CAV Review '08-'09

CENTER FOR ACOUSTICS & VIBRATION

20 Years Directing the CAV—A Retrospective by Gary Koopmann

Koopmann and Chen will retire from the CAV in June.

In 1989, John Brighton, then the Dean of Engineering, appointed me as Director of a new Center for Acoustics and Vibration. The college-wide center had an ambitious set of objectives:

- To strengthen basic and applied research in related engineering areas;
- To foster graduate education in acoustics and vibration engineering;
- To provide a base for technology transfer to industry.

Creating Synergies was a key to meeting those objectives. We began by forming 'affinity' groups, bringing together colleagues of common research interests and this arrangement continues to create synergies and partnerships. Technical group leaders organize weekly seminars highlighting CAV member's research and providing presentation training for students (free pizza also encourages student attendance). Highlights of our affinity groups' research are a feature of our May workshop and the CAV newsletter. Group leaders are Dean Capone, Steve Hambric, Bernie Tittmann, Karl Reichard, Vic Sparrow, George Lesieutre and Ed Smith. They are a critical part of the CAV and they are much appreciated.

Transforming Laboratories- Through the years, the CAV laboratories have gone through a series of transformations to keep abreast of research trends. In the Hammond Building, we now have a sound transmission loss chamber, an anechoic chamber that accommodates jet noise research complete with a forward flight feature, a library/conference room, a well-equipped structural vibrations laboratory and ample room for graduate students in a variety of disciplines.

Dr. Weicheng Chen has been a critical person for the success of the CAV. Chen, as everyone calls him, has been the laboratory director for nearly the entire existence of the CAV. He provided technical support, advice and encouragement for a multitude of students, faculty, visiting faculty, scholars, etc. Chen's talents, creativity and helpful attitude are much appreciated by all and he deserves high praise and a thank you from everyone.

Fostering International Links in Europe and Asia is another CAV educational achievement. Our European liaisons Antonio Concilo—(CIRA (Italy), Wolfgang Neise—DLR (Germany), Michael Brennan—ISVR (U.K.) give us overviews of research at their institutions during the May workshops. These are invaluable for our faculty and students. International cooperation fosters exchanges of researchers as well. Ten students affiliated with the CAV have studied in Europe and Asia and have gained enormously from their experience. In turn, the CAV has hosted more than 30 visiting faculty, post-docs, grad students and visiting scholars. These visitors have contributed to our research projects and their work is gratefully acknowledged.

Corporate Participation is a key component in the successes of the CAV. Our corporate sponsors are active participants in our summer short courses, conferences, *etc.* and have been generous in sharing their expertise with us during our May workshops. Over the years, we have had 25 corporate sponsors join the CAV. Among this number, several have been with us for most of the twenty years.

Penn State Support - During the last twenty years, the support and encouragement of a multitude of colleagues within and beyond Penn State, has helped CAV make good progress meeting those original goals. Within Penn State there are many people to thank: Ray Hettche, former director of the Applied Research Laboratory and its present director, Ed Lizska, encouraged their researchers to actively participate in CAV projects and supported many CAV researchers and graduate students. Within the COE, Dean David Wormley provided support and guidance on new initiatives within the CAV. Jiri Tichy and Anthony Atchley, two former acoustics directors of the Graduate Program in Acoustics, provided a critical link for and with the faculty and students. Support from my department heads, Bob Jacobs, Dick Benson and presently Karen Thole has also been important in our continuing success.

I especially want to acknowledge the continuing contributions of George Lesieutre, who became our Associate Director in 1993 when Allan Pierce (who assisted in setting up the CAV) headed to Boston University. George, now the head of aerospace engineering, has been a stalwart friend and enjoyable companion in shaping the CAV through the years into meeting its missions. George will begin as interim director July, 2009.

During these twenty short years, mostly I have enjoyed the friendships developed with colleagues and students in the CAV. Mentoring graduate students and younger faculty combined with the satisfaction of creating new technologies together with such an energetic group of highly talented researchers has been a continuing joy, which I will savor for a long time.

CAV Workshop May 3—5, 2009

The Center for Acoustics and Vibration's annual workshop will be held at the Penn Stater Conference Center. To begin the events, on Sunday evening, George and Annie Lesieutre will host a dinner party for all participants. On Monday, following the formal presentations, we will offer a series of 'practicals' to give attendees exposure to advanced measurement methods in sound and vibration-related applications. As in the past, the program will be a mixture of the Center's technical group leaders, international liaisons from ISVR in England, DLR in Germany and CIRCA in Italy and a couple of the corporate sponsors of the Center. The graduate students and their advisors will be available for questions concerning their research. While formal presentations are organized to allow for the exchange of technical information, there will be ample opportunity for informal discussion during the breaks, meals and on Tuesday afternoon following the wrap-up luncheon.

CAV Members Receive Honors and Awards

George Lesieutre:	AIAA Fellow
Mary Frecker:	ASME Fellow
George Lesieutre:	ASME Fellow—Best Paper
Mary Frecker:	ASME Fellow—Best Paper
Vipul Mehta:	ASME Fellow—Best Paper
Sabih Hayek:	ASEE-ONR Distinguished Fellowship
Kenji Uchino:	Master Degree, Certificate of Appreciation, Out standing Participant, Applied Electromagnetics and Mechanics Award, Outstanding Book
Victor Sparrow	Promoted to Full Professor

Corporate Members and International Liaisons

Corporate Members & Representatives

Bettis Atomic Power Lab—Eric Shook
Copeland Corporation—Macinissa Mezache
Electric Boat—Albert Kirwan
Emerson Process & Management—Al Fagerlund
Lockheed Martin/KAPL—Kristin Cody
Sinoceramics—Jingru Zhang
Trane Corporation—William Rockwood
United Launch Alliance—Ed Heyd
United Technologies Research Center—Jeff Mendoza
Westinghouse Electric Company—Larry Corr
Dresser-Rand—Zheji Liu
Applied Physical Sciences Corp.—Marty Pollack

International Liaisons and Representatives

ISVR (UK) - Michael Brennen
DLR (Germany) - Wolfgang Neise
CIRA (Italy) - Antonio Concilo

CAV Welcomes New Corporate Sponsors

Applied Physical Sciences Corps – Corporate Liaison, Dr. Marty Pollack

APS is a Research, Development and Engineering consulting firm specializing in Acoustics, Signal Processing, Marine Hydrodynamics and Electromagnetics. APS provides services and innovative products to the National Defense R&D community, and also for the commercial market through direct commercial support and the Small Business Innovative Research (SBIR) program. Roughly half of othetechnical staff hold PhDs in Engineering, Physics and Mathematics.

APS is headquartered in Groton, Connecticut and has regional offices in Arlington, Virginia and Lexington, Massachusetts. Originally incorporated in 2002, APS has been growing through a measured expansion of our technical staff, maintaining our focus on capability for innovative solutions to our customers' challenges. In September 2006, APS acquired Acoustech Corporation of Philidelphia, PA, establishing APS as an industry leader and innovator in the field of directional underwater transducers. In July 2007, APS acquired C&M Technology Inc of Old Saybrook, CT. For over 20 years, C&M Technology had developed and produced oceanographic data collection systems and special purpose underwater devices for government laboratories, universities, and industry. These acquisitions have boosted APS' capability for producing prototype systems for application of our innovative research and development concepts.

Dresser-Rand, Olean Operations, Olean New York—Corporate Liaison, Mr. Zheiji Liu

All over the world, Dresser-Rand products are being used every day to find and refine the oil and gas the world depends on, to generate the power that industry needs, and to manufacture the chemicals and petrochemicals that are essential components of a multitude of items we take for granted.

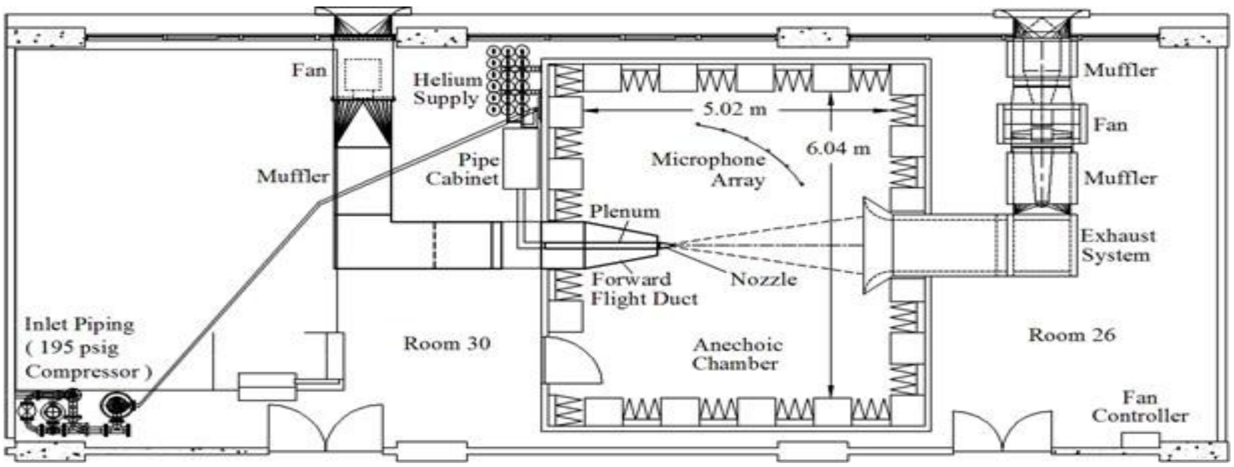
Being one of the world's leading rotating equipment solutions company means more than delivering efficient compressors, turbines and other equipment on time and on budget. Dresser-Rand's integrated team approach helps us find creative solutions that go well beyond delivering innovative products. By focusing on the desired end result instead of on the standard way of doing business, we're able to provide the most efficient, cost-effective answer for each energy conversion requirement.

Jet Noise Facility Undergoes Major Upgrade

The Penn State jet noise lab has recently been upgraded to conduct more relevant experiments. This facility consists of an anechoic chamber into which high pressure air is exhausted through a nozzle, effectively creating a high speed jet. These air jets model the exhaust jets of aircraft turbo-jet engines. Experiments are conducted to measure various aspects of the model jet noise in order to understand the aircraft engine noise. Efforts are underway to reduce this noise which is serious annoyance to society and a danger to military support personnel. Much research has been conducted with the goals of predicting and reducing this noise. Small scale tests are frequently performed as alternatives to expensive full scale tests with aircraft engines can be used to predict the noise of a full scale engine exhaust jet. However, these small scale experiments are usually performed in static conditions, with the jet exhausting into stationary air. This doesn't accurately model an airplane in takeoff conditions where the jet exhausts into air moving past the nozzle.

To model the effects of the moving air around the jet, an open wind-tunnel was installed in the Penn State high-speed jet noise lab. The wind tunnel duct is centered on the jet plenum. The duct converges from 3ft square to 15 inches square and ends just before the jet nozzle exit. An exhaust system ingests the flow and maintains approximately constant operating conditions in the chamber. The forward flight wind tunnel flow is powered by two fans, one upstream of the chamber and the second, the exhaust fan, downstream of the chamber. Both upstream and downstream ducts are acoustically treated, as well as include 90 degree bends and mufflers. The forward flight duct provides a maximum flow of Mach 0.2 across the 15" by 15" square exit. The jet plenum has an interface to which several scale model nozzles of varying inner contours and diameters can be attached.

The work on the upgrade was completed almost entirely by students being advised by Dennis McLaughlin, Professor of Aerospace Engineering and a member of the Center for Acoustics and Vibration for over 20 years. Under the guidance of Dr. McLaughlin and his graduate students, undergraduate students designed, fabricated supports, and installed the duct, upstream fan, muffler, and inlet. The final installation and initial testing of the upgrade was completed by an undergraduate team in a projects course this past semester. Over the two years from design to installation on the upgrade, nine undergraduates had a hand in the project, with a small amount of help from professionals. This makes the Penn State lab the only university with this capability actively engaged in jet noise research. The two figures below show a schematic diagram of the room size anechoic chamber facility and a photograph of the inside of the facility looking toward the jet exhaust and the forward flight nozzle.



The Pennsylvania State University high speed jet noise facility.

The jet plenum and flward flight duct installed in the anechoic chamber.

CAV Host Ignazio Dimino, Visiting Scholar from Italian Link, CIRA

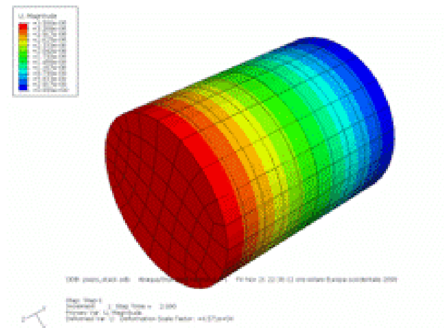
Ignazio Dimino

Vibro-acoustics and Smart Structures Laboratory

ACTIVE WINDOW PROJECT - The research activity focuses on the development of an aircraft active window prototype, based on piezoceramic actuators bonded or embedded in the aircraft windows or trim panels. The objective is to achieve aircraft interior noise reduction by efficiently controlling the direct sound radiation from vibrating side walls of aircraft fuselage.

Numerical and experimental activities have been performed in order to investigate the potential of a "speaking panel" concept, composed by an aluminium plate excited by piezo stacks embedded in the panel, conceived as fuselage trim panel vibration absorber and/or acoustic actuator.

The piezo stacks as well as the integrated panel have been numerically simulated in order to predict the dynamic behaviour of the coupled system. Experiments have been carried out in order to characterize the piezo actuation capabilities and the modal behaviour of the prototype. The experimental modal analysis has been performed by using both SISO techniques and Laser Vibrometer scanning. Finally, the structural sensitivity to the boundary condition effects has been experimentally investigated by applying compressive forces to each panel side and verifying the modal frequencies and amplitudes variations.



CAV Members help direct ASME's Noise Control and Acoustics Division (NCAD)

Dr. Stephen Hambric,

Dr. Michael Jonson and Dr. Stephen Hambric of Penn State's Center for Acoustics and Vibration are both currently on the Executive Committee of ASME's NCAD. Mike is now Chair of the Executive Committee, and Steve is incoming Chair. The division meets once a year, usually at ASME's Fall International Mechanical Engineering Congress and Exposition (IMECE). However, last year ASME NCAD left IMECE to join with the Institute of Noise Control Engineering (INCE) at NoiseCon 2008 in Dearborn, Michigan. The joint meeting helped ASME and INCE members working in noise to interact with each other, many for the first time.

Dr. Michael Jonson

Dr. Marty Pollack

One of our CAV corporate sponsors – Dr. Martin Pollack, formerly of Lockheed Martin and now with Applied Physical Sciences Corporation – delivered the prestigious Rayleigh Lecture at the 2008 ASME NCAD/ NoiseCon conference. Marty presented a history of ASME NCAD, and his talk included several key contributions made to the noise and vibration field by ASME NCAD members.

ASME NCAD members also serve on the editorial staff of the ASME Journal of Vibration and Acoustics, and on ASME industrial noise standards committees. If you'd like to learn more about the division, see: http://divisions.asme.org/NCAD/ anytime.

We're always looking for volunteers to work on our technical committees in Structural Acoustics, Active and Passive Noise Control, and Aero/Hydro Acoustics. If you're interested, contact Mike (mxj6@psu.edu) or Steve (sah19@psu.edu)

Technical Research Group Highlights

Quiet Product Design

Dr. Gary Koopmann, Group Leader
ghk1@psu.edu

Faculty Affiliates: Dr. Ashok Belegundu, Dr. Weicheng Chen, Dr. Chris Rahn
Visitors: Ignazio Dimino, Vibro-Acoustics and Smart Structures Laboratory, CIRA, Naples Italy

This past year, the SBIR project sponsored by the ONR on Applications of Smart Tethers continued with KCF Technologies. Professors Gary Koopmann and Dr. Weicheng Chen worked on the project led by KCF Technologies VP for Research, Richard Geiger and Senior Engineer, David Kraige. The focus of this research is to develop methods of localizing underwater devices (ROV's) relative to a fixed position on the surface. Initially, a tether (or series of tethers) that links the device, say an inspection vehicle, with a surface buoy (whose position is known via a GPS measurement) is instrumented with inclinometers and magnetometers. Using tether models (e.g. a catenary), the xyz position of the vehicle can be computed nearly in real time

The Smart Tether is a new product in the field of underwater navigation, allowing an ROV operator to know the GPS location of the ROV in real time, with minimal additional equipment. Sensor nodes placed in the tether allow the Smart Tether software to calculate the shape of the tether and plot it so the user can see the position of the entire ROV and tether system, even in zero visibility operating conditions.

The Smart Tether is also used as a search tool, as the operator can mark targets and view the current and past coverage areas of the ROV video camera or attached SONAR device. In addition, all this data can be geo-referenced instantaneously in Google Earth.This project is now in the Phase II SBIR funding mode.

Profs. Koopmann and Rahn and Andrew Kankey continued on their ONR-funded FNC project entitled "Underwater Threat Neutralization: Defence of Harbor and Near-Shore Naval Infrastrucure. Their group is responsible for the control architecture of the source/receiver transmissions that focus on interdiction strategies. This past summer, the group conducted final tests l tests at Coddington Cove Newport ,RI

Prof. Koopmann and Dr. Chen teamed with Resodyn (Butte, Montana) to work on a Phase I technology development project focused on improving the low transmission loss of panels. Using Resodyn's spray-on polymer technology, initial tests on small scale panels proved successful leading to an on-going Phase II funding from ONR.

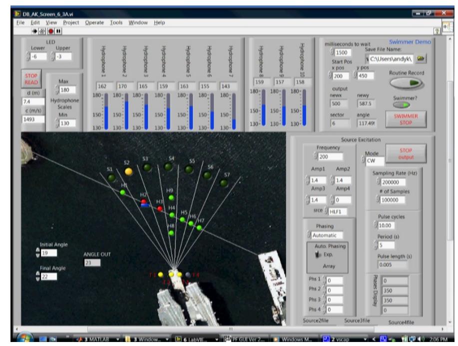
Completed Thesis Topics

A Method for Focusing Sound in Harbor Environments at Low Frequencies: Theory and Experiment

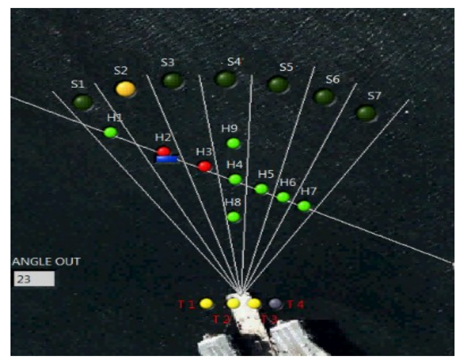
Dr. Andrew T. Kankey
Sponsor: Office Naval Research
Advisor: Gary Koopmann

Abstract:

An investigation of the ability to focus low-frequency acoustic energy in very shallow water was carried out in a semi-protected harbor in June 2008. From the end of a finger pier, a linear array of 7 acoustic sources was suspended 2 meters from the harbor bottom. The mean water depth in the harbor was 11 meters with surficial sediments characterized by silts, sandy silts, and clay. The acoustic field was measured by an array of 11 hydrophones oriented in a cross pattern in the harbor. The phones ranged from 100 meters to 325 meters from the center of the array. The objective of this work was to explore alternative methods to time-delay beamforming for focusing the sound field in the harbor. The approach is based on optimizing the phase of the individual sources to provide maximum sound pressure levels at a particular location in the harbor. The optimization scheme requires *a priori* interrogation of the harbor with a number of hydrophones in the area of interest. However, it is designed to be insensitive to vertical boundaries and other obstructions that can be found in typical working harbors. Results from recent field work are discussed. An acoustic finite element program was also



LabVIEW Screen shot



Crropped LavVIEW screen shot

developed in order to predict the sound field when the interrogation is unavailable.

The Effects of Porous Sea Bottoms on the Propagation of Underwater Shock Waves Using the P-α Equation of State

Rebecca Buxton, MSME
Sponsor: Office of Naval Research
Advisors: Steve Hambric, Gary Koopmann

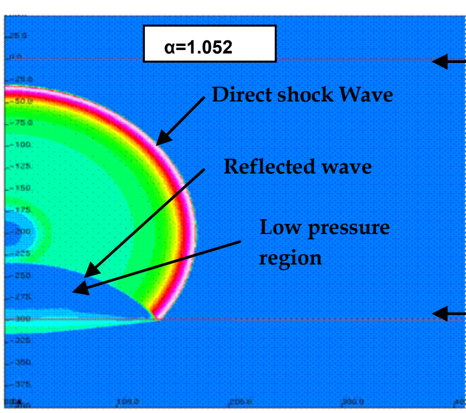
Non-contact explosions in underwater environments pose a significant threat to Navy vessels. The detonation of an explosive charge underwater generates a high pressure shock wave. That high pressure wave can have a direct path to the vessel and can also reflect from the surrounding environment and load the vessel. This necessitates a better understanding of shock reflections off of a

Technical Group Research Highlights

Quiet Product Design—Continued

porous sea bottom. DYSMAS (a Navy finite difference code used in the simulation of underwater explosions) includes the P-α equation of state for the modeling of porous materials. The equation of state uses the parameter α, the ratio of solid and porous specific volumes, to create an irreversible compressibility simulating the crush of air pockets in porous sand. This work uses the P-α equation of state to model two dramatically different porosities of sand subjected to loading conditions corresponding to key values for P-α behavior. Measurement points are selected in the water field of an axi-symmetric model to record pressure and impulse intensity (the cumulative integral of pressure and a good indicator of potential for structural damage). The figure shows the resulting pressure fields for the highest porosity bottom condition when a 1 kg charge is detonated. This study demonstrates that a porous sea bottom affects the peak pressures in the water in a limited region near the sand bottom. It is also shown that changes in porosity affect impulse intensities near the water-sand interface, reduce shock speed and pressure propagation in the sand, and affect the characteristics of the water reflection.

Pressure field at 1 msec for the 1 kg charge weight and high porosity



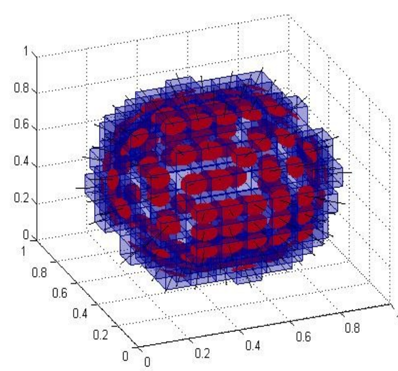
Air-Water Interface

Water-Sand Interface

A Wave Superposition Method Formulated in Digital Acoustic Space

Dr. Germain Huang
Advisor Gary Koopmann, Vic Sparrow
Sponsors: The Graduate Program in Acoustics

A new formulation of the Wave Superposition method is presented. As sound quality is in demand in almost all product designs and also because of fierce competition between product manufacturers, faster and accurate computational method for the sound power calculation is always desired. Because the conventional Wave Superposition method relied solely on mesh geometry, it could not accommodate fast shape changes in the design stage of a consumer product or machinery, where many iterations of shape changes are required. In the presented method, geometry is represented with voxels that can easy adapt to shape changes, therefore it is more suitable for shape optimization. The new method was validated with simple and complex geometries with complex mode shapes. It was shown that matching volume velocity is a key component to an accurate analysis. The sensitivity study showed that it required at least 6 elements per acoustic wavelength and the complexity study showed a minimal reduction in computational time.



Acoustics Characterization of Materials

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

Jikai Du

Jikai Du successfully completed the requirements for his doctoral degree in Spring 2008 and has taken a research position at South Dakota State University. His Ph.D. thesis was titled, "Scanning Acoustic Microscopy on Soft Thin Films with Variable Bond Strength." Jikai can be reached at Jikai.Du@sdstate.edu or 605-688-5930.

Matt Kropf

Matt Kropf also successfully completed the requirements for his doctoral degree in Spring 2008. His Ph.D. thesis is titled, "High Temperature Studies of Refractory Metals for Space Applications."

Technical Group Research Highlights

Acoustics Characteriztion of Materials—Cont.

Matt (mmk230@psu.edu) is continuing his research in renewable fuel processing and biofuels at Penn State.

Kate Boudreau

Brian Reinhardt

Two new masters degree candidates, Kate Boudreau and Brian Reinhardt, joined the group in August 2008. Kate (kbb151@psu.edu) received her BS in Mechanical Engineering at the University of Idaho. She will be studying fracture mechanics on specialty alloys. Brian (btr5016@psu.edu) received his BS in physics (with a minor in computer science) at Lebanon Valley College. He will be studying nonlinear ultrasonics on tensile specimens.

Atsushi Baba

Atsushi Baba, Ph.D., a senior researcher at Hitachi Ltd., Hitachi-shi, Ibaraki-ken, Japan, is visiting the group through mid August. While here, Dr. Baba (axb66@psu.edu or atsushi.baba.br@hitachi.com) will be participating in the development of high-temperature ultrasonic techniques.

Structural Vibration and Acoustics

Stephen A. Hambric, Group Leader
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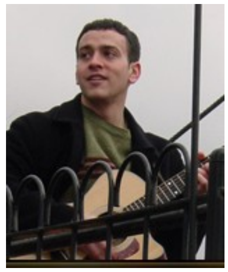


Andrew Munro

Our group held two lunchtime seminars over the past year – one given by Andrew Munro of Bose Corporation (MS Penn State Acoustics 2002) and the other by Dr. Randall Allemang, Director of the famous Structural Dynamics Research Lab (SDRL) at the University of Cincinnati.

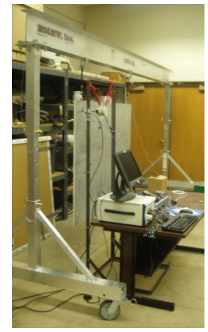
Along with our CAV group, many members of Penn State's Audio Engineering Society attended Andrew's talk, which focused on the structural-acoustic, sometimes nonlinear, behavior of loudspeakers. Andrew also discussed how obtaining accurate properties of complex materials is critical to estimating speaker performance. Andrew also briefly mentioned his side career as a composer of music for independent films and video games.

Randy Allemang is one of the most well known structural dynamicist in the world, pioneering many of the techniques used in modern experimental modal analysis. Randy presented a brief history of the UC-SDRL, including some key advancements made there. Randy also discussed UC-SDRL's current involvement in non-linear structural dynamics – an extremely challenging area of research.

Randall Allemang

During the 2008 Spring Workshop, the Structural Vibration and Acoustics Group highlighted several research programs, including:

- Dr. Marty Trethewey's work in monitoring crack propagation in rotating machinery shafts using torsional vibrations
- Dr. Stepehn Conlon's Research on using structural intensity as an indicator of structural damage. Steve has applied the technique to beams, plates, and rotorcraft blades, and has been collaborating with CAV's Rotorcraft Group (under the direction of Dr. Ed Smith) and the Condition Monitoring Group (under the direction of Dr. Karl Reichard)
- Micah Shepherd's (PhD student) attempts to develop optimization procedures to minimize the sound radiated by automotive transmissions
- The Graduate Program in Acoustics' measurements of the noise levels at recent Penn State Football game



Finally, we're pleased to announce that one of our CAV corporate sponsors – United Launch Alliance – is funding a new project on the transmission of vibrations between spacecraft panels. The panels, constructed from honeycomb cores and either Aluminum or carbon-fiber composites, are bolted together, driven with shakers, and measured with accelerometers and a laser vibrometer. The results are being compared to classical Statistical Energy Analysis (SEA) simulations.

To highlight the research activities, along with others by CAV team members, several recent research projects and the graduate students/staff working on the projects are summarized below:

Title: Intensity based structural health monitoring
Sponsor: Aviation Applied Technology Directorate (AATD)
PIs: Steve Conlon, Jeff Banks, and Ed Smith
Post-Doctoral Student: Fabio Semperlotti (Ph.D. candidate), Walter Schmidt (M.S. candidate), Ben Grisso (Ph.D. Virginia Tech 2008), Peter Romano (M.S. candidate)

Title: Structure-borne sound through connected launch vehicle panels
Sponsor: United Launch Alliance
PIs: Steve Hambric and Steve Conlon
Post-Doctoral Student: Benjamin Grisso (Ph.D. Virginia Tech 2008)

Title: Vibration of bilaminar spheroidal shells
Sponsor: NUWC/ONR
PIs: Sabih Hayek and J.E. Boisvert (NUWC)

Technical Group Research Highlights

Structural Vibration and Acoustics—Cont.

Title: Acoustics of elliptic-cylindrical shells
Sponsor: NUWC/ONR
PIs: Sabih Hayek and J.E. Boisvert (NUWC)

Title: Intensity-based Nearfield Acoustic Holography in Reverberant Water Environments
Sponsor: NAVSEA 073R
PI: Steve Hambric
Student: Andrew Barnard (Ph.D. candidate)

Title: Measurements of distributed dynamic impedance of fluid film bearings
Sponsors: ARL and E&F
PIs: Steve Hambric and Karl Reichard
Student: Harrison Gyurko (Ph.D. candidate)

Title: Effects of high vibration levels on propeller hydrodynamic performance
Sponsor: NAVSEA 073R
PI: Steve Hambric
Student: Marc Reese (M.S. candidate)

Title: Structure-borne sound through rolling element and fluid film 'wave' bearings
Sponsor: NASA
PIs: Ed Smith and Steve Hambric
Student: Micah Shepherd (Ph.D. candidate)

Title: Flow-induced self noise in torpedo sonar arrays
Sponsor: Office of Naval Research
PI: Steve Hambric

Title: Acoustics of Shaftless Propulsors
Sponsor: DARPA and US Navy
PI: Steve Hambric

Title: Acoustics of Large Unmanned Underwater Vehicle (LUUV) Propulsors
Sponsor: ONR
PIs: Steve Hambric and Dean Capone

Title: Commercial Nuclear Reactor Flow-Induced Vibration and Fatigue Failure
Sponsor: Nuclear Regulatory Commission
PI: Steve Hambric

Flow-Induced Noise

Dean Capone—Group Leader
dec5@psu.edu

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

Mr. William Bonness and Dr. Dean Capone completed an experimental study of low wavenumber turbulent boundary layer wall pressure spectra in a cylindrical pipe. The work addressess longstanding questions about the amount of low waveneumber energy in a turbulent boundary layers. They also investigated the role of fluctuating wall shear stress on structural excitation. Additionally, Dr. Capone and Mr. Bonness have completed and investigation into the transmission of turbulent boundary layer unsteady shear stress through elastomeric coatings in water.

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

Dr. Timothy A. Brungart, ARL Penn State, Professor Michael S. Howe, Boston University, and Ms. Alia W. Foley, Ph.D. candidate, Boston University, have completed a three year investigation into the noise generated by the impingement of a ventilating jet on the gas-water interface of a ventilated supercavity. A ventilated supercavity is a gaseous envelope generated around an underwater vehicle that allows for order-of-magnitude increases in vehicle speeds. The radiated sound was written in terms of the force exerted by the jet on the cavity wall. This research was sponsored by the Office of Naval Research and the following publications have resulted from their work:

1. Howe, M.S., Colgan, A.M. and Brungart, T.A., "On self-noise at the nose of a supercavitating vehicle, Journal of Sound and Vibration (2008), doi:10.1016/j.jsv.2008.11.019.

2. Foley, A.W., Howe, M.S. and Brungart, T.A., "Sound generated by a jet-excited spherical cavity," Journal of Sound and Vibration (2008), doi:10.1016/j.jsv.2008.01.039

3. Foley, A.W., Howe, M.S. and T.A. Brungart, "Sound generated by gas-jet impingement on the interface of a supercavity," Proceedings of IMECE2008, 2008 ASME International Engineering Congress and Exposition, November 2-6, Boston Massachusetts, USA.

Over the past several years Mr. Lee Gorny, Dr. Gary Koopmann, and Dr. Dean Capone have conducted experimental investigations in the CAV, aimed at increasing the applicability of quarter wavelength resonators for the reduction of tonal noise generated by ducted axial fans. Recently, methods have been explored for use in obtaining bi-directional attenuation simultaneously from a given fan. This can be achieved by introducing a configuration of flow-driven resonators such that they generate a dipole-like canceling secondary sound field. Single flow-excited, tunable quarter-wavelength resonators acting as monopole sources have been previously integrated into the shrouds of ducted subsonic axial fans to reduce tonal noise in a single direction. Two independently tunable resonator chambers oriented axially to either side of the blade passing region of a fan utilize the 180 degree change in phase that occurs in this region. Using several tuning techniques, dipole-like sources can be tuned independently in terms of magnitude and phase, allowing for an out-of-phase response to be generated with similar magnitude to the BPF tone, thus reducing tonal noise in both directions. Blade passage frequency (BPF) noise reductions of 12.9 dB and 11.6 dB, were achieved for a ducted, statored, 260 mm radiator cooling fan, simultaneously in the upstream and downstream directions. Resulting blade tones were reduced to levels within 5 dB of the broadband noise level.

In addition to this project, a numerical method has developed to predict and simplify the implementation of canceling flow-driven quarter wavelength resonators to existing fans. The method combines a finite element based propagation technique with transmission line theory resonator modeling and source superposition methods. With these tools, and measurements taken from a fan in normal operation, it is possible to predict resonator response and the impact of introducing a resonator array numerically for optimal tonal noise reduction.

Propagation and Radiation

Victor Sparrow—Group Leader
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2008 was an active year for the propagation and radiation group. Much of our funding still comes from NASA and Federal Aviation Administration (FAA) grants and contracts related to outdoor sound propagation and the perception of subsonic and supersonic aircraft noise. The FAA work is funded through the PARTNER Center of Excellence (www.partner.aero). The Penn State Graduate Program in Acoustics is a founding member of PARNTER (

Technical Group Research Highlights

(Partnership for AiR Transportation Noise and Emissions Reduction), led by MIT

Ongoing PARTNER projects include Project 2, led by V. Sparrow related to aircraft noise emission and propagation, Project 10 led by Kathleen Hodgdon of the Penn State Applied Research Laboratory related to community outreach on aircraft noise, and Project 24 led by V. Sparrow related to aircraft noise simulator design. In addition, Dean Anthony Atchley leads a Project 2 spin off contract on advanced aviation propagation modeling to Penn State from the Volpe National Transportation Systems Center in Cambridge, MA.

NASA is continuing its funding of V. Sparrow through a NASA Research Announcement cooperative agreement to study sonic boom diffraction around buildings using computational simulations. The effort is focusing on developing spatially and temporally accurate acoustic scattering models for sonic boom loading on residential buildings. Such models will then be compared and validated using data taken by NASA at houses subjected to low-amplitude sonic booms at Edwards Air Force Base in the summers of 2006 and 2007.

V. Sparrow has also been working with Wyle in Arlington, VA related to two additional NASA Research Announcement contracts to Wyle with Penn State as a subcontractor. The first project is related to the transmission of sonic boom through the walls of residential houses using finite element modeling. The second project is focusing on adding improved atmospheric turbulence models to Wyle's flagship sonic boom program, PCboom.

For additional information about any of these projects, please contact Anthony Atchley,

Kathleen Hodgdon, or Victor Sparrow. The PARTNER and NASA projects will be a major focus of the CAV Propagation and Radiation Group activities during the next few years.

Graduate Students:

Joyce Rosenbaum, Ph.D. expected spring 2010

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

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

Advisor: A. Atchley

Kimberly Lefkowitz, Ph.D. expected summer 2010

Thesis topic: Urban canyon effects for low-boom sonic booms.

Sponsor: NASA

Advisor: V. Sparrow

Sang Cho, Ph.D. expected summer 2010

Thesis topic: Sonic boom diffraction around buildings

Sponsor: NASA

Advisor: V. Sparrow

Brian Tuttle, Ph.D. expected summer 2009

Thesis topic: Nonlinear Acoustic Streaming in Conical Thermoacoustic Devices

Sponsor: Office of Naval Research

Advisor: V. Sparrow

Denise Miller, Ph.D expected fall 2009

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

Sponsor: National Science Foundation

Advisor: V. Sparrow

Beom Soo Kim, Ph.D expected fall 2010

Thesis topic: Sonic boom transmission from outdoors to indoors

Sponsor: NASA/Wyle

Advisor: V. Sparrow

Amanda Lind, M.S. expected fall 2009

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

Sponsor: FAA

Advisor: V. Sparrow

Active Structures

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

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

Title: Morphing Aircraft Structures

Sponsor: AFOSR

Summary: Develop and demonstrate concepts for reconfiguring flight vehicle structures: primary structure, skin, and actuation. These must be capable of carrying realistic loads and not be substantially heavier than structures that perform similar functions today. Recent focus is on compliant structures actuated using active tendons. New design methodologies have been developed to optimize truss members, tendons and actuators within a wing structure. Recent results address the benefits of contact-aided compliant mechanisms for stress relief.

Collaborator: Dr. Mary Frecker (ME)

Student: Vipul Mehta

Ph.D. expected: December 2009 ("Stress Relief in Contact-Aided Compliant Cellular Mechanisms")

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

Sponsor: NASA / Army Vertical Lift Research Center of Excellence

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

Collaborators: Dr. Mark Maughmer, Dr. Farhan Gandhi

Student: Michael Thiel

Ph.D. expected: August 2010

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

Sponsor: NASA Glenn Research Center

Summary: A robust vibration damping system for integrally bladed rotors can dramatically reduce high-cycle fatigue in turbomachinery. Such a system can be implemented using piezoelectric materials in both passive and active roles. Current research focuses on passive vibration methods using a fairly simple, Ritz-type model. As more advanced models are developed, they will be used to evaluate more realistic blade geometry and patch placement. More advanced damping concepts will also be considered, such as a hybrid harvesting-switching approach. Finally, these models will be used to optimize these damping systems' ability to reduce high cycle fatigue and extend blade life.

Student: Jeff Kauffman

M.S. completed: December 2007

Ph.D. expected December 2010

Technical Group Research Highlights

Active Structures—Conti.

Title: Lag Dampers with Frequency-Variable Properties

Sponsor: Lord Corporation

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

Collaborator: Dr. Edward Smith

Student: Conor Marr

M.S. completed: August, 2007

Ph.D. expected August 2010

Machinery Prognostics and Condition Monitoring

Karl Reichard – Group Leader

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

HBCT Vehicle Prognostic Development

Jeff Banks from ARL Penn State is creating a methodology for the development of prognostic capabilities for selected platform sub-systems for the U.S. Army Heavy Brigade Combat Team (HBCT) family of vehicles. These vehicles consist of the M1A2 Abrams SEP tank, M2/M3 Bradley Fighting Vehicle, M109A6 Paladin and M88 Hercules.

The development work includes a degrader analysis to determine where the implementation of embedded predictive and prognostic technology on the vehicles would provide the highest return on investment. The degrader analysis is then used to select sub-systems and components for the prognostic development based on the degrader analysis results and to select sensors and build embedded data acquisition hardware to support the prognostic technology development. ARL will develop prognostic algorithms, models and techniques for the selected components/sub-systems.

ARL is also evaluating methods for developing and validating prognostic algorithms and techniques including: small scale component based testing, full scale component based testing, platform based laboratory testing and platform based field testing. The team is also developing a Matlab-based tool for the testing and evaluation of prognostic algorithms and techniques. The goal is to define and document a standard methodology that could be utilized for the development of prognostic capability for all HBCT platforms

The results of the prognostic technology development can be used to provide projected sub-system level health assessment that can be utilized to determine accurate sensor- based future vehicle readiness. An example of how this vehicle information can be conveyed is shown in Figure 1. The maintenance information display shows the health status for a group of vehicles with the four color coded icons next to each vehicle ID providing a sensor based health assessment for turret, hull, drive train and weapons systems. The textual data in the lower portion of the interface provides vehicle supply status information as well as maintenance history for the selected vehicle. The data in the display is expected to be accurate and timely in order to be effectively used by the maintenance officers to optimally manage their vehicle assets. This capability is enabled with the prognostic technology on the vehicles.

Bell Helicopter Prognostic Development

ARL Penn State is developing embedded diagnostics and prognostics technologies for the power system components for commercial Bell helicopters and U.S. Army Helicopters. The objective of this U.S. Army Aviation Applied Technology Directorate (AATD) and Bell Helicopter Corporation joint program is to develop and demonstrate an integrated set of system health assessment technologies to support Army Operations Support and Sustainment Technology (OSST) objectives and enable transition to a CBM based philosophy. This effort will focus on technology development of effective diagnostics and prognostics of helicopter electrical starter-generators, power converters (inverter) and batteries. The objective commercial helicopter is the Bell 407 as shown in Figure 2 and the proposed objective Army helicopter is the OH-58D Kiowa Warrior.

Diagnostic and prognostic technology development for the starter-generator will utilize an electromagnetic finite element analysis model as shown in Figure 3. After validation, the FEA model will be used to quickly and inexpensively evaluate the various health monitoring methods that are under consideration and to perform coupled generator/power converter simulations. Seeded fault testing will be performed on the starter-generator using a prototype prognostics system. Potential seeded fault tests based on a failure modes and effects analysis (FMECA) include: stator winding faults, rotor PM demagnetization or broken magnet, rotor eccentricity – static & dynamic and rotor bearing fault.

M2 Bradley Fighting Vehicle Sub-System Health and Maintenance Status

After validation, the FEA model will be used to quickly and inexpensively evaluate the various health monitoring methods that are under consideration and to perform coupled generator/power converter simulations. Seeded fault testing will be performed on the starter-generator using a prototype prognostics system. Potential seeded fault tests based on a failure modes and effects analysis (FMECA) include: stator winding faults (turn-to-turn, phase-phase, and phase-ground; rotor PM demagnetization or broken magnet; rotor eccentricity – static & dynamic and rotor bearing fault

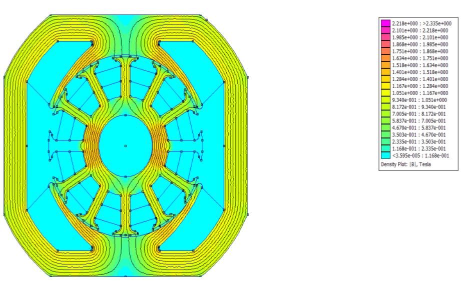
Bell 407 Helicopter.

For the inverter effort the team will focus on monitoring of the critical components of the helicopter power inverter – the semiconductor switches and filtering components. Parameters such as temperature, forward voltage drop and ripple voltage will be monitored and fault

Technical Group Research Highlights

Machinery Prognostics and Condition Monitoring—Cont.

detection and reasoning techniques will be applied to detect fault conditions. Using a prognostics technique known as Symbolic Dynamics, sensors can be placed on the electronic device to measure certain observables (such as output voltage ripple, temperature, etc.) and monitor the system for anomalies as the device ages under normal operation. An analyze will be conducted to analyze the inverter circuitry, and will characterize typical loading, operational and environmental conditions seen by the inverter. In addition, the power converter FEA model developed in conjunction with the generator tasking will also be utilized in evaluating the effects of the various inverter failure modes and to understand the dynamic interactions between the inverter and the generator Data collection on the inverter module will also be conducted to further characterize the inverter and to validate the FEA model. Fault detection and classification algorithms will be developed as a result of the FEA modeling and simulations, along with analysis of the inverter data collection results. Hardware and software will be developed that can be implemented within an operating inverter. Seeded fault testing will be conducted to validate the technology.



FEA of Stater- Generator

ARL Penn State's approach for the battery prognostics utilizes wideband impedance spectroscopy. Dominant failure modes are being identified and characterized in order to understand the effect of the various failure modes on battery degradation. Battery specifications are being analyzed in order to determine the extent of modifications required to the current instantiation of battery prognostics software / hardware.

Next, impedance data will be collected from a cross-section of batteries (new, aged, faulty) as part of comprehensive laboratory testing. Once the model parameters have been determined, classifier algorithms are used to map the parameters to state of charge (SOC) and state of health (SOH) algorithms that were trained using test data collected during comprehensive laboratory testing. The remainder of the effort will be focused on creating the software and hardware necessary to enable the battery prognostics to work in an operational setting, testing and validating the technology, and performing technology demonstrations.

Student projects

Harrison Gyurko (Ph.D., Acoustics) – Harrison has constructed a test bed to collect vibration, fluid pressure, and displacement data from journal bearings. Data from the test bed will be used to validate numerical models of journal bearing noise mechanisms and to collect data for bearing health management algorithms. Harrison presented results from his work at Noise Con 2008.

J. Harrison Gyurko, Stephen A. Hambric, Karl M. Reichard, "Confirmation Testing And Preliminary Dynamic Measurements Of A Journal Bearing Test Rig," Proceedings of the Joint ASME NCAD / Noise Con 2008 Conference, Dearborn MI, July 2008.

Greg Bower (Ph.D., EE) – Greg is developing prognostic health management techniques for silicon carbide semiconductor electronics. The project involves developing models for SiC semiconductor failure modes, the collection of failure data, and the development and implementation of prognostic health monitoring algorithms based on the application of symbolic dynamics. In his thesis research, Greg is applying symbolic dynamics for prognostic and diagnostic health monitoring. Greg presented results of this research at the 2008 International Conference on Prognostics and Health Management.

Gregory Bower, Jeffrey Mayer, Karl Reichard, "Symbolic Dynamics for Anomaly Detection in a dc-dc Forward Converter," Proceedings of the 2008 International Conference on Prognostics and Health Management, Denver, CO, October 2008.

Scott Laurin (MS, Acoustics) – Scott is studying the application of prognostic health management techniques to electromagnetic actuators. He is collecting data on a set of 20 mid-size loud speakers and applying different health management metrics to study their effectiveness for health prediction. Scott presented the results of baseline characterizations of the speakers at the 125th Convention of the Audio Engineering Society.

Scott Laurin, Karl Reichard, "Determining Manufacture Variation In Loudspeakers Through Measurement Of Thiele/Small Parameters," Presented at the 125th Convention of the Audio Engineering Society, San Francisco, CA, October 2008.

Terrance Lovell (M.S. Electrical Engineering) – Terrance is applying diagnostic and prognostic monitoring techniques to the electrical power inverter for a UH60 helicopter. He is supporting the Bell helicopter AATD program.

CAV Information

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