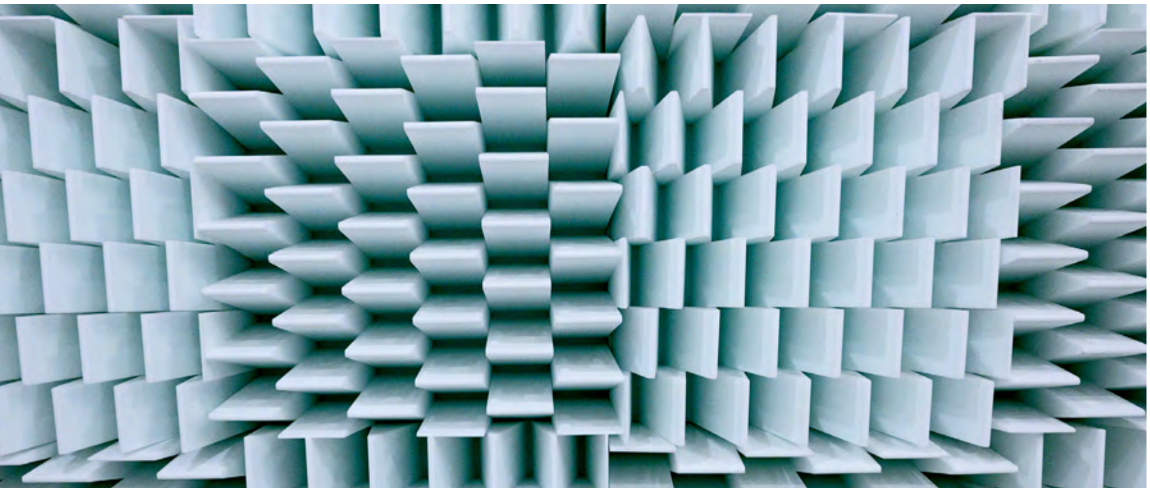

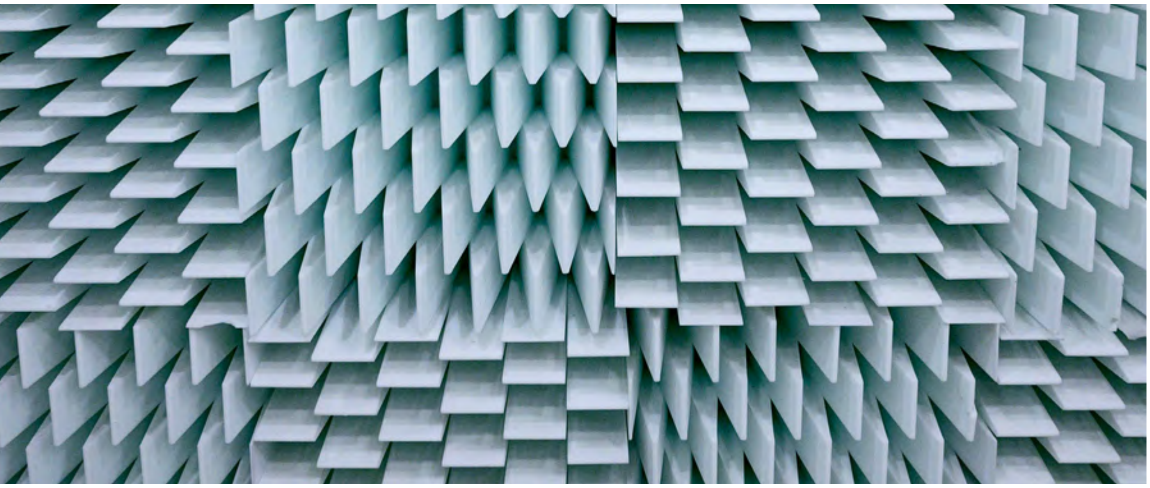

CENTER FOR ACOUSTICS AND VIBRATION

Newsletter 2021

PennState College of Engineering | CENTER FOR ACOUSTICS AND VIBRATION

Note from the Director

Assembling our annual Center for Acoustics and Vibration (CAV) newsletter is a highlight of my year. This time, however, I had lowered my expectations due to the difficulties our students and faculty faced as they tried to continue their research with lab access restrictions due to the pandemic. Instead, I was amazed at the breadth and quality of work going in our groups—I hope you are as well. My thanks to all for their diligence and perseverance during a challenging year.

You will notice a new technical group in the highlights section: Artificial Intelligence and Machine Learning in Vibration in Acoustics. We held a special roundtable on this emerging topic at last year's CAV workshop and, based on its popularity, started up the new group, co-directed by Daning Huang and Karl Reichard. Read more in our feature article on the group on page 4 of the this newsletter.

Holding our workshop online led us to recording our sessions, which in turn led to the obvious creation of a CAV YouTube page. We've arranged our videos into playlists for workshops and our semester seminars. After a sparse selection of seminars last fall, we are grateful to our spring speakers, particularly those from outside Penn State who would normally have visited us in person, for a strong collection of talks, accessible on our YouTube channel.

The pandemic, while a horrible tragedy for so many, has led us to change how we operate—for the better. While we plan to hold our fall workshop (October 19-21) in person this year, we will also stream our talks and archive them on the YouTube channel. While the workshop is best experienced in person for its networking and camaraderie, streaming will reach a wider audience, including those who may not be able to travel or be comfortable with traveling yet.

To our sponsors—thank you so much for your continued support even though you haven't been able to connect with us in person. We look forward to reengaging with you at your locations or on campus soon. We also very much hope many of you can join us at the fall workshop—we have a lot of catching up to do.

– Steve Hambric // sah19@psu.edu

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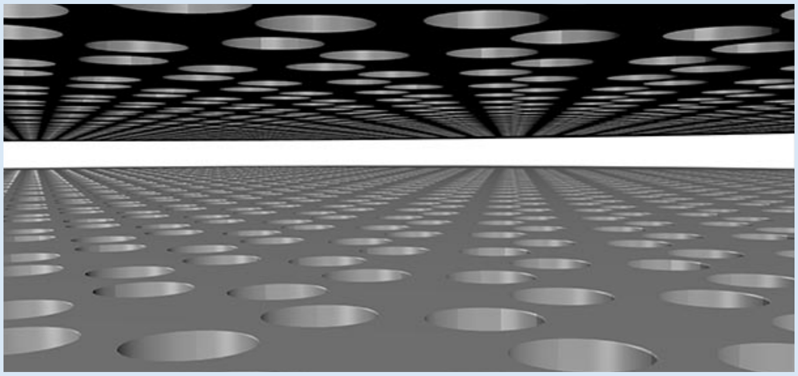

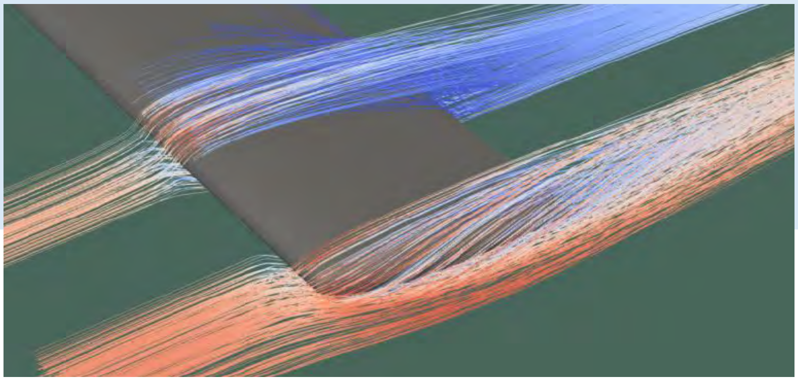

Featured Stories

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CAV initiates new artificial intelligence and machine learning in vibration and acoustics research group

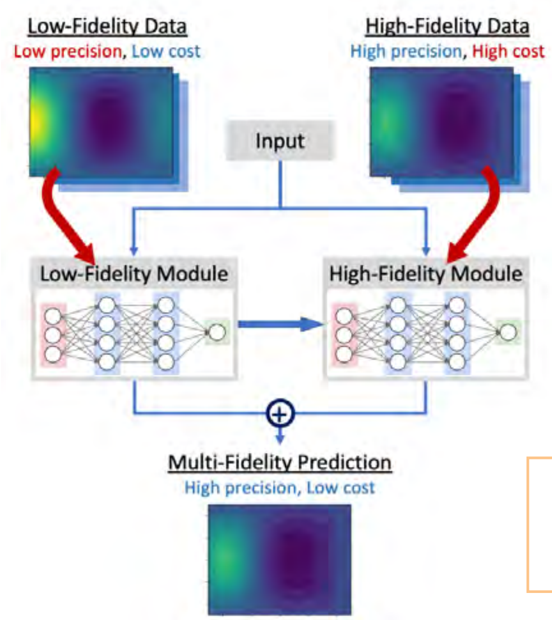
"The mission of the artificial intelligence and machine learning technical group is to explore and leverage applications of AI and ML in all areas of acoustics and vibration. The overarching goal of the group is to solve traditionally challenging problems in acoustics and vibration, particularly involving sensing, prediction, estimation, and control, in realistic industrial scenarios. The methodology of AI and ML ranges from the conventional supervised and unsupervised learning to the more sophisticated operator-theoretic and information-theoretic methods, and to active, transferrable, and explainable learning."

The roundtable on artificial intelligence (AI) and machine learning (ML) in vibration and acoustics was the most attended session at our fall 2020 Center for Acoustics and Vibration (CAV) workshop, bit.ly/CAV_AIML. During the roundtable, our sponsors overwhelmingly supported starting a new technical research group in that area. Daning Huang, assistant professor of aerospace engineering and acoustics, and Karl Reichard, associate research professor in the Penn State Applied Research Lab and in acoustics, are leading the new group.

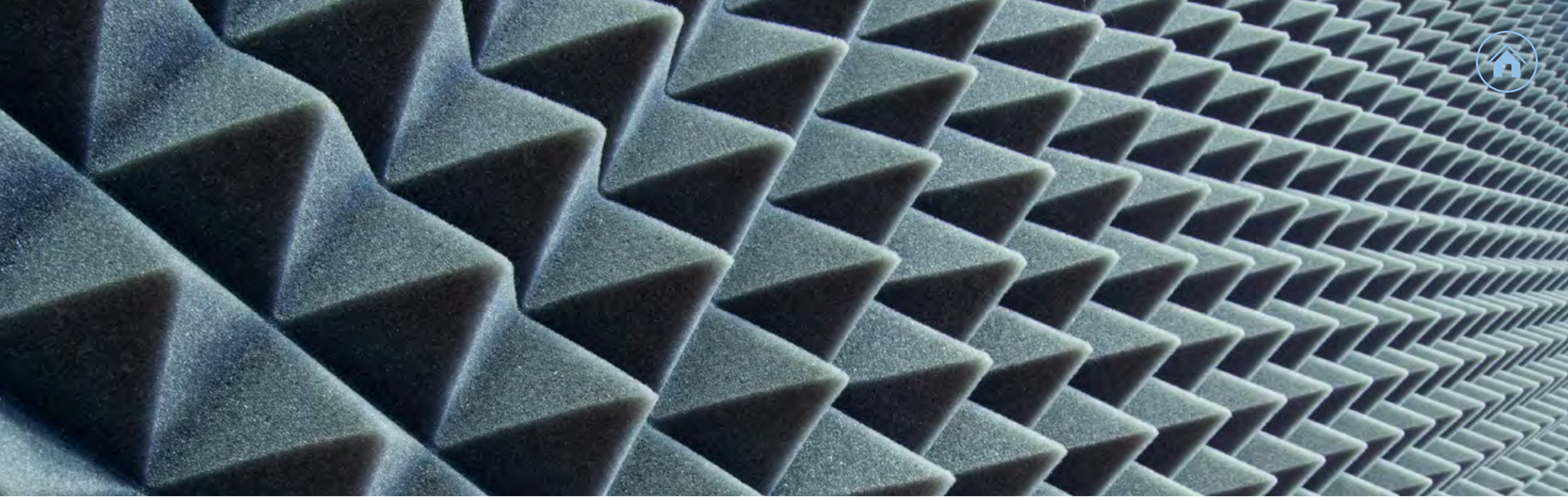
The group's current list of research topics includes:

- Reduced-order modeling of multidisciplinary dynamical systems
- Data-augmented design and optimization of complex mechanical systems
- Feature engineering and extraction, representation, and mining of big measurement data sets
- Multi-fidelity multi-variate information fusion and predictive inference
- Data-driven predictive analytics and decision making
- Classification and pattern recognition

According to Huang and Reichard, the field of AI and ML is changing rapidly. They expect the group's research topics to evolve and grow quickly.



Example of reduced-order modeling of multidisciplinary dynamical systems



CAV Virtual Workshop 2020

The 2020 Center for Acoustics and Vibration (CAV) annual workshop was held virtually and featured talks led by the CAV faculty, students, and international liaisons, with the largest student poster competition yet. Interacting in person was missed during the workshop, but plans to resume the workshop series at Penn State University Park this fall are in the works. View the archived talks on the CAV YouTube channel: bit.ly/CAVW-channel

The CAV channel includes playlists for:

- Pre-recorded talks from each technical group
- Pre-recorded talks from each international liaison
- Pre-recorded talks for the roundtable on AI and ML in vibration and acoustics
- Archives of the live sessions, which included short versions of the pre-recorded talks and discussions with our attendees

For the student poster competition, CAV used iPoster. Students' posters can be viewed here: bit.ly/CAV-PosterComp

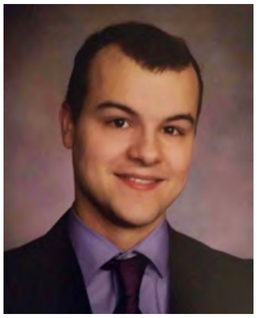
The three student winners were:

Daniel Giraldo Guzman

"Topology optimization design of metamaterials to control surface wave propagation"

Janna Sloand

"Ultrasound sensitive nanopeptisomes as theranostic for deep vein thrombosis"



Jake Elliott

"Passive cavitation imaging of focused ultrasound in an elastic phantom"

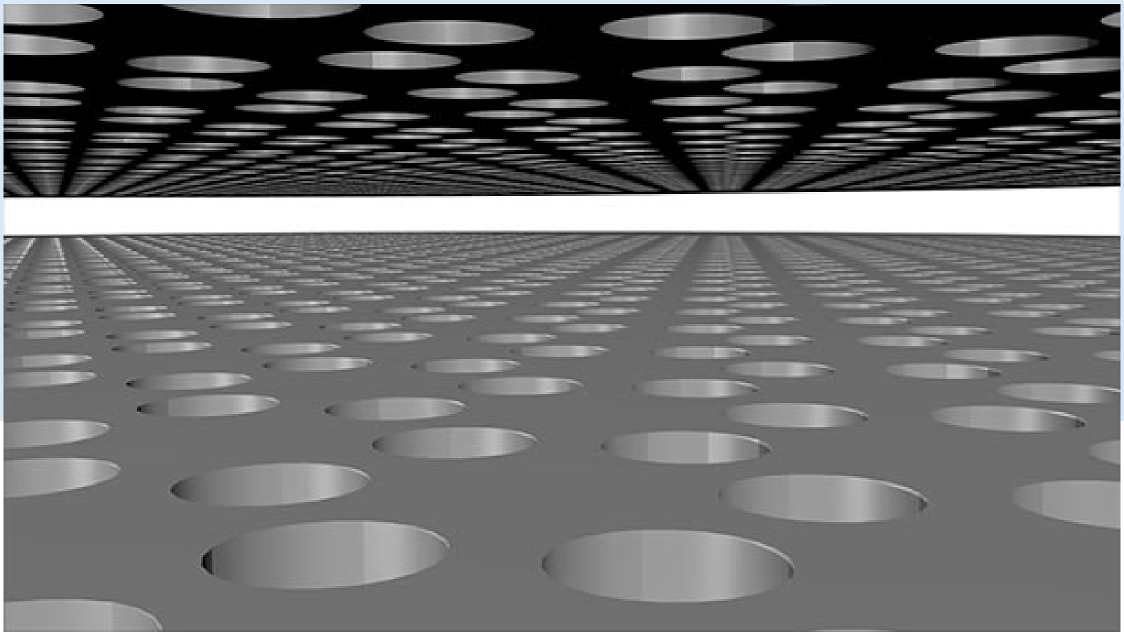
Save the Date: CAV Annual Workshop 2021

Mark your calendars for the 2021 CAV workshop planned for October 19-21 at the Penn State Hetzel Union Building (HUB)!

CAV Seminars Information

CAV members may access our previous lunchtime seminar series online. Each CAV group hosts seminars every semester. You can find links to our most recent archived seminars on the CAV YouTube channel (bit.ly/CAVW-channel) and links to older seminars on the CAV website (bit.ly/CAV-SeminarArchive).

Speaker	Affiliation	Date	Seminar Topic
Jackie O'Connor	Penn State Mechanical Engineering	June 19, 2020	Introducing the Penn State Center for Gas Turbine Research, Education, and Outreach
Stephen Hambric	Penn State CAV	July 15, 2020	Fantastic Vibroacoustic Resources and Where to Find Them
Daning Huang	Penn State Aerospace Engineering	February 23, 2021	Surrogate and Reduced-Order Modeling for Enabling Efficient Aerothermoelastic Design and Analysis of Hypersonic Structures
Yun Jing	Penn State Graduate Program in Acoustics	April 1, 2021	Bilayer phononic and photonic graphene: a new playground for twistronics
Hong Chen	Washington University in St. Louis	April 14, 2021	Targeting the brain with focused ultrasound
Andrea Arguelles	Penn State Engineering Science and Mechanics	April 28, 2021	Ultrasound Beyond Imaging: Quantitative Tools for Materials Characterization
Roland Platz	Deggendorf Institute of Technology, Germany	May 6, 2021	Approaches for Semi-Active and Active State Control in Structural Dynamics under Uncertainty
Ted Worden	Naval Surface Warfare Center, Carderock Division	May 11, 2021	Aeroacoustic Characteristic of Supersonic Impinging Jets



A visualization of the acoustic graphene array.

Researchers apply nanoscale graphene 'magic' angle to acoustics

By Gabrielle Stewart

Two atomically thin carbon sheets stacked on top of each other, called bilayer graphene, exhibit unique properties when one of the layers is twisted at a certain angle—a "magic" angle. The study of magic and other angle misalignments between two layers of material and their effects on material properties has been dubbed twistronics, a rapidly expanding field of condensed matter physics.

To bring twistronics to the macroscale, a team of Penn State researchers has designed an acoustic equivalent of magic-angle bilayer graphene. Their paper was recently accepted" to "was published" and add bitly link in parantheses after journal name (bit.ly/physical-revb)

"Examining analogues of condensed matter physics concepts can give us new ideas and applications in acoustics," said Yun Jing, associate professor of acoustics and biomedical engineering.

In a simulation, the research team built the acoustic design from a flat plate containing a hexagonal pattern of holes analogous to the arrangement of atoms in graphene at the nanoscale. They added another graphene-like plate layer, aligning the plates but leaving a vertical air gap between the two, and twisted the top plate. This twist created a characteristic Moiré pattern—also seen in typical magic-angle graphene—resulting from two overlaid similar patterns where one is slightly rotated or offset.

Researchers then simulated the movement of sound waves within the array. They found that as waves propagated between the plates at certain twist angles, acoustic energy concentrated around specific areas of the Moiré pattern where holes on the top and bottom layers aligned. This behavior, the researchers said, mirrored the behavior of electrons in magic-angle graphene at the atomic scale.

"Electrons moving through materials like graphene are similar mathematically to acoustic waves moving through the air between repetitive structures," said Yuanchen Deng, doctoral student in acoustics.

These similarities can help researchers theoretically explore further applications of conventional magic-angle graphene without the restrictions that come with experimenting on it, the team said. Their acoustic system would be easier to fabricate in a laboratory because it's not designed at the nanoscale, Jing said, and the twist would be easier to control given the sample's larger size.

The researchers also found that their setup created new possibilities for exploring magic angles, for which existing research has focused on small angles below three degrees. The researchers could manipulate the distance between the graphene plates to control the magic angle—something extremely difficult for magic-angle graphene at the nanoscale. The researchers found that their development yielded a much larger number of magic angles than previously thought.

"With a larger twist angle, we can reduce the size of the structure," Jing said. "Samples will be easier to simulate and eventually fabricate."

The concentration of wave energy in certain locations of the acoustic graphene array could have applications for energy harvesting. If the graphene plates are engineered to be piezoelectric at the regions where the acoustic energy is confined, they could convert mechanical energy from acoustic wave vibrations into electrical energy. With further research, acoustic magic-angle graphene could become suitable for collecting energy in a variety of scenarios.

The researchers plan to examine further possibilities for the acoustic magic-angle graphene as well as expand their research into areas concerning different types of waves.

"Bringing this bilayer setup into the macroscopic scale, you can experiment with different structures and waves," Deng said. "Our system is acoustic but can provide feedback for any systems using mathematical functions similar to wave equations."

Penn State's Kenji Uchino retires

By Tessa Pick

After contributing almost 30 years of teaching and research to Penn State, Kenji Uchino will retire in December. Uchino served as the founding director of the International Center for Actuators and Transducers at the Penn State Materials Research Institute and a professor of electrical engineering.

Uchino earned his doctoral degree from the Tokyo Institute of Technology in Japan in 1976, and then became a research associate and assistant professor in the institute's physical electronics department. In 1985, he joined Sophia University in Japan as an associate professor in physics before coming to Penn State in 1991.

From 2004 to 2010, Uchino served as the founder, senior vice president, and chief technical officer of Micromechatronics Inc. in State College, Pennsylvania. From 2010 to 2014, he was the associate director of global technology awareness at the U.S. Office of Naval Research.

Considered by many as a pioneer of piezoelectric actuators, Uchino's research in solid-state physics, specifically in ferroelectrics and piezoelectrics, covers a breadth of topics in the field, including basic research on theory, materials, device designing and fabrication processes, as well as application development of solid-state actuators/sensors for precision positioners, micro-robotics, ultrasonic motors, smart structures, piezoelectric transformers, and energy harvesting. Uchino is known in the field as the inventor and discoverer of the following topics: lead magnesium niobate (PMN)-based electrostrictive materials; cofired multilayer piezoelectric actuators (MLA); superior piezoelectricity in relaxor-lead titanate-based piezoelectric single crystals (PZN-PT); photostrictive phenomenon; shape memory ceramics; magnetoelectric composite sensors; transient response control scheme of piezoelectric actuators (Pulse-Drive technique); micro ultrasonic motors; multilayer disk piezoelectric transformers; and piezoelectric loss characterization methodology. He continues to conduct research in many of these areas.

Uchino has authored 582 papers, eighty-three books, and thirty-three patents in the ceramic actuator area. Fifty-five of the papers/books among his publications have been cited more than 100 times, leading to an average h-index of seventy-eight. His work has been cited a total of 32,000 times, and his annual average citation number is 1,500.

Uchino has been a life-time fellow of the American Ceramic Society since 1997, a fellow life member of IEEE since 2012, and a senior member of the National Academy of Inventors since 2019. He has received thirty-one awards/honors over the years, including the Wilhelm R. Buessem Award from the Center for Dielectrics and Piezoelectrics at Penn State in 2019; Distinguished Lecturer of the IEEE UFFC Society in 2018; the International Ceramic Award from Global Academy of Ceramics in 2016; the IEEE-UFFC Ferroelectrics Recognition Award in 2013; the Inventor Award from Center for Energy Harvesting Materials and Systems at Virginia Tech in 2011; and the Premier Research Award from the Penn State Engineering Alumni Society in 2011.

New Faculty Biography

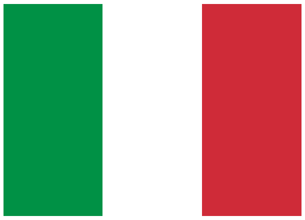
Ryan Harne

MECHANICAL ENGINEERING

James. F. Will Career Development Associate Professor of Mechanical Engineering

Ryan Harne is the James F. Will Career Development Associate Professor in the Penn State Department of Mechanical Engineering, where he directs the Laboratory of Sound and Vibration Research. Harne earned his doctorate degree in mechanical engineering at Virginia Tech in 2012. Previously, Harne served as a research fellow at the University of Michigan and as an assistant professor at The Ohio State University. His research expertise spans acoustics, mechanics, dynamics, vibrations, materials, electronics, applied math, and manufacturing. He has led research efforts yielding more than eighty publications, two patents, one book, twenty-five student awards, and one startup company. Harne is an active member of the American Society of Mechanical Engineers (ASME), Acoustical Society of America (ASA), and the International Society for Optics and Photonics (SPIE), serving in multiple organizational roles. Harne's contributions to science and engineering have been acknowledged with many awards, including the 2020 ASME CD Mote Jr. Early Career Award, the 2019 ASME Gary Anderson Early Achievement Award, the 2018 National Science Foundation CAREER Award, the 2017 ASME Best Paper Award in Structures and Structural Dynamics, the 2016 ASME Haythornthwaite Young Investigator Award, and the 2011 ASA Royster Award. He currently serves as an associate editor for ASME Journal of Vibrations and Acoustics and for the Journal of the Acoustical Society of America, Proceedings of Meetings on Acoustics.

International Liaisons



Centro Italiano Ricerche Aerospaziali (CIRA), Italy

Consortium for Sound and Vibration Research at Hong Kong Polytechnic University, Hong Kong

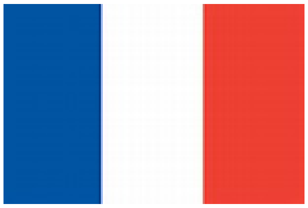
Deutsches Zentrum fur Luft und Raumfahrt (DLR), Germany

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

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CAV Member and Student Honors and Awards

George Lesieutre, associate dean for research and graduate programs and professor of aerospace engineering and acoustics, has been awarded the SPIE 2020 Smart Structures and Materials Lifetime Achievement Award. Lesieutre was recognized for his contributions to the field that impacted its early growth and direction. In particular, he pioneered developments in a breadth of adaptive structures technologies and applications to flight structures, including shunted piezoelectric materials for energy harvesting and vibration control; key insights into and exploitation of electro-mechanical coupling; solid-state and rectifying actuators for flight control; and morphing structures.

Reginald F. Hamilton, associate professor of engineering science and mechanics, was awarded the 2019 Defense Advanced Research Projects Agency Young Faculty Award. 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.

The following students and faculty received the Eugene J. Skudrzyk Award:

- **Jun Ji,** advised by Yun Jing
- **Trevor Jerome,** advised by Micah Shepherd

The following students and faculty received the Kenneth T. Simowitz Award:

- **Chad Smith,** advised by Thomas Gabrielson
- **Eric Rokni and Scott Zinck,** advised by Julianna Simon
- **Yuanchen Deng,** advised by Yun Jing
- **Molly Smallcomb and Jacob Elliott,** advised by Julianna Simon
- **Matthew Neal,** advised by Michelle Vigeant

The following students and faculty received the Kenneth T. Simowitz Citation:

- **Dan Watson,** advised by Karl Reichard
- **Gary Rhoades,** advised by Micah Shepherd

CAV 2020 Graduate Student Theses

You can access graduate students' theses on the CAV website at: bit.ly/cav-stu-theses.

NAME	PROGRAM	DEGREE	TITLE
Jerome, Trevor	Acoustics	Ph.D.	Determining Contact Stiffness, Contact Pressure, and Modal Frequencies of Fastened Metallic Joints
Pyzdek, Andrew	Acoustics	Ph.D.	Centered Coprime Array Performance in the Shallow Water Environment
Wells, Stephen	Acoustics	Ph.D.	Industrial Chiller Systems Using a Hybrid Statistical Energy Simulation Based on Experimental and Finite Element Methods
Huang, Zhendong	Acoustics	Ph.D.	3-D Acoustic Ray-Tracing Model of Mach Cutoff Flight
Goldschmidt, Margalit	Aerospace Engineering	Ph.D.	Design, Control, and Acoustics of a Marine Hydrokinetic Cycloturbine Vehicle
Prakash, Keerti	Aerospace Engineering	Ph.D.	Fiber Reinforced Composites with Carbon Nanotubes for Structural Damping of a Rotorcraft Blade
Walters, Gage	Mechanical Engineering	Ph.D.	Application of Generalized Polynomial Chaos to Flow-Induced Vibration and Sound

NAME	PROGRAM	DEGREE	TITLE
Botre, Mrunali	Aerospace Engineering	Ph.D.	Rotorcraft noise prediction system validation and analysis for generating noise abatement procedures
Corle, Ethan	Aerospace Engineering	Ph.D.	Time-Domain Aeroelastic Stability Predictions of a Semi-Span Tiltrotor
Gawali, Sumeet	Acoustics	M.S.	Effects of Perturbations on the Reverberant Sound Field of a Room
Krainc, Kathryn	Acoustics	M.S.	Vibrational Analysis of Ash and Composite Hurleys
Ambaskar, Adwait	Acoustics	M.S.	Improved Outdoor Sound Propagation Model Using Geographic Information Systems Software and ISO 9613-2
Bradel, Joseph	Acoustics	M.S.	Investigation of Transducers in Small Enclosures
Downey, Keagan	Acoustics	M.S.	Loudspeaker Array and Testing Facilities for Performing Large Volume Active Noise Cancelling Measurements
Ochoa, Ana	Acoustics	M.S.	Three-Channel Correlation Analysis in Mems and Electret Microphones
Rhoades, Gary	Acoustics	M.S.	Measuring Plate Vibration Using Deflectometry: The Advantages and Limitations of Add-On Reflective Material
Mukherjee, Bhaskar	Aerospace Engineering	M.S.	A Preliminary Investigation of Propeller-Wing Interaction Noise for eVTOL Aircraft
Scupski, Nick	Aerospace Engineering	M.S.	Experiments On The Reduced Noise Benefits of A New Configuration of Fluid Shields In Aircraft Engine Exhaust Nozzles
Yao, Yao	Aerospace Engineering	M.S.	Soft Optoelectronic Skins for Flexible and Foldable Structures
Hahn, Michael	Materials Science and Engineering	M.S.	Flexoelectricity in the Barium Strontium Titanate (BST) System for Hydrophones
Jaworski, Thomas	Aerospace Engineering	M.S.	Development of an Acoustic Prediction System for Conceptual Design and Analysis of Rotorcraft
Blessington, Ryan	Aerospace Engineering	M.S.	Passive Balancer Development for Rotor Systems in Icing Conditions
Romero, Moniara	Electrical Engineering	M.S.	Wireless underwater-to-air communications via water surface modulation and radar detection
Sadroleslami, Sohail	Architecture	M.S.	Seeing Noise : the Correlations between Urban Configuration and Spatial Perception of Noise in NYC
Broyles, Jonathan	Architectural Engineering	M.S.	Structural-Acoustic Optimization of Shaped Concrete Floors in Buildings
Kore, Rugved	Industrial Engineering	M.S.	Development and Evaluation of Anti-Vibration Toolkit for a Pneumatic Blueberry Handheld Harvester
Strollo, John	Mechanical Engineering	M.S.	The Effects of Hydrogen on Steady-State and Transient Combustion Characteristics
Carder, Nick	Acoustics	M.S.	Viability of Motor Current Sensors for Tool Condition Monitoring During Peck Drilling Operations with Coolant and Inverter-fed AC Motors
Furlong, Trent	Acoustics	M.S.	Tool Condition Monitoring Using the Hilbert-Huang Transform: An Application to Vibration and Motor Current Signals

Penn State Graduate Program in Acoustics Distance Education Courses

The Graduate Program in Acoustics at Penn State is a unique interdisciplinary program leading to master of science and doctorate in acoustics. The program is focused entirely on acoustics, a subject touching many diverse disciplines such as architectural acoustics, biomedical ultrasound, noise and vibration control, transducer design, underwater acoustics, signal processing, aeroacoustics, structural vibration, speech and communication, outdoor propagation, computational methods, and more.

www.acs.psu.edu

Fall 2021 Distance Education Course Schedule

CLASS DATES

Class Dates: August 23–December 17

- All classes video streamed and archived for review
- All courses available for credit or audit

TUITION FEE

Tuition rate and IT fee for Fall 2021 will be approximately $2,900.00 for a 3-credit course. The exact amount will be decided this summer by the Penn State Board of Trustees and will be posted at that time.

In order to guarantee fall course enrollment: All NEW non-degree student applications and application fees or Resume Study non-degree student requests must be completed with The Graduate School no later than 5:00 PM ET, Friday, August 13.

All Resume Study DEGREE student requests must be completed with The Graduate School no later than 5:00 PM ET, Monday, August 16.

COURSE SCHEDULE

ACS 501: ELEMENTS OF ACOUSTICS AND VIBRATION
Instructor: Dan Russell
Credits: 3
Tuition: See Tuition Fee announcement above.
Prerequisite: Undergraduate physics, differential equations, and complex numbers.
Course Material: This course introduces the fundamentals of acoustics and vibration, focusing on structural vibration and sound waves in simple objects such as mass-spring systems, strings, rods, and plates. The fundamental concepts of vibration are presented along with applications to engineering and industrial problems. Topics covered: simple harmonic oscillator; mechanical resonance and damping; forced vibration and normal modes; transverse waves on strings; boundary conditions and standing waves; elasticity; longitudinal, torsional, and transverse vibration of bars; transverse vibrations of membranes; and flexural vibrations of thin plates.
Text: TBA

ACS 502: ELEMENTS OF SOUND WAVES IN FLUIDS
Instructor: Julianna Simon
Credits: 3
Tuition: See Tuition Fee announcement above.
Prerequisite: Undergraduate physics and differential equations.
Course Material: This course lays the fundamental groundwork for the propagation of acoustic waves in fluids. Topics include: basic equations of fluid dynamics, development of the linear wave equation, acoustic lumped elements, speed of sound, linear acoustic wave propagation of plane and spherical waves, radiation of sound from sources and arrays, sound intensity and power, reflection and transmission of sound at boundaries, absorption of sound, propagation of sound in pipes and acoustic filters.
Text: Fundamentals of Physical Acoustics, Blackstock, David T., 2000 (Wiley)

ACS 503: SIGNAL ANALYSIS FOR ACOUSTICS AND VIBRATION
Instructor: Dan Brown
Credits: 3
Tuition: See Tuition Fee announcement above.
Prerequisite: Undergraduate physics, differential equations, and complex numbers as well as some familiarity with programming in MatLab or equivalent.
Note: This course replaces ACS 516, Acoustical Data Measurement and Analysis. Students may enroll in this course if they have not taken ACS 516. Students who have previously taken ACS 516 may not enroll in this course.
Course Material: Time- and frequency-domain analyses for sampled, discrete-time acoustic and vibration measurements. Development, application, and consequences of filtering, spectral analysis, and correlation for single- and multi-channel data.
Text: Instructor notes.
Software: MatLab or MatLab Student Version, available at webapps.psu.edu.

ACS 519: SOUND AND STRUCTURE INTERACTION
Instructor: Steve Hambric
Credits: 3
Tuition: See Tuition Fee announcement above.
Prerequisite: ACS 501, Elements of Acoustics and Vibration, and ACS 502, Elements of Sound Waves in Fluids
Course Material: This course mixes fundamental theory and real-world approaches to modeling and solving structural-acoustic problems. Classic and current journal articles supplement the instructor's course notes and the textbook. Topics include: flexural waves in beams, plates, and shells; sound radiation; structural vibration induced by impinging sound waves; forced response; sound transmission loss; coupled behavior of structures and enclosed acoustic volumes; and numerical vibroacoustic methods (Finite Element Analysis, Boundary Element Analysis, Statistical Energy Analysis).
Text: Engineering Vibroacoustic Analysis, Hambric, Nefske and Sung, 2016 (Wiley)

ACS 597: NONLINEAR ACOUSTICS
Instructor: Vic Sparrow
Credits: 3
Tuition: See Tuition Fee announcement above. ACS 502,
Prerequisite: Elements of Sound Waves in Fluids, or instructor approval
Course Material: Review of thermoviscous linear sound; nonlinear equations of acoustics; steepening and harmonic generation; weak shocks and N-waves; Burger's equation; sonic booms; acoustic saturation; radiation pressure; acoustic levitation; nonlinear reflections and standing waves; biomedical harmonic imaging; streaming; cavitation and sonoluminescence; parametric arrays and the "audio spotlight"; scattering of sound by sound; computational nonlinear acoustics.
Text: Nonlinear Acoustics, M. F. Hamilton and D. T. Blackstock, 1995 or 2008 (available through The Acoustical Society of America)

ACS 597: ADVANCED TRANSDUCERS & ACOUSTIC SYSTEM MODELING
Instructor: Steve Thompson
Class Time: TBA
Credits: 3
Tuition: See Tuition Fee announcement above.
Prerequisite: ACS 501, Elements of Acoustics and Vibration, ACS 502, Elements of Sound Waves in Fluids and 514 Electroacoustic Transducers.
Course Material: Topics for this course include: condenser, electret, piezoelectric, moving coil, and balanced-armature transducers; and the interaction of closely spaced transducers. Computational modeling for transducer systems will use the methods of dynamic system modeling using Simscape (which is included in the PSU student license for The MathWorks product line). This course will include a significant emphasis on modeling of magnetic circuits and devices and will cover methods for modeling the nonlinearities that are present in most actual transducer devices.
Software: The SimScape modeling software from The MathWorks. SimScape and all required toolboxes are included with the Penn State student license to the MathWorks software. This license is often referred to as the MATLAB license. However, a full installation of the Penn State student license also includes Simulink, SimScape, and many toolboxes. This license must be purchased from the Penn State software store. Please note that all of the required software components may not be included in the standard student license purchased from the MathWorks web site, and are likely not included in many corporate licenses. Distance Ed students who have been able to use their employer's corporate license for other courses may find that license does not include enough features for this course. In that case, it would be necessary to buy the Penn State student license for this course.

Spring 2022 Distance Education Course Schedule

CLASS DATES

January 10-May 6, 2022

- All classes video streamed and archived for review
- All courses available for credit or audit

TENTATIVE COURSE SCHEDULE

ACS 514: ELECTROACOUSTIC TRANSDUCERS
Credits: 3
Prerequisite: Undergraduate physics, basic linear circuit theory, differential equations, and complex numbers. Must have working knowledge of required software

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ACS 515: ACOUSTICS IN FLUID WAVES
Credits: 3
Prerequisite: ACS 502, Elements of Sound Waves in Fluids or ACS 597B, Introduction to Acoustics and Fluid Media, ACS 598E, Engineering Mathematics I or equivalent, or instructor consent

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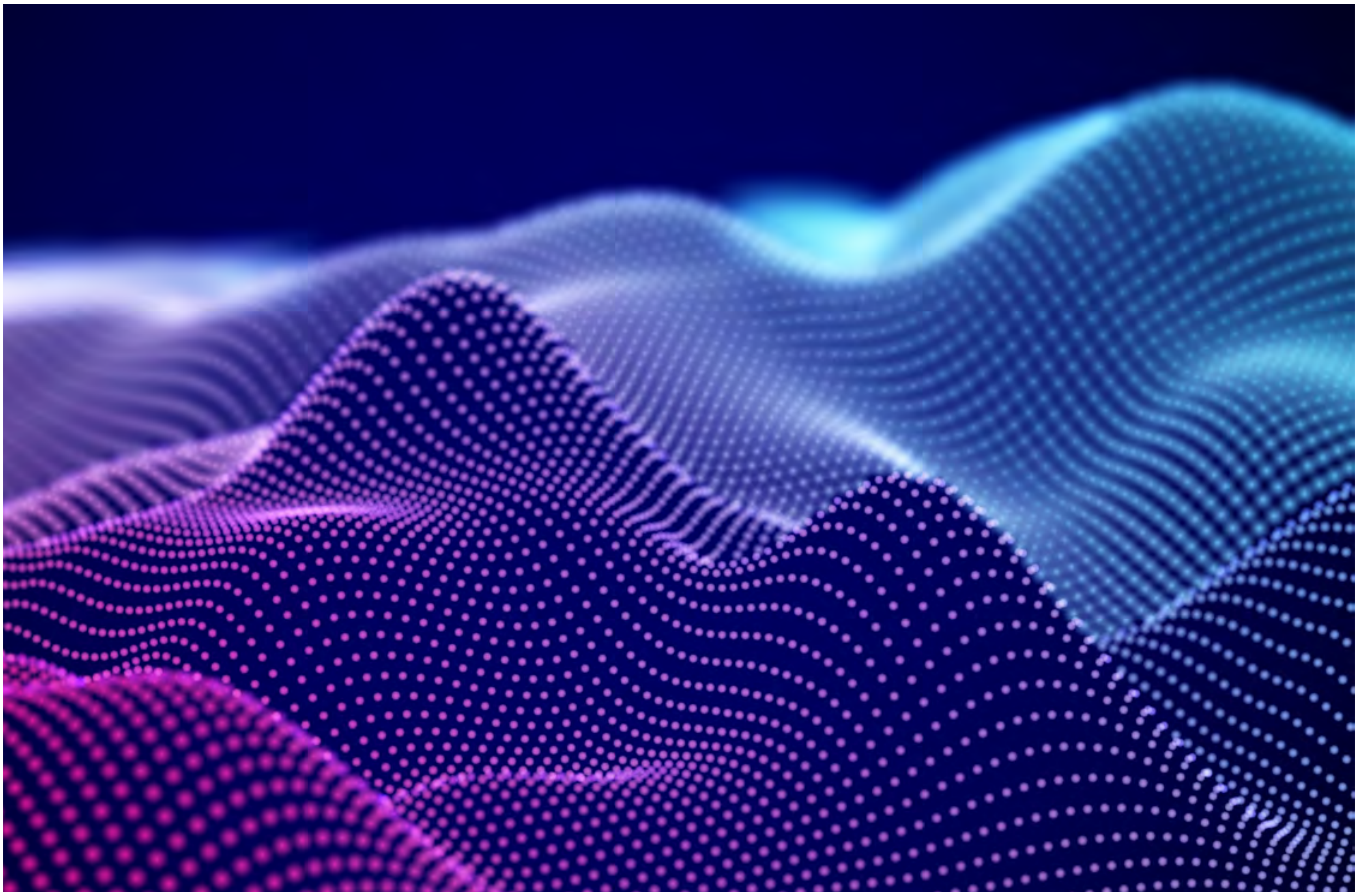
ACS 597: ADVANCED SIGNAL ANALYSIS FOR ACOUSTICS AND VIBRATION
Credits: 3
Prerequisite: ACS 503 or ACS 597, Signal Analysis for Acoustics and Vibration
Note: This course replaces ACS 513, Digital Signal Processing. Students may enroll in this course if they have not taken ACS 513. Students who have previously taken ACS 513 may not enroll in this course.

ACS 598: ENGINEERING MATHEMATICS I
Credits: 3
Prerequisite: Undergraduate physics, differential equations, and complex numbers.

Technical Research Group Highlights



Acoustic Materials and Metamaterials

Group Summary

The Center for Acoustics and Vibrations's 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.

The Acoustic Materials and Metamaterials Technical Group is happy to welcome Ryan Harne to Penn State. Harne's work encompasses many technical groups within the CAV including this group.

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.

Group Leader: Amanda Hanford
Assistant research professor in acoustics

The Acoustic Materials and Metamaterials Technical Group is happy to congratulate Yun Jing on the National Science Foundation award to investigate acoustic graphene properties. Jing's research will involve investigation of how twisting two layers of graphene can impact the concentration of acoustic energy. If layers of graphene are twisted at a "magic" angle of roughly 1.1 degrees, the material becomes a remarkably efficient electric conductor. This award was recognized in several PSU news outlets. [Read more]

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

Active and Adaptable Acoustic Metamaterial Plates

Sponsor: NAVSEA 073
Principal investigators: Benjamin Beck, assistant research professor in the Penn State Applied Research Laboratory and engineering program manager in the Radiation Science & Engineering Center
Student: Aaron Stearns, doctoral student in mechanical engineering
Summary: Acoustic metamaterials are engineered structures with subwavelength resonant inclusions which enable manipulation of elastic and acoustic waves in ways beyond the capabilities of conventional materials. However, novel wave manipulation properties of metamaterials are typically limited to the frequencies near the resonance frequencies of the local resonators. The goal of this project is to apply active control to acoustic metamaterials to achieve broadband and adaptable vibration suppression in thin plate structures. A thin plate metamaterial unit cell is designed using the finite element method. A cutaway resonator is machined in the unit cell and shunted piezoelectric actuators are applied to the unit cell which enable stiffness control of the structure. An optimization approach for the piezoelectric shunt circuit based on an electromechanical finite element model of the unit cell is also developed. Experiments are also performed to validate the finite element modeling and optimization. Results so far show that the active cutaway plate metamaterial is a good candidate for vibration reduction and isolation in thin structures.

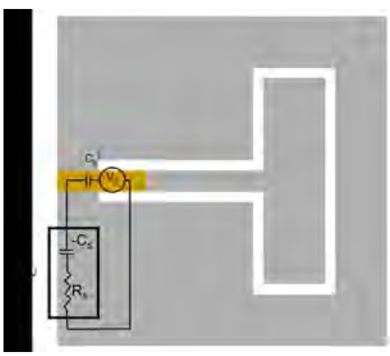


Figure 1: Active metamaterial plate

Acoustic Cloaking Modeling Performance

Sponsor: General Dynamics Mission Systems
Principal investigators: Amanda Hanford, assistant professor of acoustics and mechanical engineering; Benjamin Beck, assistant research professor in the Penn State Applied Research Laboratory and engineering program manager in the Radiation Science & Engineering Center
Summary: The objective of this work is to develop, design, and model an acoustic cloak. The models for acoustic scattering of a cloaked object will evaluate material design variables, as a function of frequency, to determine the acoustic propagation and interaction with the cloaked object.

Control of low-frequency Lamb wave propagation

Sponsor: National Science Foundation, Penn State College of Engineering
Principal investigators: Parisa Shokouhi, associate professor of engineering science and mechanics and acoustics; Cliff Lissenden, professor of engineering science and mechanics and acoustics
Student: Christopher Hakoda
Publication: C. Lissenden, C. Hakoda, P. Shokouhi, "Control of low-frequency Lamb wave propagation in plates by boundary condition manipulation," Journal of Applied Physics, 129 (9), 2021.
Summary: Locally resonant metasurfaces can control the propagation of Lamb wave modes in a plate. The resonator is typically designed through frequency matching: adjusting its geometry and/or materials properties by trial and error until its resonance frequency matches the frequency of the target Lamb wave mode. We demonstrate that although frequency matching appears effective for controlling the A0 wave mode, it may fail in the case of the S0 mode. This paper proposes a fundamentally different approach to design a specific metasurface to forbid the propagation of a prescribed Lamb wave mode in a plate. The proposed approach is based upon manipulating the boundary conditions on the top surface of the plate. Different types of Cauchy boundary conditions applied to the surface are shown to control the reflections and mode conversions of low-frequency A0 and S0 Lamb waves. Even a small patch with the modified boundary conditions can be effective. Finally, we show that a local "clamping" resonator that assimilates Cauchy boundary conditions on the surface of the plate changes the plate dispersion characteristics resulting in mode conversion and reflection. This finding provides a rational procedure to design a specific metasurface. The surface-mounted resonators enable control of wave propagation in plates without compromising structural integrity, are easily installed, and can be retrofit to the existing planar structures. The numerical results agree well with the experimental results reported in the literature

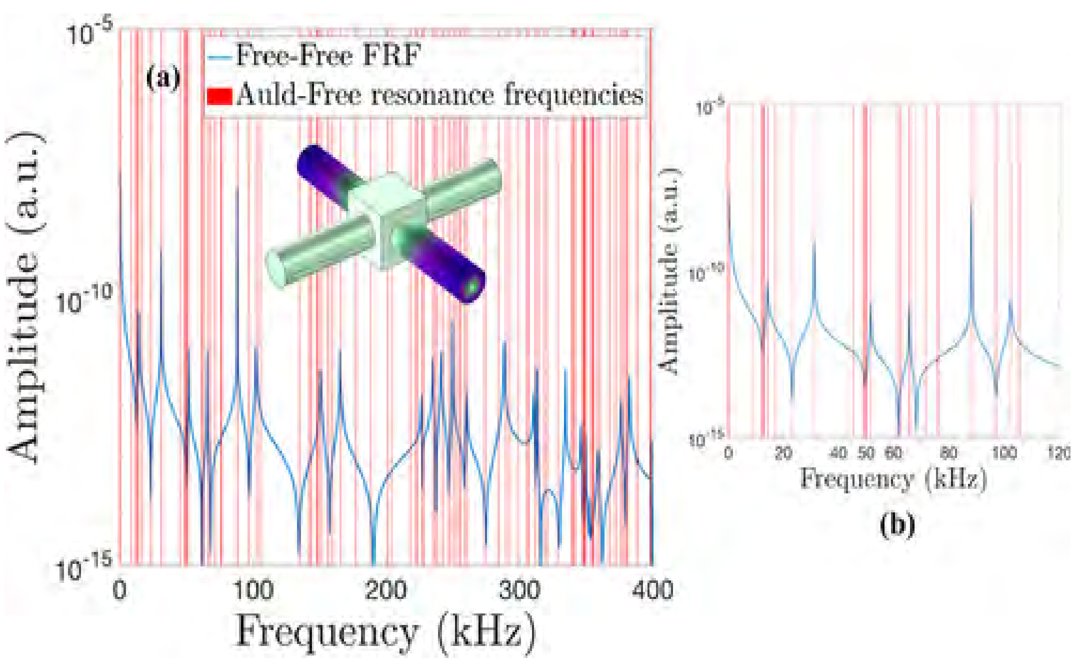


Figure 2: Four-armed clamping resonator: (a) Frequency response function (u1 at base obtained from harmonic T1 at base) of free-free resonator overlaid on natural frequencies of an Auld-free BC resonator and (b) zoomed in view in the low-frequency regime. The inset in (a) shows the mode shape of the resonator at 49.863 Hz

Adaptive Structures and Noice Control

Group Summary

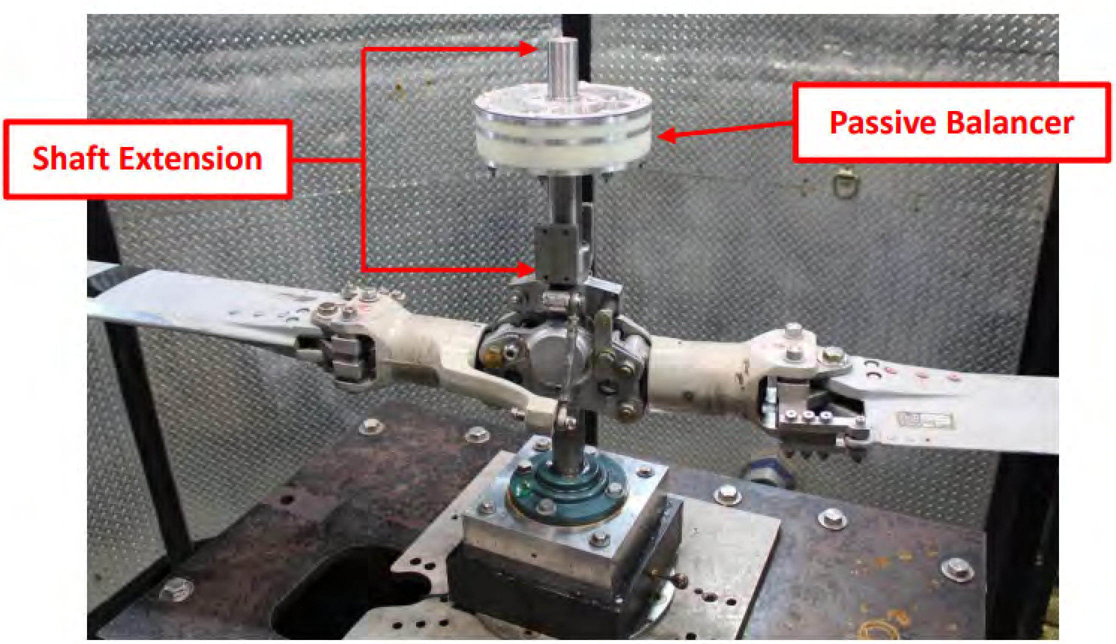
The mission of the Adaptive Structures and Noise Control Technical Group is to pursue strategies for reducing vibration and noise in engineering systems. This involves the development of active materials and devices, accurate modeling approaches, passive control methods, discrete and distributed sensors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

Group Leader: Jose Palacios
Associate professor
of aerospace engineering

Supercritical Rotor Passive Balancing Modeling for Reduction of Ice Shedding Imbalance

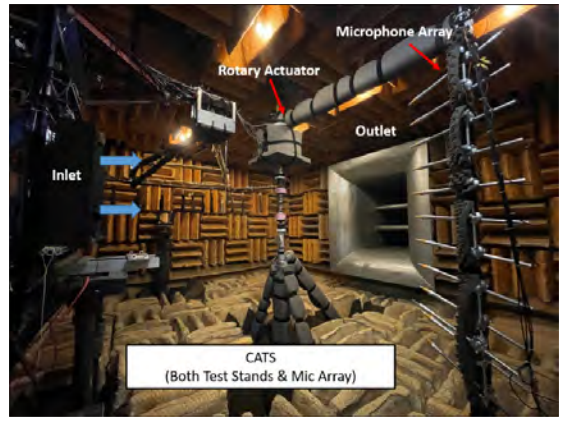
Sponsor: HRL/Boeing
Principal investigator: Jose Palacios, associate professor of aerospace engineering
Student: Ryan Blessington, 2020 graduate, master of science in aerospace engineering
Summary: Passive balancing devices for rotary systems consist of masses that are free to move in concentric guides about a shaft axis. At supercritical shaft speeds, the balancing masses automatically assume positions that counter any imbalance due to uneven mass distribution in the system. The problem is highly nonlinear and requires comprehensive modeling to achieve satisfactory prediction of the balancing behavior. A passive balancing device on a supercritical 10 ft. diameter rotor has been designed and fabricated based on prior developed comprehensive model. The device has allowed for consecutive ice shedding event testing as well as performing rain erosion testing on ten-foot diameter rotors spinning at 1000 RPMs.

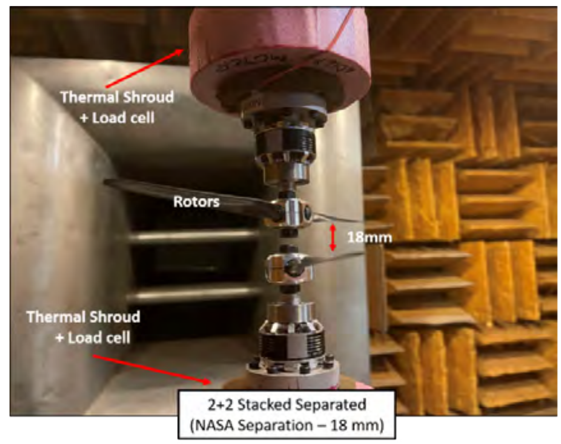


Photograph of passive balancer in the ten-foot diameter rotor in the Penn State hover stand.

Anechoic Wind Tunnel Testing of Co-axial Rotors

Sponsor: NASA Langley
Principal investigators: Eric Greenwood, assistant professor of aerospace engineering; Jose Palacios, associate professor of aerospace engineering
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. The market of UAS has been developing in recent years. The 2018 aerospace forecast report from Federal Aviation Administration estimates that 1.2 million model or hobbyist UAS units and 110,604 non-model or commercial UAS units are registered in United States. The forecast also predicts that total amount of hobbyist UAS units will increase to 2.4 million and 451,800 commercial units will be operated by 2022*. Multi-rotor UAS, due to its maneuverability, is a UAS configuration that has received increasing attention. 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.





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

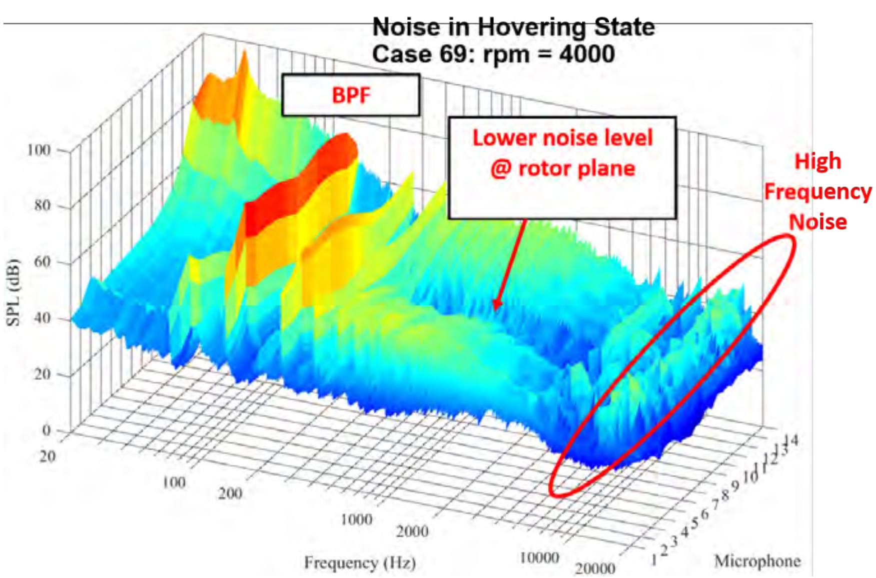
Amazon, UPS, Domino's Pizza, UBER, and other companies planning drone delivery could cause noise pollution that is more annoying than that of ground vehicles even at the same noise level+. One of the key reasons is related to how slowly most commercially available UAS move, providing "loitering" noise. The integration of UAS to commercial applications is inevitable, but the acceptance of such applications will require understanding and mitigation of UAS acoustics perceived as irritating to the population.

Strategically, developing test facility to test UAS configurations is needed.

The team has designed, fabricated, and calibrated a rotor stand to test co-axia rotors (with the capability to control rotor spacing and relative angular position) and is working with NASA Langley to verify the facility capability.

The capabilities of the configuration are valuable for the comparison of the baseline rotor of and the novel anti-phase vortex rotor, and for the fundamental understanding of UAS rotor and motor noise. An example result is shown below.

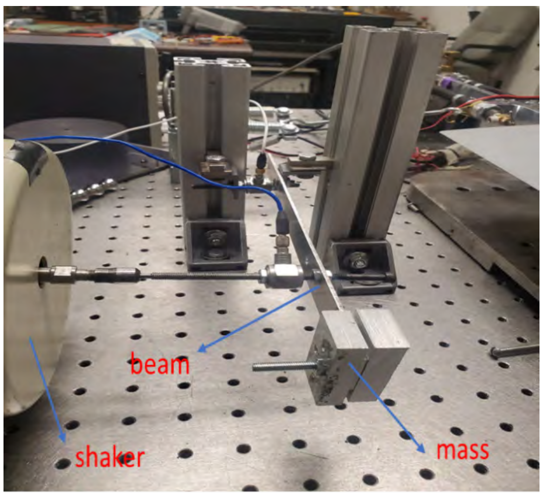
** Federal Aviation Administration, "FAA Aerospace Forecast Fiscal Years 2018-2038." TC18-0004,2018.*
+Christian, A., and Cabell, R., "Initial Investigation into the Psychoacoustic Properties of Small Unmanned Aerial System Noice," 17th AIAA Aviation Technology, Interation, and Operations Conference (AVIATION 2017); 5-9 Jun. 2017; Denver, CO; United States.

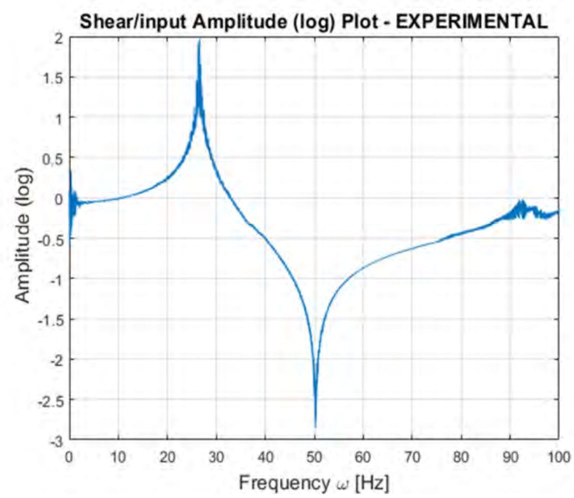


Sound pressure collected by the microphone array for a hover condition. The facility can provide forward speeds of up to ten m/sec.

Fluid free Tuned Vibration Absorber

Sponsor: Parker Lord corporation
Principal investigator: Chris Rahn, J. Lee Everett Professor of Mechanical Engineering
Student: George Rai
Summary: Fluidic vibration absorbers are often used due to their improved isolation, performance, and low maintenance requirements under normal design conditions. However, they exhibit an increased sensitivity to thermodynamic variations as compared to a strictly elastomeric or other typical mechanical absorber. This project investigates the feasibility of designing a fluid free vibration absorber that matches the performance of a fluid filled device. The design utilizes the concept of antiresonance on continuous dynamic systems, whereby an oscillating mass would cancel the excitation forces acting on the isolated body. Experimental results below show the promise of flexible structures for vibration isolation (see notch at 50 Hz in frequency response plot).

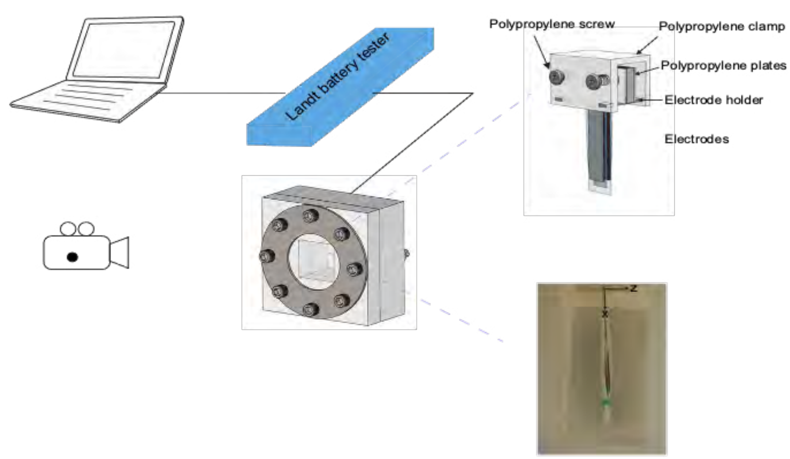




Experimental Testing Set-up and Sample Results

Multifunctional Lithium-ion Batteries with Silicon Anodes

Sponsor: National Science Foundation
Principal investigators: Chris Rahn, J. Lee Everett Professor of Mechanical Engineering; Mary Frecker, Riess Chair of Engineering and professor of biomedical and mechanical engineering; and Donghai Wang, professor of mechanical engineering
Students: Shuhua Shan, Cody Gonzalez, doctoral candidate in mechanical engineering
Summary: The volume expansion of Si during lithiation is over 300%, indicating its promise as a large strain electrochemical actuator. A Si-anode battery is multifunctional, storing electrical energy, and actuating through volume change by lithium-ion insertion. To utilize the property of large volume expansion of silicon anodes, we design, fabricate, and test two types of Si anode cantilevers with bimorph actuation: (1) double-unimorph configuration and (2) double-side-coated-anode configuration. Both bimorph configurations exhibit deflections in two directions and store energy. A 1D shape optimization is used to explain the varied charge distribution along the length for a LIB actuator and thereby the effect of distance between electrodes in charging,



Experiment setup: A transparent battery chamber made of polypropylene is fabricated, provided with NMC cathodes, and filled with electrolyte. The relationship between state of charge and deformation of electrodes is measured using current integration and high-resolution photogrammetry, respectively.

Endoscopic Flexible Pancreatic Tumor Ablation System with Reduced Force Effector and Specialized Ablation Zone

Sponsors: National Institutes of Health, with Actuated Medical Inc
Principal investigator: Mary Frecker, Riess Chair of Engineering and professor of biomedical and mechanical engineering; Snook (AMI)
Students: Brad Hanks, Fariha Azhar
Summary: We are developing specially shaped deployable probe tips for radio frequency ablation of pancreatic cancer.for vibration isolation (see notch at 50 Hz in frequency response plot).

Multifunctional Lithium Ion Batteries with Silicon Anodes

Sponsor: National Science Foundation
Principal investigators: Chris Rahn, J. Lee Everett Professor of Mechanical Engineering; Mary Frecker, Riess Chair of Engineering and professor of biomedical and mechanical engineering; and Donghai Wang, professor of mechanical engineering
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.

Design of multifield responsive material systems

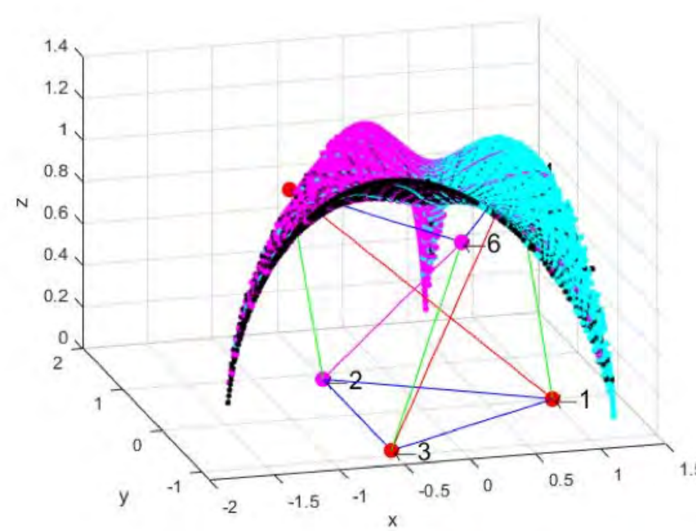
Principal investigators: Mary Frecker, Riess Chair of Engineering and professor of biomedical and mechanical engineering; Zoubeida Ounaies, professor of mechanical engineering
Student: Wei Zhang
Summary: We are developing finite element modeling and systematic design optimization methods for active materials that respond to multiple applied fields such as electric and magnetic.

Design for additive manufacturing (DFAM) of cellular contact aided compliant mechanisms (C3M) for energy absorption

Principal investigator: Mary Frecker, Riess Chair of Engineering and professor of biomedical and mechanical engineering
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.

Articulated Tensegrity Structures for Space Applications

Sponsor: United States
Principal investigator: George Lesieutre, associate dean for research and graduate programs; professor of aerospace engineering and acoustics
Student: Kaila Roffman, doctoral student
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.



Additive Manufacturing of Functional Hierarchical Shape Memory Alloys Structures

Sponsor: Defense Advanced Research Projects Agency
Principal investigator: Reginald F. Hamilton, associate professor of engineering science and mechanics
Publication: 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, Siddhartha Pathak, 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.

Artificial Intelligence and Machine Learning

Group Leader: Daning Huang
Assistant professor of aerospace engineering

Group Leader: Karl Reichard
Associate research professor of acoustics

Group Summary

The mission of the Artificial Intelligence (AI) and Machine Learning (ML) Technical Group is to explore and leverage applications of AI and ML in all areas of acoustics and vibration. The overarching goal of the group is to solve traditionally challenging problems in acoustics and vibration, particularly involving sensing, prediction, estimation, and control, in realistic industrial scenarios. The methodology of AI and ML ranges from the conventional supervised and unsupervised learning, to the more sophisticated operator-theoretic and information-theoretic methods, and to active, transferrable and explainable learning.

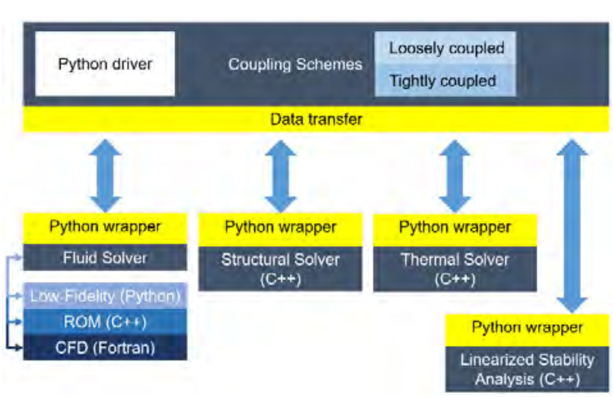
Research Topics

- Reduced-order modeling of multidisciplinary dynamical systems
- Data-augmented design and optimization of complex mechanical systems
- Feature engineering and extraction, representation, and mining of big measurement data sets
- Multi-fidelity multi-variate information fusion and predictive inference
- Data-driven predictive analytics and decision making
- Classification and pattern recognition

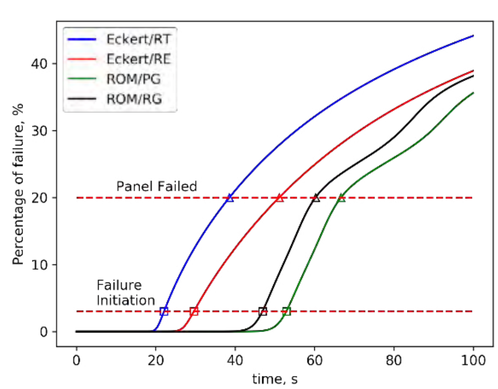
Below are some highlights of this group's recent work.

Impact of High-Temperature Effects on the Aerothermoelastic Behavior of Composite Skin Panels in Hypersonic Flow

Principal investigator: Daning Huang, assistant professor of aerospace engineering
Student: Aravinth Sadagopan, doctoral student in aerospace engineering
Summary: This study investigates the impact of the high-temperature effect, esp. the real gas effect and the chemical reactions, on hypersonic aerothermodynamic solutions and the aerothermoelastic behavior of a typical skin panel in hypersonic flow. First, several computational fluid dynamics codes that were developed in significantly different ways were benchmarked and compared for hypersonic aerothermodynamics, emphasizing the impact of high-temperature effects as well as turbulence modeling on heat flux prediction. Subsequently, a reduced-order model (ROM) for hypersonic aerothermal loads accounting for the high-temperature effect is developed. Particularly, a ROM correction approach for high-temperature effect was presented, so that a ROM constructed based on the perfect gas assumption can generate fluid solutions that account for the real gas effect with reasonable accuracy. Finally, the new fluid ROM was applied to study the impact of the high-temperature effect on the aerothermoelastic response of a hypersonic skin panel, with an emphasis on its stability boundary.



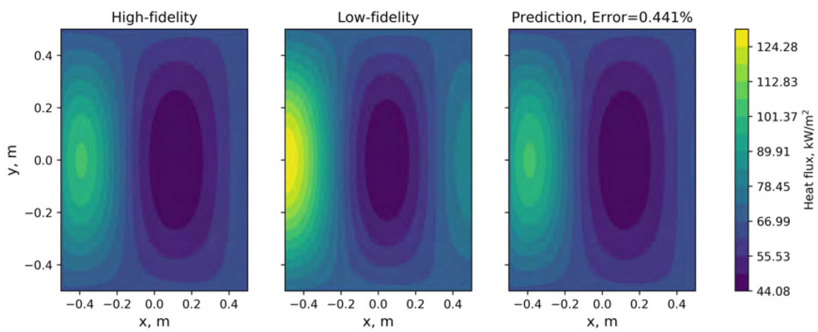
Code structure of the extended hypersonic aerothermoelastic simulation framework



Percentage of upper surface area of failed region, highlighting the erroneous trend of simplistic aerothermal models (Eckert) when compared to higher-fidelity models (ROM).

Assessment of High-Temperature Effects on Hypersonic Aerothermoelastic Analysis using Multi-Fidelity Multi-Variate Surrogates

Principal investigator: Daning Huang, assistant professor of aerospace engineering
Student: Aravinth Sadagopan, doctoral student in aerospace engineering
Summary: This study investigates the impact of the high-temperature effect, esp. the real gas effect and the chemical reactions, on hypersonic aerothermodynamic solutions of double cone and double wedge configurations, as well as the aerothermoelastic behavior of a double wedge configuration in hypersonic flow. First, a high-temperature computational fluid dynamics code was benchmarked and correlated with experimental results, emphasizing the impact of high-temperature effects as well as turbulence modeling on heat flux prediction. Subsequently, an aerothermal surrogate based on the multi-fidelity Gaussian process regression method was developed. The model achieves a balance between model accuracy and computational cost of sample generation, using the combination of a few high-fidelity sample and many low-fidelity samples. Finally, the new aerothermal surrogate was applied to study the impact of the high-temperature effect on the aerothermoelastic response of a hypersonic skin panel, emphasizing the necessity of the accurate characterization of the localized heat flux for reasonable assessment of the response of a compliant structure in high-speed high-temperature flow field.



Comparison between multi-fidelity prediction and the low- and high-fidelity data for a high-speed configuration.

Expedient Hypersonic Aerothermal Prediction for Aerothermoelastic Analysis Via Field Inversion and Machine Learning

Principal investigator: Daning Huang, assistant professor of aerospace engineering
Student: Carlos Vargas Venegas, graduate student in aerospace engineering
Summary: The accurate and efficient prediction of aerothermal loads over the hypersonic vehicles during atmospheric flight is critical for the aerothermoelastic design, analysis and optimization of the structures of this class of vehicles. Reduced-order models (ROMs) and surrogates are typical approaches to reducing the computational cost to a tractable level. However, the existing ROMs and surrogates suffer from the curse of dimensionality that roots from the need to parameterize and sample the thermal-structural responses. This work presents a novel physics-informed ROM for the aerothermal load calculation on a deforming structure in high-speed flow, based on the combination of the classical turbulent viscous-inviscid interaction (TVI) model and the field inversion and machine learning technique. It is demonstrated that the new model, termed augmented TVI model, can achieve an accuracy close to that of CFD solvers when predicting the flow solutions over a wide range of complex surface deformations with a limited number of high-fidelity solutions. These results underline its potential to be used as a new generation of ROM for the aerothermal load prediction in hypersonic aerothermoelastic design and analysis.

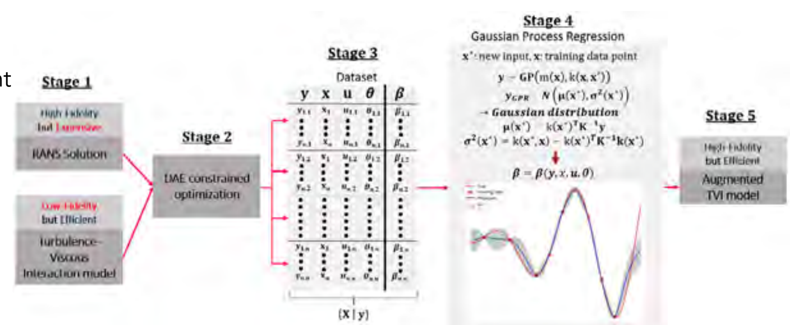
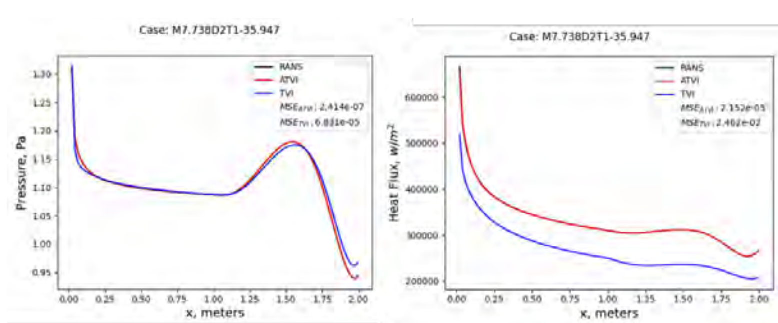


Illustration of the field inversion and machine learning method for model augmentation.

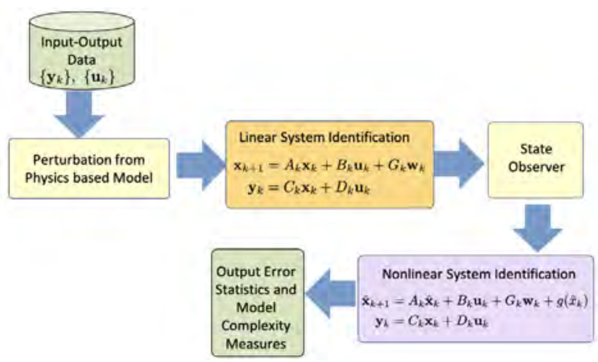


Demonstration of the approach – data-augmented model (ATVI) v.s. a first-principle model (TVI) and high-fidelity model (RANS).

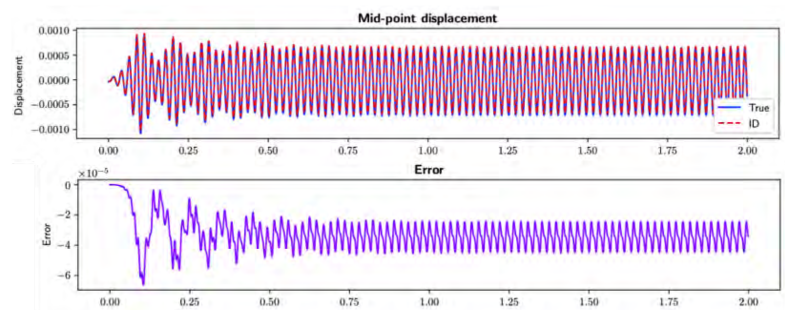
Reduced Order Models for Hypersonic Aerothermoservoelastic Analysis

Principal investigators: Puneet Singla and Daning Huang
Student: Damien Gueho (Ph.D., Aerospace Engineering)

Summary: The coupling between the flight dynamics, structural dynamics, heat transfer, and hypersonic aerothermodynamics, viz. AeroThermoServoElasticity (ATSE), is a key ingredient for analyzing performance, stability, and reliability of hypersonic vehicles. Uncertainties in individual models propagate across the coupling interfaces between the models and aggregate over time in the ATSE analysis, and this situation poses an outstanding challenge related to uncertainty quantification (UQ) and propagation. A thorough UQ analysis for ATSE is computationally intractable with high fidelity models for each discipline and hence, there is a need to develop accurate reduced order models (ROM) for aerothermodynamics as well as thermoelasticity. In this respect, the main focus of this work is to exploit recent advances in machine learning in conjunction with dynamical system theory to develop reduced order models that preserve the characteristic features of ATSE effects while being amenable to analysis and design. A time varying Koopman operator theory is being developed which automatically select the appropriate basis functions to generate accurate reduced order models.



A schematic of ROM Framework



Evaluation of Mid-Point Displacement

Biomedical Acoustics

Group Summary

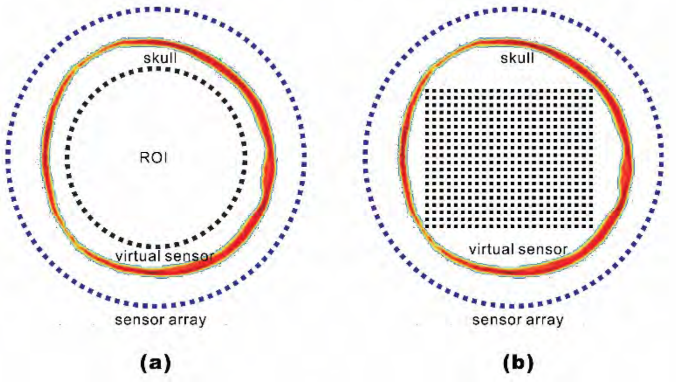
The mission of the Biomedical Acoustics Technical Group is to understand and apply acoustics towards improving human health. The group joined Center for Acoustics and Vibration (CAV) in fall of 2017. Currently, the group consists of ten faculty members and approximately twenty students. Research interests include advanced image processing, ultrasound imaging and therapeutics, photoacoustic imaging, shear wave elastography, drug delivery, and more! Some highlights for 2020-21 include Janna Sloand and Jacob Elliott receiving recognition at the Fall 2020 CAV Workshop Poster Competition, and an excellent seminar on focused ultrasound in the brain by Hong Chen from Washington University in St. Louis, Missouri.

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

Group Leader: Julianna Simon
Assistant professor of acoustics and biomedical engineering

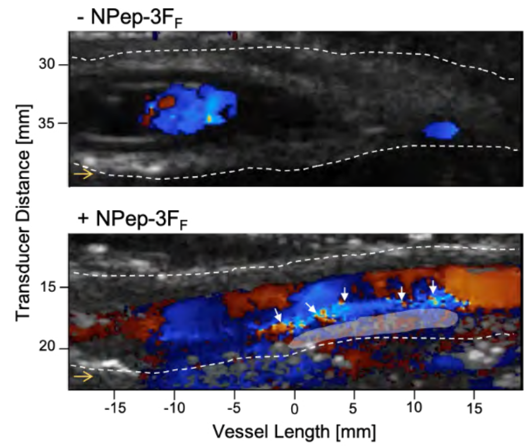
Transcranial Photoacoustic Imaging using a Virtual Array

Sponsor: National Institutes of Health (1R21EB027981)
Principal investigator: Yun Jing, associate professor of acoustics and biomedical engineering
Student: Hyungjoo Park, doctoral student in acoustics
Summary: Modern brain imaging techniques have allowed neuroscientists to gather a wealth of anatomic and functional information about the brain. Among these techniques, by virtue of its rich optical absorption contrast, high spatial and temporal resolutions, and relatively deep penetration, photoacoustic tomography (PAT) has attracted substantial attention. However, to bring PAT to studying human subjects or non-human primates, one critical issue must be addressed. That is, the human or non-human primate skulls severely distort the photoacoustic (PA) signals, giving rise to substandard images. Time-reversal based reconstruction is considered one of the most accurate and sophisticated reconstruction algorithms for transcranial PAT. Time-reversal based methods are capable of correcting for both the phase and amplitude distortions due to the skull when imaging the brain. However, this method is slow, which presents a significant hurdle to the application of real-time functional imaging. We aim to develop an innovative virtual array approach for achieving accurate and real-time transcranial PAT to image the brain cortex of non-human primates and humans. Instead of using the actual PA signals for image reconstruction, we propose to use virtual signals received by a virtual array situated inside the skull, which is considerably less affected by the skull. This can be implemented in real-time as the Green's function can be pre-computed. The results from this project will provide a route for probing brain cortex functions in a highly efficient and accurate manner and pave the way for future applications of this novel PAT technique.



Ultrasound-enabled strategies for synchronous imaging and therapy of venous blood clots

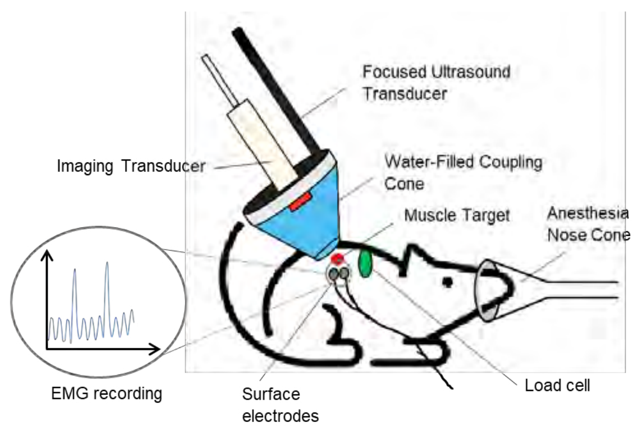
Sponsor: 2019-20 Penn State College of Engineering Multidisciplinary Seed Grant Program
Co-principal investigators: Scott Medina, assistant professor of biomedical engineering; Julianna Simon, assistant professor of acoustics and biomedical engineering; Keefe Manning, professor of biomedical engineering
Students: Erik Rokni, doctoral student in acoustics; Janna Sloand, doctoral candidate in biomedical engineering, Connor Watson, doctoral student in 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. In this project, we used high-resolution ultrasound imaging along with phase-change contrast agents to detect and treat DVT.



Doppler ultrasound imaging showing clot formation in an ex vivo bovine blood vessel without (upper) and with (lower) targeted phase-change contrast agents. The addition of targeted contrast agents made it easier to delineate the clot border and partially inhibited clot formation.

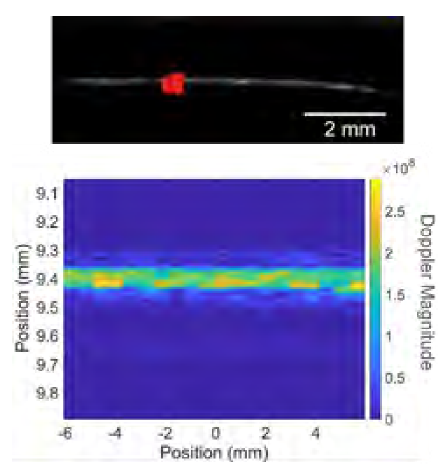
Developing novel rehabilitation to combat low back pain: A focused ultrasound intervention for muscle activation

Sponsor: 2021-22 Penn State College of Engineering Multidisciplinary Seed Grant Program
Co-principal investigators: Meghan Vidt, assistant professor of biomedical engineering; and Julianna Simon, assistant professor of acoustics and biomedical engineering
Students: Jacob Elliott, doctoral student in acoustics; Zoe Moore, doctoral student in biomedical engineering
Summary: Chronic low back pain is highly prevalent, expensive to treat, and disabling for patients. While exercise is known to be effective at strengthening spine stabilizing muscles, no specific exercise has shown superiority and patient compliance is low. In this project, we plan to develop and evaluate focused ultrasound to activate muscle fibers. Focused ultrasound has potential as a low back pain therapy due to its ability to target deeper structures and its ability to activate brain neurons.



Ultrasound to diagnose and treat heterotopic ossification

Sponsor: Congressionally Directed Medical Research Program—Peer Reviewed Medical Research Program
Principal investigator: Julianna Simon, assistant professor of acoustics and biomedical engineering
Co-principal investigator: Dan Hayes, professor of biomedical engineering
Students: Lucas Ruge-Jones, graduate student in acoustics; Lisa Bernstein, doctoral candidate in biomedical engineering
Summary: Heterotopic ossification (HO), or the presence of bone in soft tissues where bone does not normally exist, occurs in over half of musculoskeletal blast injuries. HO has also been found to occur in up to 90% of patients after surgical musculoskeletal injury. After trauma, the calcifications are not visible on x-ray or computed tomography for at least seven weeks post-injury. Further, current therapies for HO produce mixed success rates with the potential for severe side-effects and require patients to wait more than a year after diagnosis for HO to mature before treatment to reduce the risk of recurrence. This proof-of-concept proposal proposes evaluating new ultrasound modalities to identify and treat early HO, which has the potential to change the clinical paradigms for the diagnosis and treatment of HO.



Flow-Induced Noise

Group Leader: Mike Jonson
Research associate in aerospace engineering

Group Summary

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 data bases permits the description of possible noise control methods that can be evaluated analytically or numerically, and then with confidence, prototype apparati may be evaluated in the laboratory.

Research Topics

- Wind/marine turbine noise
- Noise radiation from non-circular and coaxial supersonic jets
- Noise generated by intermittent, transitioning boundary layer flows on surfaces
- Axial flow fan noise radiation and its control
- Centrifugal pump and blower noise radiation and its control
- Flow noise and structural response induced by turbulent flow
- Bluff body flow noise
- Computational aeroacoustics

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

Cold Spray Helium Recovery System Noise Study

Sponsor: Applied Research Laboratory
Principal investigators: Michael Jonson, research associate in the Penn State Applied Research Laboratory and aerospace engineering; Timothy Brungart, research professor in the Penn State Applied Research Laboratory and acoustics; and Steven Young, research and development engineer in the Penn State Applied Research Laboratory
Summary: The Applied Research Laboratory (ARL) currently uses cold spray technology for manufacturing applications requiring metal powder coatings and repairs. To reduce future manufacturing costs, ARL plans to construct a new helium recovery system adjacent to the cold spray facility located at the ARL West I Building. This industrial system will contain multiple compressors, fans, valves and other mechanical components which are likely to radiate considerable sound to the outdoor environment. To provide assurance to the local township and Penn State of complying with the neighborhood noise ordinance requirements prior to the start of construction, a representative helium recovery system at the manufacturer's facility in South Dakota was operated onsite at steady and peak operating conditions to quantify its radiated noise levels. In addition, sound pressure level (SPL) measurements of a broadband baffled sound source were acquired at varying orientations and distances out to the residential neighborhood property line at 50 meters to assess the noise propagation loss in the acoustic environment at the proposed system installation location, as shown in Figure 1. The SPL measurements acquired at both the manufacturer's facility and ARL West I were found to

Figure 1: SPL measurement locations from baffled sound source at ARL West I Building

collapse reasonably well with spherical spreading principles for outdoor measurements (i.e. inverse square law). Thus, the measured and scaled radiated noise levels from the representative recovery system at 1 meter were then scaled to the residential property line location assuming spherical spreading propagation to compare with township noise ordinance requirements, as shown in Figure 2. For steady operation, the predicted overall sound pressure level (OASPL) at the residential property line located 50 meters from the planned construction site was 55 dBA. This noise level is equivalent to the local township noise ordinance requirement of 55 dBA after 7:00 p.m. Radiated noise measurements of the representative recovery system were repeated for the peak operating conditions, during which noise from the pressure swing absorption (PSA) purge event was captured. Figure 3 shows the measured and scaled radiated noise levels from the peak noise event at one meter scaled to the residential property line location at 50 meters assuming spherical spreading losses. The peak overall sound pressure level is predicted to be 61 dBA at the property line, which is 5 dBA above the 7:00 p.m. noise ordinance level of 55 dBA; however, these estimates indicate the recovery system is not expected to radiate significant noise levels into the residential area during normal daytime operating hours. Additional noise measurements under varying environmental conditions are recommended after the helium recovery system is installed at ARL West I to validate these predictions. In addition, noise control efforts should be investigated to address any potential concerns for unwanted noise that could impact the neighboring residential area. These efforts include design changes to the recovery system exhaust flow and vents, PSA purge noise mitigation (tailored purge duration/pressure, relocation of mufflers), and installation of noise barriers/absorbers along the propagation path.

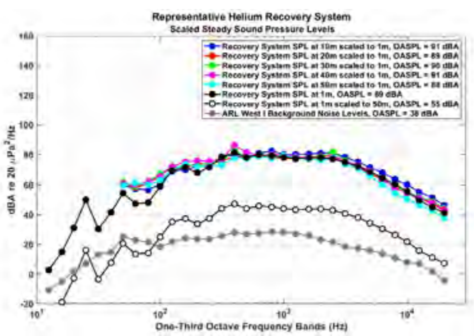


Figure 2: Steady-operation SPL measurements from representative recovery system scaled to residential property line

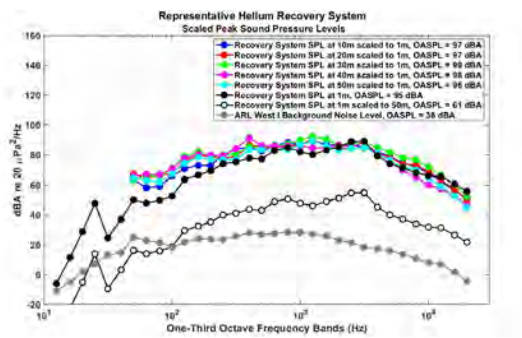
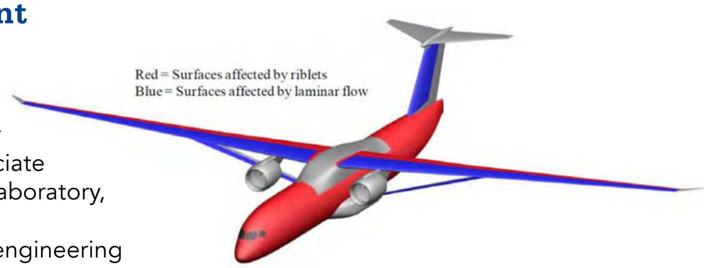


Figure 3: Peak-noise event SPL measurements from representative recovery system scaled to residential property line

Towards the flutter analysis of a Strut-Braced Slotted Natural Laminar Flow Wing: Model Development

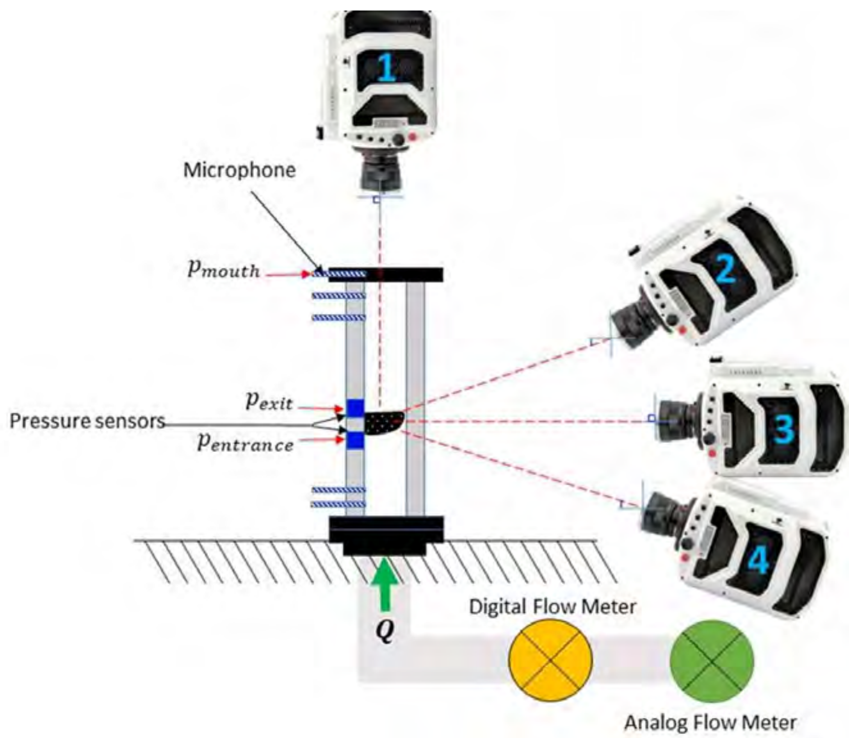


Visualization of airflow for SUGAR High Transonic, Truss-Braced Wing (source: https://nasa-uli.utk.edu/timeline/)

Sponsor: NASA
Principal investigators: Michael Jonson, research associate in the Penn State Applied Research Laboratory and aerospace engineering; and Robert Campbell, associate research professor in the Penn State Applied Research Laboratory, acoustics and mechanical engineering
Student: Auriane Bottai, doctoral student in aerospace engineering
Summary: The NASA University Leadership Initiative engages six universities and several industrial partners in designing a strut-braced (SB) slotted natural laminar flow (SNLF) wing. This fixed two-element airfoil profile stands out by its ability to maintain an extended region of laminar flow on both upper and lower surfaces, thereby reducing drag and improving aerodynamic efficiency. As part of the wing design study, our efforts focus on investigating the static and dynamic stability of the SB-SNLF wing. For this purpose, a MATLAB-based aerodynamic model based on Theodorsen theory in time domain has been developed. This tool estimates the unsteady aerodynamic loads for a given flow condition on the wing represented by its one-dimensional mode shapes. In parallel, the wing model has been improved from a single-element rectangular shell model to a three-dimensional SNLF wing, to which internal structure was added to maintain the airfoil profile integrity under loading: ribs, stringers and spars make the wing-box and increase the wing stiffness. The mode shapes are extracted at the elastic axis which is calculated within the shear flow theory framework and being currently validated in a commercial Finite Element software, ABAQUS.

Glottal Jet Aerodynamics

Sponsor: NIH NIH 5R01DC005642-14
Principal investigator: Michael Krane, associate research professor in the Penn State Applied Research Laboratory, aerospace engineering, mechanical engineering, and acoustics
Collaborators: Jeff Harris, assistant research professor in the Penn State Applied Research Laboratory; Adam Nickels, assistant research professor in the Penn State Applied Research Laboratory; Rommel Pabon, research and development engineer in the Penn State Applied Research Laboratory; David DeVilbiss, research and development engineer in the Penn State Applied Research Laboratory; Michael McPhail, Mayo Clinic; Stephanie Zacharias, Mayo Clinic; Lucy Zhang, Rensselaer Polytechnic Institute; Timothy Wei, Northwestern University; Daryush Mehta, Massachusetts General Hospital; Robert Hillman, Massachusetts General Hospital; and Sid Khosla, University of Cincinnati Medical School
Students: Paul Trzcinski, graduate student in aerospace engineering; Feimi Yu, mechanical engineering student at Rensselaer Polytechnic Institute; Abigail Howarth, mechanical engineering student at University of Nebraska-Lincoln; Dylan Rogers, mechanical engineering student at University of Nebraska-Lincoln; Hunter Ringenberg, mechanical engineering student at University of Nebraska-Lincoln; and Nathan Wei, Caltech
Summary: Project uses a combination of reduced-order modeling, aeroacoustic-aeroelastic computer simulation, and benchtop model measurements to address current open questions regarding the physics of human phonation, and to translate these findings into improved clinical measures. Current focus areas: (a) energy utilization and voice efficiency, (b) the relationship between glottal jet fluctuations and cycle-to-cycle variations in voice, and (c) the development of measurements suitable for computational model validation.



For the first study, a control volume analysis of the vocal system has yielded new definitions of voice efficiency for the voice source in the larynx, and the transmission in the vocal tract. The standard voice efficiency measure characterizes the system as a whole, and thus can't distinguish between these two effects. The new efficiency measures have been characterized using computer simulation, and in benchtop experiments.

The second study used time-resolved PIV and pressure measurements in a scaled-up model, with water as the working fluid. These measurements were used to determine the features of laryngeal flow that contribute most to vocal fold drag, the source of voiced sound. Cycle-to-cycle variations in vocal fold drag were shown to correlate to fluctuations in glottal jet direction.

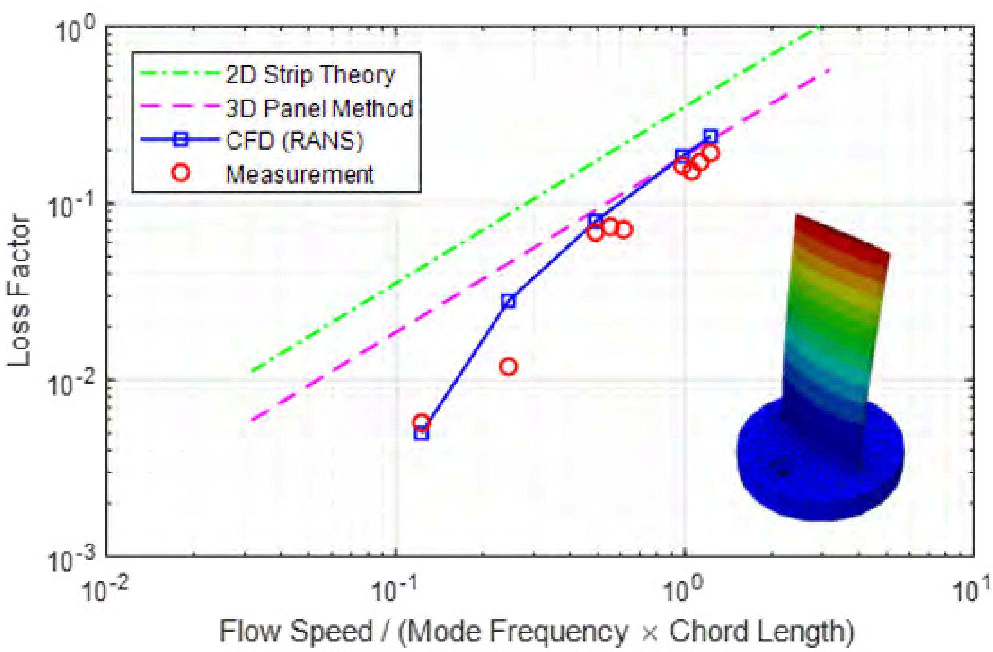
The third study has involved spinning up the capability to perform simultaneous measurements of acoustic and aerodynamic pressure, vocal fold wall motion using Digital Image Correlation, and glottal jet flow using Particle Image Velocimetry, and working with simulation specialists to integrate these measurements into a procedure to interactively assess their aeroelastic-aeroacoustic computational models of phonation.

Aerodynamic-Aeroacoustic performance of poroelastic wings, inspired by the silent plumage of owls

Sponsor: NSF CBET-1804445
Principal investigator: Michael Krane, associate research professor in the Penn State Applied Research Laboratory, aerospace engineering, mechanical engineering, and acoustics
Collaborator: Justin Jaworski, Lehigh University
Students: Zachary Yoas, 2021 graduate, master of science in biomedical engineering; and Huansheng Chen, mechanical engineering student at Lehigh University
Summary: Inspired by the wing structure thought to underlie quiet owl flight, this project studies the effect of wing porosity on trailing edge noise. The project is a collaboration with Lehigh University, who performs the theoretical side of study, while experiments are performed at Penn State Applied Research Laboratory. In this study, trailing edge noise is abstracted to its fundamental features, namely, the convection of a vortical eddy past the edge of a non-compact plate. In this study, we examine the effect of plate porosity on the level and directivity of sound radiated by the convection of a vortex ring past the edge of a flat plate. Plate porosity is thought to affect trailing edge sound radiation by altering the nearfield of the edge—as plate porosity increases, the nearfield flow is more able to load the edge force, as in the case of a compact edge. Relative to an impermeable plate, this alteration of the nearfield modifies the radiated sound by attenuating sound levels, and by transitioning directivity from a cardioid to a dipole pattern. Measurements to date show that sound levels and directivity change as predicted by the theory.

Prediction of Hydrodynamic Damping

Sponsor: Applied Research Laboratory, U.S. Navy
Principal investigators: Peter Lysak, assistant research professor in the Penn State Applied Research Laboratory; Ted Bagwell, research and development engineer in the Penn State Applied Research Laboratory; and Steve Hambric, research professor in the Penn State Applied Research Laboratory and acoustics
Summary: Flow past a vibrating surface generates a resistive force, known as hydrodynamic damping, due to vorticity shed from the trailing edge. Classical methods to predict this effect are based on two-dimensional unsteady airfoil theory applied in a strip-wise manner. However, this can result in overprediction of the damping in three-dimensional structures that involve more complex mode shapes and aspect ratio effects. Recent work has investigated the use of computational fluid dynamics (CFD) to calculate hydrodynamic damping efficiently over a wide range of non-dimensional speeds. Validation of the CFD methods using experimental data obtained in the Applied Research Laboratory twelve-inch water tunnel by former student Marc Reese (2010, master of science in acoustics) demonstrates the viability of this approach.



Propagation and Radiation

Group Summary

Group Leader: Vic Sparrow
Director of graduate programs in acoustics

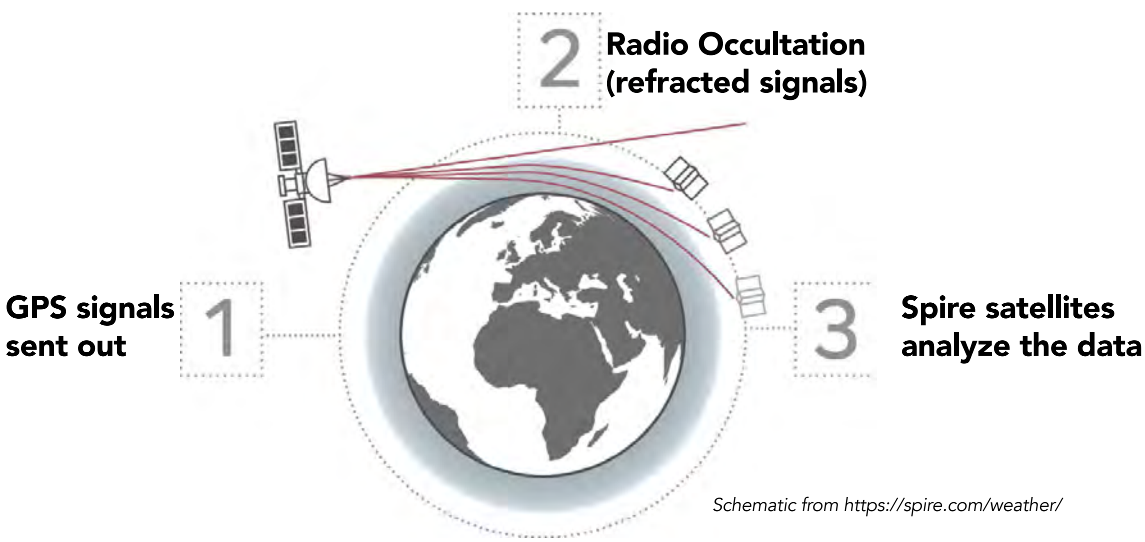
The mission of the Propagation and Radiation Technical Group is to develop a new understanding of how sound is generated, propagated, and perceived in realistic environments, to translate this understanding into techniques for making decisions about the use and control of sound, for making inferences about sources and the environment, and to apply this understanding to the design of devices and systems. Propagation and radiation studies closely tie in with transduction techniques, noise impact on the public, sound quality assessment, and 3D spatial audio.

Penn State has continued to participate in the Federal Aviation Administration (FAA) Center of Excellence in Alternative Jet Fuels and the Environment. As part of the Aviation Sustainability CENTer (ASCENT), 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 understanding and providing new technologies for FAA's current noise tools, particularly in improving the propagation modeling for noise around airports. Further work has centered on improving our understanding of sonic boom impacts from future supersonic aircraft.

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

Using Satellite Data to Better Predict Aircraft Noise Around Airports

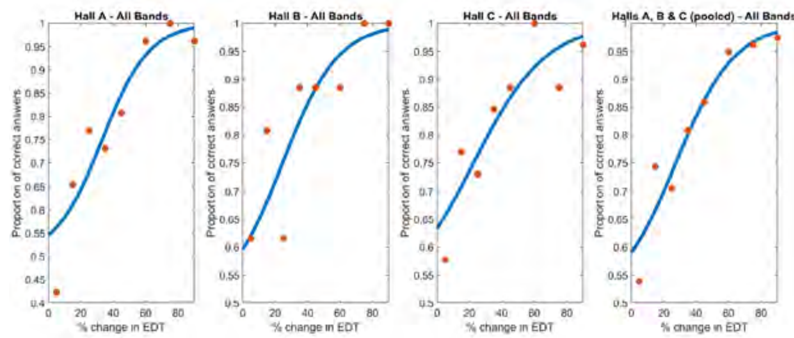
Sponsor: FAA
Principal investigator: Victor W. Sparrow, United Technologies Corporation Professor of Acoustics
Student: Harshal Patankar, doctoral candidate in acoustics
Summary: As part of Penn State's collaboration with Georgia Tech on ASCENT Project 62 "Noise Model Validation of AEDT" Penn State is using high resolution meteorological data around airports, including three-dimensional temperature and humidity as a function of time. The new high-fidelity weather data is being provided by Spire Global (spire.com), a company that has many low Earth orbiting satellites. By analyzing standard GPS signals refracted by the atmosphere, Spire Global can provide highly detailed meteorological maps with resolution much better than existing techniques. Current capabilities include providing this data on an hourly basis on a one kilometer by one kilometer grid for every 500 meters of altitude. This is allowing Penn State to understand the propagation of aircraft noise through a complex 3D and time-dependent atmosphere around airports. One aim of the project is for the research team to utilize the high-fidelity weather data in FAA's Aviation Environmental Decision Tool (AEDT) to make better noise predictions with greater accuracy.



Schematic from https://spire.com/weather/

Just Noticeable Difference of Early Decay Time (EDT)

Principal investigator: Michelle Vigeant, associate professor of acoustics and architectural engineering
Student: Fernando del Solar, doctoral candidate in acoustics
Summary: Several perceptual attributes contribute to the perception of the acoustics in a concert hall. One of the most important is the perception of reverberance, the perception of sound lingering in a space. This perception is quantified using the metric of early decay time (EDT), however, the just noticeable difference (JND) of EDT has not been established. This quantity is necessary to know if significant perceptual differences will arise as a result of design decisions for new halls or when comparing existing spaces. There have been past studies on the JND of reverberation time, but work has shown that EDT is a much better predictor of reverberance. A subjective study was conducted wherein 30 participants listened to sets of stimuli based on measured room impulse responses of three North American concert halls that were varied in terms of EDT. The stimuli were presented in the AUralization and Reproduction of Acoustic Sound-fields (AURAS) facility at Penn State, which is a 30.2 loudspeaker array housed in an anechoic chamber. The spatial sound fields were reproduced using the method of third-order Ambisonics. The EDT JND was found to be approximately 28% of the EDT value when broadband changes in EDT were made ranging from 5% to 95%. The EDT JND results for each of the three halls and the overall result using a combined data set are shown to the right.

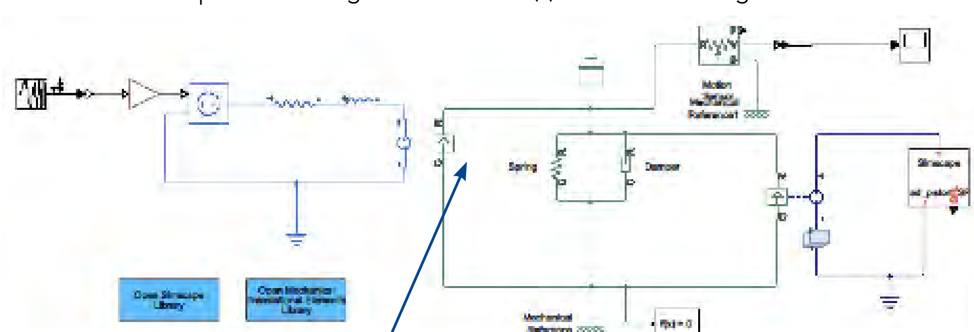


Realistic Modeling of Moving Coil Loudspeakers

Principal investigator: Stephen C. Thompson, research professor of acoustics
Summary: Small signal linear models of moving coil loudspeaker performance using the methods developed by Thiele and Small a half century ago remain the most often used models today. While those methods are a good starting point, practical speaker systems are seldom used with truly small driving signals. Deviation from small signal behavior is often seen when driving commercial speakers to only several per cent of their rated maximum drive level. The Simscape physical modeling methods that are included in the Matlab/Simulink software system provide a way to include

1. Nonlinear magnetic force factor as a function of cone displacement Bl(x).
2. Nonlinear mechanical restoring force as a function of cone displacement k(x).
3. Semi-inductive electrical impedance caused by eddy currents.
4. Nonlinearity caused by signal coupling to the magnetic circuit.
5. Thermoviscous loss in enclosures and acoustic transmission paths

These and other practical features of design and implementation can be included in the Simscape models. The example of including the nonlinear Bl(x) is shown in the figure.



$$F = B\ell(x)i$$
$$V = B\ell(x)v$$
where
$$B\ell = B\ell_0 + B\ell_1 x + B\ell_2 x^2 + B\ell_3 x^3 + B\ell_4 x^4$$

Rotorcraft Acoustics and Dynamics

Group Summary

Group Leader: Edward Smith
Professor of aerospace engineering

The Penn State's Center for Acoustics and Vibration (CAV) Rotorcraft Acoustics and Dynamics Technical Group continues to be at the core of our Vertical Lift Research Center. Penn State is home to one of only three National Rotorcraft Technology Center Vertical Lift Research Centers of Excellence (VLRCOE) in the country. In the summer of 2016, our center was successfully renewed for another five years. As part of our new program, we started fourteen new research projects. We are grateful to our industry partners at LORD Corporation, Bell, and Sikorsky for their support of our proposal. The center currently supports more than fifty full-time graduate students and involves more than twenty-five 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 U.S. Army, U.S. 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, novel anti-icing systems, variable speed rotors, structural health monitoring, and rotor loads control/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 facilities have also been recently developed for acoustic testing small scale rotor models (single and coaxial configurations) in an anechoic environment.

An outdoor acoustic flight test array capability has also been brought online. Our annual Rotorcraft Technology Short Course will be offered for the 54th consecutive year on August 9-13. Topics in the comprehensive course include rotorcraft aerodynamics, dynamics, acoustics, composite structures, flight controls and propulsion. For more information, please visit rotary-wing.outreach.psu.edu/. The 2021 course will be taught in an online format.

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

Measurements to Support Noise Certification of UAS and UAM Vehicles

Sponsor: Federal Aviation Administration
Principal investigators: Eric Greenwood, assistant professor of aerospace engineering, and Ken Brentner, professor of aerospace engineering
Students: Blaise Konzel, Joel Rachaprolu, and Keon Wong Hur
Summary: The goal of this project is to develop measurement and data processing techniques for the repeatable characterization of noise for unconventional aircraft, such as Unmanned Aerial System (UAS) and Urban Air Mobility (UAM) vehicles. Outdoor noise measurements of UAS and UAM vehicles pose unique challenges relative to conventional aircraft due to the use of distributed electric propulsion which is likely to increase the variability of noise during a flyover. Under this project noise measurements are being collected for a wide range of UAS and UAM configurations across different operating modes, flight speeds, and altitudes. A unique thirty-six-channel field-deployable outdoor noise measurement system with GPS time synchronization has been developed to support this project. A variety of IEC Class 1 measurement microphones are available with SAE ARP 4055 inverted ground board and elevated installations. Other instrumentation includes Differential GPS survey equipment, ground-based weather stations, and ultrasonic anemometers for measurements of turbulence intensity. This outdoor noise measurement system has recently been deployed to collect data for a long endurance 27 kg octocopter developed by the Penn State UAS Research Lab (PURL) at Mid-State Regional Airport, as well as Beta Technologies' ALIA-250 UAM aircraft in a conventional takeoff and landing configuration at their facility in Plattsburgh, New York. A reconfigurable

Figure 1: UAS Noise Measurement at Mid-State Regional Airport

multirotor UAS is being developed and will be tested to assess the effects of rotor number, blade design, and position on the radiated noise and the measurement and analysis process. In addition, a data analysis process has been developed that will allow the contributions of the individual rotor or propeller noise sources to be separated and modeled independently, allowing the variability in noise generation to be correlated to the variability in the vehicle flight state.

Flyover noise measurement of the Beta ALIA-250 at Plattsburgh, NY.

Efficient Modeling of Interaction Noise for UAM Vehicles

Sponsor: National Institute of Aerospace/NASA Revolutionary Vertical Lift Technology Project
Principal investigator: Eric Greenwood, assistant professor of aerospace engineering
Student: Rob Rau
Summary: The goal of this project is to develop a proof-of-concept method of modeling the unsteady loading noise caused by the aerodynamic interactions between the rotors of multirotor Advanced Air Mobility (AAM)—formerly termed Urban Air Mobility (UAM)—vehicles. At present, there are no modeling methods for rotor-rotor interaction noise suitable for the design of AAM vehicle configurations and low noise operations, due to the computational expense of modeling the complex aerodynamic interactions that cause interaction noise using current tools. This research aims to develop a hybrid modeling approach, where the flow around the vehicle and the convection of the rotor wakes is modeled using efficient potential flow methods and a near-body lattice Boltzmann method is used to predict the fluctuating pressures that generate noise on the blade surfaces. Recently, rotating blade motion has been added to the near-body solver (called the Aeroacoustic Lattice Boltzmann Method, or ALBM) using a field-velocity coupling approach. ALBM has also been coupled to the PSU-WOPWOP noise prediction code. A wake transport model is currently under development using three-dimensional actuator disk theory.

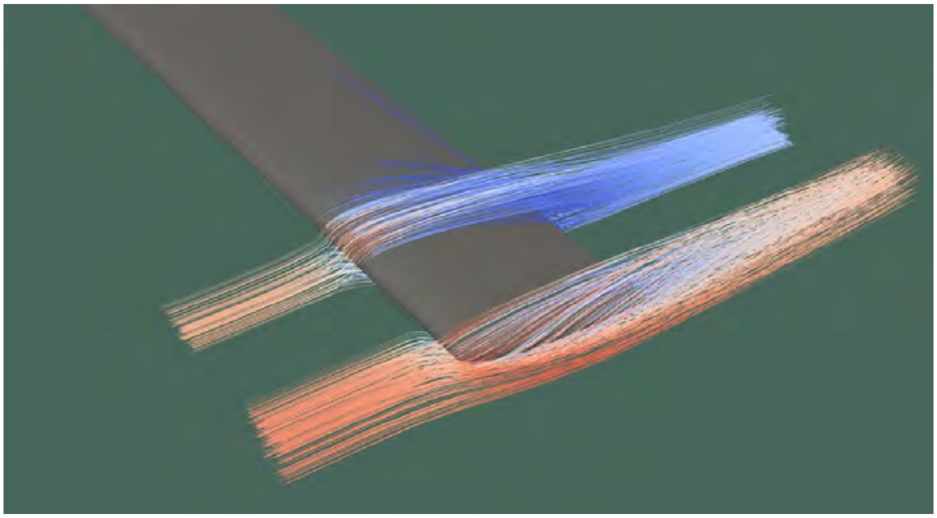
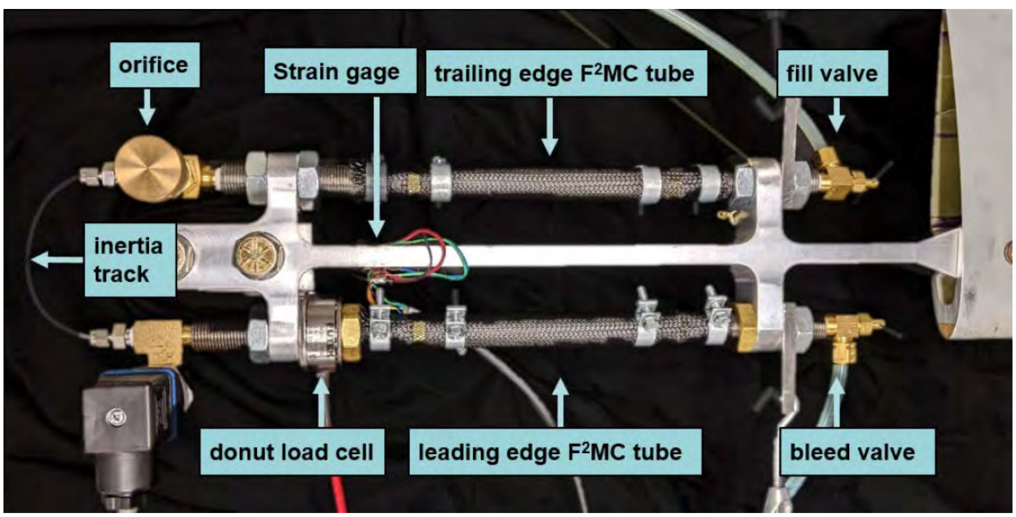


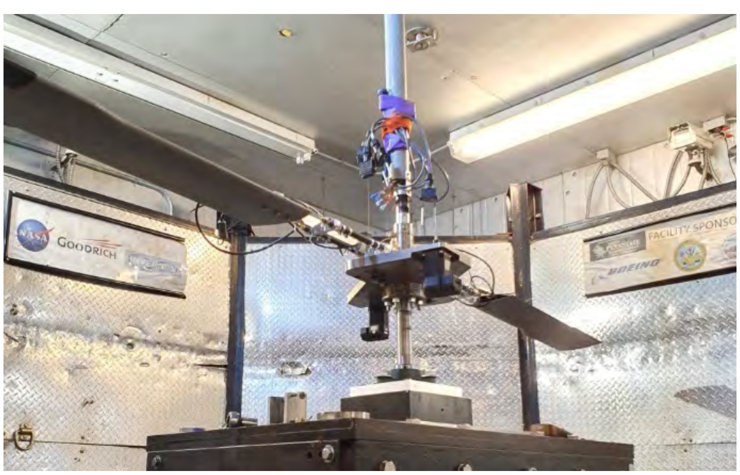
Figure 2: Streamlines of rotor tip vortex formation in ALBM.

Testing of fluidic flexible matrix composites (F2MC) damped vibration absorber for stiff in-plane hingeless rotorcraft blades

Sponsor: US Army Vertical Lift Research Center Program (VLRCOE)
Principal investigators: Edward Smith, professor of aerospace engineering; and Chris Rahn, professor of mechanical engineering
Student: Valentin Laneri, 2020 graduate
Summary: In the past year, the coupled F2MC lag damper was integrated to a small-scale (1.3 m radius) stiff in-plane blade with a first lag frequency at 1.4/rev. This year, first lag damping ratio was increased to 13% vs. 0.8% for the baseline benchtop test. The working fluid is at 40 psi. In benchtop testing, damping was characterized with either shaker or tip impulses. A controllable and repeatable blade excitation methodology was designed and tested to provide adequate deflection during rotating test, where a shaker can no longer be used. A high torque stepper motor pulling a cable attached at the blade tip is the selected system to excite the first lag mode. Blade response is measured with strain gages at the blade root and a pressure gage connected to the fluidic circuit. A second blade and F2MC system was assembled to have two blades connected to the hub during the rotating test. Benchtop testing of the entire hub assembly helped to address issues with coupled vibrations between the two blades.

Rotating tests were conducted at 140 RPM and demonstrate a damping ratio of the first lead-lag mode up to $\zeta = 10.5\%$ with the F2MC treatment when compared to the blade without lag damper where the measured damping is only of $\zeta = 3.5\%$. Vibration reduction between the two cases is observed in both the strain and the pressure signals at different excitation levels. Slip ring and Bluetooth measurements agree with each other. The system performance outside its tuned condition was studied varying the rotor RPM from 130 RPM to 210 RPM. Results showed only a 2.5% drop in the damping ratio of the F2MC treated blade when operating far from the tuned condition. Experimental results proved that the F2MC damping treatment is effective in a rotating environment.

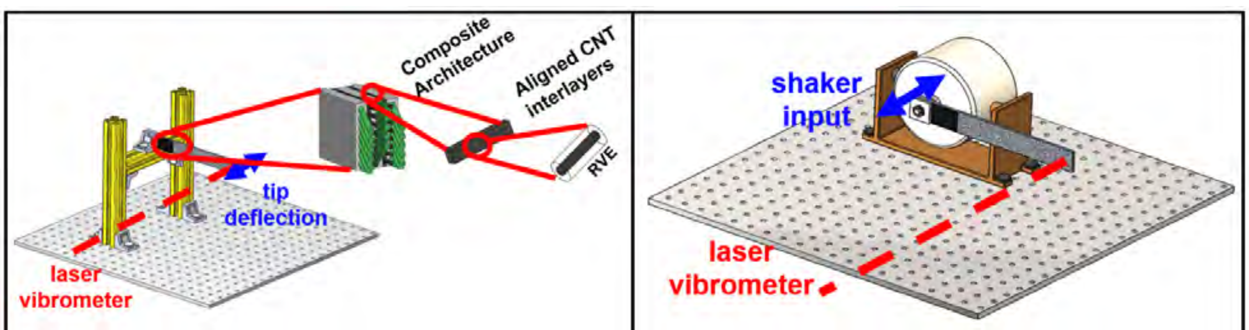




Enhanced damping for high-speed rigid rotors via tailored hybrid nanocomposites

Sponsor: US Army Vertical Lift Research Center Program (VLRCOE)
Principal investigators: Edward Smith, professor of aerospace engineering; and Charles Bakis distinguished professor of engineering science and mechanics
Students: Avery Brown and Keerti Prakash, 2020 graduate
Summary: In the past year, a multidirectionally-reinforced laminate, [0/±45]s, was used exclusively for tensile damping tests. The dynamic tensile testing plan was expanded markedly to evaluate new surfactants, different macroscopic forms of CNTs, tensile-tensile fatigue effect, and an expanded strain range into the compressive state, up to -3000 με. For the first time, we evaluated the effects of CNT yarns on the interlaminar shear strength. CNT yarn pullout testing was expanded to determine the interfacial strength during static and dynamic portions of the test along with post failure analysis. The most promising new surfactant, 2,3-Dibromo-1,4-Butanediol, decreased the static interfacial strength from ~3.5 MPa to ~2.8 MPa, and the dynamic interfacial strength from ~2.3 MPa to ~1.5 MPa (a critical value for micromechanical modeling). Damping in compression was found to be similar to that in tension, although strains of about -3000 με can cause microcracking and delamination originating at the CNT yarn – epoxy interface. A new form of CNTs, a longitudinally aligned CNT film, increased damping by 28% at strain excursions up to 3000 με compared to CNT yarns previously/currently used in the study. A surfactant concentration study with the new surfactant, was done to decrease surfactant concentration from 4:1 (surfactant:CNT) down to 0.15:1. This reduction in concentration will lead to a higher glass transition temperature compared to previously used surfactant.

Baseline composite and hybrid nanocomposite blades with [±45/0]s stacking sequence were fabricated. Two CNT interlayers, 64 g/m2, were placed between the carbon/epoxy for the first 20% of length near the root. The volume fraction of CNTs added to the composite was 1%, which corresponds to a weight change of ~0.65%. The nanocomposite and baseline blades were subjected to rotating tests. Excitation was provided by a torque impulse. Wireless data acquisition was used to obtain point strains near the root of the blades. A maximum damping ratio of ~5.8 % was seen for the hybrid nanocomposite blades vs. ~4.0% for the baseline blades and ~3.8% for aluminum. The micromechanical model to capture damping from CNTs was also modified to include CNT-CNT and CNT-epoxy damping. The updated model can capture strain dependence of critical shear stress. The updated micromechanical model was able to better capture the experimental results of coupon testing.



Schematic for Free and Forced Vibration Test Setup

Conceptualization to Fabrication of Rotating Test Setup

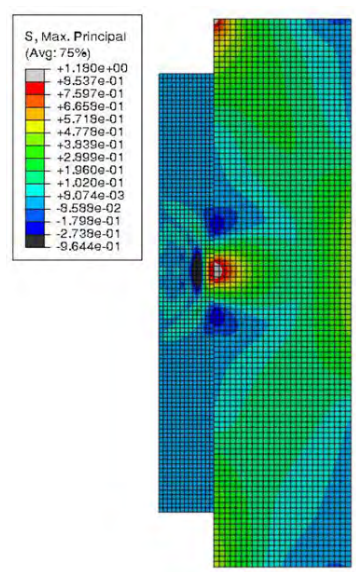
Design, analysis, and experimental testing of a compact, high reduction ratio and low noise Pericyclic transmissions

Sponsor: U.S. Army VLRCOE
Principal investigators: Edward Smith, professor of aerospace engineering; R. Bill, H. DeSmidt, University of Tennessee
Student: Randy Redfield, graduate student in mechanical engineering
Summary: A detailed physics-based design analysis of various transmission components—gears, bearings, shafts, and housing has led to manufacturing of a Pericyclic Drive prototype for 50 HP and 5000 RPM nominal input. NASA, APG ARL, and Penn State ARL's experience is being leveraged for assembly and testing. This project will conduct low-power tests to evaluate backlash and oil churning and conduct high power tests at APG ARL VIPER test rig. Following this, gear noise, vibration modes will be predicted, and an optimal torque range will be evaluated for each load case. The results from the experiment will be then used to validate the mechanical design as well as the noise and vibration analysis. Develop and exercise an optimization methodology to achieve higher efficiency, reliability, and reduced weight will be the final step.

With all components procured and any required reworks finished the assembly procedure and all components have been checked for accurateness compared to the drawings. The process of assembling, procurement of fasteners and O-rings, and creation of a detailed assembly procedure, has begun at the Penn State ARL. Dynamic studies and scale-up studies were conducted on several configurations and varying constraints earlier in quarter two. Preparations have begun for the transition of the pericyclic drive into the VIPER rig located at the APG ARL lab in order to undergo high power testing.

The final assembly and gear interfacing analysis has begun with components that required rework having been verified for accuracy. Penn State ARL is assisting with assembly and tolerancing verification as well as part adjustments for backlash. All of this will be completed at the start of year five along with preparation required to get the prototype to properly interface with the VIPER rig at APG. After data acquisition and testing has been completed the final verification of the calculated predictions can begin. The data will be compared with both static and dynamic predictions of the gear train behavior. The ending portion of the project will consist of documenting all design methodology and data acquisition and comparison.

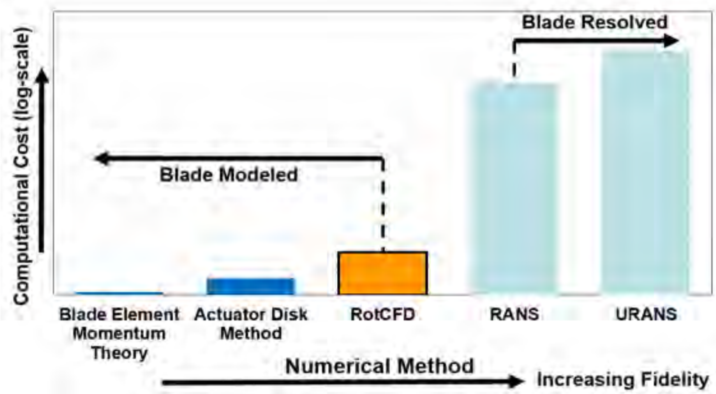
Identifying bonded elastomeric bearing manufacturing defects with acoustic emission testing



Principal investigators: Edward Smith, professor of aerospace engineering, and Clark Moose, research and development in the Applied Research Laboratory
Student: Daniel Jaep, graduate student in mechanical engineering
Summary: This project involves using acoustic emission to test for manufacturing defects in center trunnion bearings used in main rotor transmission mounts. A peripheral device was designed and fabricated to allow for load and extension data from the test machine to be fully synced and integrated with the acoustic emission data acquisition system and software. Trunnion bearings and double lap shear (DLS) coupons with simplified geometry have been tested thus far. Finite Element Analysis has been implemented to assist in finding the optimum sensor placement for a given geometry. Shortly, we will be investigating the effect of elastomer aging on resultant acoustic emission signals to see if we can detect age through acoustic emission.

Using a Hybrid Actuator Disk RANS Approach for Coaxial Rotor Performance Predictions

Sponsor: National Science Foundation
Principal investigator: Sven Schmitz, associate professor of aerospace engineering
Student: Jason Cornelius, doctoral student in aerospace engineering
Summary: A detailed physics-based design analysis of various transmission components—gears, bearings, sThe commercially available program RotCFD, which is short for Rotorcraft Computational Fluid Dynamics, has been used for coaxial rotor performance predictions. RotCFD combines an actuator disk representation of the rotors with a time accurate RANS flow solver in the domain. The approach allows for capturing relevant aspects of the rotor system such as hub effects, rotor-rotor interactions, and the full rotor inflow and wake while also greatly reducing the computational cost as compared to blade-resolved approaches. The figure below displays how RotCFD compares in terms of computational cost and model fidelity with other common predictive capabilities. A methodology has been developed to create C81 airfoil input decks for sectional angles of attack from -180 to +180 degrees. These are used for imparting momentum into the flowfield through the actuator disk representation of the rotors and allow for realistic values of lift, drag, and pitching moment in a wide variety of flight conditions. The methodology combines two-dimensional thin-layer Reynolds Averaged Navier-Stokes CFD predictions from ARC2D in the attached flow regime with experimental data in the separated flow regions. The Viterna-Corrigan correction is used to blend between the two data sets post-Clmax. Comparisons of the RotCFD model to experimental data taken in the Langley 14- by 22- ft. Subsonic Tunnel Facility show agreement within 5-10% of rotor thrust and torque from rotor angles of attack -90 to +90 from the freestream flow. This predictive capability comes at a much lower computational cost as compared to the conventional higher fidelity rotor CFD approaches.



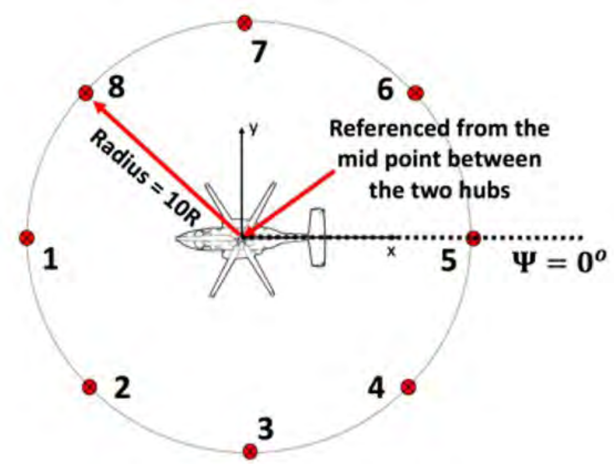
Fundamental Aeroacoustics of Coaxial Helicopter Rotors

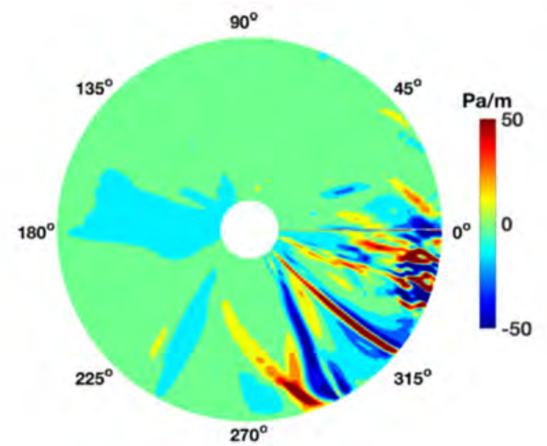
Sponsor: U.S. Army VLRCOE
Principal investigator: Ken Brentner Schmitz, professor of aerospace engineering; S. Lee, University of California, Davis
Students: Kalki Sharma, doctoral student in aerospace engineering; Henry Jia, doctoral student, University of California, Davis
Research Objectives: The objective of this research is to advance the fundamental knowledge of the generation and propagation of coaxial rotorcraft aerodynamic noise, and develop and evaluate high-fidelity numerical aerodynamics and acoustics predictions for lift-offset coaxial rotors. The specific goals are described as follows:

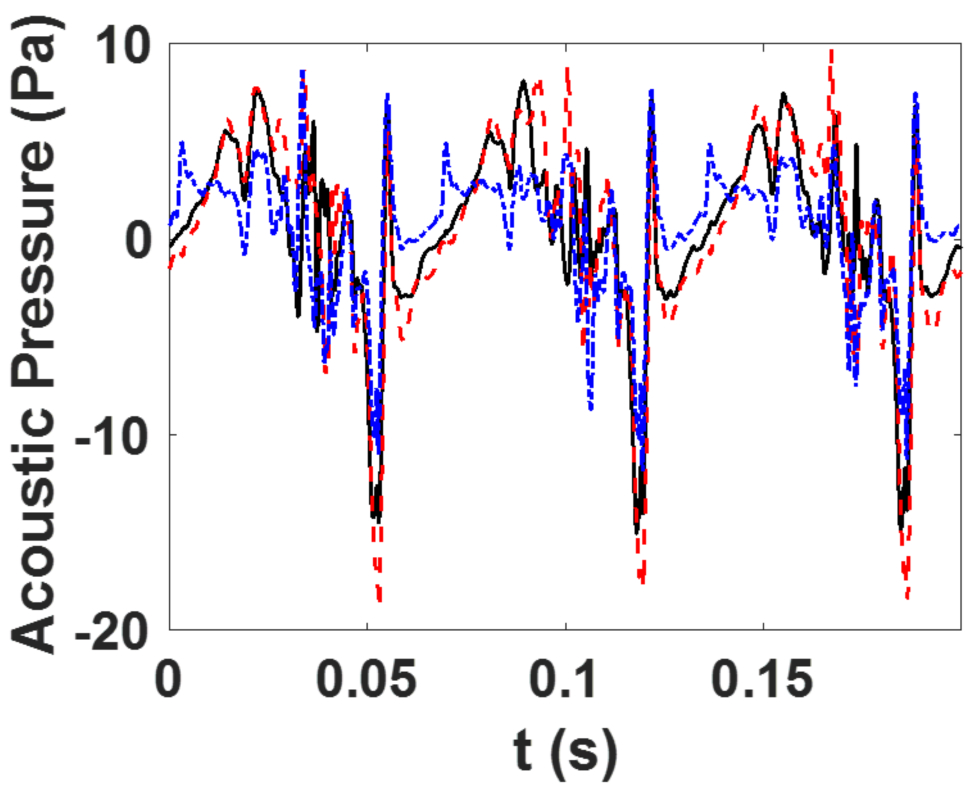
- Identify the physical noise generation mechanisms and characterize the acoustics of the extra noise inherent to a coaxial rotor system.
- Characterize and quantify the contributions of different noise sources of a lift-offset coaxial configuration.
- Investigate the influence of physical and numerical parameters relevant to the noise.

Approach:
The aerodynamic computations will focus on the unsteady interactions uniquely identified with a coaxial rotor system (edgewise rotors). These include unique aspects of blade-vortex interaction; however, interaction geometry, wake skew angle, and vortex strength are expected to be significantly different than that for a single rotor operating at the same flight condition. These sources of unsteady loading are directly related to the loading noise, which will be thoroughly studied to develop and understanding of the potential "excess" noise associated with the coaxial, and lift-offset coaxial configurations in different potential modes of operation.

To achieve the research objectives, high-fidelity CFD-CSD loose coupling simulations and medium-fidelity free-wake simulations will be performed to capture the complex aerodynamic interactions of a lift-offset coaxial system under various flight conditions. Aerodynamic loads and acoustic sources will be investigated through detailed analyses of simulation outputs. Acoustic comparisons between a lift-offset coaxial rotor and a corresponding isolated rotor are also critical to identifying the unique characteristics of lift-offset coaxial rotor system. Parameter sensitivity including the lift-offset value, flight speed, rotor separation distance, vehicle pitch angle will be performed. The coaxial rotor system was also analyzed using mid-fidelity methods such as the Viscous-Vortex Particle Method (VVPM) and the Free-Wake Model (FWM).







Structural Vibration and Acoustics

Group Summary

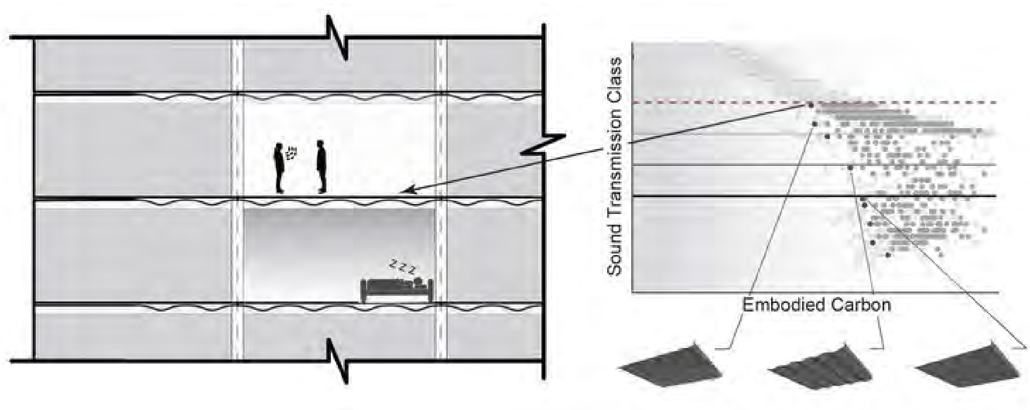
The Structural Vibration and Acoustics Technical Group investigates how structures vibrate and radiate sound. We develop novel methods to analyze, measure, and control structural vibrations and radiated noise.

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

Group Leader: Steve Hambric
Research professor in the Penn State Applied Research Laboratory and acoustics

Optimization of structural-acoustical shaped concrete slabs in buildings

Sponsor: HRL/Boeing
Principal investigator: Nathan Brown, assistant professor of architectural engineering
Co-principal investigator: Micah Shepherd, assistant research professor in the Penn State Applied Research Laboratory
Student: Jonathan Broyles, doctoral student in architectural engineering
Summary: With advancements in digital design tools, architects and engineers have developed novel sustainable building components that reduce the amount of embodied carbon in structures while maintaining structural integrity. However, these optimized structures can neglect secondary design objectives such as acoustics during the computational process. This research investigates the relationship between structural and acoustic performance for shaped concrete slabs with curved, non-standard geometry. Design space exploration techniques such as sampling, multi-objective optimization, and constrained optimization are used to find broad structural-acoustic trends and identify the best performing shaped slabs at varying acoustic performance levels.

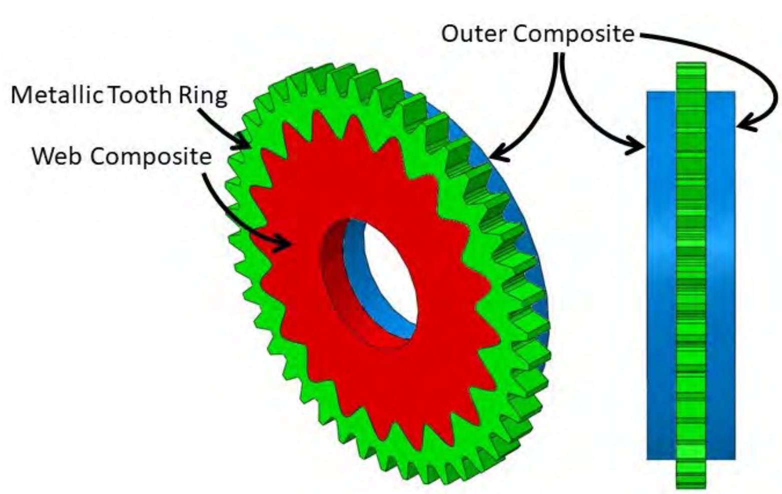


Carbon Nanotube Loudspeaker Technology Development

Sponsor: Joint Non-lethal Weapons Directorate
Principal investigators: Tim Brungart, research professor in the Penn State Applied Research Laboratory and acoustics; Benjamin Beck, assistant research professor in the Penn State Applied Research Laboratory and engineering program manager in the Radiation Science & Engineering Center
Student: James Chatterley, senior research assistant in the Penn State Applied Research Laboratory
Summary: Development of a coupled electrical, thermodynamic, fluid dynamic and mechanical model of carbon nanotube (CNT) loudspeaker sound generation to: Explore the pertinent multiphysics interactions leading to CNT sound generation; Identify means to increase CNT sound generation efficiency, sound pressure output and power handling; Identify technology limitations focusing on CNT sound generation efficiency including fundamental physical limits to the transduction efficiency and major contributors to system inefficiencies; Explore the utility of signal processing as a means of increasing the CNT sound generation efficiency; Identify CNT forest and film properties that could be tailored to increase sound generation efficiency, power handling, and robustness. Additionally, we will perform benchtop testing with CNT film samples to complement and begin verifying the multiphysics modeling and use of signal processing to increase sound generation efficiency.

Experimental and Computational Analysis of Thermal and Dynamic Performance of Hybrid Gears under Normal and Loss-of-Lubrication Operation

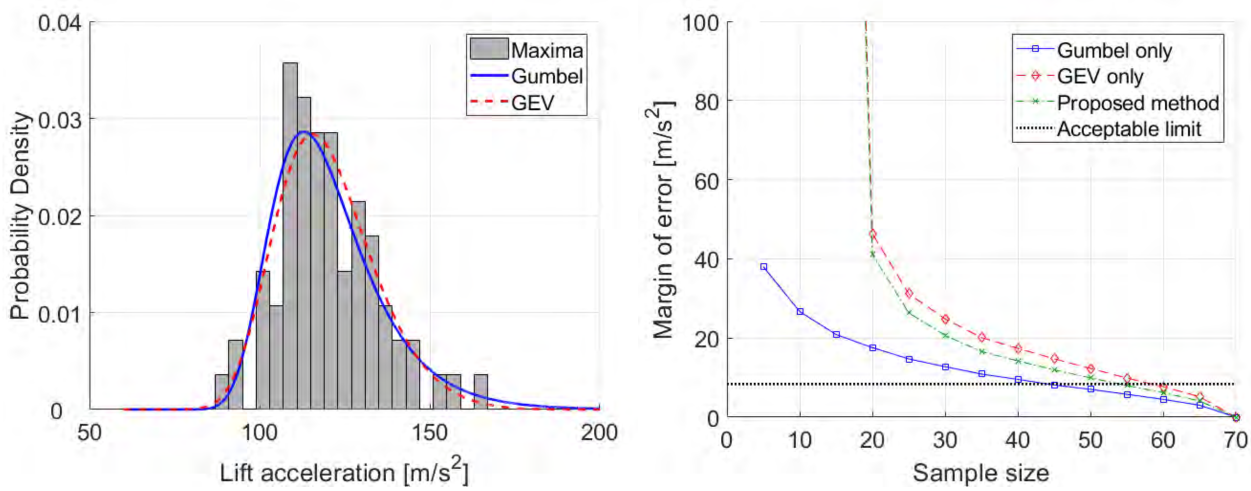
Sponsors: U.S. Army, U.S. Navy and NASA (via PSU VLRCOE award)
Principal investigators: Sean McIntyre, assistant research professor in the Penn State Applied Research Laboratory; Robert Campbell, associate research professor in the Penn State Applied Research Laboratory, acoustics and mechanical engineering
Student: Sean Gauntt, doctoral student in mechanical engineering
Summary: The hybrid gear concept focuses on decreasing rotorcraft drivetrain weight by coupling a composite body with an outer rim of steel gear teeth. Current research has focused on assessing whether hybrid gears can be designed for realistic-scale applications that significantly reduce weight without adversely affecting vibration performance. An optimization technique was developed to determine optimal gear topologies for small and large-scale hybrid spur gears with a sinusoidal interlock and integral composite shaft. The optimization objectives were to minimize gear mass, shear tractions at the composite-steel interface and gear tooth deflections. Finite element models of the optimized designs were then incorporated into system-level drivetrain models. Gear tooth profile modifications were optimized to minimize peak-to-peak transmission error. The final designs were used to compare transmission error predictions of hybrid gears to baseline steel gears. From the results, it appears that hybrid gears will be able to reduce weight by 15%-45% without negatively affecting vibration performance for low and medium speed applications, as hybrid gear models predict similar performance to their all-steel counterparts. At higher speeds, drivetrains featuring hybrid gears are predicted to have significantly different dynamic response than all-steel drivetrains, but whether this difference is an improvement is design- and speed-dependent.



Extreme value statistics of flow-induced vibration and fatigue

Sponsor: NAVSEA 073R
Principal investigators: Stephen Conlon, research professor in the Penn State Applied Research Lab; Manton Guers, assistant research professor in the Penn State Applied Research Laboratory
Student: Connor McCluskey, doctoral candidate in acoustics

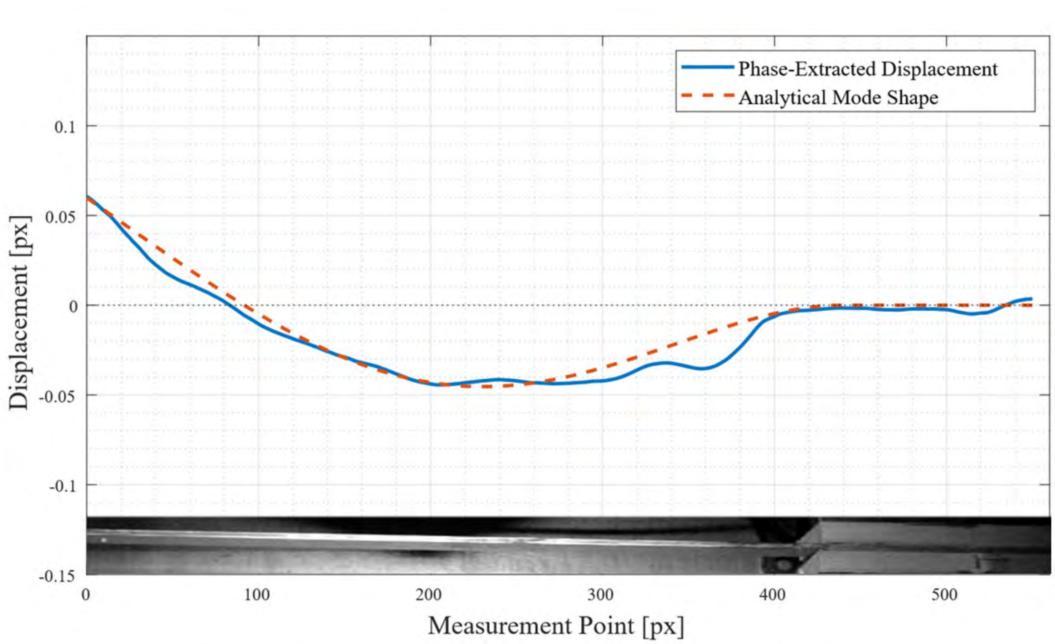
Summary: Flow-induced noise and vibration produce cyclic loading on structures such as wind turbines and vehicle control surfaces. Since the flow excitation is often random in nature, infrequent large amplitude loads are expected to occur in these applications. These large outlier loads ultimately decrease the fatigue performance of these structures. The goal of this work is to develop the theory for predicting the flow-induced structural response to extreme events and the resulting impact on maximum design loads and cyclic fatigue. Extreme value statistics are used to predict outlier loads based off measurements. Single degree of freedom models and flow-induced vibration response measurements demonstrated the effects of structural response on prediction. An improved methodology for determining maximum design loads was developed, including a method to estimate minimum sample sizes for extreme value distributions based off the variance in conservative prediction. Currently, stress-strain cycles from a finite element model are being collected to determine how extreme stresses affect structural fatigue life. An improved methodology for predicting this damage is being developed.



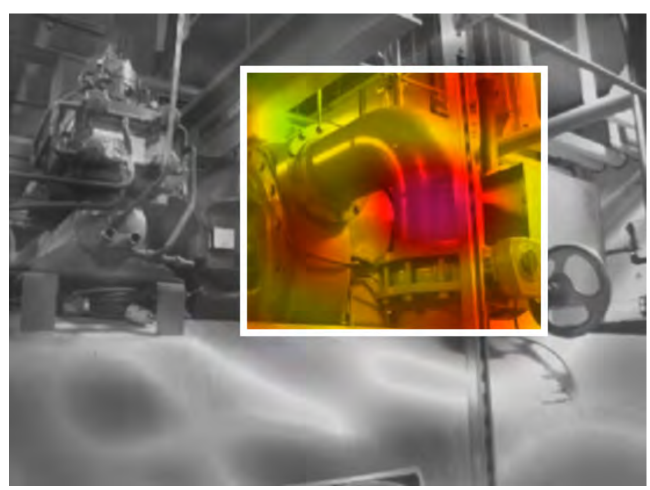
Two extreme value distributions (a) were fit to the extreme loads of a cantilever fin to obtain a conservative prediction to use as a maximum design load. The variance of this prediction (b), quantified as a margin of error, decreases as more samples are collected. The developed method calculates the margin of error for several sample sizes using both extreme value distributions until the margin of error is acceptable.

Motion magnification for vibrations measurements

Principal investigator: Tyler Dare, assistant research professor in the Penn State Applied Research Laboratory
Student: Sean Collier, doctoral student in acoustics
Summary: Motion magnification is a video processing technique in which sub-pixel motions are made to appear large. Recent advances in video processing algorithms—including the Riesz pyramid and the Complex Steerable Pyramid—have been implemented to magnify vibration within a given frequency band; further, this (spatial) phase-based approach allows for the extraction of vibration signals from video. However, these methods can fail when combined with bulk motion of the vibrating structure or when the vibration itself is too large or too small. This research involves developing techniques to separate large (super-pixel) motion from vibration and investigating whether high-speed video with phase-based motion extraction can be used as a robust, non-contact vibration measurement technique for a wide variety of vibrating structures.



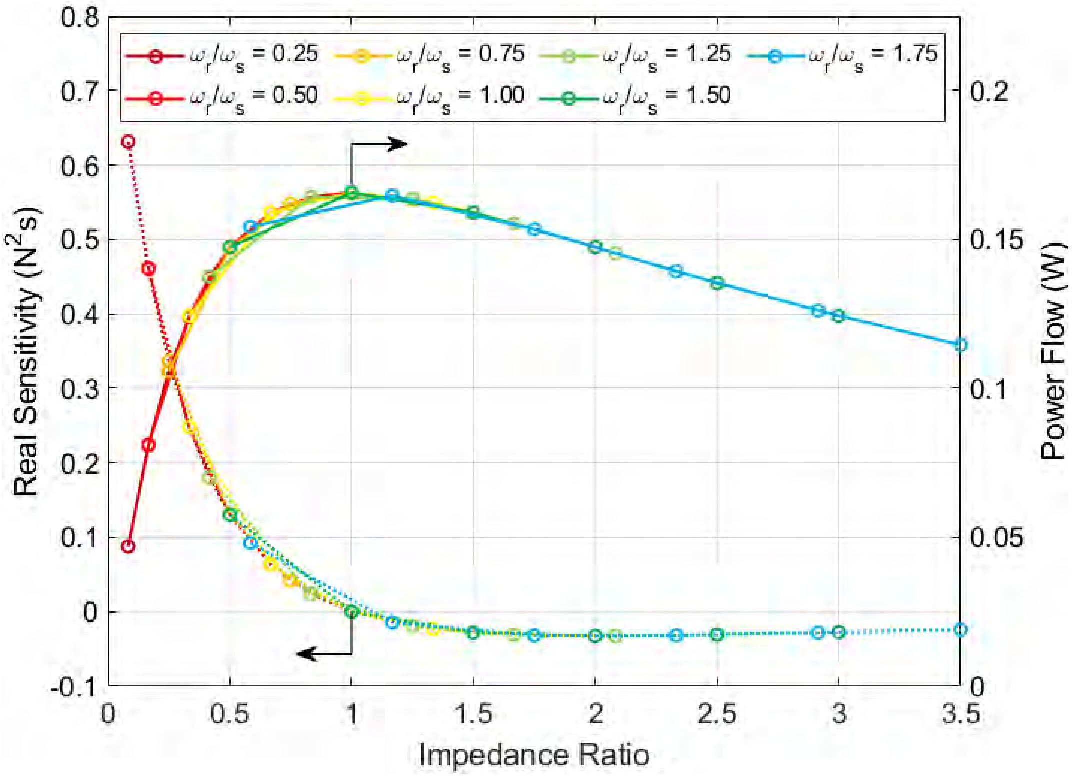
Large chiller noise and vibration



Sponsor: UTC Building and Information Systems (Carrier)
Principal investigators: Steve Hambric, research professor in the Penn State Applied Research Laboratory and acoustics; Tim Brungart, research professor in the Penn State Applied Research Laboratory and acoustics
Student: Stephen Wells, doctoral candidate in 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 has been constructed to simulate the chiller vibration and sound.

Power Flow Sensitivity Analysis for General Structural Modifications

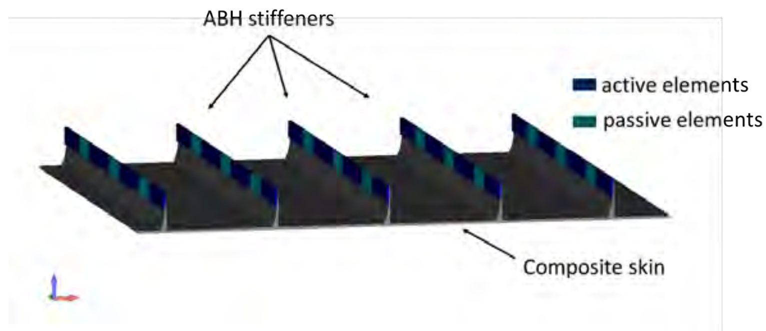
Sponsor: Walker Assistantship
Principal investigator: Kyle Myers, assistant research professor in the Penn State Applied Research Laboratory
Student: Jonathan Young, doctoral student in mechanical engineering
Summary: Power flow between source and passive receiver structures is a common metric for characterizing the dynamics of coupled structures. The objective is generally to reduce the amount of power flow between the structures by means of structural modifications, insofar as to reduce the overall levels of vibration of the coupled system. As such, the sensitivity of power flow to changes in inertial, elastic, and dissipative properties of the receiver are quantified. It is shown that sensitivity of zero corresponds to maximum power flow between a source and receiver structure and can be used as a proxy for matching interface impedances for multi-degree-of-freedom systems. A positive sensitivity corresponds to an increase in power flow with respect to a small perturbation in a structure's properties, and a negative sensitivity indicates a decrease. Relationships between power flow, sensitivity, and impedance matching are identified which can be readily applied to substructures with many degrees of freedom to select locations on the receiver to modify so as to reduce power flow.



Acoustic Black hole Evaluation for Reduced Radiation Efficiency

Sponsor: Fluor Marine Propulsion, LLC
Principal investigators: Micah Shepherd, assistant research professor in the Penn State Applied Research Laboratory and acoustics; Amanda Hanford, assistant research professor in the Penn State Applied Research Laboratory, mechanical engineering, and acoustics
Student: Emily Stimson, graduate student in acoustics
Summary: Acoustic black hole (ABH) technology will be expanded to exploit its ability to the reduce radiation efficiency when embedded in a structure. Design guidance will be developed which utilizes the ABH parameters and locations to create a meta-structure plate which exhibits reduced radiation efficiency when compared to standard plate. To demonstrate, prototype panels will be fabricated and tested.

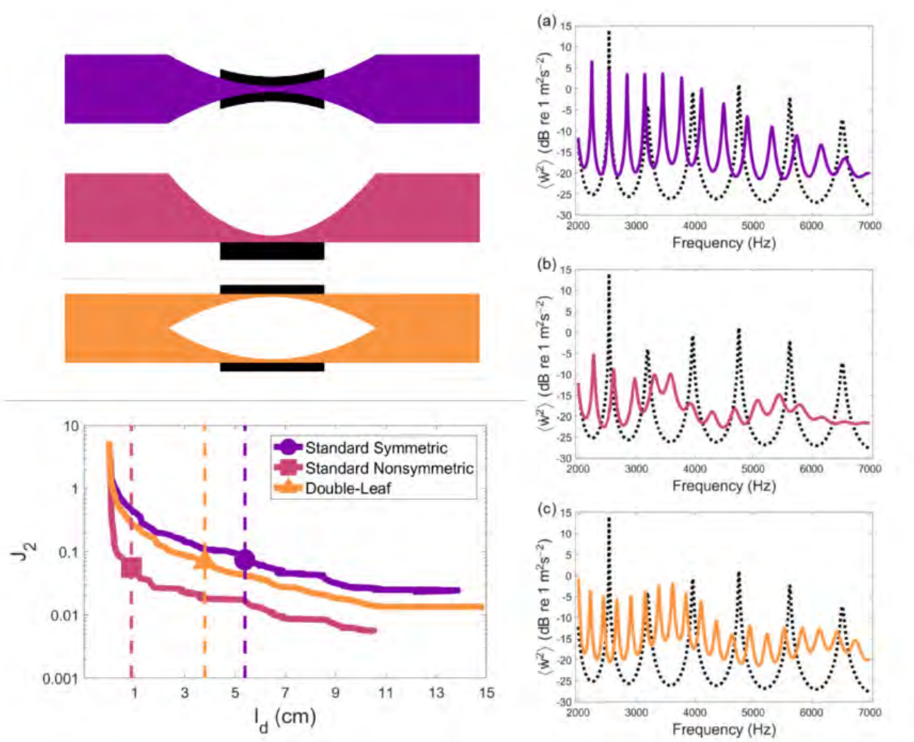
Advanced Damping System for Broadband Vibration and Interior Noise Control of Composite Airframes on Transport Rotorcraft



Sponsor: Office of Naval Research
Principal investigators: Micah Shepherd, assistant research professor in the Penn State Applied Research Laboratory and acoustics; Ben Beck, assistant research professor in the Penn State Applied Research Laboratory and engineering program manager in the Radiation Science & Engineering Center; and Ed Smith, professor of aerospace engineering
Summary: The object of this research is to determine the trade-off in the stiffening, mass and damping performance of an ABH-stiffened composite panel. The stiffener cross-section will be an ABH shape with damping elements near the tip with the design parameters determined using formal, multi-objective optimization. Additionally, a combined active/passive damping system will be investigated to achieve the best broadband reduction of the meta-structure.

Optimization of acoustic black hole design for improved structural acoustics

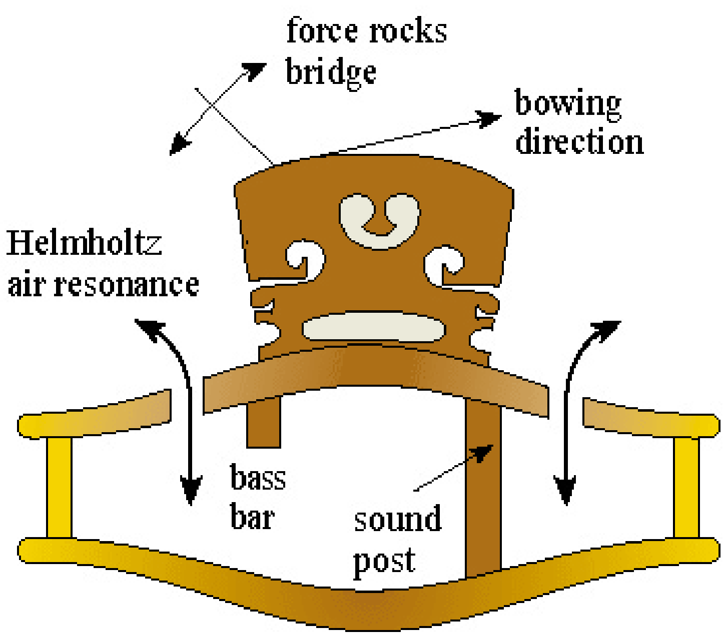
Sponsor: Applied Research Laboratory Walker Fellowship
Principal investigator: Micah Shepherd, assistant research professor in the Penn State Applied Research Laboratory and acoustics
Student: Cameron McCormick, doctoral candidate in acoustics
Summary: Arrays of Acoustic Black Holes (ABHs) have the potential to significantly reduce structural vibration and radiated sound. However, the optimal ABH 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.

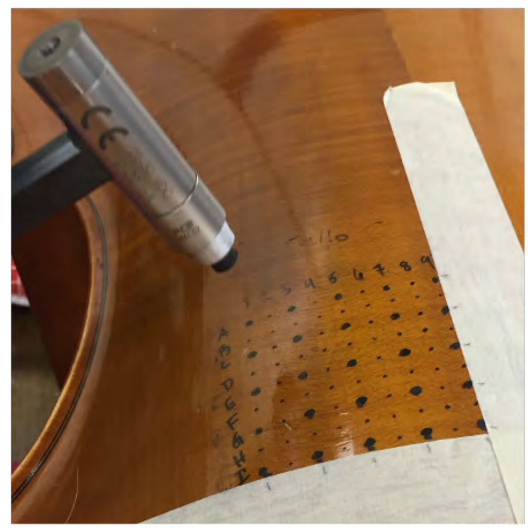


Determining the location and influence of cello soundposts

Principal investigators: Micah Shepherd, assistant research professor in the Penn State Applied Research Laboratory and acoustics; Tom Blanford, assistant research professor in the Penn State Applied Research Lab
Students: Eric Rokni, doctoral candidate in acoustics; Molly Smallcomb, doctoral candidate in acoustics

Summary: The soundpost in a cello plays an important role in the dynamics of the body and ultimately the sound produced by the instrument. A series of studies is being performed to localize the soundpost and determine its effect on carved and laminate cellos.





Systems and Structures Health Management

Group Leader: Cliff Lissenden
Professor of engineering science and mechanics and acoustics

Group Leader: Karl Reichard
Associate research professor in the Penn State Applied Research Laboratory

Group Summary

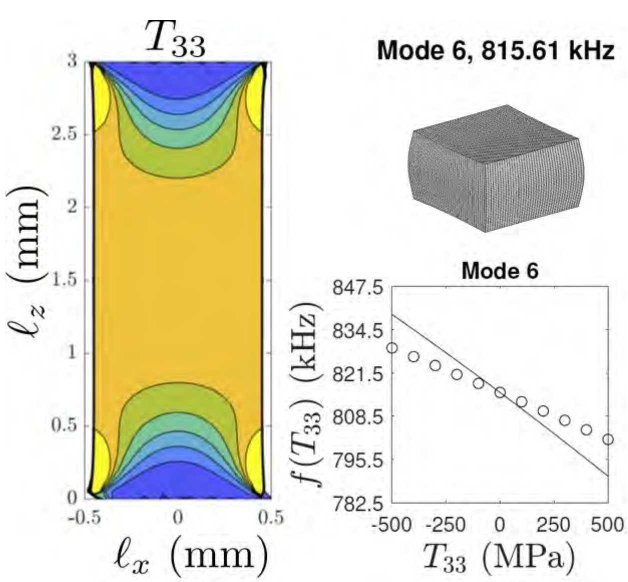
The mission of the Systems and Structures Health Management Technical Group is to develop new methodologies and technologies to manage the life cycle of systems and structures. This includes the full range of material state awareness, health and usage monitoring, and condition-based maintenance, to support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

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

Residual stress influence on the free vibrations of elastic solids

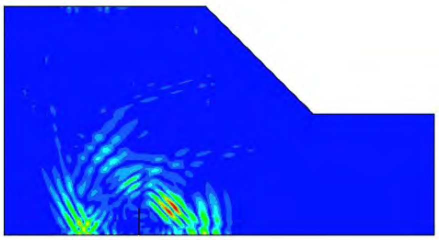
Sponsor: U.S. Air Force Research Laboratory
Principal investigator: Christopher Kube, assistant professor of engineering science and mechanics and acoustics
Student: Jared Gillespie, graduate student in engineering science and mechanics
Summary: The presence of an initial or residual stress existing in a solid is usually neglected when considering its vibratory response. While the volume average residual stress field and tractions at the boundaries must satisfy equilibrium, the distribution of residual stress within the volume can have a strong influence on the structure's resonance frequencies. In this work, the team developed a micromechanical model to introduce stress-dependent effective elastic properties into the traditional variational model that governs the resonance behavior of elastic solids. The figure below shows that a realistic residual stress field with a dominant stress component T33 is predicted to change the resonance frequency significantly for a rectangular parallelepiped sample. While this work is supporting the use of resonance behavior for quality control of AM sample, the results are applicable to general vibratory structures.



Photograph of passive balancer in the ten-foot diameter rotor in the Penn State hover stand.

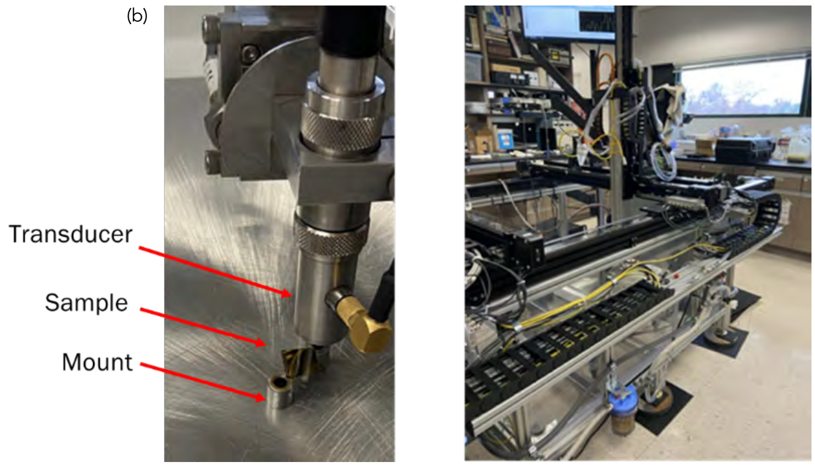
Computational Modeling of Vertical Crack Scattering

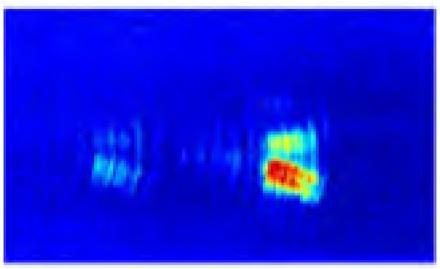
Sponsor: Intel Corp.
Principal investigator: Andrea P. Argüelles, assistant professor of engineering science and mechanics and acoustics
Student: Lauren Katch, doctoral student in engineering science and mechanics
Summary: Semiconductors are susceptible to micro-sized cracking during manufacturing. These cracks can be vertical and undetectable using traditional scanning acoustic microscopy methods. We are researching oblique incidence pulse echo methods that rely on shear wave scattering for detection. Currently, we are developing a combined modeling and experimental approach that optimizes detection and sizing of vertical cracks.



(a)

(b)



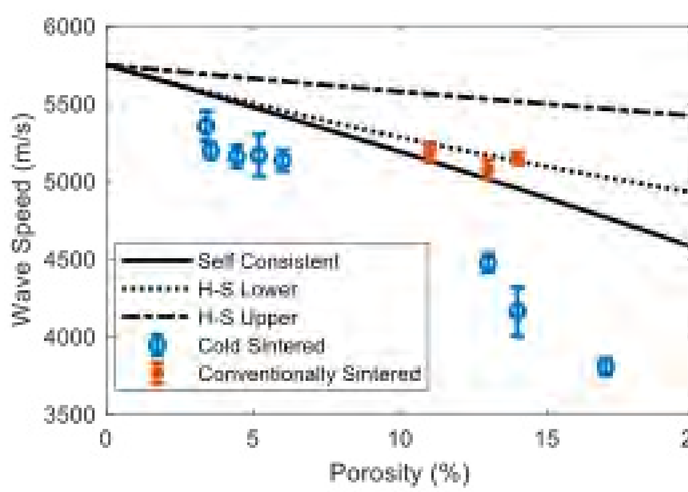


(c)

(a) Scattering of an angled shear wave from a vertical crack in a silicon sample modeled in Abaqus; (b) experimental setup for testing of silicon wafers, and (c) C-scan image of shear wave reflection from verticals cracks in silicon wafer.

Acoustic Characterization of Cold Sintered Components

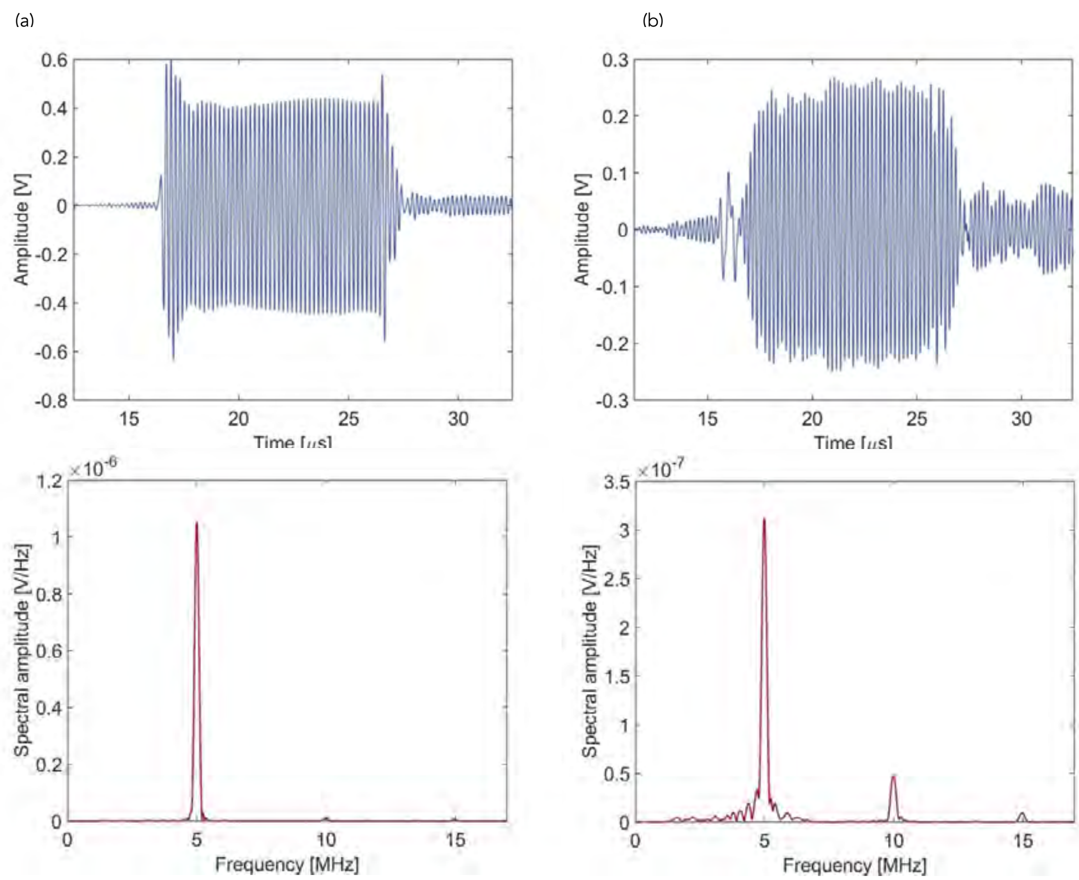
Sponsor: Center for Dielectrics and Piezoelectrics, Penn State
Principal investigators: Andrea P. Argüelles, assistant professor of engineering science and mechanics and acoustics; Susan Trolier-McKinstry, Evan Pugh Professor and Steward S. Flashchen Professor of Materials Science and Engineering and professor of electrical engineering
Students: Elizabeth Trautman, Shruti Gupta
Summary: The cold sintering process (CSP) is a low temperature processing technique used to synthesize ceramics and composites. In some CSP parts, density gradients arise due to pressure gradients in the die, inhomogeneities in the temperature, and/or heterogeneous distribution of the flux. Relative density measurements alone cannot distinguish between small, isolated pores and larger defects, which encourages the development of new techniques to identify the homogeneity of cold sintered parts. This work focuses on the ex situ ultrasonic characterization of cold sintered samples. The preliminary results demonstrate significant differences in the response of cold vs. conventionally sintered ceramic samples.



Porosity dependent wave speeds for cold and conventionally sintered ZnO samples, where the data points correspond to the mean wave speed for each sample and the error bars are the standard deviation. The lines represent analytical estimates of the porosity dependence based on Hashin-Shtrikman and self-consistent averaging.

Nonlinear laser ultrasonics for reduced variability in additive manufacturing

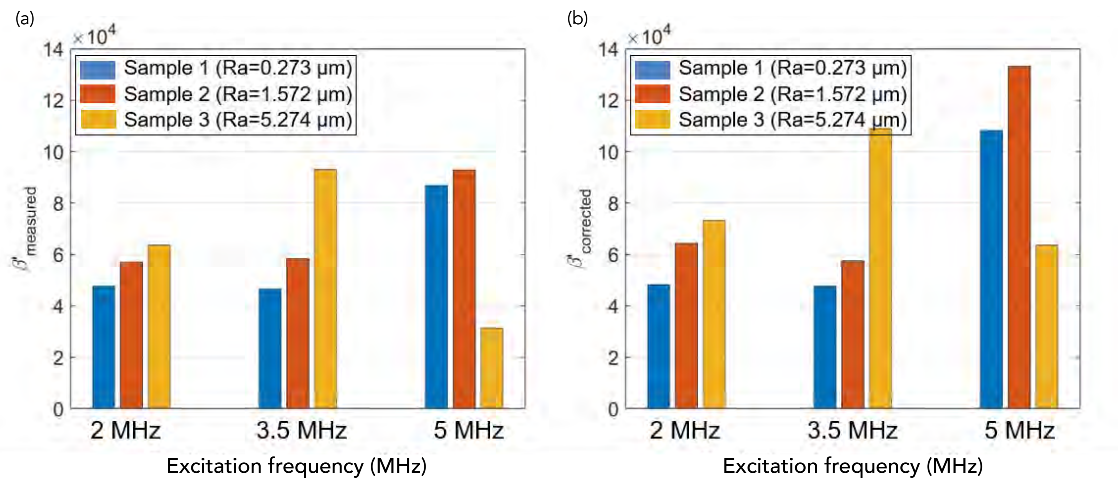
Sponsor: Penn State Vertical Lift Research Center of Excellence (U.S. Army, U.S. Navy, NASA)
Principal investigators: Cliff Lissenden, professor of engineering science and mechanics and acoustics; Ted Reutzel, associate research professor in the Penn State Applied Research Laboratory, engineering science and mechanics, and mechanical engineering
Students: Chaitanya Bakre, doctoral student; Gerald Boddie, doctoral student in engineering science and mechanics
Summary: High reliability and low variability is crucial for flight critical rotorcraft parts, but additive manufacturing processes, despite providing revolutionary capabilities, have complex physics that typically result is some level of material variability. We are investigating laser generated Rayleigh waves to interrogate the current surface layer in an AM build in-situ in order to provide feedback for process control and stop the build process if defects are detected. Measured ultrasonic nonlinearity, for example second harmonic generation, is due in part to material nonlinearity. Our recent results indicate that the ultrasonic nonlinearity of an additively manufactured Ti-6-4 sample is 15 times larger than the baseplate of the same material. Research is ongoing to explain why this is so.



A-scan and frequency spectrum for: (a) Ti-6-4 baseplate and (b) Ti-6-4 additively manufactured sample. A1 and A2 are the spectral amplitudes at the primary (5 MHz) and secondary (10 MHz) frequencies respectively.

Mixing elastic waves to nondestructively characterize microstructure during additive manufacturing of metals

Sponsor: National Science Foundation
Principal investigators: Cliff Lissenden, professor of engineering science and mechanics and acoustics; Abdalla Nassar, associate research professor in the Penn State Applied Research Laboratory, engineering science and mechanics, and mechanical engineering
Students: Chaitanya Bakre, 2021 graduate, doctoral degree; Gerald Boddie, doctoral student in engineering science and mechanics
Summary: Process monitoring during additive manufacturing can assess the material and provide feedback. Laser ultrasonics provides a means to generate and receive Rayleigh waves that interrogate the part's surface as it is built layer-by-layer. Information about the material's microstructure can be obtained based on the distortion associated with nonlinear Rayleigh waves. However, the surfaces are quite rough. Therefore, it is important to understand the effect that a rough surface has on Rayleigh wave distortion. Wave distortion is commonly described by the relative nonlinearity parameter β'. The figure below shows that increasing roughness, as Ra increases from 0.273 to 1.572 to 5.274 µm, causes the measured β' to increase. Surface roughness increases attenuation, which is known to effect distortion. However, the corrected value of β' based on attenuation worsens the correlation of β' to material nonlinearity. Thus, our understanding of the effect of surface roughness on Rayleigh wave distortion is lacking and needs to be examined further.

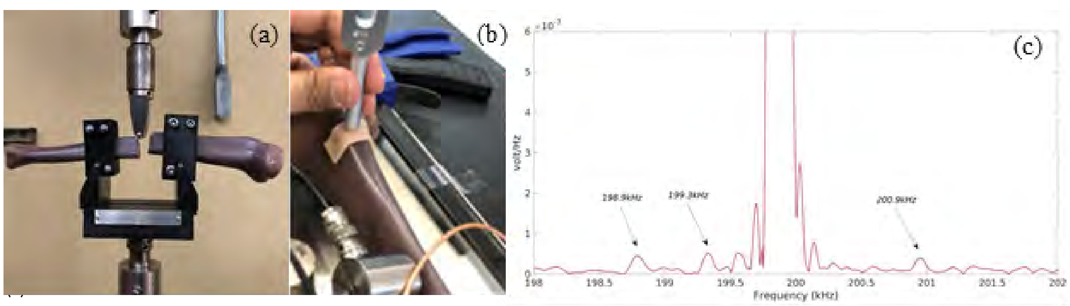


Relative nonlinearity parameter for each excitation frequency: (a) measured, (b) corrected.

Ultrasonic guided waves as a diagnostic tool to evaluate fragility fractures

Sponsor: National Science Foundation
Principal investigators: Michael Aynardi, staff physician of orthopaedics at the Milton S. Hershey Medical Center; Greg Lewis, assistant professor of orthopaedics and rehabilitation; Cliff Lissenden, professor of engineering science and mechanics and acoustics; and Parisa Shokouhi, associate professor in engineering science and mechanics and acoustics
Students: Anurup Guha, doctoral student in engineering science and mechanics; Tyler Duane, 2021 graduate, bachelor of science in engineering science and mechanics; and Colin Slavtcheff, bachelor of science in engineering science and mechanics
Summary: The figure below highlights our current progress in using vibration-mode frequencies in vibro-acoustic nonlinear characterization of closed fatigue fracture in synthetic human tibia. We uniquely use tuning forks matched closely to the identified modal frequencies of tibia to generate high amplitude low frequency vibration, and we couple that with low amplitude high frequency ultrasonic waves generated using an omni-directional shear transducer. Unlike the case where there is no fracture in the bone, the presence of a fatigue crack leads to the generation of sideband peaks centered around the ultrasonic excitation frequency. The fatigue fracture in tibia was created using a dynamic three-point bending test rig.

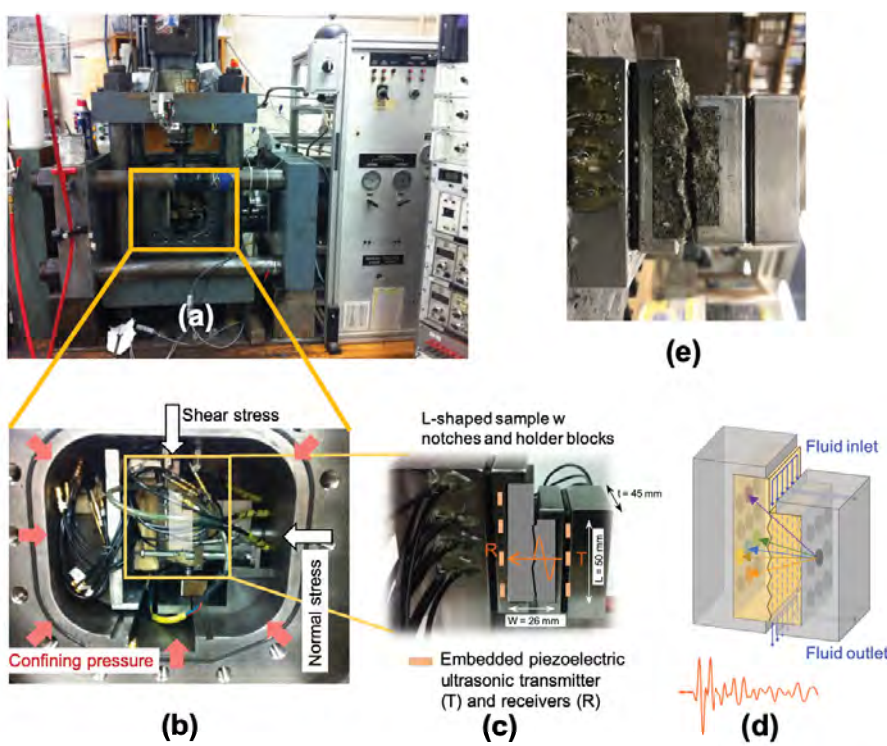
Based on the resonance frequency of the specific tuning fork used, sidebands are seen around the 200kHz frequency peak. Two cases are considered where in one the tuning fork directly contacts the tibial tuberosity, and in the other a synthetic skin layer is present in-between the tuning fork and the tibial tuberosity. In both cases sidebands are observed although, the peak heights and their count are reduced by the synthetic skin. In essence, the presence of sidebands and their relative amplitude may be useful for monitoring fractures during the healing process.



The overall vibro-acoustic setup and analysis; (a) fatigue fracture created in diaphyseal region of tibia, (b) holding tuning fork on tibial tuberosity, (c) resulting frequency spectrum showing sidebands created by 512 Hz tuning fork.

Illuminating key mechanistic feedbacks among transport, seismic, and frictional properties of fractured rock

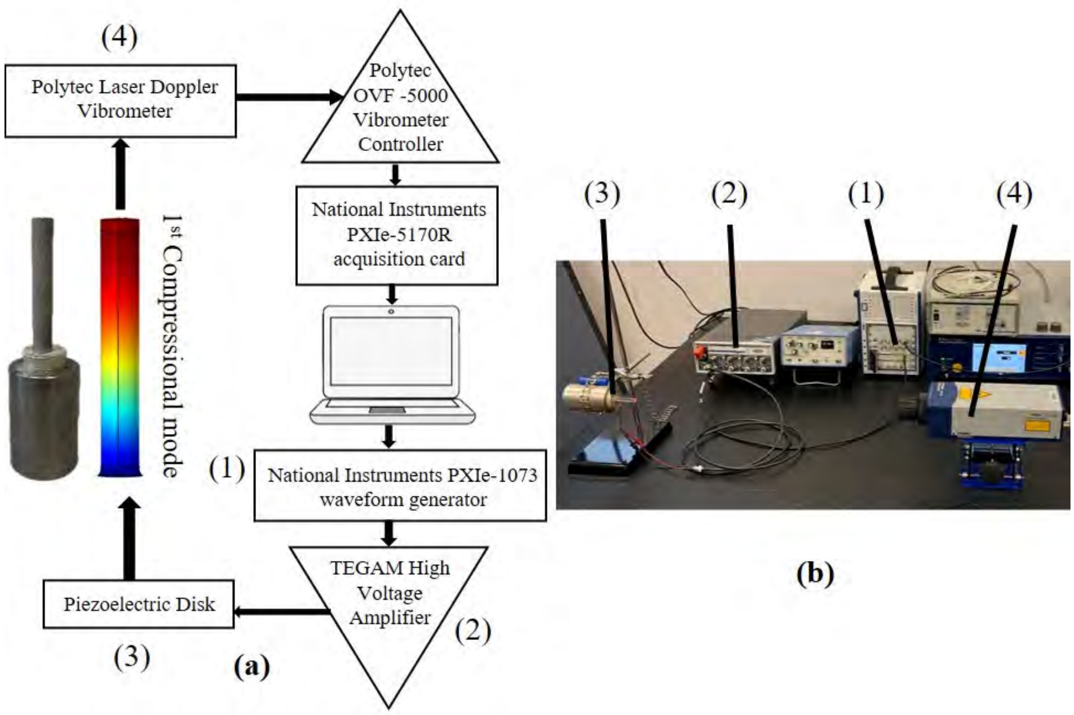
Principal investigator: Parisa Shokouhi, associate professor of engineering science and mechanics and acoustics
Co-investigators: Jacques Rivière, assistant professor of engineering science and mechanics and acoustic; Chris Marone, professor of geosciences; and Derek Elsworth, distinguished professor of energy and mineral engineering and of geosciences
Students: Clay Wood, doctoral student in geosciences; Prabhakaran Manogharan, doctoral student in engineering science and mechanics
Summary: The project goal is understanding the fundamental mechanisms that govern fluid flow, friction, and elastic properties of fractured rock. Specifically, we conduct experiments to: (I) decouple the influence of fracture aperture distribution and roughness from unclogging on the elastic and flow properties, explore these behaviors for (II) shear-reactivation of fractures, and develop complex analyses that: (III) assimilate these data, illuminate key mechanistic feedbacks and address upscaling of our results to field scale. The work addresses societally-relevant issues such as induced seismicity, probes frontier scientific problems related to nonlinear elasticity and the coupling between transport and elastodynamic properties and utilizes machine learning techniques to maximally illuminate correlations from the mechanism-rich geophysical data. Our proposed plan includes unusually well-controlled lab experiments to measure friction and flow. We are using new techniques including synchrotron X-ray computed tomography of fracture properties and plan to combine 4D microstructural and ultrasonic imaging of fractures under dynamic stressing to probe causative mechanisms linking permeability and stiffness. The primary elements of this project include: 1) active and passive ultrasonic measurements to determine the elastodynamic response of fractured samples and simulated faults, 2) permeability studies of fractured samples subject to elastic loading and inelastic deformation, 3) measurement of friction constitutive properties under steady state shear and during stick-slip sliding, and 4) physics-based and data-driven modeling to predict hydraulic properties and controls on induced seismicity. The laboratory program includes a subset of simple tests with isolated measurement of one variable, but the majority of our work will focus on coupled processes as revealed by simultaneous monitoring of the evolution of elastodynamic properties, permeability, and friction constitutive behavior during elastic loading and inelastic deformation. We follow a systematic approach by studying both intact rock and comparing it to well-characterized fractures (with and without infilling) under a range of stress and saturation conditions. The role of microstructure and shear fabric will be illuminated by our laboratory data and also by studies that involve synchrotron X-ray imaging. Our research will provide a new understanding of coupling between poromechanical and acoustic properties of rock and new insights into the evolution of rock properties and seismic hazards associated with energy production and the injection of fluids in deep reservoirs.
Funding: Department of Energy – Office of Basic Energy Sciences (awarded in 2020)
Post-doc: Samson Marty, postdoctoral scholar in geosciences



(a) The biaxial loading apparatus in Penn State's Rock Mechanics lab including (b) a pressure vessel to apply triaxial stress to the sample. (c) The L-shaped sample is sandwiched between two holder blocks with embedded piezoelectric transducers. (d) The experimental setup allows simultaneous measurements of flow and multi-channel ultrasonic data. (e) Picture of an in-situ fractured sample of Westerly Granite.

Ultrasonic Measurements of Additively Manufactured (AM) Materials

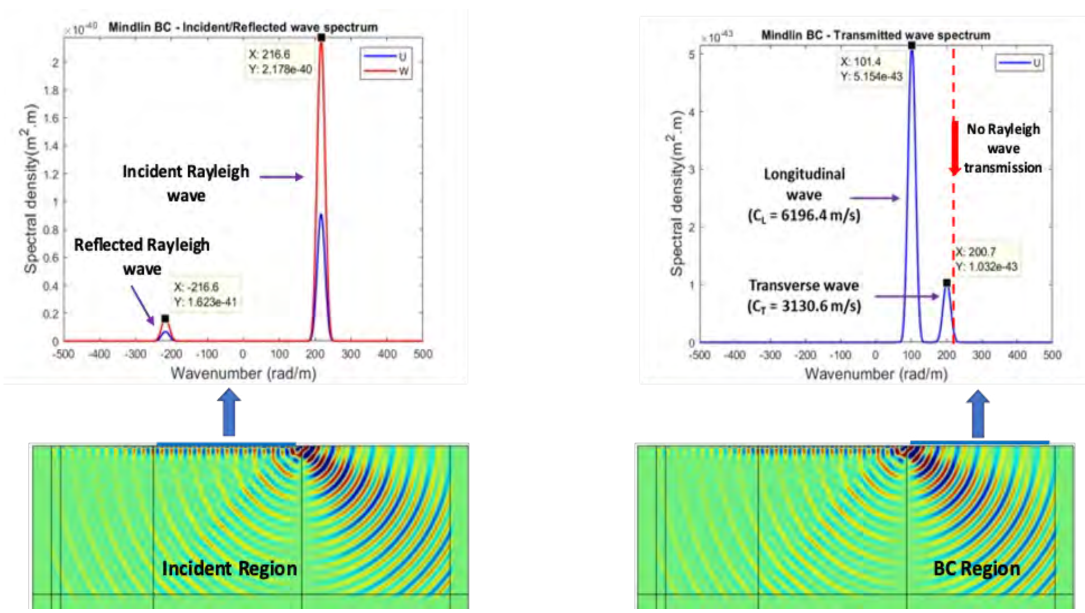
Principle investigator: Parisa Shokouhi, associate professor of engineering science and mechanics and acoustics
Students: Colin Williams, graduate student in engineering science and mechanics; Evan Bozek, graduate student in engineering science and mechanics; and Zach Martinez, undergraduate student in engineering science and mechanics
Summary: The goal of this project is to devise new ultrasonics based methods for AM part qualification. We test a series of AM samples and their wrought counterparts with various linear (velocity and attenuation) and nonlinear ultrasonic testing methods (nonlinear ultrasound spectroscopy and second harmonic generation) as shown below. The samples undergo various heat treatments and are characterized independently using X-ray micro-CT, ESM and other characterization methods. The outcome will be microstructure-property linkage through linear and nonlinear ultrasonic parameters.
Funding: Triad National Security, LLC (Los Alamos National Lab/Department of Energy)



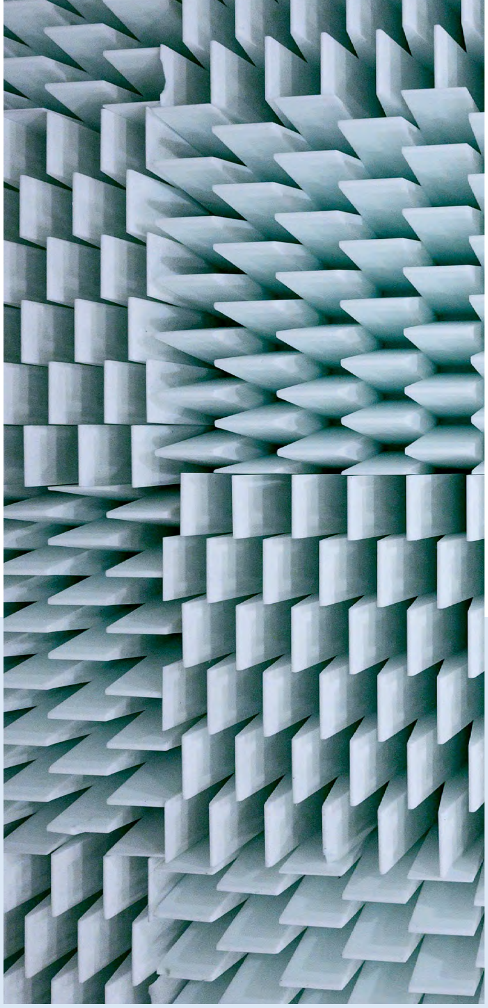
Experimental setup: (a) diagram and (b) testing components.

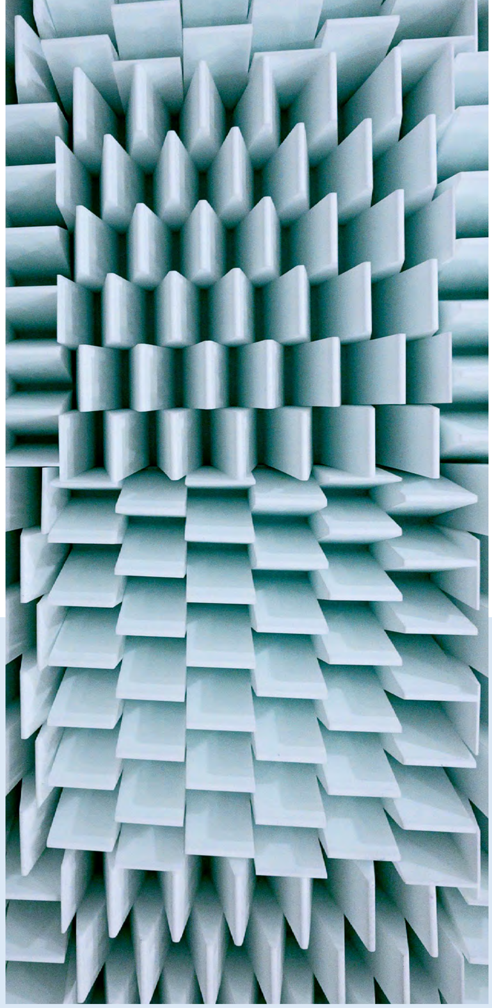
A meta-surface to control surface wave propagation

Sponsor: National Science Foundation
Principal investigators: Parisa Shokouhi, associate professor of engineering science and mechanics and acoustics; Mary Frecker, Riess Chair of Engineering, director of the Penn State Center for Biodevices, and professor of mechanical engineering and biomedical engineering; and Cliff Lissenden, professor of engineering science and mechanics and acoustics
Students: Daniel Giraldo Guzman, doctoral student in mechanical engineering; Lalith Pillarisetti; Eric Sullivan, undergraduate student in engineering science and mechanics; Jeremy Keirn, undergraduate student in engineering science and mechanics; and Sashank Sridhar, undergraduate student in engineering science and mechanics
Summary: Our research objective is to control the motion of Rayleigh surface waves through modifying the surface along which the waves propagate i.e., by purposefully changing the boundary conditions on the surface in order to promote desirable reflections and mode conversions as shown in below. One way to impose the necessary BCs for a given range of frequencies is to place an assembly of resonators on the surface at sub-wavelength spacing. Such resonant meta-surfaces are typically designed through a parametric study of the dispersion curves and tuning the resonance frequencies for a periodic unit cell. Our proposed method takes the view that BCs are the key to providing the desired control. This new approach suggests a systematic strategy for creating a meta-surface, a departure from the commonly used parametric process. The fundamental knowledge gained in this research will have potential applications across length scales. Examples include, but are not limited to, design of next-generation miniature surface acoustic wave (SAW) filters, narrow-band actuators and sensors, vibration isolating barriers as well as seismic and explosive shields for vulnerable structures or even towns.



The wavenumber spectrum along the surface indicates that no Rayleigh waves are transmitted past where the change in boundary conditions occurs; i.e., the Mindlin BCs cause mode conversion to longitudinal and transverse waves and some reflection of the incident Rayleigh waves.





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