivery, and more! Some highlights for 2018--2019 include Scott Medina receiving an NSF CAREER grant and Molly Smallcomb receiving an NSF Graduate Research Fellowship.



Acoustics graduate student Molly Smallcomb training Biomedical Engineering undergraduate Marisa Deichert on how to use equipment in the Biomedical Acoustics Simon Lab (BASiL).

Below are some highlights of our group's recent work.

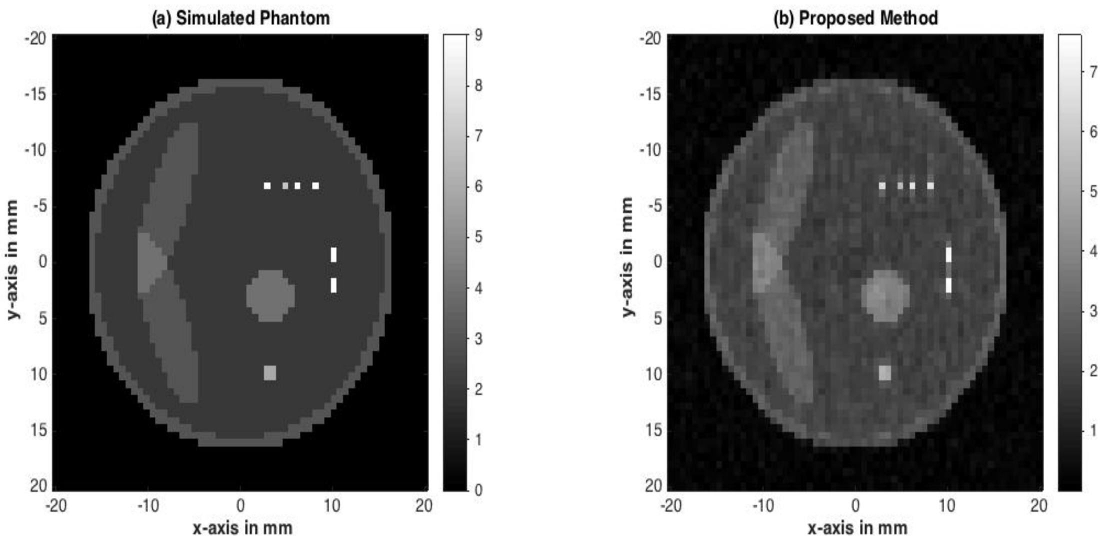
Title: Ultrasound-enabled strategies for synchronous imaging and therapy of venous blood clots
Sponsor: Penn State College of Engineering Multidisciplinary Seed Grant Program
PI: S. Medina, **Co-PIs:** J. Simon, K. Manning
Students: Erik Rokni (PhD student, Acoustics), TBD Biomedical Engineering
Summary: Deep vein thrombosis (DVT) is a blood clotting condition that, if not rapidly treated causes deadly pulmonary embolisms, heart attacks and stroke. Here we plan to use high-resolution ultrasound imaging along with phase-change contrast agents to detect and treat DVT.



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

Title: CAREER: Rational Design of Phase-Changing Nanomaterials for Spatiotemporal Protein Delivery
Sponsor: NSF
PI: S. Medina
Students: Janna Sloand (PhD student, BME), Scott Zinck (MS students, Acoustics)
Summary: This project seeks to understand the physicochemical criteria that governs the acoustic activation of phase-changing nanoparticles, and explore their utility for ultrasound controlled delivery of biomacromolecules (e.g. proteins, peptides) in tissues with spatial and temporal precision.

Title: Solving the ultrasound inverse scattering problem of inhomogeneous media for breast cancer detection
PI: M. Almekkawy
Student: Xingzhao Yun (MS student, Electrical Engineering and Computer Science)
Summary: Although tumors are not always lethal, cancer cells from tumors can invade important organs such as liver, brain or lungs thereby destroying the normal function of these organs. Ultrasound tomography (UT) is motivated by the need to locate and identify malignant human breast tissue for the purpose of detecting breast cancer. The proposed project develops computational models for high quality reconstruction in UT. In the figures below, (a) shows the distribution of the speed of sound in a simulated phantom as a percentage increase over the background medium and (b) is the reconstruction of the phantom after 10 iterations with the distorted Born iterative algorithm using our proposed method with 2 MHz frequency and 25 dB signal to noise ratio.



Flow-Induced Noise

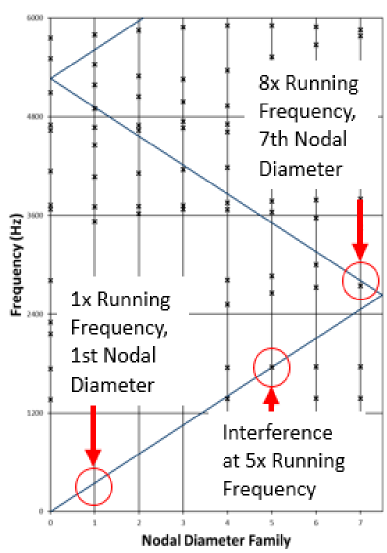
Michael Jonson, Group Leader - mxj6@psu.edu

The focus of the Flow-Induced Noise Technical Group is the basic understanding and control of acoustic noise and structural vibration generated by fluid flow. The engineering challenges cover a very wide range of fluid/acoustic phenomena involving atmospheric acoustic media and the noise created by compressible fluid flow, as well as liquid acoustic media and the associated noise and vibration generated by essentially incompressible flows. Progress in developing models and supporting experimental databases permits the description of possible noise control methods that can be evaluated analytically or numerically, and then with confidence, prototypes may be evaluated in the laboratory.

Below are some highlights of our group's recent work.

Title: Evaluating splitter blade designs to avoid impeller failure in a high speed unshrouded centrifugal compressor
PIs: Reid Berdanier, Robert Kunz, and Michael Jonson
Student: Alex Curtin of FS-Elliott

Summary: This study investigates splitter blade failures experienced during testing of an unshrouded transonic centrifugal compressor. Specifically, when the impeller was deeply throttled using an upstream inlet guide vane to introduce significant pre-swirl, the splitter blades exhibited cracking near the root of the leading edge. The observed failures are of particular interest because the impeller does not exhibit a mode shape typical of this type of failure corresponding to either the upstream IGV or downstream diffuser vane count, nor the anticipated surge frequencies. Accordingly, modal analysis and CFD modeling were performed leading to an understanding of the failure mechanism, and a successful splitter blade cut-back solution was implemented. Specifically, excitation sources developed from a CFD model of the IGV and impeller were used in a blade flutter calculation, in order to determine the aerodynamic damping and unsteady loading on the blade. The CFD model indicates that shockwaves arise near the splitter leading edge for this off-design condition. Due to interactions with the high incidence/separated boundary layer, these shockwaves exhibit streamwise unsteadiness, thereby leading to the observed failure mechanisms. It was determined that by cutting back the splitter blade at the leading edge, the failure could be avoided while minimally affecting the overall stage performance.



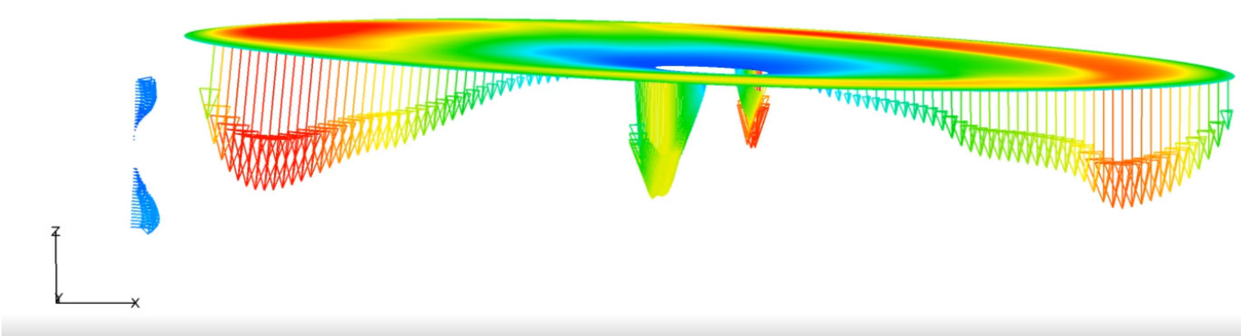
Singh's Advanced Frequency Evaluation (SAFE) Diagram

Title: Aeroelastic behavior and flutter mitigation of multi-element wings.
Sponsor: NASA through University Leadership Initiative Program
PIs: Robert Campbell and Michael Jonson
Student: Auriane Bottai (Ph. D. Candidate)

Summary: The objective of the project is to assess the static and dynamic aeroelastic stability of a very high aspect ratio wing. In both cruise and maneuvering flight, such a flexible structure is subject to larger deformation than conventional wings, and therefore linear model may fail to predict the deflection and torsion of the high-aspect ratio wing. Flutter is a dynamic instability that arises when aerodynamics and structural deformation sustain each other. The wing undergoes complex coupled oscillations in torsion, in-plane and out-of-plane bending, which may lead to structural fatigue and failure. Studies have shown that flutter is driven by nonlinear aerodynamics and nonlinear elastic behavior. The current research focuses on a high-aspect ratio truss-braced, Slotted-Natural-Laminar Flow (TB-SNLF) wing, and is split into analytic and numerical studies. The analytic work investigates the modal characteristics of slender wing, with and without truss, under linear and stalled aerodynamics. Finite Element Method will next be employed to include the geometric and structural features of the wing, as well as airfoil characteristics, in the flutter stability analysis.

Title: An approach to develop noise abatement procedures using a comprehensive noise prediction system and flight test data
PI: Professor Kenneth Brentner
Student: Mrunali Botre (Ph.D. candidate)
Sponsor: FAA

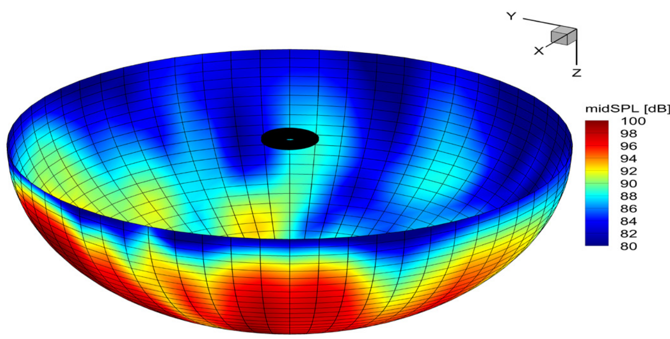
Summary: A comprehensive noise prediction is required to analyze and develop noise abatement procedure for rotorcrafts. Most of the prediction tools used for designing noise abatement procedure are based on some experimental data or empirical relations and lacks the sophistication required for detailed analysis of different noise source. The project will focus on developing the system required for predicting noise from a maneuvering flight that incorporates the time-dependent information of flight procedure like; trajectory, attitude, blade loads and rotor thrust for predicting noise generated by a complex maneuver. The system capability is demonstrated by comparing the predicted sound exposure levels (SEL) with that measured from the flight test. An advantage of such a comprehensive noise prediction system is the capability to analyze different noise sources and thus gaining an essential insight in developing noise abatement procedures.



Aerodynamic forces on main rotor blades

Title: Aeroacoustic analysis of high-speed coaxial rotor systems capable of lift offset
Sponsor: Army
PI: Kenneth Brentner
Student: Kalki Sharma (Ph.D. candidate)

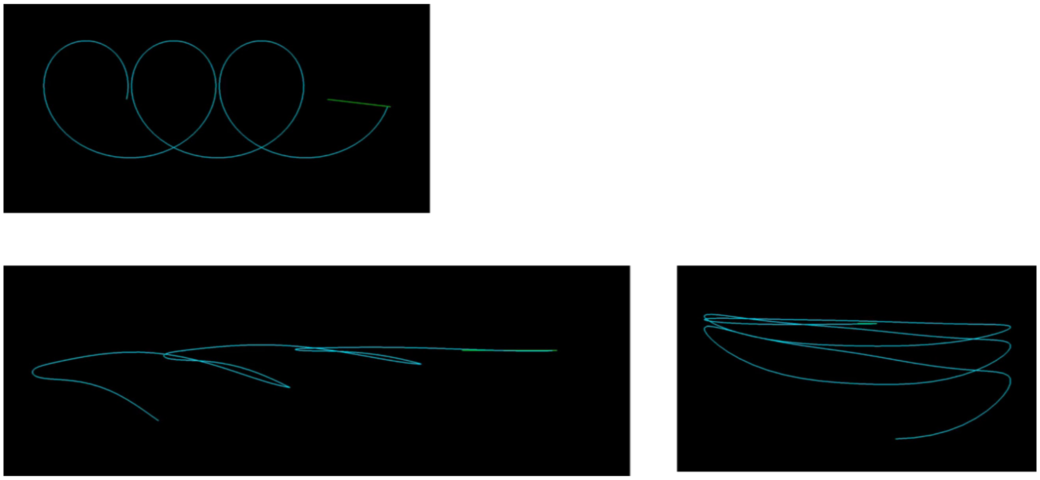
Summary: This project entails the aerodynamic analysis of a coaxial rotor system (rotor system with contra-rotating rotors stacked on top of one another) with a focus on high flight speeds. The aerodynamic analysis is followed by acoustic analysis of the rotor system. The coaxial system studied in this project is unique in that it allows for the redistribution of the loading along a rotor blade and operates in an aerodynamic environment more complex than the conventional single main rotor, single tail rotor helicopter. The proximity of the rotors results in the mutual interaction effects, and these interactions cause highly impulsive loading events. The most prominent is blade-vortex interaction (the interaction of a rotor blade and a rotor wake). The impulsive loading events cause the coaxial rotor system to produce highly impulsive noise. In this project the aerodynamic interaction is studied along with varying parameters of the coaxial rotor system (loading distribution, rotor geometry, trim conditions) to understand the impact on aerodynamics and acoustics, with the goal of reducing the resulting noise.



Overall sound pressure between the 10th and 50th blade harmonics radiating from a coaxial rotor system (black disks in the center of the hemisphere

Title: Acoustics Prediction Tool for Conceptual Design
Sponsor: Army
PI: Kenneth Brentner
Student: Thomas Jaworski (MS candidate)

Summary: Noise calculations often require high fidelity CFD computations, which are often not feasible for computational design work. Low fidelity tools like NASA's Design and Analysis of Rotorcraft (NDARC) are computationally inexpensive and can provide the necessary information on blade forces, and moments required for noise prediction. The goal of the project is to be able to use NDARC to generate the necessary information required by PSU-WOPWOP to predict noise sources. Different noise sources; thickness, loading, broadband and high-speed impulsive noise (HSI), and aerodynamic interaction noise will all be modeled to give noise prediction capability to designers in early stages. The project will also be focused on enhancing NDARC's capability of predicting blade loads required to predict blade vortex interaction noise.



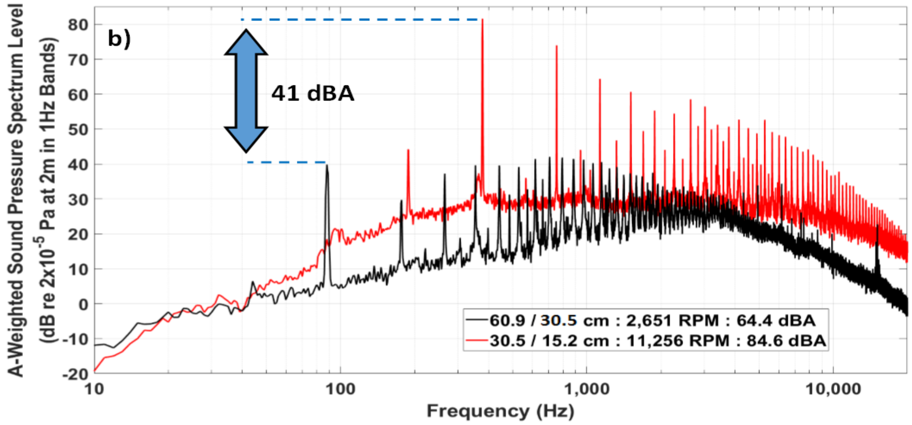
Representation of a tip vortex of a rotor blade

Title: System Noise Analysis for Boeing SUGAR-high Aircraft
Sponsor: NASA ULI
PI: Professor Kenneth Brentner
Student: Ryan McConnell

Summary: System noise analysis will be conducted on a notional commercial transport aircraft with a slotted natural laminar flow wing on the Boeing SUGAR-high aircraft. Initial calculations will begin by examining the noise from the wing using an empirically derived method. Since the most significant contributor to noise is thought to be trailing edge noise, the method developed by Brooks, Pope and Marcolini will be used to obtain a baseline estimate of turbulent boundary layer trailing edge noise and laminar boundary layer vortex shedding noise. A second empirical method derived by Howe will also be used to determine differences in noise generated when the wing is in different configurations. Once the initial calculations have been completed, full-scale airframe noise will be calculated using NASA's ANOPP code, and these results will be compared to previously obtained data for the aircraft.

Title: The control of quadcopter propeller noise
PI: Timothy A. Brungart
Sponsor: Rapid Reaction Technology Office

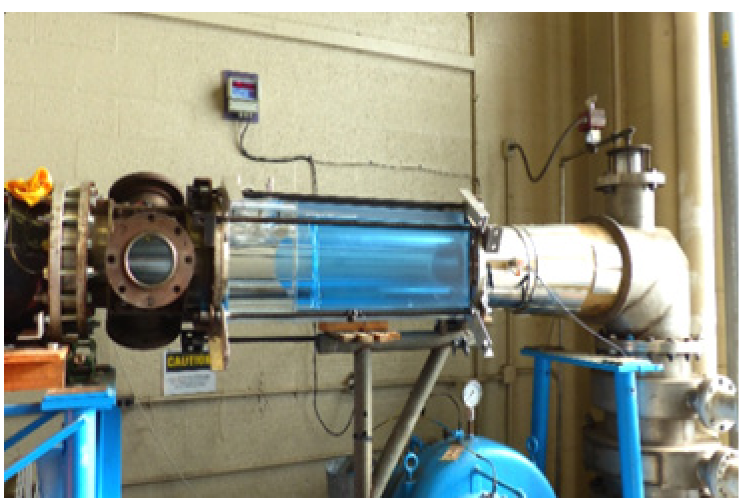
Summary: Fan affinity laws are combined with a simple scaling relationship for fan noise to show that truly significant reductions in propeller noise can be achieved by increasing the fan or propeller diameter while reducing its rotational speed, thereby reducing its blade tip speed, while maintaining a given level of static thrust. Fan affinity laws are also used to show that efficiency improvements accompany the reductions in radiated noise. The significant reductions in noise and increases in efficiency predicted from the scaling relationships were verified experimentally by measuring the radiated noise and power requirements for both large, slowly rotating propellers and small, high speed propellers, at equivalent static thrusts, where the large propellers serve as possible replacements for the small propellers in typical quadcopter applications. The bulk of the noise reductions offered by large and slowly rotating propellers compared with small, high speed propellers are shown to be maintained at equivalent net force (thrust minus weight) conditions, as required for practical implementation into a quadcopter UAV, even using readily available hobby grade components. Further significant noise reductions are possible with lightweight and custom engineered components.



Comparison of the sound pressure spectrum measured for the 60.9 cm propeller and 30.5 cm propeller at 27.8 N of static thrust.

Title: Symmetry methods for axisymmetric turbulent flow
PIs: Zachary Berger, Ryan Murray, Michael Jonson, and Amanda Hanford
Sponsor: Applied Research Laboratory

Summary: Modeling turbulence is a central problem in modern fluid mechanics and engineering, and in order to make advances in this field, turbulent flow must be better understood and modeled accordingly. This research is interested in looking at turbulence from an axisymmetric viewpoint, which means that there are symmetries identifiable with respect to some axis in a flow with a preferred direction. The hope is to obtain simplified forms of 2nd order Reynolds Averaged Navier-Stokes (RANS) and Euler equations in cylindrical coordinates by finding families of invariant solutions. Using a well-established, classical method called Lie theory, transformations and symmetries can be solved for which allow us to come up with these solutions/simpler models. Another important aspect of this research is obtaining experimental PIV data in a fully-developed turbulent pipe to validate the mathematical findings of the symmetry analysis. Two-point correlations will be extracted from the PIV data and used to compare with what was found through the mathematical analysis and to obtain scaling laws. This research is still in its early stages, but so far has identified several symmetries deemed relevant to the flow. Going forward, the goal is to further analyze the RANS and Euler equations for more possible symmetries, collect/analyze PIV data, and compare the two approaches for validation of our model.



ARL/Penn State's Glycerin Tunnel Test Section

Title: Glottal Jet Aerodynamics
Sponsor: NIH
PI: Michael Krane
Collaborators: Michael McPhail (ARL PSU), 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)
Student: Paul Trczinski

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.

Title: Aerodynamic-Aeroacoustic performance of poroelastic wings, inspired by the silent plumage of owls
Sponsor: NSF
PI: Michael Krane
Student: Zachary Yoas (MS, Bioengineering, PSU)

Summary: Inspired by the wing structure of quiet owl flight, project studies the effect of trailing edge porosity and compliance on trailing edge noise. Project is collaboration with Lehigh University, who performs theoretical side of study, while experiments are performed at PSU ARL. Experiments include vortex ring interaction with edge of given porosity and elasticity, and measurements of radiated noise and glide slope on a radio-controlled glider.

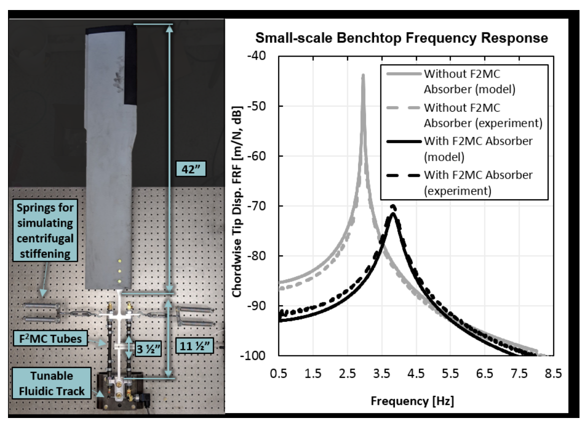
Rotorcraft Acoustics and Dynamics

Ed Smith, Group Leader - ecs5@psu.edu

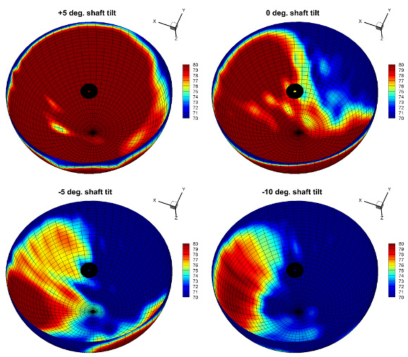
The Penn State's CAV Rotorcraft Acoustics and Dynamics Group continues to be at the core of our Vertical Lift Research Center. Penn State is home to one of only three NRTC Vertical Lift Research Centers of Excellence (VLRCOE) in the country. In summer of 2016, our Center was successfully renewed for 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. The 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 52nd consecutive year on August 5-9. Topics in the comprehensive course include rotorcraft aerodynamics, dynamics, acoustics, composite structures, flight controls and propulsion. https://rotary-wing.outreach.psu.edu/

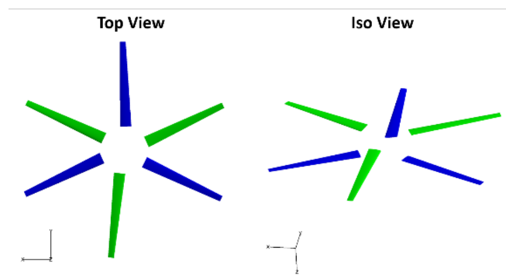
Below are some highlights of our group's recent work.

Title: Rotor Blade Damping via Fluidic Flexible Matrix Composites (F2MC)
Sponsor: US Army VLRCOE Program , LORD Corp.
PIs: Ed Smith, Chris Rahn
Student: Michael Trowbridge (MS candidate)
Summary: Helicopter rotor blades have inherently low damping in the lag mode (in the plane of rotation). Penn State researchers are developing new light-weight technologies to introduce substantial damping into cantilevered rotor blades. Fluidic Flexible Matrix Composite (F^2MC) damped vibration absorbers are being investigated for their damping potential for stiff-inplane hingeless rotor blades. The results from small-scale benchtop testing agree closely with model predictions and show a dramatic increase in critical damping from $\zeta = 0.005$ to $\zeta = 0.041$.



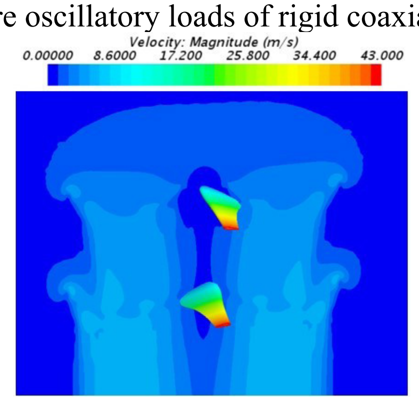
Title: Fundamental Study of Coaxial Rotor Aeroacoustics
Sponsor: US Army VLRCOE Program
PI: Prof. Ken Brentner
Student: Kalki Sharma (PhD candidate)
Summary: Coaxial rotors are being developed for high speed rotorcraft. Fundamental computational simulations are required to understand the aeroacoustic behavior of these complex systems. The upper rotors are colored blue and the lower rotor are colored green. Overall sound pressure level from the 10th to 50th blade harmonic are presented on a hemispherical grid. The source of noise is the coaxial rotor system (black disks), which is traveling at 100 knots in the positive x-direction at varying shaft tilts (negative for forward tilt; positive for rearward tilt). The tilt of the rotor shaft influences the severity of the interactions between the closely spaced rotors, and has an impact on the strength and direction of the rotor system's mid-frequency range sound pressure level.

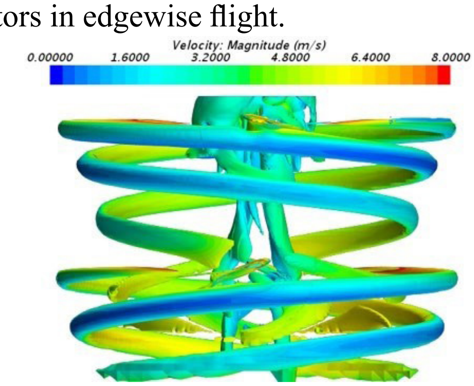




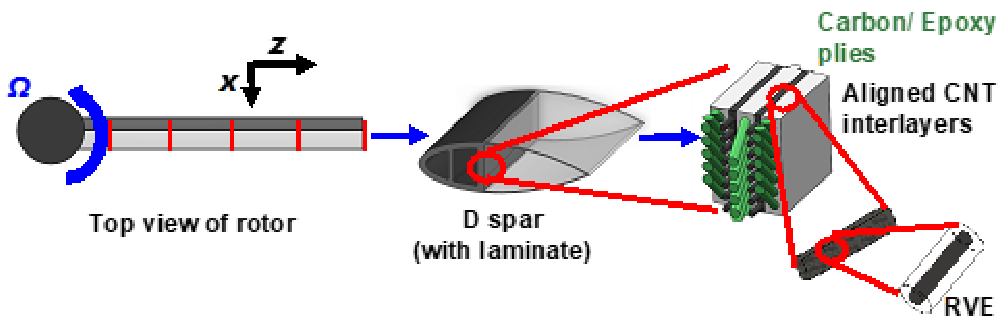
Title: Computationally Efficient Simulations for co-axial rotor performance
Sponsor: NSF, PI: Prof. Sven Schmitz
Student: Jason Cornelius (PhD candidate)
Summary: The mixing-plane approach, a method first implemented in turbomachinery, has been applied to a coaxial rotor in hover. The approach allows for simplifying assumptions such as periodic boundaries, rotating reference frames, and a steady solution of the Navier-Stokes equations. This allows for a dramatic decrease in computational time while still producing a high-fidelity result. The image on the left below shows the two resolved blades of the coaxial rotor with the mixing-plane approach. A cut plane shows the velocity magnitude around and beneath the rotors. The blade tip vortexes and the contraction of the wake can be observed.

The image on the right below is a graphic of the baseline time-accurate simulation that was used to measure the accuracy of the mixing-plane approach. The model setup and solution method follows the conventional state-of-the-art best practices in the context of an unsteady Reynolds-averaged Navier-Stokes simulation. The mixing-plane approach yielded a 430 times reduction in computational time, or more than two orders-of-magnitude, over the conventional time-accurate approach. The largest deviation of rotor thrust and torque between the two models is less than two percent, which shows the feasibility of the mixing-plane approach as a high-fidelity analysis method with low computational expense. Time accurate CFD solutions are also being utilized to explore oscillatory loads of rigid coaxial rotors in edgewise flight.

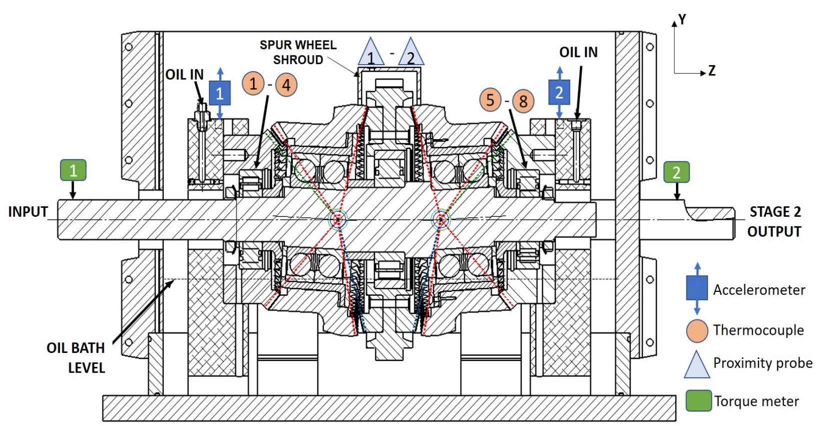




Title: Hybrid Nanocomposites for Enhanced Rotor Blade Damping
Sponsors: US Army VLRCOE, LORD Corp.
PIs: Chuck Bakis, Ed Smith
Students: Keerti Prakash (PhD candidate), Jeff Kim (MS candidate)
Summary: Composite laminates with carbon fibers and thin interlayers comprised of carbon nanotube yarns exhibit substantial damping increases compared to baseline composite laminates. This novel approach can lead to development of light-weight high damping structures. While this technology is widely applicable, one promising aerospace application currently being explored in enhanced damping for hingeless (i.e. cantilevered) helicopter rotor blades. The role of the nanotube yarns and surfactants has also been investigated. Analytical models of rotor are also underway. Loss factors between 5-10% appear to be possible.



Title: Design, Analysis and Experimental Testing of a Compact, High Reduction Ratio and Low Noise Pericyclic Transmissions
Sponsor: US Army VLRCOE
PIs: Ed Smith, R. Bill, L. Chiang, H. DeSmidt
Students: Tanmay Mathur (PhD candidate)
Summary: Based on component level and system level design analysis tools developed in the past years, an internally-driven torque sharing, twin configuration, Pericyclic drive concept has been developed to operate within allowable operating conditions of the NASA Glenn Transmission Test rig. In this work, design refinements and additional features required for successful fabrication, assembly, and testing of the prototype transmission are described. Thereafter, the weights and inertia of the components are updated in the design analysis to predict performance characteristics of the test article such as efficiency, bearing loads and life, tooth loads, lubrication requirements, and component stiffness. Some of these results will be validated from test runs of the prototype scheduled for near future.



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

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

Title: Load Alleviation Control Design Using High Order Dynamic Models
Sponsor: US Amry VLRCOE
PI: Joe Horn
Student: Umberto Saetti (PhD candidate)

Title: Fundamental Investigations into Future Low-Drag Single/and Co-axial Rotor Hub Systems
Sponsor: US Army VLRCOE
PI: Sven Schmitz
Student: Charles Tierney (PhD candidate)

Structural Vibration and Acoustics

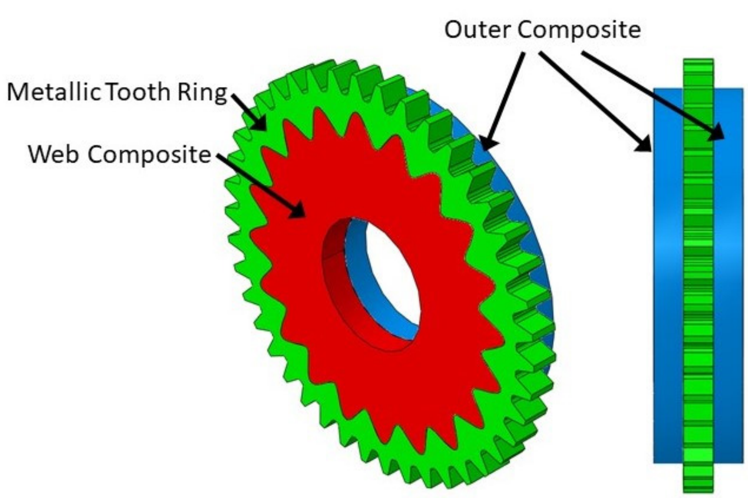
Steve Hambric, Group Leader - sah19@psu.edu

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.

Below are some highlights of our group's recent work.

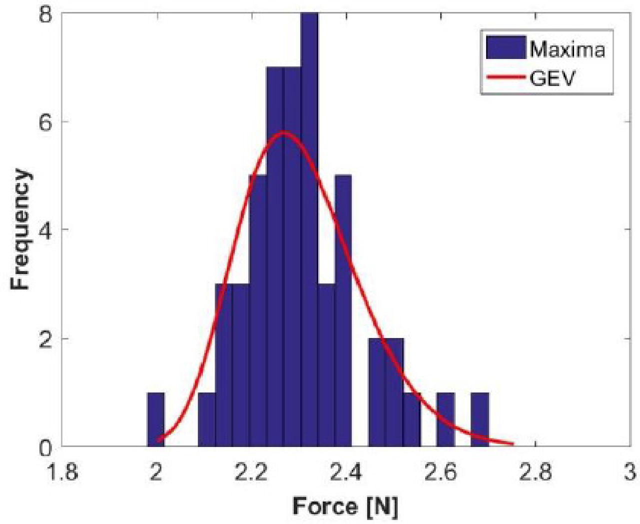
Title: Experimental and Computational Analysis of Thermal and Dynamic Performance of Hybrid Gears under Normal and Loss-of-Lubrication Operation
Sponsor: U.S. Army, U.S. Navy and NASA (via PSU VLRCOE award)
Principal Investigators: Sean McIntyre and Rob Campbell
Student: Sean Gauntt (PhD – Mechanical Engineering)

Summary: The hybrid gear project focuses on decreasing rotorcraft vehicle weight by decreasing the weight of the drive system through integration of composite materials into gear design. Current work for the normal operation aspect of the project is focused on developing an optimization technique for a sinusoidal interlock design of a 3.5" hybrid spur gear. (The loss-of-lubrication aspect is a separate, but related, student effort.) The design consists of a metallic outer ring—to support high contact stress—bonded to a composite inner web—for weight reduction (see image below). The composite-steel interface is defined by a sinusoidal interlock. In the initial optimization, two objectives (mass and shear traction on the metal-composite interface under static loading conditions) are minimized for four design variables subject to two constraints. Borg MOEA, a multi-objective evolutionary algorithm developed at The Pennsylvania State University, and an in-house finite element solver are used to generate Pareto-optimal solutions to the problem. Two of the optimal designs were analyzed in greater detail to determine stress distributions throughout the gear, which is important for material fatigue assessment. Future work will assess the effect of the hybrid gear on transmission error. Techniques developed and demonstrated for the 3.5" spur gear will be applied to a larger, more complex gear that offers greater potential for overall weight savings.



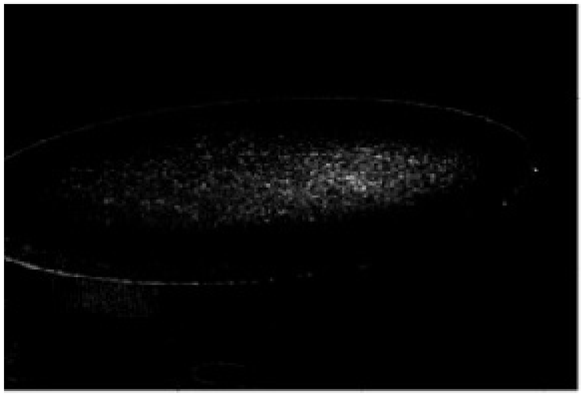
Title: Extreme value statistics of flow induced noise and vibration
Sponsor: NAVSEA 073R
Principal Investigators: Drs. Stephen Conlon and Manton Guers
Student: Connor McCluskey (PhD, Acoustics)

Summary: Flow induced noise and vibration produces cyclic loading on structures such as wind turbines and vehicle control surfaces. This cyclic loading can often produce fatigue damage in these structures. Since the flow excitation is often random in nature, infrequent large amplitude loads are expected to occur in these applications. These large outlier loads ultimately decrease the fatigue performance of these structures. The goal of this work is to develop improved methodologies for predicting and modeling these rare events in order to establish relevant design loads. To accomplish this, the Generalized Extreme Value (GEV) model is applied to flow-induced vibration response maxima, extracted using Block Maxima methodology. Vibration response measurements are repeated and compared to GEV model to evaluate if extreme events were predictable.



Title: Digital Image Correlation for Vibration Measurements
Sponsor: Walker Graduate Assistantship Program
Principal Investigator: Dr. Tyler Dare
Student: Sean Collier (Ph.D. Acoustics)

Summary: Digital image correlation (DIC) is a common technique for measuring flowfields. Though some research groups have successfully used DIC for vibration measurements, most efforts have been on relatively simple structures. The current state-of-the-art for DIC measurements is restricted to structures where the vibration displacement is large compared to the size of the structure, such was tuning forks and helicopter blades. This research is leveraging the Applied Research Laboratory's DIC expertise and equipment to address the drawbacks in current DIC methods and become a leader in DIC vibration measurements.



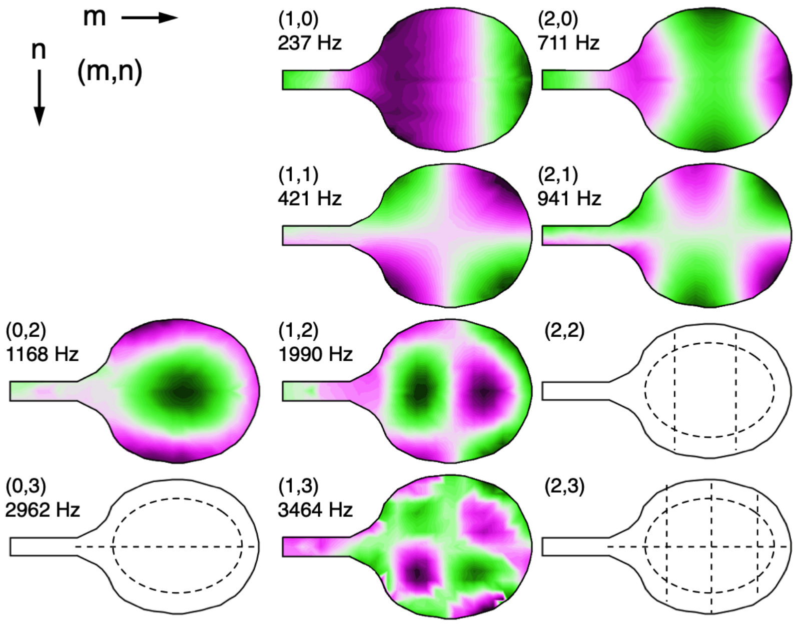
Top: Acoustically-excited drum head measured at a frame rate of 4000 Hz. Bottom: Low-order mode shape extracted using edge detection and eigenanalysis.

Title: A Study of the Fatigue Damage Spectrum for Accelerated Testing
Principal Investigators: Drs. Manton Guers and Clifford Lissenden
Student: Odissei Touzanov (M Eng, Acoustics)

Summary: In some cases it is desirable to shorten the time required for conducting electrodynamic shaker vibration testing of engineering structures. However, the parameters selected for an accelerated test must not overload the structure being examined. In this work, the Fatigue Damage Spectrum (FDS) methodology was examine for this purpose. A MATLAB code was developed for computing the FDS of a 'standard' loading profile and then computing the corresponding Autospectrum required for accelerated electrodynamic shaker vibration testing. The developed code was applied to a vehicle road loading profile and an experimental validation was performed. The experimental results showed good agreement with the FDS theory. The accelerated test specimens failed in approximately ½ the time compared to standard test parameters as expected.

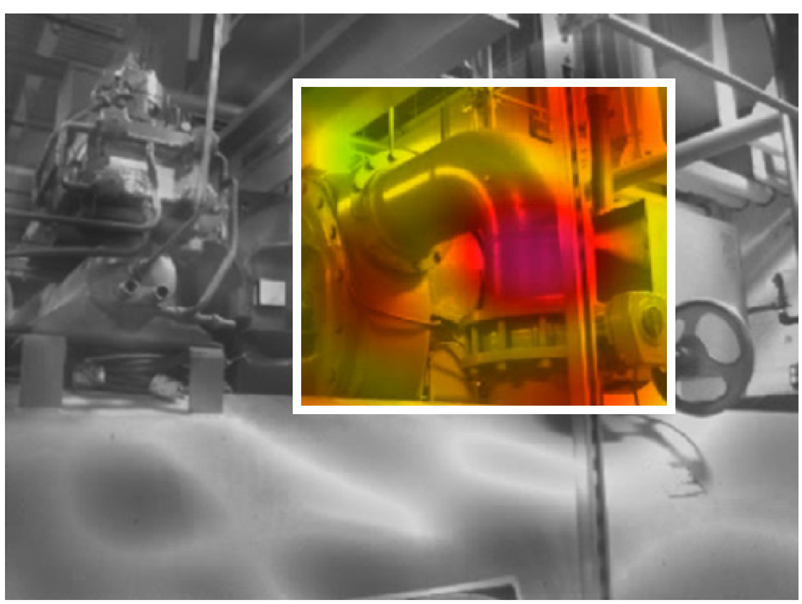
Title: Vibroacoustic investigation of hand-held sports equipment
Principal Investigator: Dan Russell

Summary: Recent research on the acoustics and vibration of hand-held sports equipment include several projects with golf putters and balls, baseball bats and field hockey sticks, and ping pong paddles. The influence of golf ball parameters on the sound and vibration of the putter-ball impact is being explored in order to better understand player preferences regarding sound and feel. A current study with field hockey sticks and baseball bats is exploring attempting to correlate lab measurements of vibration to field studies with player feedback regarding sting and feel. A recently published project revealed that the impact sound of a ping-pong paddle and ball is almost entirely due to one particular structural vibration mode of the paddle while the acoustic spherical shell modes of the ball being surpassed due to the relatively long contact time with the paddle.



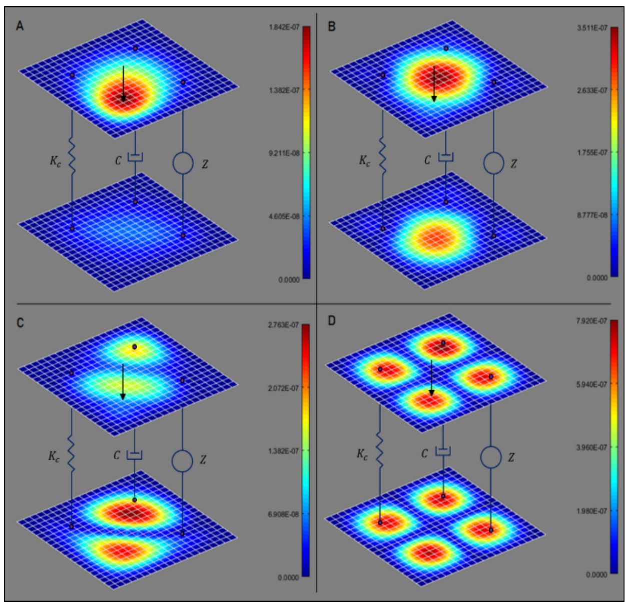
Title: Large chiller noise and vibration
Sponsor: UTC Building and Information Systems (Carrier)
Principal Investigators: Steve Hambric, Tim Brungart
Student: Stephen Wells (Ph.D., Acoustics)

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: Power flow through structural joints
Principal investigators: Dr. Kyle Myers (ARL), Dr. Robert Campbell (ARL)
Student: Jonathan Young (Ph.D, Mechanical Engineering)

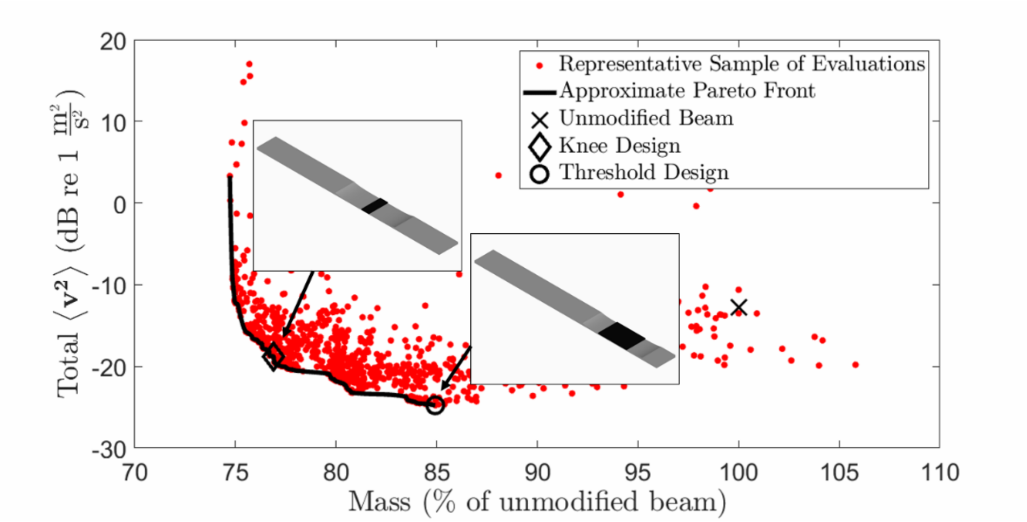
Summary: Connected structures subject to applied dynamic loads transfer vibrational energy through their connecting junctions. Identifying the dominant paths of transmission and characterizing the power flow through those paths is important for designing a quiet structure. This work focuses on transmitted power flow when structures are mechanically coupled via complex springs, dashpots, point impedances, and generalized impedances, for example. 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.



Response of fixed plate structures at A) 1 kHz, B) 2 kHz, C) 3 kHz, D) 4 kHz. Steel plates coupled by a spring, dashpot, and point impedance demonstrate which structures are most responsible for power transmission and dissipation

Title: Optimization of Acoustic Black Hole Design for improved Structural Acoustics
Sponsor: ARL Walker Fellowship
Principal Investigator: Micah Shepherd
Student: Cameron McCormick (PhD - Acoustics)

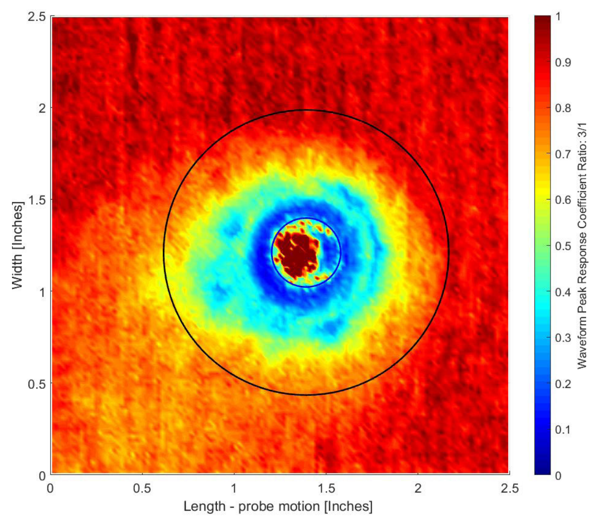
Summary: Arrays of Acoustic Black Holes (ABHs) have the potential to significantly reduce structural vibration and radiated sound. However, the optimal hole profiles, sizes, damping, and spacing are difficult to determine. An automated global optimization procedure and high performance parallel computing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



The Pareto front for an ABH vibration absorber illustrates trade-off between reduced vibration and the added mass of the damping material.)

Title: Nonlinear structural joint dynamics
Sponsor: NAVSEA 073R
Principal Investigators: Micah Shepherd, Steve Hambric
Student: Trevor Jerome (Ph.D., Acoustics)

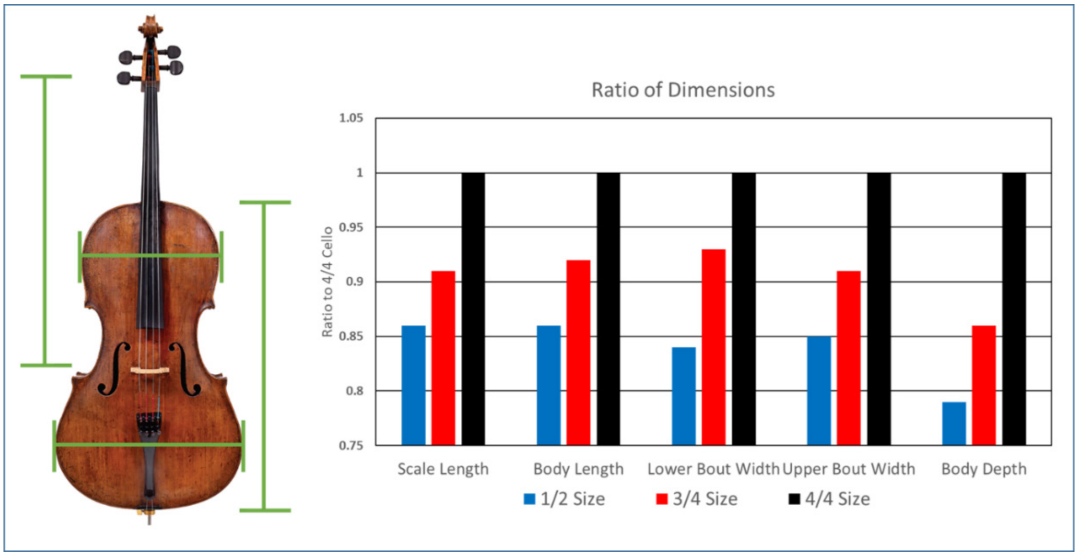
Summary: The dynamics of structural joints, despite much research, remain poorly understood. A rigorous treatment of two plates with a bolted L-joint is underway, including ultrasonic scanning of the contact pressures on the faying surface, non-contact acoustic excitation of the structure and analysis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



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: Investigation of the Vibroacoustic Scaling of Cellos
Principal Investigator: Micah Shepherd
Students: Tom Blanford (PhD - Acoustics), Trevor Jerome (PhD - Acoustics)

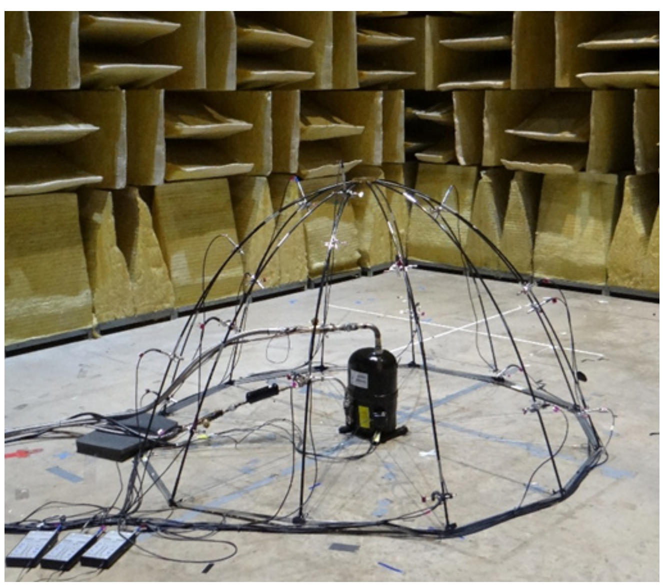
Summary: Fractional-sized cellos (3/4, 1/2, etc.) are designed for the same musical playing range as a full-sized cello (4/4) but with scaled proportions for players for whom a full sized cello is too large. To compensate for the shorter string length of the smaller instruments, the strings are adjusted in order to obtain the correct tuning. The cello body vibration, which is strongly coupled to the internal air cavity, would not be expected to scale in the same manner as the strings. To understand the impact these different scaling factors, the vibroacoustic of several different sized cellos were analyzed using measurements and simulations.



The geometric scaling of fractional-sized cellos varies across all dimensions.

Title: Small reciprocating compressor noise and vibration
Sponsor: Bristol Compressors
Principal Investigators: Tim Brungart, Steve Hambric
Student: John Cunsolo (MS - Acoustics)

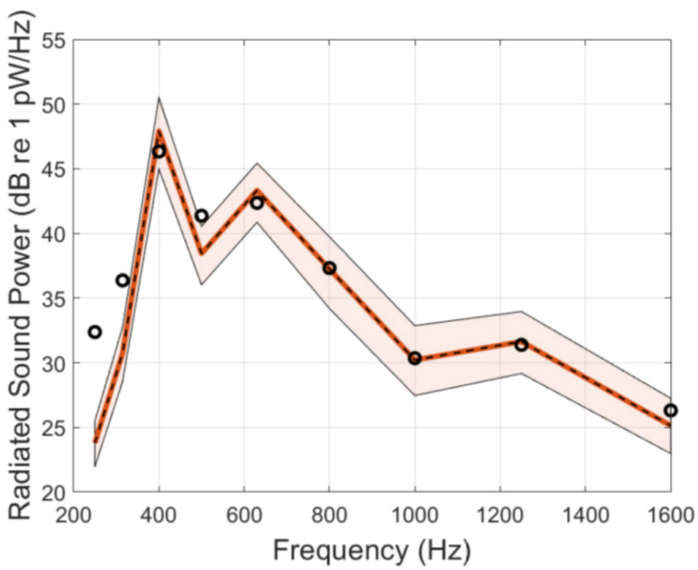
Summary: The noise radiated by small reciprocating compressors is dominated by a wide distribution of tonal harmonics. The harmonics are amplified by the structural resonances of the cylindrical housing, particularly near the coincidence and ring frequencies. Experimental modal analyses are used to measure the modal distribution, and combined with radiated sound/force transfer functions to identify strongly radiating modes. Internal structural design changes have been 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: Uncertainty quantification in flow-induced vibro-acoustic simulations
Sponsor: NAVSEA 073R
Principal Investigators: Andrew Wixom and Sheri Martinelli
Student: Gage Walters (Ph.D., Mechanical Engineering)

Summary: This work is focused on developing computational tools to predict the uncertain response of vibro-acoustic systems that have uncertain inputs. In particular, we focus on structures that are subjected to flow excitations such as turbulent boundary layers or ingested turbulence and consider cases where uncertainty arises in both the forcing function and the structure itself. Generalized Polynomial Chaos (GPC) is used to tackle this problem and has the advantage that it only relies on deterministically sampled evaluations of the underlying deterministic model (i.e. a “blackbox” approach). The underlying model may utilize finite elements, computational fluid dynamics, or any number of other well understood modeling approaches. Recent work has focused on the creation of optimal, low-point, multidimensional quadrature rules that enable rapid evaluation of the necessary GPC coefficients even when the number of uncertain parameters is large.



Radiated sound power of a TBL forced plate in one-third octave bands – colored region shows possible responses including uncertainty as computed by GPC, black circles are experimental measurements

Systems and Structures Health Management

Group Leaders:
Cliff Lissenden, lissenden@psu.edu
Karl Reichard, kmr5@psu.edu

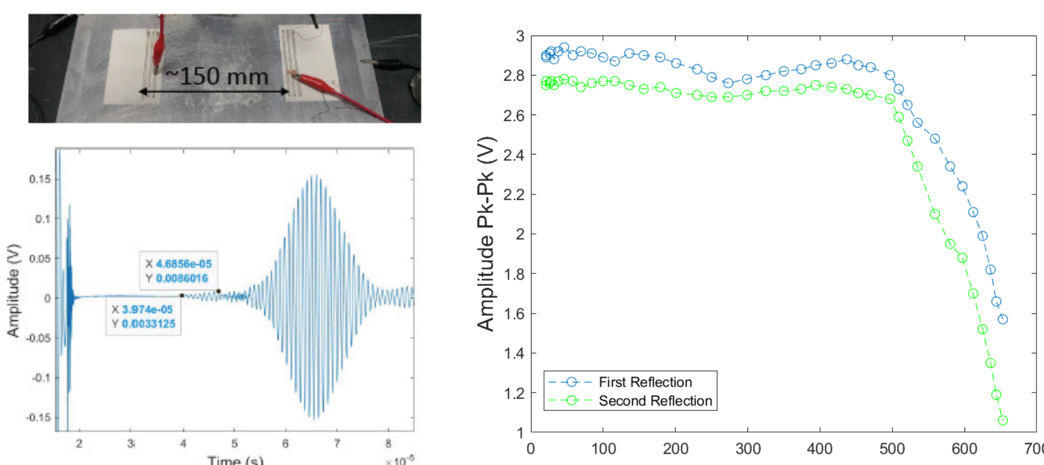
The mission of the Systems and Structures Health Management Technical Group is to develop new methodologies and technologies to manage the life cycle of systems and structures. This includes the full range of material state awareness, health and usage monitoring, and condition based maintenance, to support 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.

Research conducted in the laboratories of Prof. Tittmann and Prof. Lissenden by Yaman Trivedi (MS ESM, SP 2019) shows that bismuth titanate films can generate ultrasonic guided waves for structural health monitoring of plate or shell structures. The figure below shows two comb transducers, each having three elements, that send and receive the S1 and A1 Lamb modes in an aluminum plate. The coating is 200 mm thick and the element pitch is 5.6 mm. The transducers have strong potential for crack and corrosion detection. These film transducers have two intrinsic advantages:

(1) The Curie temperature of bismuth titanate is 670°C, enabling them to operate at temperatures up to 500 degrees C, as shown below;

(2) The films can be field-applied using a straight-forward process with inexpensive raw materials.

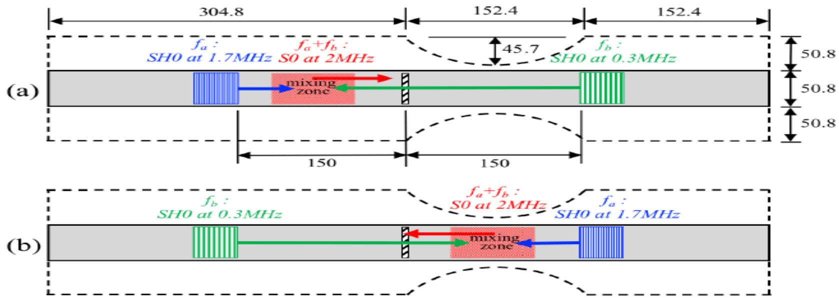
The transducer processing involves mixing bismuth titanate powder with an inorganic binder and water, curing at room temperature, applying the electrode and then connecting a lead wire. The coating is then poled, which can also be done at room temperature.

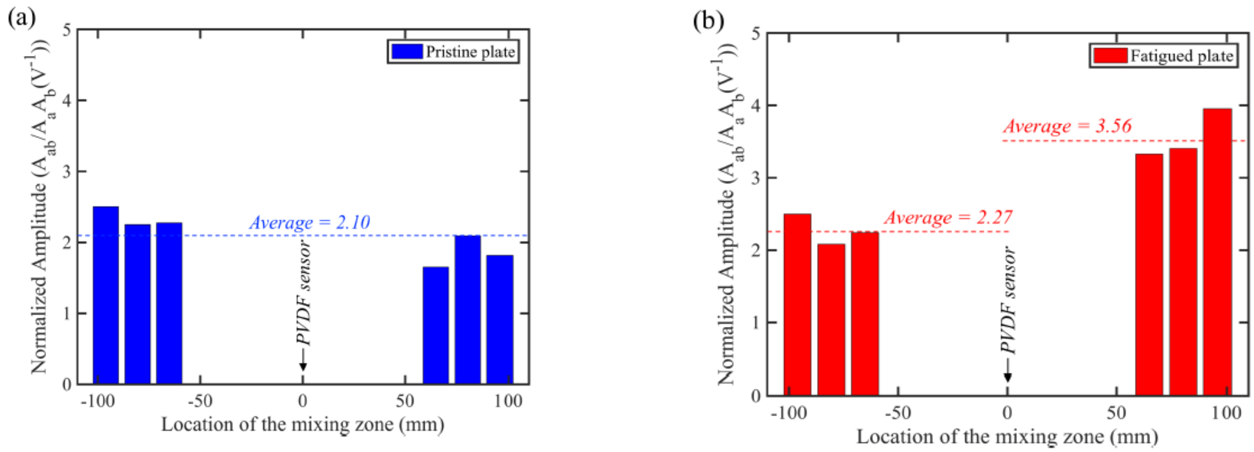


(a) (b)

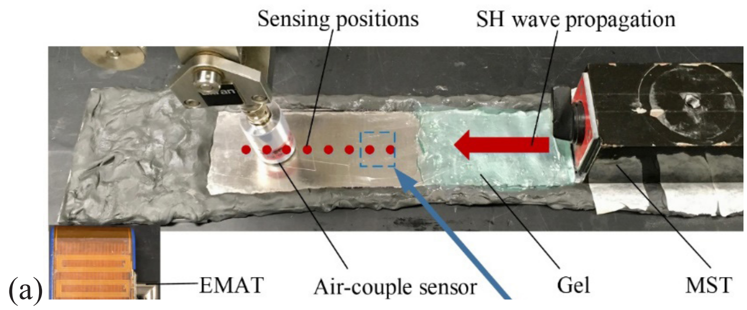
(a) Bismuth Titanate film transducers send and receive Lamb waves in an aluminum plate. Both S1 and A1 modes are generated, with A1 dominating. (B) Longitudinal pulse-echo measurements in a furnace.

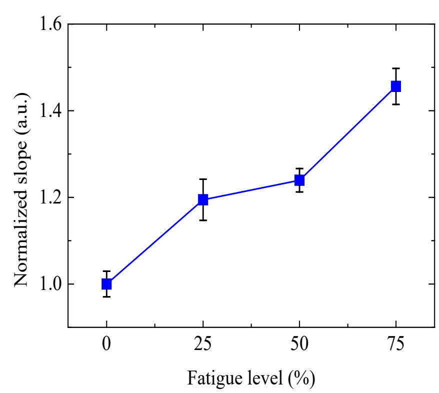
The mixing of shear-horizontal (SH) ultrasonic guided waves is sensitive to incipient fatigue damage in a plate. Prof. Lissenden's group has shown that the mutual interaction of SH waves generates an S0 Lamb wave at the sum frequency. If the SH waves are counter-propagating, then the plate can be scanned to identify localized material degradation as shown below. If the SH waves are co-directional, then the power flow to the secondary S0 waves is larger and the results are highly sensitive to the early stages of material degradation as shown in the final figure below.





Notched aluminum plate with incipient fatigue damage is instrumented with magnetostrictive and PVDF transducers. (a) Normalized nonlinearity parameter from pristine plate is relatively uniform spatially. (B) Normalized nonlinearity parameter indicates localized incipient fatigue damage in the notch region.



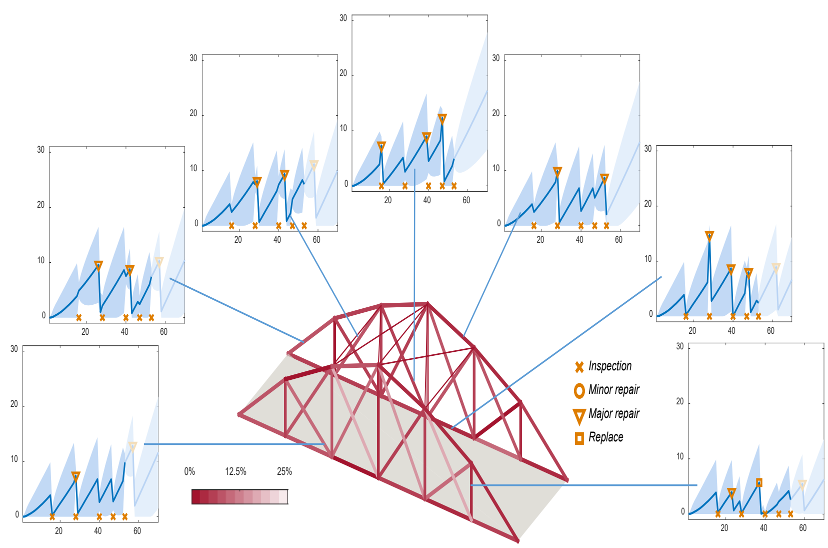


(b)

(a) Notched aluminum plate with incipient fatigue damage is instrumented with magnetostrictive. The nonlinearly-generated Lamb waves are received by an air-coupled transducer that is scanned along the length. (b) The slope of the nonlinearity as a function of propagation distance is very sensitive to early-stage material degradation.

Title: Life-cycle structural health management for large engineering systems through deep reinforcement learning
PI: Kostas Papakonstantinou
Student: Charalampos Andriotis

Summary: Efficient life-cycle management of large-scale engineering systems requires advanced and flexible decision frameworks that are able to account for real-time data, noisy sensors and partial information, model unavailability, and resource limitations, while at the same time providing effective scaling in multi-component domains and long-term planning horizons. Markov Decision Processes (MDPs) and Partially Observable Markov Decision Processes (POMDPs) provide sound mathematical formulations for sequential decision problems and have been shown to reach competent solutions for stochastic control problems related to maintenance and inspection planning, surpassing the performance of conventional life-cycle methodologies. We have developed Deep Centralized Multi-agent Actor Critic (DCMAC), a novel Deep Reinforcement Learning (DRL) approach using deep policy gradient actor-critic schemes with off-policy learning and experience replay. DCMAC has the modeling capacity to reduce the complexity related to action space scaling at the system level and can also handle massive state spaces through highly nonlinear deep network parametrizations. Application of DCMAC in structural and generic engineering systems with large state and action spaces showcases unprecedented outperformance of standard asset management inspection and maintenance approaches. The figure below shows possible life-cycle optimum DCMAC policy realizations for a bridge steel structure with a snapshot at t=53 years, based on the system state beliefs at each time step. The truss snapshot shows the observed section losses due to corrosion. Indicative steel member plots show the mean section loss (%) ± 2 st.dev. over the 70-year horizon (x-axes), together with the DCMAC selected actions (watch full policy video at https://youtu.be/uKg3cPP8H48). The full details are given in Andriotis and Papakonstantinou, https://arxiv.org/abs/1811.02052.



Title: Rapid Automation Technology Evaluation – Health Monitoring of Automated Drilling Systems (ADS)
PIs: Jeff Banks, Matt Rigdon
Sponsor: US Navy Manufacturing Technology Program
Students: Trent Furlong, M.S., Acoustics (2020), Nicholas Carder, M.S., Acoustics (2020)

Summary: The increase in complexity for Department of Defense (DoD) aircraft requirements has led Northrop Grumman Aerospace Systems (NGAS) to create innovative designs. Due to the design complexity, the F-35 center-fuselage is fabricated using a highly automated DoD aircraft assembly line called the Integrated Assembly Line (IAL). NGAS has developed and implemented several robotic assembly systems to support manufacturing activities for the award winning F-35 IAL such as the Automated Drilling Systems (ADS), Inlet Duct Robotic Drilling (IDRD), automated spray robotic system, automated injection molding system (MIPS), robotic and gantry-style drilling/countersinking, and the inclusion of Automated Guided Vehicles

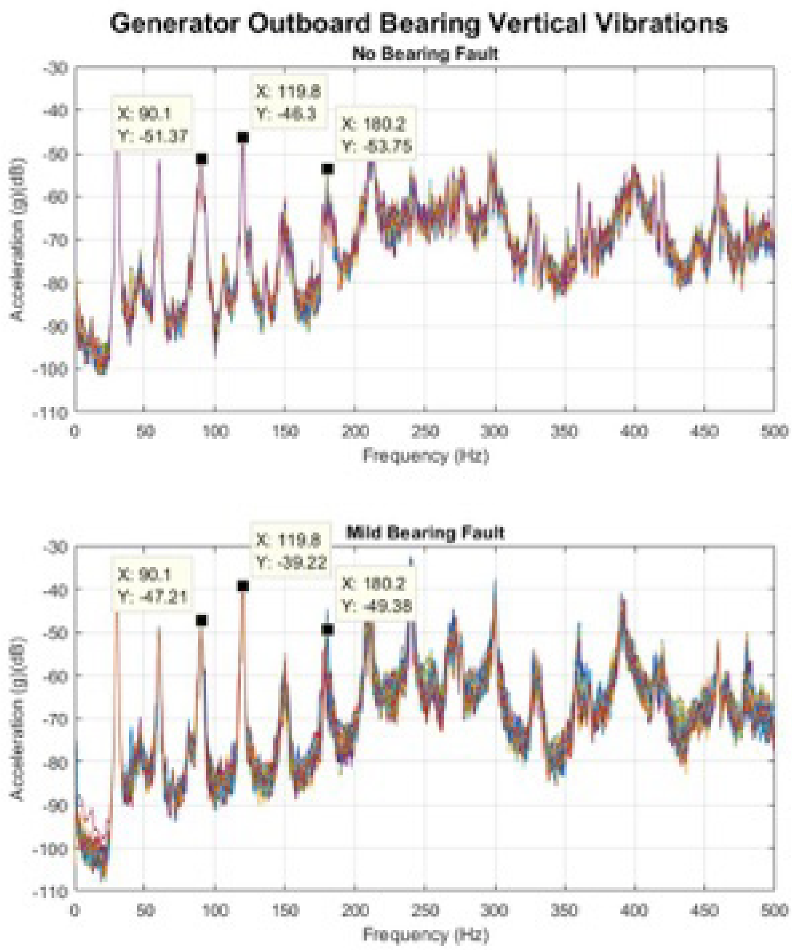
(AGVs) capable of autonomously transporting large fuselage components and tooling. Automation Engineers, Production Operations, and Facilities Engineers require a predictive machinery failure indication capability on critical automation assets to proactively manage these systems in order to guarantee their capacity to manufacture quality parts within the program production intervals.

ARL Penn State and NGAS are developing a digital manufacturing architecture for critical assets in the IAL system. The team will focus on three organizational operations for the design and development requirements of specific capabilities for the digital manufacturing architecture. The three operations include implementation of a condition-based maintenance (CBM) capability, on-line product quality measuring during manufacturing, and manufacturing operations forecasting and schedule optimization. One target for CBM selected by the PSU and NGAS team is the automated drilling system. The figure below shows a similar system used in the production of civilian passenger aircraft. The ADS will be instrumented with microphones, accelerometers, and inertial measurement sensors to track the orientation of the drill and collect vibration and airborne acoustic data. These data will be used to assess the wear state of the cutting tools, and to detect bearing and gear faults in the cutting head and the robotic positioning system. The team is currently collecting data on representative numerically controlled machines at Penn State and will begin collecting data at the F-35 manufacturing facility this summer.

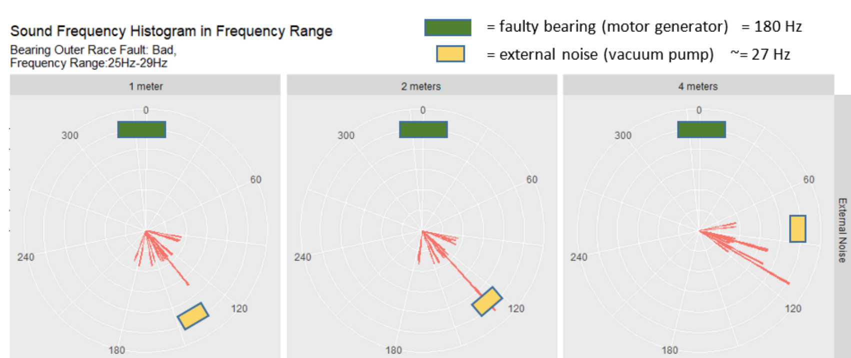
Robotic drilling systems used in the production of civilian aircraft fuselage.

Title: Area Acoustic and Electromagnetic Emissions Monitoring
Sponsor: Electric Power Research Institute
PI: Karl Reichard

Summary: 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. The current focus of the research in this ongoing project is the localization of faulted machines using an array of microphones, with and without a second interfering noise source.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 the measured acoustic spectra from the generator with no faulty bearing and with a mild bearing fault. The data from the 3-microphone array are used to identify the location of specific frequency components identified with vibrations from faulty components, or noise from other machinery in the space. The next figure shows the location of the external noise source (a vacuum pump) in the measured spectra from the generator other machinery in the space.



Composite acoustic spectra from health and faulted generator bearings.

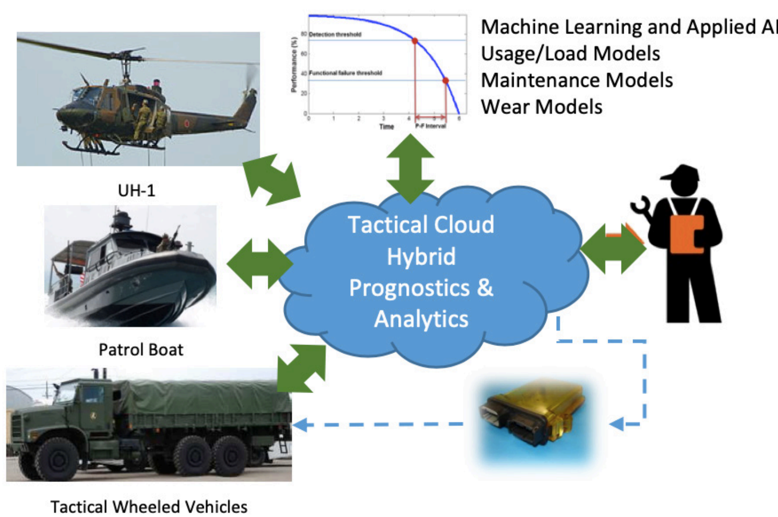


Bearing plots showing identification of external noise source in measured acoustic data.

Title: Hybrid Prognostics at the Tactical Edge
Sponsor: Office of Naval Research
PIs: Karl Reichard, Jeff Banks
Students: Daniel Watson, Ph.D, Acoustics (2022), Veronica Gruning, M.S., Mechanical Engineering (2020)

Summary: The goal of this project is to develop hybrid approaches to prognostic health management which combine traditional physics and engineering-based models of machinery health and damage progression with machine learning and artificial intelligence-based techniques. Many modern systems such as aircraft, ships, trucks, and manufacturing systems collect operational and performance data, but typically lack data from sensors specifically chosen to monitor critical faults or failure modes. While some systems, such as helicopters do have onboard health and usage monitoring system to collect health-related sensor data as well as general state data.
The research program is concentrating on three areas:

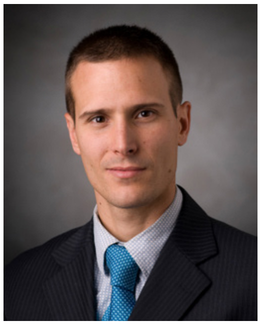
- Collection of platform performance and state data from ground vehicles, helicopters, and ships,
- Development of machine learning health assessment models
- Development of hybrid prognostic architectures to incorporate physical and engineering models in the machine learning process.



Hybrid prognostics combines machine learning from platform performance and sensor data with physics and engineering models to improve predictive capability

Adaptive Structures and Noise Control

Jose Palacios, Group Leader - jlp324@psu.edu

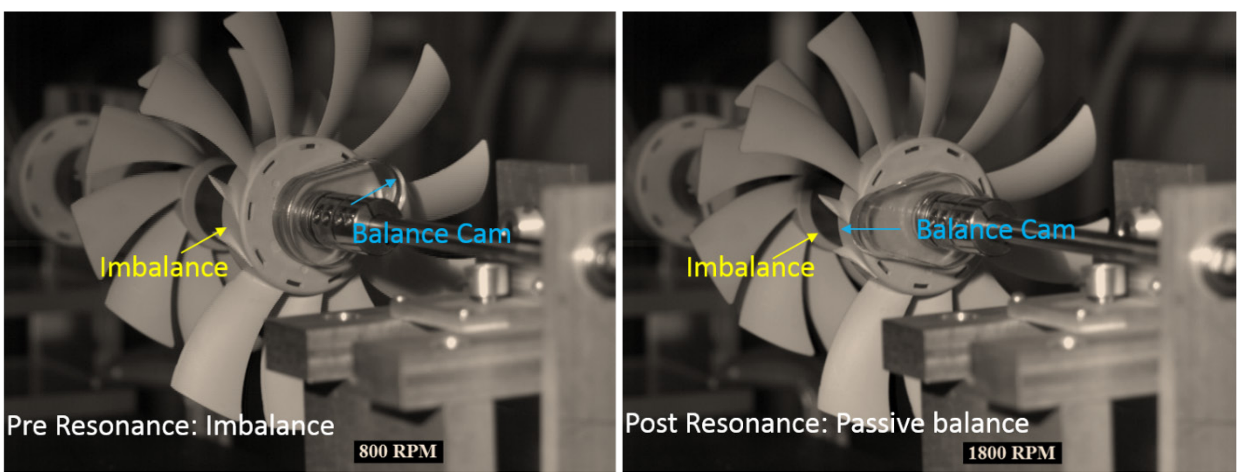


The mission of the Adaptive Structures and Noise Control Technical Group is to pursue strategies for reducing vibration and noise in engineering systems. This involves the development of active materials and devices, accurate modeling approaches, passive control methods, discrete and distributed sensors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

Below are some highlights of our group's recent work.

Title: Supercritical Tail Rotor Shaft Passive Balancing Bearing Modeling, Design and Testing.
Sponsor: LORD Corp.
Principal Investigator: Palacios
Student: Ahmad Haidar, Ph.D. Graduate August 2018 (Working at Leonardo Helicopters).

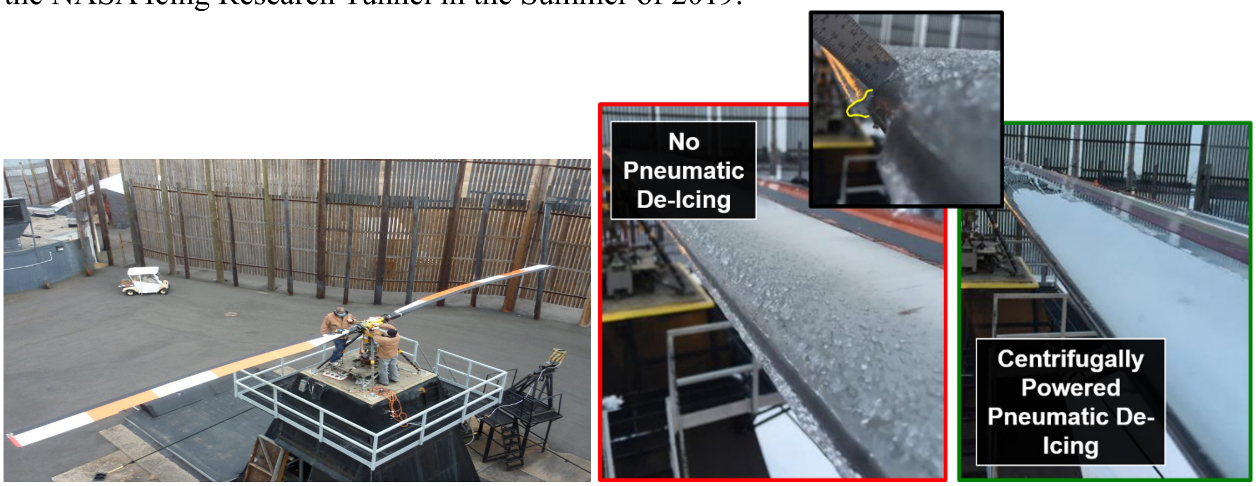
Summary: Passive balancing devices for rotary systems consist of masses that are free to move inconcentric guides about a shaft axis. At supercritical shaft speeds, the balancing masses automatically assume positions that counter any imbalance due to uneven mass distribution in the system. The problem 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. 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.



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.
Principal Investigator: Palacios
Student: Carter Forry, M.S. graduation May 2019.

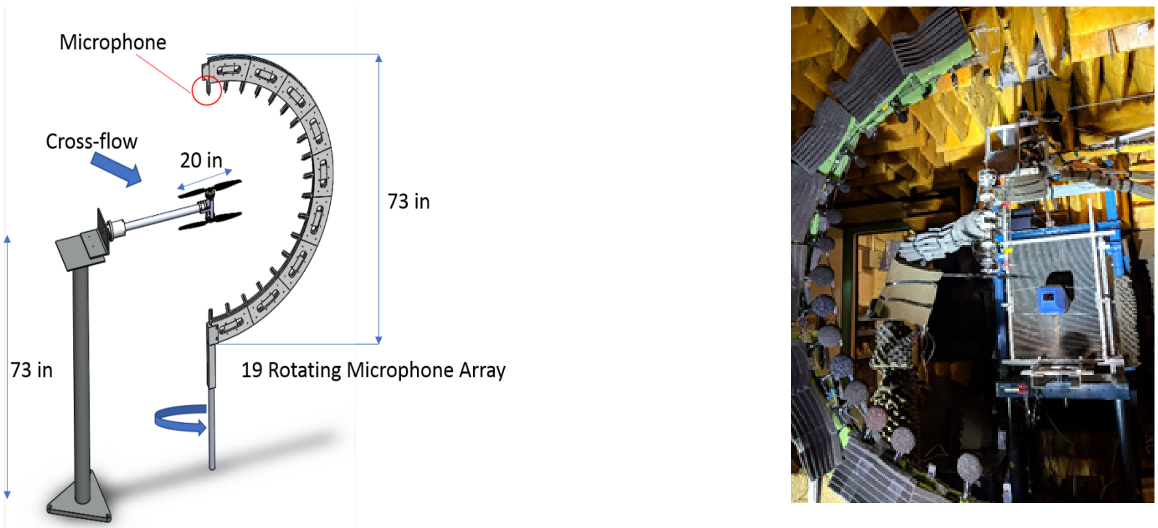
Summary: A novel low power, low weight, erosion resistant, pneumatic actuators combined with a bi-stable latch is modeled and experimentally evaluated. The system has been demonstrated in a full-scale helicopter rotor blade using centrifugal pumping to inflate and deflate the rotor leading edge. The 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 push the ice onto the wing preventing ice removal, 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 Summer of 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.

Title: Anechoic Wind Tunnel Testing of Anti-Phase Vortex Reduction Control for Rotor Noise Suppression
Sponsor: NASA Ames.
PI: Jose Palacios
Students: Sihong Yan, Raja Akif Bin Raja Zahirudin

Summary: Palacios' group has also become active in the field of Unmanned Aerial System (UAS) Acoustic testing. Commercial manufactures are developing heavy-lift multi-rotor UAS for cargo and transportation purposes, such as the Boeing Heavy-lift project+ or the Uber Elevate Project. Certification procedures will be needed to ensure the safety of these commercial UAS units in the future. The team has fabricated and tested UAS rotor blades and is working with NASA to demonstrate their anti-phase vortex reduction rotor concept for noise suppression. An open section anechoic wind tunnel facility hoses a 19-microphone array that surrounds the rotor system. The effort tests a baseline off-the-shelf rotor (20 cm. radius) and the NASA proprietary rotor platform.

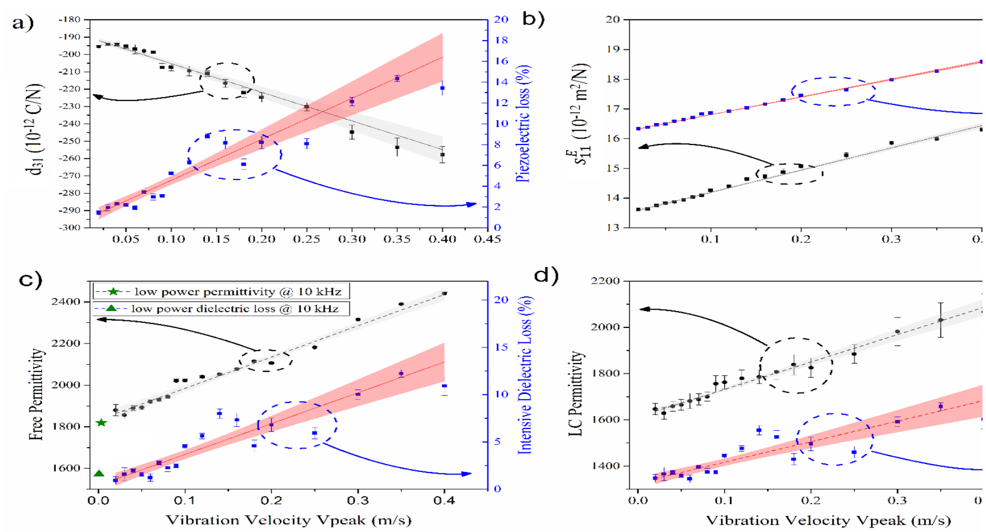


Schematic of co-axial UAS system with concentric microphone array, and photograph of the system installed in the anechoic wind tunnel.

Title: Loss Mechanisms in High Power Piezoelectric Single Crystals and Ceramics
Sponsor: Office of Naval Research
PI: Uchino
Students: Minkyu Choi (MatSE Ph.D.), Hossein Daneshpajooh (EE Ph.D.), Yuxuan Zhang (EE Ph.D.), Yoonsang Park (EE Ph.D.)
Summary: We clarify the macro- and microscopic mechanisms of the losses in piezoelectric single crystals and ceramics, aiming at development of high power density piezoelectric materials and devices for the Navy's application. This program is composed of three aspects: loss phenomenology, characterization methodology, and materials development.

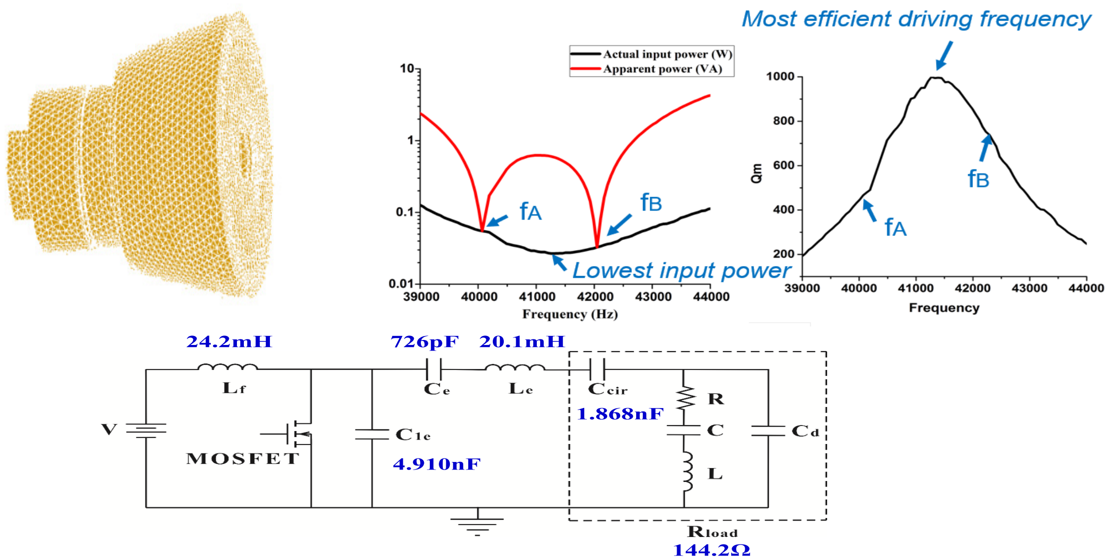
Three research topics were conducted During FY2018:

(1) **Permittivity Measurement at the Resonance**: Measurement of permittivity and dielectric loss was conucted at its resonance mode by using a newly developed Burst Mode HiPoCS. This is the world-first success in determine permittivity and dielectric loss at its resonance frequency region.



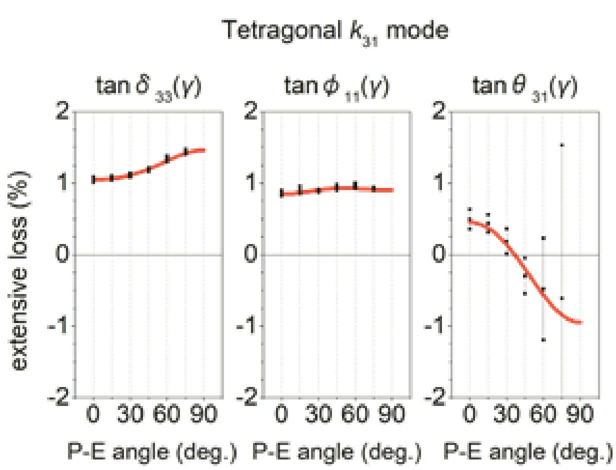
(a) Change in piezoelectric d_{31} and its loss factor, (b) change in elastic compliance s_{11}^{E} and its loss, change in free (c) and longitudinally-clamped (d) dielectric permittivity and their intensive and extensive loss factors with vibration velocity for PIC 255 (Soft PZT).

(2) **Frequency Dependence of Q_M**: Based on the maximum mechanical quality factor observed in a frequency in-between the resonance and antiresonance frequencies, the efficiency improvement of Langevin transducers was discovered (required power was reduced 1/3 of the resonance drive). Great discovery from the piezo-transducer operating viewpoint.



(a) Langevin transducer structure; (b) Apparent and actual electric power to generate the constant output mechanical vibration velocity 30 mm/s; (c) Mechanical quality factor measured using real electrical power (including the phase lag) for a Hard PZT APC 851 k31 plate; (d) Class E inverter with impedance converter. The required input power can be reduced by 1/3.

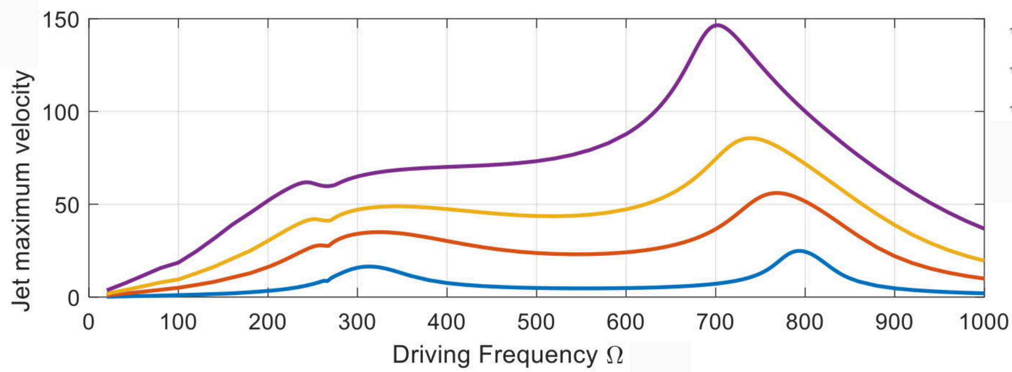
(3) **Crystal Orientation Dependence of Losses**: Dielectric, elastic and piezoelectric parameters and losses were measured in soft $Pb(Zr,Ti)O_3$-based piezoelectric ceramics as a function of the polarization direction in a k_{31} type plate specimens, in order to clarify the origin of the piezoelectric loss in terms of the domain wall dynamics. We discovered a negative extensive piezoelectric loss $\tan q_{31}$ in a tetragonal composition PZT in large P-E angle samples > 45°, which may accelerate the theoretical studies on domain dynamics.



Extensive loss parameters for effective k_{31} type vibration in Tetragonal PZT. Note the negative extensive piezoelectric loss in a tetragonal PZT in a high P-E angle range > 45°.

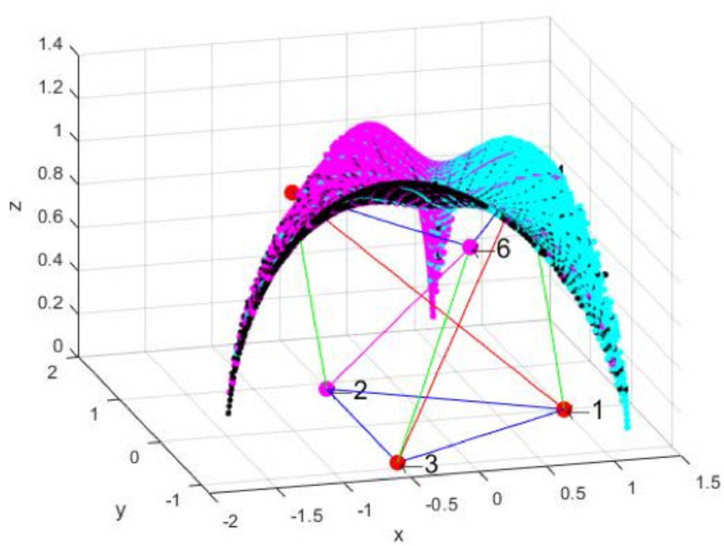
Title: Piezoelectric Actuators for Synthetic Jets
Sponsor: Boeing
Student: Tianliang Yu, Ph.D. August 2019 (expected).

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. A low-order coupled electro-elasto-acoustic model was developed as the basis for performance analysis and initial device optimization. A linear model does not accurately capture device response at different drive levels. A first-principles nonlinear damping model was developed to more accurately model losses. The optimal device determined using the nonlinear model offers about twice the net jet momentum as the device obtained using the linear model.



Title: Articulated Tensegrity Structures for Space Applications
Sponsor: US Government
Student: Kaila Roffman, M.S. August 2019 (expected); Ph.D. December 2022 (expected)

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, 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 states.



Title: Additive Manufacturing of Functional Hierarchical Shape Memory Alloys Structures
Sponsor: Defense Advanced Research Projects Agency
Principal Investigator: Hamilton

Summary: The proposed project will develop materials engineering approaches for LDED AM of lamellar shape memory alloy smart material structures (LSMAS) with tunable stiffness for vibration mitigation. The work is in collaboration with sub-contractor, Dr. Siddhartha Pathak. Dr. Pathak is an Assistant Professor of Chemical and Materials Engineering at the University of Nevada, Reno. Multi-scale thermo-mechanical experimentation and in-situ microstructure and mechanical characterization will bridge local shape memory properties to the performance of the bulk AM build. Data acquisition and analysis protocols will establish critical understandings of the energy loss dependence on the interplay between the geometrical and microstructural hierarchy.

Title: Endoscopic Flexible Pancreatic Tumor Ablation System with Reduced Force Effector and Specialized Ablation Zone
Sponsor: National Institutes of Health, with Actuated Medical Inc.
PIs: Frecker (PSU), Snook (AMI)
Student: Brad Hanks, Fariha Azhar

Summary: We are developing specially shaped deployable probe tips for radio frequency ablation of pancreatic cancer.
Title: Multifunctional Lithium Ion Batteries with Silicon Anodes
Sponsor: National Science Foundation
PIs: Rahn, Frecker, D Wang
Students: Jun Ma, Cody Gonzalez

Summary: Multifunctional Li-ion batteries that are capable of actuation and sensing, as well as energy storage, and being developed using modeling and experimental approaches.
Title: Design of multifield responsive material systems
PIs: Frecker, Ounaies
Student: Wei Zhang

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.
Title: Design for additive manufacturing (DFAM) of cellular contact aided compliant mechanisms (C3M) for energy absorption
PIs: Frecker
Students: Jivtesh Khurana, Brad Hanks

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.

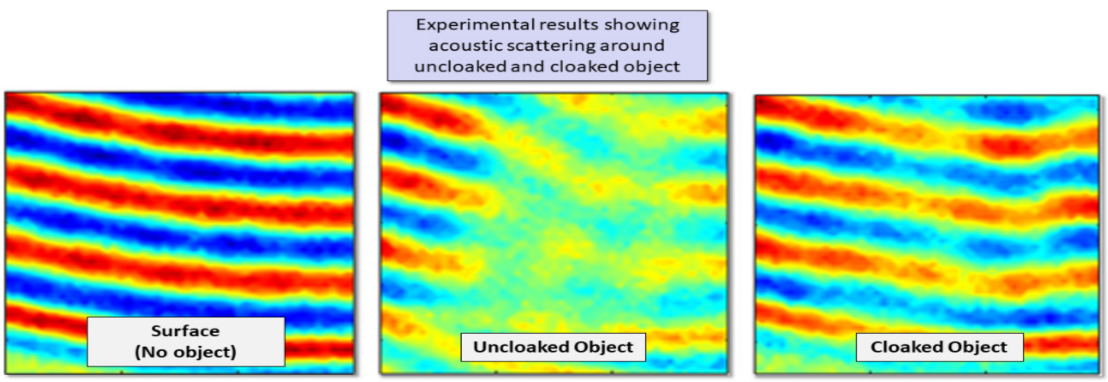
Acoustic Materials and Metamaterials

Amanda Hanford, Group Leader, ald227@psu.edu

The Acoustic Materials and Metamaterials technical group performs research in many areas involving the interaction between acoustics and materials. Example topics include material characterization, manufacturing techniques for novel materials, novel applications such as acoustic cloaking, metamaterial inverse design, active metamaterials, and structural vibration control through novel materials.

At the end of last year's CAV workshop, the Acoustic Materials and Metamaterials technical group hosted a successful short course in Acoustic Metamaterials. The short course covered key aspects of Acoustic Metamaterials and was taught by contributions from: Dr. Amanda Hanford (PSU), Dr. Douglas Werner (PSU), Dr. Claus Claeys (KU Leuven), Dr. Matthew Guild (Naval Research Laboratory) and Dr. Charles Rohde (Naval Research Laboratory)

Dr. Peter Kerrian recently graduated with his PhD in Acoustics (2018), 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. Dr Kerrian's work was presented by his advisor, Dr. Amanda Hanford, at the Acoustical Society of America's semiannual meeting in Minneapolis, May of 2018. As a result of media attention from the work presented, Dr. Hanford and Dr. Kerrian's work appeared in many popular science news outlets including USA today and BBC news.

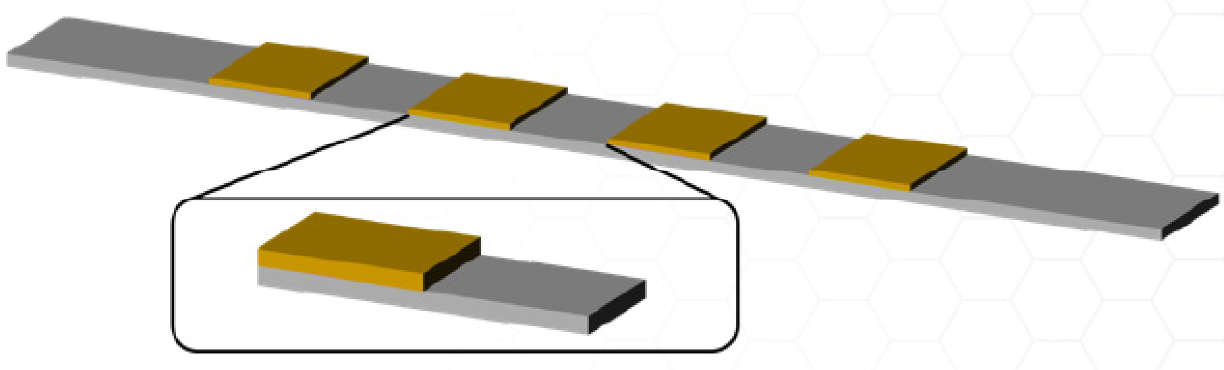


Other group work involves designing a metamaterial by performing unit cell analysis with subwavelength geometry. There are several techniques used for unit cell analysis when designing acoustic properties of interest for metamaterial applications. Such techniques include, but are not limited to, band diagrams, effective material properties, or half-space homogenization. Different work from the group evaluates the challenges and tradeoffs between analysis techniques and types of structures that lend to one method or another. Unit cell analysis methods are typically used to perform trade space exploration, including validation and parametric studies for metamaterial design.

Below are some other highlights of our group's recent work.

Title: Modeling and Optimization of an Active Acoustic Metamaterial
Sponsor: NAVSEA 073
PIs: Ben Beck and Rob Campbell
Student: Aaron Stearns (PhD Mechanical Engineering)

Summary: The research objectives are to (a) increase the bandwidths and adaptability of acoustic metamaterials for vibration control through application of active adaptable piezoelectrics, (b) optimize active acoustic metamaterials for vibration control for performance in specific frequency ranges, and (c) demonstrate effectiveness of modeling and optimization through experimental realizations. Current work is focusing on bonded piezoelectric actuators with attached shunt circuits on transversely vibrating structures.

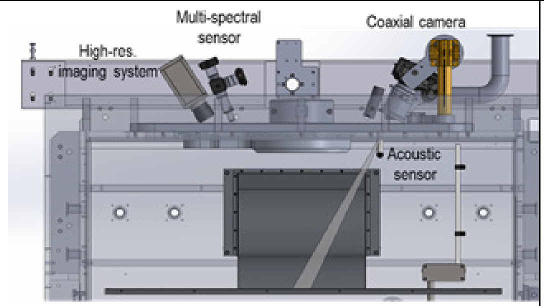


Title: Acoustic Metamaterials Survey Study
Sponsor: 3M
PI: Amanda Hanford

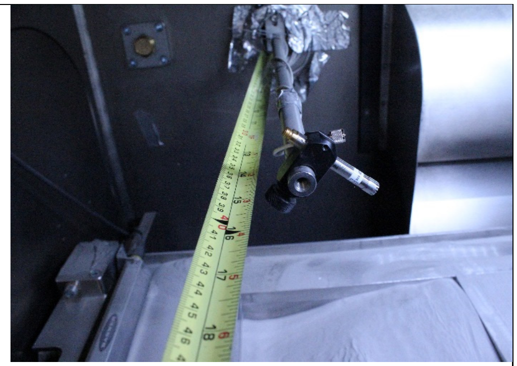
Summary: The objective of this work is to develop design and modeling expertise to optimize decorated membrane (DM) acoustic metamaterials for noise control solutions.

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

Summary: Powder Bed Fusion Additive Manufacturing offers both the capability to produce components that cannot be made by any alternative means as well as the capability to produce replicas of conventionally manufactured components on-site that might be difficult to deliver to remote platforms--offering a "component delivery by internet" logistical option. Acoustic monitoring of the deposition process during powder bed fusion additive manufacturing can be used for detecting flaws in components during the additive manufacturing process.



Commercial 3DS ProX320 with multiple sensors.

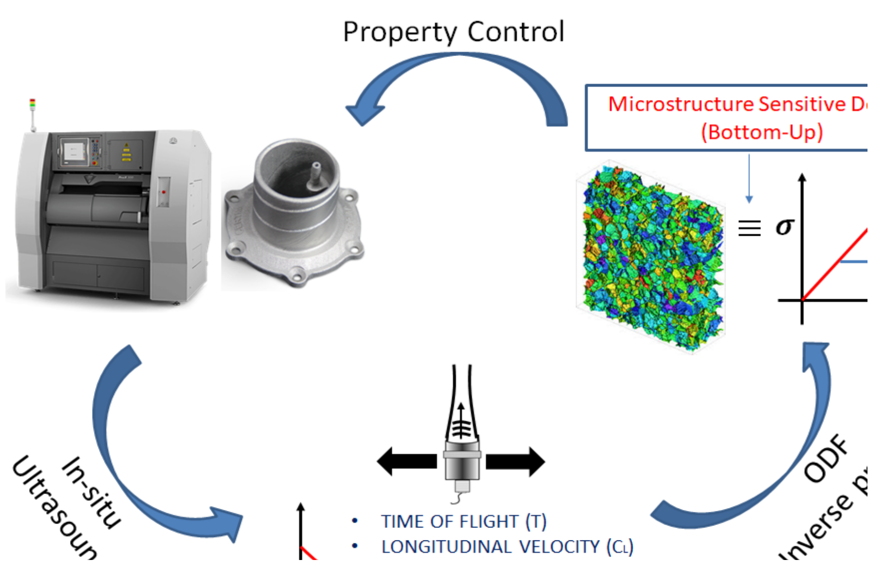


Left: *Typical additive manufacturing build chamber layout, showing monitoring cameras at off-axis locations for detection of flaws. Material is fused in horizontal layers in this image, and after each layer is complete, the build plate moves down a distance of one powder layer.*

Right: *Microphone placement for acoustic measurements relative to the build plate. As placed, the microphone is approximately 0.3 meters from the center of the build plate horizontally. In use, the average acoustic propagation delay is very significant in comparison with the particle size: at 1m/s scan, a 1 millisecond phase delay is one millimeter. However, it is possible to develop a map of the acoustic propagation delay over the build surface. Phase speed varies as the square-root of absolute temperature, and is thus not expected to be a large variable component in the achievable spatio-temporal synchronization.*

Title: A bottom-up approach to modeling wave propagation and scattering in polycrystalline materials
PI: Chris Kube
Student: Anubhav Roy

Summary: Traditional models of wave propagation and scattering in polycrystalline materials contain significant limitations because of infinite grain assumptions. Thus, they are not compatible with modern material design frameworks. The present work, based on discretizing microstructural functions into spherical harmonics, considers finite a number of grains. Wave propagation and scattering models in this approach align with a bottom-up approaches to microstructure-sensitive material design. Ultrasonic measurables are linked to the objective property in the material design. Here, a linkage between ultrasonic wave velocity and anisotropic Young's modulus is established during a material
design process that aggregates a grains one by one.



Propagation and Radiation

Vic 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 2018-2019 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 noise around airports including atmospheric profile 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.

Last year NASA wrapped up its SonicBAT project, which focused on the effects of atmospheric turbulence on low-boom sonic booms. The lead for this project was KBRwyle, and Penn State was a subcontractor on the effort. Penn State developed a new propagation code that includes the effects of atmospheric turbulence in addition to nonlinearity and loss mechanisms, and the code was validated against sonic boom measured data using actual F-18 supersonic overflights. This work was spearheaded by Graduate Research Assistant Trevor Stout, who completed his Ph.D. on the topic in December 2018. A number of journal manuscripts generated in the SonicBAT project are currently in preparation.

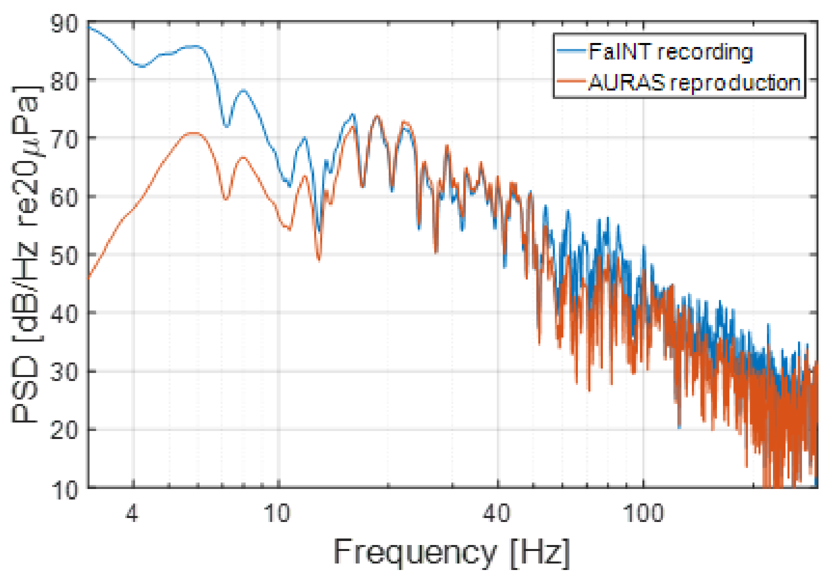
In 2018 Dr. Michelle Vigeant received tenure and was promoted to Associate Professor of Acoustics and Architectural Engineering. Congratulations, Michelle! She leads the Sound Perception and Room Acoustics Laboratory (SPRAL), which currently consists of 1 M.S. and 4 Ph.D. students. The most recent graduate from the group is Martin Lawless, who received his Ph.D. in Acoustics in May 2018. She is currently pursuing research in three areas: (1) concert hall acoustics, (2) office noise, and (3) aircraft noise.

Matthew Neal and Fernando del Solar are both researching topics on concert hall acoustics:

a) Neal is working on developing a metric to predict the perception of overall acoustic quality in concert halls. Subjective studies are underway where the stimuli are convolutions of spatial impulse responses taken from a subset of the 15 American and 6 European halls measured in 2017-18.
b) del Solar is investigating which octave band(s) are the most important in human perception of reverberance and clarity, with the goal of proposing single-valued weighted frequency averages of early decay time (EDT) and clarity index (C80), respectively, as design metrics.

In the second topic area of office noise, Zane Rusk has been exploring the effects of different levels of masking and intermittent noises on cognitive, physiological, and perceptual responses. Cognitive tasks include those to evaluate possible effects of the different noise environments on memory, reasoning, concentration and memory.

In the final topic area of supersonic aircraft noise, Dr. Vigeant is working in collaboration with Dr. Sparrow. Nick Ortega and Jonathan Broyles have bee studying human response to a special type of noise generated from supersonic flight that is produced when aircraft fly slightly above the speed of sound around Mach 1.3 – known as Mach cut-off. Nick studied the relationship between the perceptual attribute of thunderous and annoyance, while Jonathan is studying the degree to which these signals are annoying relative to other traffic noise, i.e. road, rail, and subsonic aircraft.



Measured and reproduced Mach cutoff signature in AURAS

Other Projects:

Title : Degree of annoyance due to Mach cut-off flight
Sponsor: FAA
PI: M. Vigeant
Student: Jonathan Broyles, M.S. expected Summer 2020

Title: Assessing new perceptual aspects of concert hall acoustic metrics through 3rd order Ambisonics auralizations
Sponsor: Penn State College of Engineering
PI: M. Vigeant
Student: Fernando del Solar Dorrego, Ph.D. expected Summer 2021

Title: Improved sonic boom models for lateral cutoff and over the top booms
Sponsor: NASA
PI: V. Sparrow
Student: William Doebler, Ph.D. expected Summer 2021

Title: Corrected three-dimensional ray theory for the prediction of Mach cut-off sonic boom
Sponsor: FAA
PI: V. Sparrow
Student: Zhendong Huang, Ph.D. expected Fall 2019

Title: Low frequency noise of aircraft noise transmission from outdoors to indoors
Sponsor: FAA
PI: V. Sparrow
Student: Beom Soo Kim, Ph.D. expected Fall 2019

Title: Predicting perceived acoustical quality of concert halls using a combination of room acoustics metrics
Sponsor: NSF
PI: M. Vigeant
Student: Matthew Neal, Ph.D. expected Summer 2019

Title: Investigating the degree of resolution needed when using measured head related transfer functions (HRTFs) for room acoustics listening tests
Sponsor: College of Engineering Graduate Excellence Fellowship
PI: M. Vigeant
Student: Nick Ortega, Ph.D. expected Fall 2021

Title: Uncertainty and validation for aircraft noise propagation predictions
Sponsor: FAA
PI: V. Sparrow
Student: Harshal Patankar, Ph.D. expected Fall 2021

Title: Meteorological reanalysis data inputs for improved aircraft noise modeling
Sponsor: FAA
PI: V. Sparrow
Student: Rachel Romond, Ph.D. expected Fall 2019

Title: Effects of open-office acoustics on cognitive, physicological and perceptual responses.
Sponsor: Industry
PI: M. Vigeant
Student: Zane Rusk, Ph.D. expected Summer 2023

Title: Simulation of N-wave and shaped supersonic signature turbulent variations
Sponsor: KBRwyle/NASA
PI: V. Sparrow
Student: Trevor Stout, Ph.D. earned December 2018

Title: Improved sound mapping tools using Python and ArcGIS
Sponsor: U.S. National Park Service
PIs: V. Sparrow and P. Newman
Student: Nathan Tipton, M.S. expected Summer 2019

Title: Analysis of a certification procedure for supersonic overflights
Sponsor: FAA
PI: V. Sparrow
Student: Luke Wade, Ph.D. expected Summer 2022

CAV Contact Information

Dr. Stephen A. Hambric

Director
ARL/Penn State
PO Box 30
State College PA 16804
Tel: 814-863-3030
Cell: 814-404-0653
Email: sah19@arl.psu.edu

Dr. Clifford Lissenden

Associate Director
Penn State University
411D EES Building
University Park PA 16802
Tel: 814- 863-5754
email: cjl9@psu.edu

Diane Bierly

Coordinator
302 Earth and Engineering Sciences Building
Tel: 814-863-6491
Email: dkb11@psu.edu

Kelly Driftmier

Workshop and Corporate Sponsor Liaison
225 Penn State Conference Center
Tel: 814-865-9202
Email: kmd5315@psu.edu

Mark Your Calendar for the 2020 CAV Workshop!

Tuesday-Wednesday, 27-28 October 2020 | Penn State Hetzel Union Building (HUB)