Session 1aAAa

Architectural Acoustics: Towards a Benchmark in Computational Room Acoustics

Alexander C. Bockman, Cochair
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Chair’s Introduction—7:30

Invited Papers

7:35

1aAAa1. Round robins in room acoustics. Michael Vorländer (Inst. of Tech. Acoust., RWTH Aachen Univ., Aachen, Germany)

In 1995, an intercomparison on room acoustics computer simulations was launched, the so-called round robin I. The object of interest was a mid-sized auditorium. That project also included a small measurement project, where sessions of impulse response measurements were carried out with several teams and instrumentation. Since that time, the variations in the results obtained by computer simulations and those obtained by measurements were studied more deeply, and this was the starting point for two more round robins focusing on aspects of other room sizes such as a multi-purpose hall and a rather small recording studio. Also, investigations on the uncertainty in ISO 3382 measurements were initiated. In this short presentation the historic round robins I to III are re-visited and plans for a round robins IV focusing on auralization on room acoustics are discussed.

7:45

1aAAa2. Benchmarks in computational room acoustics. U. Peter Svensson (Dept. of Electron. and Telecomm., Norwegian Univ. of Sci. and Tech., NO-7491 Trondheim, Norway, svensson@iet.ntnu.no)

A benchmark project called “A Benchmarking Framework for Wave-Based Computational Methods” was run in Japan, 2003–2005, coordinated by Tetsuya Sakuma, University of Tokyo, and with a few European participants. The project defined a number of interior and exterior (scattering) cases, ranging from very simple shapes to more realistic cases. A web site was set up where results, timing data, and methods could be submitted in great detail. A recent benchmark initiative, by Dirk Schroder and Michael Vorländer from RWTH, Aachen, is to create an “open measurement” web site where measurement results, software, etc., can be gathered and openly available. Brief presentations of those benchmark efforts will be given.

7:55

1aAAa3. Reverberation modeling workshops. John S. Perkins (Naval Res. Lab., Washington, DC 20375, john.perkins@nrl.navy.mil) and Eric I. Thorsos (Univ. of Washington, Seattle, WA 98105-6698)

To evaluate progress made in basic and applied underwater acoustic reverberation modeling and to make recommendations for transitions to operational systems, a series of two reverberation modeling workshops (RMWs) was held (the last in May 2008). A basic goal of the RMWs was to provide well-defined problems and consensus solutions to support verification and validation for new models, upgrades to Navy Standard models, and geoaoustic inversion techniques based on reverberation data. The basic problem in designing the workshop was that even the simplest reverberation problems of interest to the Navy do not have closed form solutions and are still (essentially) beyond our computational capabilities to solve using standard “exact” numerical techniques. All current, practical underwater reverberation models replace the physical problem by employing scattering and loss functions or tables. We discuss the development of a sequence of well-defined problems (physics-based), with the equivalent loss/scattering input, which increases in complexity. We also discuss the lessons learned in this process and point out some of the unexpected results from the workshops, and make recommendations for future benchmarking workshops. [Work supported by the Office of Naval Research.]

8:05—8:35 Panel Discussion
Session 1aAAb

Architectural Acoustics and Underwater Acoustics: Computational Methods for Auralization in Air and Water I

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Chair’s Introduction—8:50

Invited Papers

8:55


Sound field modeling and auralization have been used in architectural acoustics for many years. Today, the technique of auralization can also be implemented with real-time performance. Then it is part of the technology of virtual reality. Apparent simple scenarios of interaction, however, for instance, when a person is leaving a room and closes a door, require complex models of room acoustics and sound transmission. Otherwise the coloration, the loudness, and timbre of sound within and between rooms are not represented adequately. Still numerous approximations must be made to reach this goal. In the end, the resulting sound is not intended to be physically correct, but perceptively plausible. Knowledge about human sound perception is, therefore, a very important prerequisite to evaluate auralized sounds. In this paper the algorithms for sound field rendering and spatial reproduction are reviewed and discussed with regard to future research.

9:15

1aAAb2. Time series simulation of underwater sound: Key issues and techniques. Robert P. Goddard (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105-6698, robert_goddard@apl.washington.edu)

Computer systems for generating simulated underwater sound have been in use for more than 30 years. Such systems, including the author’s sonar simulation toolset (SST), enable users to build an artificial ocean that sounds like a real ocean, as heard by a user-specified listening system. Such signals are useful for designing new acoustic systems for undersea sensing or communication, testing existing systems, predicting performance, developing tactics, training operators, planning experiments, and interpreting measurements. Signals of interest include reverberation, target echoes, discrete sound sources, and background noise. The author will describe, in broad outline, techniques for generating simulated underwater sound and criteria for choosing among them, focusing on target echoes and reverberation for active sonar systems. The characteristics of the ocean as an acoustic medium, the characteristics of the sensors, the processing and display systems behind the sensors, the purpose of the simulation, and the computational resources available for the simulation all strongly influence the choice of algorithms to achieve useful, cost-effective, simulated underwater sound. The characteristics of the human auditory system are of minor importance.

9:35

1aAAb3. Sound propagation at micro-scale in urban areas. Jian Kang (School of Architecture, Univ. of Sheffield, Sheffield S10 2TN, United Kingdom)

While large scale noise-mapping techniques have been applied extensively in practice, as required by the EU Directive on environmental noise, they are often not applicable for micro-scale urban areas, such as a street or a square. This talk will discuss a series of simulation techniques as well as related acoustic theories for accurately calculating the sound field for micro-scale urban areas. This includes energy-based image source methods for street canyons and urban squares with geometrically (specularly) reflecting boundaries, image source method considering interference, ray-tracing, radiosity model for diffusely reflecting boundaries, transport theory, equivalent source method, and some other models. Techniques for urban acoustic animation will also be briefly discussed.

9:55—10:05 Break

10:05


In the underwater environment, electromagnetic signals are highly attenuated and therefore acoustic systems are primarily used for remote sensing, communications, and imaging. Underwater acoustic propagation modeling is used to understand performance of these systems and the subject is considered fairly mature. A variety of approaches have been developed to simulate acoustic time-series in underwater environments (i.e., the ocean). Usually the biggest challenge is simply knowing the propagation environment in enough detail for accurate simulations. Setting that aside, there are several other complicating factors that limit the quality of simulations even
in known environments. Among these are the irregular boundaries at the sea-surface and seabed boundaries which scatter the acoustic field. Solutions to these scattering problems are often formulated in the frequency domain and time-series form using Fourier synthesis. However, Doppler effects due to sea-surface motion as well as source and receiver motion add additional modeling challenges particularly for frequency domain approaches. In these cases, ray-based techniques have been used successfully to model acoustic time-series. In this presentation the various approaches to simulating underwater acoustic time-series will be described for static and dynamic environments. Applications of these simulations for predicting reverberation and multipath in the underwater environment will also be presented.

10:25

1aAAb5. The inclusion of diffraction effects in room acoustical modeling. U. Peter Svensson (Dept. of Electron. and Telecomm., Norwegian Univ. of Sci. and Tech., NO-7491 Trondheim, Norway, svensson@iet.ntnu.no)

This paper will give a brief overview of some alternatives for including diffraction effects in computational room acoustics. Geometrical acoustics is the basis for most computer modeling methods in room acoustics, and both deterministic and stochastic approaches are used. The image source method and the beam tracing method dominate for the former, and ray tracing for the latter. Deterministic methods are used for sequences of specular reflections, and diffraction effects are straightforward to include in such methods. Paths that involve at least one diffuse reflection are usually handled by ray tracing and recent work has suggested how to implement diffraction in ray tracing. The inclusion of diffraction effects might offer more accurate modeling, most notably for free-hanging reflectors, orchestra pits, balcony edges, etc. The boundary condition issue will be discussed since diffraction solutions that are useful in room acoustics exist only for ideally rigid surfaces. Underlying approximations in some formulations will be mentioned, and computational aspects will be described, including the huge number of diffraction paths that are generated in a room, with a corresponding huge range of amplitudes. Special attention will be given to singularity issues and an attempt at an outlook for the near future will be offered.

10:45

1aAAb6. Efficient acoustic radiance transfer method with time-dependent reflections. Samuel Siltanen, Tapio Lokki, and Lauri Savioja (Dept. of Media Technol., Aalto Univ. School of Sci. and Technol., P.O. Box 15400, FI00076 Aalto)

Modern desktop computers are equipped with graphics cards that provide massive parallel computation power that was previously available only in supercomputers. On the other hand, there are several room acoustics modeling methods, but only some of them scale well to hundreds or thousands of parallel processors. The scalability of the acoustic radiance transfer method is examined. It is shown that it can almost fully utilize the available computing power. In simple cases, this technique achieves real-time performance. While taking into account the limitations of the energy-based acoustic modeling approach, the presented system can model arbitrary reflections. The reflections are presented as bi-directional reflectance distribution functions, which depend on the incoming and outgoing directions of acoustic energy. It is also possible to add time-dimension to such a reflection model. Some measurements are presented to show that spreading in time dimension occurs at reflections. Most of the previous room acoustics modeling techniques have ignored that phenomenon, but the acoustic radiance transfer technique can be easily modified to take this spreading effect into account.

11:05


Many systems for real-time simulation of active sonar reflect the historical division between propagation and reverberation algorithms. Though sonar returns comprise continuas of echoes, systems treat scatterers as discrete targetlike entities or as distributed entities described by scattering strengths associated with regions of the ocean boundaries or volume. This approach limits the development of computational algorithms. In the fields of room acoustics and virtual reality there has been significant research devoted to development of efficient algorithms that enable computational simulation and real-time rendering (auralization) of sound fields resulting from complex scenarios. Such work exploits knowledge of the physical processes and limitations of the human auditory system to enhance the relevant aspects of fidelity while reducing computational load. Similar conditions exist for the simulation of active sonar. This presentation describes how concepts from room acoustics and auralization can be applied toward an active-sonar simulation that is scalable and implicitly incorporates tradeoffs between speed and accuracy. Rather than develop new propagation or reverberation algorithms, gains can be achieved by creating a system that treats all echoes within a unified framework and explicitly accounts for properties of source, path, and receiver in order to optimize use of existing algorithms.

Contributed Papers

11:25

1aAAb8. Real-time auralization of wave simulation in complex three-dimensional acoustic spaces. Nikunj Raghuvanshi, John Snyder (Microsoft Res., Redmond, WA 98052, nikunj@microsoft.com), Ravish Mehra, Ming C. Lin (Dept. of Comput. Sci. Sitterson Hall, Univ. of North Carolina, Chapel Hill, NC), and Naga K. Govindaraju (Microsoft Corp., Redmond, WA 98052)

A technique has been developed for modeling real-time sound propagation in static acoustic spaces that relies on pre-computed wave simulation. The associated system can auralize propagation that includes diffraction, interference, scattering and late reverberation, while supporting tens of moving point sources and moving listener in highly complex three-dimensional scenes. Since direct storage of simulated impulse responses for runtime use is infeasible, a novel technique was developed to extract and compactly encode the perceptually salient information in the simulated band-limited impulse responses. The response is automatically broken into early reflections (ERs) and late reverberation (LR), via a threshold on the temporal density of arriving wave-fronts. The LR is simulated and stored once per room. Detailed spatial variation in ER is simulated, and encoded by a set of peak delays/amplitudes in the time domain and a residual frequency response sampled in octave bands, at each source/receiver point on a five-dimensional grid. An efficient run-time uses this pre-computed representation to perform binaural sound rendering based on frequency-domain convolution. The system demonstrates audible wave-based effects in real-time—diffraction low-pass filtering behind obstructions, sound focusing (caustics), hollow reverberation in empty rooms, sound diffusion in fully-furnished rooms, and late reverberation with non-exponential decay.

11:40

1aAAb9. Comparison of room-acoustical parameters predicted using different surface-reaction models. Behroz Yousefzadeh and Murray Hodgson (Acoust. and Noise Res. Group, Univ. of BC, 2206 East Mall, 3rd Fl., Vancouver, BC, V6T 1Z3, Canada)

This paper presents the development of a beam-tracing model for calculating the transient responses of rooms. The model is wave-based (i.e., includes phase changes due to distance traveled and wall reflections), and can
be applied to rooms with extended-reaction surfaces. Room surfaces can be modeled as multiple layers of solid, fluid, and poroelastic materials; their acoustical properties are calculated using a transfer-matrix approach. The beam-tracing model calculates the complex transfer function of a room. Pressure impulse responses are then computed via Fourier transformation, and the room-acoustical parameters derived. Since pressure impulse responses are calculated, the model can also be used for auralization. The model has been applied to different room configurations in order to study the effects of different surface-reaction models on the predicted steady-state characteristics and temporal variations of sound-pressure fields in various room configurations. In particular, the audibility of using different boundary conditions (local versus extended reaction, wave-based versus energy based modeling, and phase changes on reflection) on the room-acoustical parameters has been investigated: In each configuration, room parameters have been calculated using different boundary conditions, and audible variations of the parameters have been studied and explained.

MONDAY MORNING, 23 MAY 2011
ISSAQUAH, 8:00 TO 11:50 A.M.

Session 1aABa

Animal Bioacoustics, Noise, and Underwater Acoustics: Ambient Noise and Marine Mammals

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Chair’s Introduction—8:00

Invited Papers

8:05

1aABa1. Merchant ship-radiated noise source levels. Stephen C. Wales (Naval Res. Lab., Code 7120, Washington, DC 20375, steve.wales@nrl.navy.mil) and Richard M. Heitmeyer (Global Strategies Inc., Crofton, MD 21114)

Ship-radiated noise is the principal source of noise in the 20–300 Hz frequency regime. This presentation provides a review of the issues relating to measuring ship-radiated noise source levels and predicting the source levels from ship parameters. The process of measuring and calculating the source levels is covered, including a discussion of propagation effects and source representation. Based on measurement results it is shown that, contrary to the classical model of shipping source levels, there is a negligible correlation between the source levels of an ensemble of ships and the transiting speeds and lengths of those ships. Issues concerning using the source level model in a modeling environment are discussed, including some effects of changing speed and source depth. Additionally, evidence is presented that predictions of increases in the source levels of the world’s ships based on increases in their speeds is not justified, while increases due to size (length) are not trivial. [Work supported by the ONR through NRL-base funding.]

8:35


Estimating the increase in noise due to commercial shipping is of interest because of naval operations and its environmental consequences to marine life. Recent low-frequency noise calculations [Evans and Carey, Proceedings of the 9th ICTCA, Univ. Bundeswehr, DE] for the mid-Philippine sea illustrate the major uncertainties due to the basin’s slope reflectivity, the number density, and the source level radiation characteristics of commercial ships. Canonical source level characteristics are based on naval studies on measurements some 3 decades ago. In the early seventies, Ross [J.O.E. 30(2), (2005)] estimated the rate of increase of noise levels based on an empirical relationship between the radiated source level and tonnage to be order 0.5 dB/year based on the commercial ships of that era. Currently there are as many as seven classes of ships with an order of magnitude increase in tonnage, hull size, drafts, and propeller size. A plausible consequence is a radiation characteristic with a different directionality and effective efficiency. Deep ocean calculations are presented illustrating the uncertainties of slope enhancement and shipping noise levels. The current commercial ships are reviewed, qualitative estimates of the radiation characteristics are presented, and ambient noise implications discussed. [Work sponsored by ONR OA.]
1aABa3. Ocean traffic noise in the context of natural ambient noise in impacts on marine mammals. Douglas H. Cato (Defence Sci. & Tech. Org. and Univ. of Sydney, P.O. Box 44, Pyrmont, New South Wales, 2009, Australia, doug.cato@sydney.edu.au)

Traffic noise, the background noise from distance shipping, is the most widespread anthropogenic component of ambient noise. There has been concern for decades that traffic noise may be limiting the ability of marine mammals to communicate, but there is little direct evidence of actual impacts or the significance of these on the well being of populations, possibly because of the difficulties in obtaining such evidence. This paper compares traffic noise with natural ambient noise in the same frequency band. Marine mammals have evolved to cope with the range of levels in natural ambient noise. It draws on studies from areas near Australia where there is a wide range in traffic noise levels. In some areas, traffic noise is so low that it is possible to determine the range of natural ambient noise in the frequency band where traffic noise usually dominates. In other areas, traffic noise reaches levels similar to some of the high levels observed near North America. Humpback whales that migrate along the east coast of Australia are subject to high levels of traffic noise and noise from passing ships, but there seems to be little impact on the whales at the population level.

1aABa4. Using auditory models to study masking due to anthropogenic sound. David C. Mountain (Dept. of Biomedical Eng., Boston Univ., 44 Cummington St., Boston, MA 02215, dcm@bu.edu)

The mammalian auditory system is a highly evolved acoustic signal processing system that performs well in highly reverberant and cluttered acoustic environments. In cetaceans, the auditory system is even more highly evolved than vision and is extremely important for navigation, foraging, and social communication. As humans inject more and more acoustic energies into the marine environment, these important acoustic functions may become compromised. Unfortunately little is known about the impact of anthropogenic sounds that could mask biologically significant signals. In this study a desktop simulation environment was used to study masking effects in a variety of conditions. The acoustic scenarios were created by mixing cetacean vocalizations recorded under relatively quiet conditions with scaled recordings of shipping noise. Biophysical computer models (http://earlab.bu.edu) based on physiological and behavioral experiments performed on humans were extrapolated to represent several different cetacean species. Model parameters for species of interest were estimated from behavioral audiograms and from other available data. These models were then used to predict how different types of biologically significant sounds are represented in neural firing patterns and how the neural representation degrades in the presence of anthropogenic noise.

10:20

1aABa5. Oceanic shipping soundscapes. Christian de Moustier and Michael Porter (HLS Res., Inc., 3366 North Torrey Pines Court, Ste. 310, La Jolla, CA 92037, cpm@hlsresearch.com)

Shipping and wind are key sources in the oceanic soundscape that affects marine mammal habitats. A new method of forming such soundscapes is presented. Frequency and range dependent transmission losses are pre-computed from a grid of virtual sources using fast ray computations (BELLOP) on a specified number of radial lines. Each radial line samples the bathymetry along its bearing out to a given maximum range. A shipping soundscape is then estimated by assigning a source spectral density level (dB re 1 μPa Hz) and a shipping density (number of ships per unit area per unit time) to the various grid nodes. Such density values are obtained directly from ships carrying an automatic identification system (AIS) that transmit information such as ship type, position, heading, and speed. They can be obtained also from compiled statistics of AIS data (e.g., number of transits per year in an area). The same gridding approach is used to predict wind-generated sound levels based on maps of average wind speeds in an area for a given epoch, or on maps of forecast wind speeds.

10:35

1aABa6. Application of automatic identification system information to ocean soundscape modeling. John E. Joseph and Christopher Miller (Dept. of Oceanogr., Naval Postgrad. School, 1 University Cir., Monterey, CA 93943)

The impact of anthropogenic noise on marine life is an important issue to both the scientific community and public policy makers. Human-generated noise has potential to disrupt critical marine mammal biological functions such as foraging, communication, and navigation. Commercial shipping contributes significantly to the ocean soundscape, typically dominating the noise field at frequencies less than 500 Hz. Market conditions, trends in vessel design and propulsion, use of more economical ship routes, operational efficiency, and environmental factors are all important variables that help shape the changing soundscape. To reliably model the temporal and spatial variability of a regional soundscape, accurate characterization of the sources of noise is needed. Acoustic recordings taken at the Point Sur Ocean Acoustic Observatory (OAO) and Automatic Identification System (AIS) reports broadcast by ships passing the OAO site have been used to determine ship source levels over the 25–600 Hz band, categorized by ship class and speed. Source levels are then applied to a model used to evaluate temporal variability of the noise field at several sites along the central California coast based on AIS-reported shipping traffic transiting the region. Results of our calculations are presented and discussed. [Research supported by US Navy CNO(N45).]
Throughout 2010, underwater recordings have been made of each ship passing two separate Haro Strait nodes of the OrcaSound.net hydrophone network. About 20 ships pass each day. Each ship has been identified in real time [automatic identification system (AIS)]. Measurements of received underwater noise levels and AIS variables are recorded as each ship passes the listening stations. Individual ships are observed multiple times moving in either northerly or southerly directions at times separated by a day or two.

A database has been developed that contains either northerly or southerly directions at times separated by a day or two. Listening stations. Individual ships are observed multiple times moving in either northerly or southerly directions at times separated by a day or two and also by intervals of months. A database has been developed that contains the spectrum level of each ship (bandwidth 96 kHz at one location and 22 kHz at the other) and the source level both in terms of intensity and angular distribution. Ship signatures in terms of frequency quantiles and angular distributions of emissions are quite reproducible. This database can be used to predict limitations on echolocating and vocalizing marine mammals’ active space due to specific ship noise emissions. In particular, predictions of marine mammal noise exposures in specific frequency bands can be made prior to specific vessels’ entry into an area opening the possibility of planning field observations to investigate correlations between behaviors and specific predicted noise exposures.

1aABa9. Measurements of radiated underwater noise from modern merchant ships relevant to marine mammal noise exposures in specific frequency bands can be made prior to specific vessels’ entry into an area opening the possibility of planning field observations to investigate correlations between behaviors and specific predicted noise exposures.

1aABa10. Behavioral response of harbor porpoises to vessel noise in a tidal strait. Brian Polagye (Dept. of Mech. Eng., Univ. of Washington, Box 352600, Seattle, WA 98195, bpolagye@uw.edu), Jason Wood (Sea Mammal Res. Unit Ltd., Vancouver, BC, V6R 1J6, Canada), Chris Bassett (Univ. of Washington, Seattle, WA 98195), Dom Tollit (Sea Mammal Res. Unit Ltd., Vancouver, BC V6R 1J6, Canada), and Jim Thomson (Univ. of Washington, Seattle WA 98105)

Admiralty Inlet, a narrow channel in Puget Sound, WA, is the proposed location of a pilot tidal energy project. A pair of hydrokinetic turbines would be deployed, for evaluation, on the seabed in approximately 60 m of water. When extracting power from strong tidal currents, these turbines will also generate broadband noise. Harbor porpoises are known to exhibit strong avoidance behavior to loud noise and occur frequently in this area. Consequently, there is a concern that the project could cause local displacement of this species. Because Admiralty Inlet is a major shipping lane and traversed by a passenger ferry, there is already periodic, high intensity anthropogenic noise in the vicinity of the proposed tidal energy project. The behavioral response of harbor porpoises to these existing noise sources is evaluated to provide context for the potential impact from tidal turbine noise. This study combines data on shipping and ferry traffic from an automatic identification system receiver, received noise levels from broadband autonomous hydrophones, and current velocity from Doppler profilers. These are correlated with porpoise presence, as assessed by echolocations detected by Chelonias C-Pods. Information collected over a full year provides insight into behavior at several time scales.
sub-arctic, temperate, and tropical systems examined. The importance of spatial pattern in ecosystems has long been recognized and its effects on predator-prey pairs has been examined in a number of previous studies; however, patchiness as the dominant force regulating an entire system has not been previously demonstrated, primarily because of the technical challenges of measuring the spatial and temporal scales of biological variability in the ocean.

8:50

1aABB2. Imaging and localizing fish and marine mammals with acoustics. Purnima Ratilal, Duong Tran, Roger Gong, David Reed, Hari Chauhan (Dept. of Elec. and Comput. Eng., Northeastern Univ., 360 Huntington Ave., Boston, MA 02115), and Nicholas Makris (MIT, Cambridge, MA 02139)

During the 2006 ocean acoustic waveguide remote sensing (OAWRS) experiment in the Gulf of Maine, large shoals of Atlantic herring were instantaneously imaged in the frequency range from 300 to 1200 Hz. Simultaneously, several thousand instances of marine mammal vocalizations were passively recorded on a high resolution towed horizontal receiving array. A vast majority of the vocalizations were from humpback whales in the 300–600 Hz frequency range. Vocalizations from other marine mammals species ranging from 40 Hz to over 3 kHz were also recorded. Various approaches are employed to localize and track the whales both passively and actively. The bearing of calling whales can be found by beamforming their vocalizations measured on the receiving array. An efficient and robust matched filter is designed to enhance the signal-to-noise ratio of the whale vocalizations. The array invariant method [Lee and Makris, J. Acoust. Soc. Am. (2006)] is then applied for instantaneous whale range estimation. The array invariant approach has been verified theoretically with modeled complex nonlinear whale vocalizations propagated long ranges exceeding 50 km in a range-dependent ocean waveguide. The whale range estimates obtained with the array invariance technique are verified by hyperbolic localization of the vocalization signals measured by the moving receiver array along a given track.

9:10

1aABB3. Active acoustic monitoring systems for detecting, localizing, tracking, and classifying marine mammals and fish. Peter J. Stein (Sci. Solutions, Inc., 99 Perimeter Rd., Nashua, NH 03063, pstein@scisol.com)

Detection, localization, tracking, and classification (DLTC) of marine mammals and fish is necessary for a wide range of bioacoustic studies. This includes those related to understanding anthropogenic effects and to the development of methods for mitigating harm. Active acoustic monitoring (AAM) is a robust method for monitoring marine life as it can detect and accurately localize a silent target, enabling full DLTC. With the growth of the offshore renewable energy industry and the need to mitigate harm from pile driving, seismic surveys, and military sonar operations, there is strong interest in developing AAM systems and integrating them with current mitigation techniques. There are a host of significant issues including the standard sonar problems of reverberation and propagation in high-clutter shallow water environments, false alarms, classification, methods of deployment, and cost. Furthermore, AAM systems transmit acoustic energy that has the potential to disturb marine life. Much work lies ahead to develop systems that balance the risks, benefits, performance, and costs. This paper will review the status and issues of AAM systems. This includes a discussion of implemented near-field (imaging) and far-field (tracking) systems, experimental results, and plans for further development, testing, integration, and permitting.

Contributed Papers

9:30

1aABB4. Acoustic characterization of pingers on Queensland Shark Control nets. Christine Erbe, Craig McPherson, and Andrea Craven (IASC0 Appl. Sci., Brisbane Technol. Park, P.O. Box 4037, Eight Mile Plains, QLD 4113, Australia)

Active acoustic applications in marine bioacoustics include the use of pingers to dissuade marine mammals. Pingers are most frequently used by the fishing industry to prevent predation and entanglement. Pingers are also used by other marine industries to dissuade animals from potentially dangerous sites, e.g., underwater turbines. The Queensland Shark Control uses pingers to prevent marine mammal entanglement in shark control nets along public beaches. We have recorded and characterized some of the most common pingers off Queensland. Sound propagation and the potential detection of pinger sounds by marine mammals were modeled. Ambient noise was recorded in the vicinity of shark nets to estimate the contribution of pingers to ambient sound budgets. [Work supported by the Australian Department of the Environment, Water, Heritage and the Arts; Australian Antarctic Division.]

9:45

1aABB5. Application of active acoustic techniques to studies of krill aggregation and interaction with higher predators. Gareth L. Lawson, Andone C. Lavery, Peter H. Wiebe, and Nancy J. Copley (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543, glawson@WHOI.edu)

Large aggregations of euphausiids are often observed in regions of abrupt topography such as continental shelf breaks and submarine canyons. Understanding the biological and physical factors that lead to such aggregations is an important problem as these regions often constitute key habitat for top predators. A series of three cruises was conducted to the margins of Georges Bank, sampling zooplankton with a broadband active acoustic system, a multi-frequency acoustic system, a video plankton recorder, and depth-stratified nets, and sampling seabirds and marine mammals via visual observations. A combination of coarse-scale acoustic mapping and fine-scale adaptive surveys were used to identify and track individual euphausiids aggregations and to observe how their structure and vertical position varied with changing conditions. Distinct spatial and temporal variabilities were observed in euphausiids abundance, patch structure, and community composition, along with changes in the abundance and distribution of higher predators. These cruises represent among the first uses of the broadband technology for the study of zooplankton ecology and allow for an assessment of the relative advantages and disadvantages of broadband vs multi-frequency approaches and of the importance of independent ground-truthing information.

10:00—10:30 Break

10:30

1aABB6. Frequency shifts of echolocation pulses in a cluttered environment: Comparison between Pipistrellus abramus and Miniopterus fuliginosus. Toshiya Takenaga, Shizuko Hiruyu (Doshisha Univ., Kyotanabe 610-0321, Japan), James A. Simmons (Brown Univ., Providence, RI 02912), Hiroshi Riquimaroux, and Yoshiaki Watanabe (Doshisha Univ., Kyotanabe 610-0321, Japan)

Changes in frequency range (ΔF) of FM echolocation pulses were recorded with an onboard wireless microphone (Telemike) for Pipistrellus abramus and Miniopterus fuliginosus in a cluttered environment created by dense chain-row obstacles. The duration of echo streams (ESD) from the chains reached ~40 ms when the bats were flying toward the chain-row
patches containing distinct size classes and mixed-size assemblages were provided validation of mysid species and size-class availability as prey to larger predators. Concurrent net and video sampling Mysid patches were analyzed to characterize the dynamics relevant to their using combined stationary and shipboard active multifrequency acoustics.

Mysid populations form into dense swarms and provide an important prey resource for large predators on the central Oregon coast including resident gray whales and a variety of fish species. The spatial and temporal characteristics of mysid patches were investigated in July and August, 2010 using combined stationary and shipboard active multifrequency acoustics. Mysid patches were analyzed to characterize the dynamics relevant to their availability as prey to larger predators. Concurrent net and video sampling provided validation of mysid species and size-class identification. Dense patches containing distinct size classes and mixed-size assemblages were observed from shipboard spatial surveys inshore of the 15 m isobath, where gray whales were actively foraging throughout the study. Bottom-mounted acoustic moorings revealed a distinct diel pattern of swarm density and vertical distribution, as mysid patches often separated into layers during night while reforming very near bottom during the day. This study demonstrates the usefulness of combining information from stationary and moving platforms of active acoustic methods while providing important information on the patch characteristics of a critical prey group.

11:00
1AABB8. Assessing juvenile Atlantic bluefin tuna schools in the Northwest Atlantic using sound data and aerial imagery, Madeline L. Schroth-Miller and Tom C. Weber (Ctr. for Coastal and Ocean Mapping, Univ. of New Hampshire, 15 Mill Rd., Durham, NH 03824, m_schroth05@yahoo.com)

Over the past 2 years, a feasibility study has been conducted in order to establish a methodology for assessing the biomass of juvenile Atlantic bluefin tuna (Thunnus thynnus). Over several days in August 2009, a 400 kHz Reson 7125 multibeam sonar installed on a commercial fishing vessel was used to collect acoustic backscatter from tuna schools. The multibeam sonar was oriented on the starboard side of the vessel to image a vertical slice of the water column. Because the fishing vessel was led to the tuna schools by a spotter plane, we were restricted to examining only near-surface tuna schools that were visible from the air. The same spotter plane collected aerial images of the same schools that were examined with the multibeam sonar. The multibeam sonar data allowed us to estimate attributes such as the maximum depth, cross sectional area, and morphology of the fish schools in a vertical plane, while metrics such as the nearest neighbor distance and number of fish were estimated from the aerial photographs. Taken together, the sonar data and aerial imagery provide a viable methodology for assessing juvenile Atlantic bluefin tuna.
Invited Papers

8:15

1aAO2. The Northwest Association of Networked Ocean Observing Systems and opportunities for acoustical applications. Jan Newton, Matthew Alford, John Mickett (Appl. Phys. Lab, Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, newton@apl.washington.edu), John Payne (POST (Pacific Ocean Shelf Tracking Project), Seattle, WA), and Fritz Stahr (Univ. of Washington, Seattle, WA)

NANOOS, the Pacific Northwest Regional Association of the U.S. Integrated Ocean Observing System (IOOS), aims to provide coastal ocean observations improving understanding and enabling decisions to improve safety, enhance the economy, and protect the environment. Biological aspects of ocean observing lag behind physical because of the difficulty of observing animal behavior beneath the surface; yet information about the behavior and survival of marine species in the ocean is identified as a critical need for fisheries management and marine spatial planning. Acoustics are poised to contribute to this need; however, limitations of acoustic arrays must be addressed. NANOOS recognizes opportunities for acoustical applications and has begun exploring these. NANOOS and POST deployed an acoustic receiver on a seaglider to test feasibility of using gliders to extend the scope of acoustic tracking arrays into deeper water and as a rapid deployment technology to test fixed arrays and investigate oceanographic features. During a 3-month test deployment, July–October 2010, a receiver mounted on the seaglider worked flawlessly and made two detections: one from a salmon and one from a Humboldt squid. NANOOS has proposed to develop methods for integrating instruments for tracking migrations of fish and marine mammals into ocean observing networks.

8:35

1aAO3. Acoustic challenges in aquatic ecosystem assessment. John K. Horne (School of Aquatic and Fishery Sci., Univ. of Washington, Box 355020, Seattle, WA 98195), Charles E. Schmid (Acoust. Society of America, Ste. 1N01, 2 Huntington Quadrangle, Melville, NY 11747), Robert McClure (BioSonics Inc., 4027 Leary Way NW, Seattle, WA 98107), and Martin Siderius (Portland State Univ., P.O. Box 751, Portland, OR 97207)

In an effort to increase communication and collaboration between members of the Acoustical Society of America and the American Fisheries Society, a joint workshop focusing on the integration of biological and physical elements in ecosystem research, current policy and regulations, and applications of acoustic technologies developed field use will be held Thursday and Friday during the conference. Topics of interest in the workshop include the following: ecosystem-based resource management, cabled observatories, monitoring renewable energy sites, acoustic species discrimination, statistical analysis for fisheries assessment, progress in fish tagging, acoustical models for fisheries assessment habitat inventory, detecting, and monitoring episodic events: natural and anthropogenic, active and passive assessment, and quantitative assessments in noisy environments. Ocean observatories is an explicit topic of interest in the workshop, but it can serve as an integrating theme that potentially expands the scope and capabilities of aquatic ecosystem assessment.

8:55

1aAO4. Listening to marine mammals at basin to local scales. Sue E. Moore (NOAA/Fisheries ST7, 7600 Sand Point Way NE, Seattle, WA 98115), Sofie M. Van Parijs (NOAA/NEFSC, Woods Hole, MA 02543), Brandon L. Southall (SEA Inc., Santa Cruz, CA 95060), and Kathleen M. Stafford (APL-UW, Seattle, WA 98105)

The successful use of SOSUS to track broad-scale occurrence patterns in whale calls during the second half of the 20th century fostered the development of autonomous recorders that can be deployed virtually anywhere in the world ocean. Over the past decade, data from these recorders have provided dramatic insights to marine mammal ecology. Patterns of call reception have demonstrated the near year-round occurrence of some baleen whale species in Arctic and Antarctic waters, a discovery that challenges long-held assumptions about the phenology of seasonal migrations. Integration of year-long calling records with physical oceanographic measures at mooring-based ocean observatories provides a means to include large whales in ecosystem-based models. The reception of anthropogenic sounds on nearly all recorders, whether deployed in coastal or remote areas, emphasizes the need to develop regional “soundscapes” based upon integrative sampling and analytical protocols. Examples from several long-term research programs will be provided as the basis for the strong assertion that passive acoustic observation of marine mammals is a vital component of any ocean observing system. Opportunities for future collaborations and the challenges of data management and access will be discussed.

Contributed Papers

9:15

1aAO5. Acoustic monitoring of beluga whales (Delphinapterus leucas) in Cook Inlet, Alaska. Manuel Castellote (Natl. Marine Mammal Lab., AFSC /NOAA, Seattle, WA), Robert Small (Alaska Dept. of Fish & Game, Juneau, AK), Shannon Atkinson (Univ. of Alaska Fairbanks, Juneau, AK), Marc O. Lammers (Hawaii Inst. of Marine Biology, Kanehoe, HI), Justin Jenniges (Alaska Dept. of Fish & Game, Juneau, AK), Anne Rosinski (Hawaii Inst. of Marine Biology, Kanehoe, HI), Christopher Garner (Joint Base Elmendorf-Richardson, Anchorage, AK), Sue Moore (NOAA Fisheries, Seattle, WA), and Whitlow L. Au (Hawaii Inst. of Marine Biology, Kanehoe, HI)

Cook Inlet belugas (CIBs) are listed as endangered under the U.S. Endangered Species Act. Their current seasonal distribution is essentially unknown and the factors impeding their recovery over the past decade are unknown, yet could include anthropogenic activities that impact their acoustic ecology, including coastal development, oil and gas exploration, shipping and military activities. Beginning in 2008, a cooperative research project has acquired new information on background noise levels and the seasonal presence of CIBs throughout Cook Inlet using passive acoustic monitoring. Mooring packages containing ecological acoustic recorders (EARs) and echolocation loggers (C-PODs) have been deployed at ten sites to continuously monitor the presence of CIBs. Cook Inlet is a challenging environment for acoustic monitoring because of extreme tides and currents, sediment dynamics, debris from rivers and seasonal ice that characterize the area. Noise from both natural and anthropogenic sources often make beluga call detection challenging. However, the effort to date has met with success and is providing valuable insights into beluga movement patterns and the
acoustic environment they face. This methodology also allows monitoring other odontocetes such as killer whales (Orcinus orca), detected mostly in the lower inlet, and harbor porpoise (Phocoena phocoena) detected throughout the inlet.

9:30
IAAO6. Seasonal and spatial patterns of cetacean occurrence off Oahu, HI observed acoustically. Marc O. Lammers, Michael Richlen, Whitlow W. L. Au, Anne E. Rosinski, and Gadea Perez Andujar (Hawaii Inst. of Marine Biology, P.O. Box 1346, Kaneohe, HI 96744)

The seasonal occurrence and distribution of cetaceans around island archipelagos is often poorly understood. This is generally due to the variability in sea surface conditions associated with islands, which make visual surveys prohibitive along exposed areas and/or during seasonal periods of rough seas. Historically, this has been the case for many cetacean species found in Hawaiian waters. Recently, however, concerns about the impacts of anthropogenic activities have created a need to better understand the long-term, spatial and temporal distributions of cetaceans in the archipelago. To meet this need, an effort was begun in February 2009 to study cetacean occurrence around the island of Oahu using a network of passive acoustic recorders. Five ecological acoustic recorders (EARs) were deployed in waters 115-575 m deep along the perimeter of the island and refurbished approximately every 4 months. Data from these deployments are providing an unprecedented perspective on the occurrence of both odontocete and mysticete cetaceans around the island. The southeastern corner of Oahu, in particular, has emerged as a hotspot of odontocetes; diversity and abundance. This and two other sites being monitored have historically received little or no visual survey attention, but are clearly important habitats for a variety of species.

9:45
IAAO7. Using acoustic cue statistics in matrix population models to study short-term and long-term marine mammal population dynamics in the northern Gulf of Mexico. Natalia Sidorovskaia (Dept. of Phys., Univ. of Louisiana at Lafayette, UL Box 44210, Lafayette, LA 70504-4210, nas@louisiana.edu), Azmy Ackleh, Nabendu Pal (Univ. of Louisiana at Lafayette, Lafayette, LA 70504), Juliette W. Ioup, George E. Ioup (Univ. of New Orleans, New Orleans, LA 70148), and Christopher O. Tiemann (Univ. of Texas at Austin, Austin, TX)

Acoustics is emerging as a viable tool for determining population trends of deep diving marine mammals in addition to conventional transect-line visual observations which are often limited by weather conditions, short-time surface presence, costs, etc. In September 2010, following the recent oil spill in the Gulf of Mexico, the Littoral Acoustic Demonstration Center (LADC) conducted a passive acoustic experiment as part of a study of short-term and long-term effects of the oil spill on the resident population of marine mammals. Environmental Acoustic Recording System (EARS) buoys were redeployed in three locations: 9 mi, 23 mi, and 50 mi away from the Deepwater Horizon-oil spill site. LADC previously collected data at these locations in 2001, 2002, 2007. The pre-spill data are used as a baseline for estimating long-term population trends. Densities of acoustic phonsations of sperm whales, beaked whales, and dolphins are extracted from collected data and used for point estimates of the resident population density. LADC extensive work on an individual acoustic identification is reviewed in the context of mark-recapture statistics used in matrix population models. Trends in population density after the spill are presented and discussed. [Research is supported by ONR and NSF. Ship services donated by Greenpeace.]

10:00—10:30 Break

Invited Papers

10:30
IAAO8. Next generation science, engineering, and education in the ocean basins: sensor-robotic networks communicating near the speed of light. John R. Delaney (School of Oceanogr., RSN Program, Univ. of Washington, Box 357940, Seattle, WA 98195-7940, j델aney@uw.edu), Kendra L. Daly (Univ. of South Florida, St. Petersburg, FL 33701), Deborah S. Kelley (Univ of Washington, Seattle, WA 98195-7940), and Douglas L. Luther (Univ. of Hawaii, Honolulu, HI 96822)

Complex processes driven by solar and internal geothermal energy within the ocean basins constitute the “flywheel” of our planetary life-support system. Ocean-atmosphere dynamics determine the weather and long-term climatic variations that continually impact the continents. New approaches to understanding the complexity and uncertainties of this “oceanic modulator” arise from the rapid implementation of submarine cable networks providing unprecedented electrical power and communications bandwidth to thousands of sophisticated robot-sensor systems distributed throughout a full ocean environment. Empowered by cable systems, oceanographers will benefit from emergent technologies driven by major investment from communities external to ocean sciences. Developments include robotics, biotechnology, cloud computing, in situ chemical and genomic sensors, digital imaging, nanotechnology, new visualization technologies, computational modeling, synthetic tomography, passive and active acoustic sensors, and the internet. More powerful than any one of these emerging technologies is the convergence of the ensemble in pursuit of ocean science. As rapidly evolving capabilities are integrated into sophisticated, remote, interactive operations, a pervasive human tele-presence throughout our once ‘inaccessible’ global ocean will be realized. Such capabilities are required to meet environmental-societal challenges in the coming decades, which can only be addressed through optimally informed national and international collaborations.

10:50
IAAO9. Acoustic monitoring of marine life with a fiber-optic, ocean-observing network. Brandon L. Southall (SEA, Inc., 9099 Soquel Dr. Ste. 8, Apts, CA 95003), Christopher Clark (Cornell Univ.), Kendra Daley (Univ. of South Florida), Sue Moore (NatI. Oceanic and Atmospheric Administration), John Payne (Univ. of Washington), Roger Payne (Ocean Alliance), Kate Stafford, Mark Stoermer (Univ. of Washington), Peter Tyack (Woods Hole Oceanograph. Inst.), William Wilcock, and John Delaney (Univ. of Washington)

The application of fiber-optic, high-bandwidth transmission technology is revolutionizing ocean observing by enabling the synoptic acquisition of high-density data streams, including acoustic measurements. A multi-disciplinary collaboration of geophysicists, acousticians, and biologists is developing acoustic observation systems within a cabled observing network being deployed off Washington and Oregon for the next 25 years. This system will include various sensors, including echosounders to detect zooplankton and fish, broadband hydrophone clusters for detecting various marine animals in biologically relevant areas, and low-frequency line arrays to locate and track vocalizing baleen whales across the Juan de Fuca plate region. These capabilities will enable monitoring of acoustically active individuals engaged in feeding, migrating, socializing, and other aspects of natural history. In combination with other tools (e.g., animal tags and remote sensors), these rich data streams will be integrated to monitor ecosystems and the physical and biological forces driving
their composition. The use of this powerful cabled monitoring network to synoptically observe and acoustically monitor marine life provides an unprecedented opportunity to systematically study this important area and the influences of climate variability and human activities on marine life. It also demonstrates the immense benefits for understanding the ocean with emerging technologies and cross-disciplinary collaboration.

**Contributed Papers**

11:10

1aAO10. Broadband acoustics on the VENUS observatory in Saanich Inlet. Tetjana Ross (Dept. of Oceanogr., Dalhousie Univ., Halifax, NS B3H 4J1, Canada, tetjana@dal.ca), Wu-Jung Lee (WHOI/MIT Joint Program, Woods Hole, MA 02543), Julie Keister (Univ. of Washington, Seattle, WA 98195), Ana Lara Lopez (Scripps Inst. of Oceanogr., La Jolla, CA 92039), and Charles Greene (Earth & Atmospheric Sci., Cornell Univ., Ithaca, NY 14853)

High-frequency sonar is by far the most cost-effective way of “profiling” the water column from an ocean observing system. From a biological oceanographic perspective, long-term acoustic observations are rich with information on the depths and abundances of fish and zooplankton. The drawback is that it is difficult to conclusively identify which species (or even functional groups) are present at any given time. This can be done, but only with plenty of supporting data, generally acquired non-autonomously. Broadband acoustics may be the key to making acoustic observations of fish and zooplankton less qualitative. Here we explore this idea. We present nearly two years (Apr. 2008–Feb. 2010) of broadband (85–155 kHz) echosounder data collected on the VENUS observatory in Saanich Inlet. Using historical and contemporaneous (July 30, 2009) zooplankton net-tow data, we attempt to automate and interpret the resulting classification of scattering layers throughout the long-term record.

11:25

1aAO11. Cabled observatory vent imaging sonar. Russell Light (Appl. Phys. Lab., Univ. of Washington, Seattle, WA 98195, russ@apl.washington.edu), Vernon Miller, Darrell R. Jackson (Univ. of Washington, Seattle, WA 98195), Peter A. Rona, and Karen G. Bemis (Rutgers Univ., New Brunswick, NJ 08901)

A cabled observatory vent imaging sonar (COVIS) has been developed to provide plume and Doppler imaging of hydrothermal vents and surrounding diffuse flow. The system was designed to be compatible with the power and data interface standards of the Neptune Canada cabled observatory. COVIS is a 4 m tall, titanium tripod employing a Reson 7125 multibeam sonar. The sonar transducers are positioned by a motor-driven three degree of freedom rotation system (pitch, roll, and yaw). A 400 kHz, 1 x 128 deg fan-beam projector is used with a receiver array that forms 256 beams having horizontal width 0.5 deg and covering a 128 deg azimuthal sector. Volumetric imaging of plumes is generated as the transducer array is scanned in 1 deg pitch steps. Doppler measurements of flow velocity over a 3-D grid are also derived. A 200 kHz, 28 x 128° broad beam projector is used to image the diffuse areas near the base of the hydrothermal vent edifices. Software allows for the creation of complex, arbitrary, autonomously executed experiments that control all aspects of the sonar and rotation system. COVIS was successfully deployed in September 2010. The design of COVIS provides insights relevant to future cabled acoustic systems. [Work supported by NSF.]

11:40

1aAO12. Multibeam sonar observations of hydrothermal flows at the Main Endeavour Field. Peter A. Rona, Karen G. Benis (Inst. of Marine and Coastal Sci., Rutgers Univ., New Brunswick, NJ 08901, rona@marine.rutgers.edu), Christopher D. Jones, and Darrell R. Jackson (Appl. Phys. Lab., Univ. of Washington, Seattle, WA 98195)

The Cabled Observatory Vent Imaging Sonar has been deployed at the Main Endeavour Node of the Canadian Neptune cabled observatory and has acquired data on plume and diffuse hydrothermal flows. Based on the Reson 7125 multibeam sonar and operating at 200 and 400 kHz, two-dimensional and three-dimensional time series are produced using plume backscattering, Doppler shift, and acoustic scintillation. Hydrothermal plumes and diffuse flow are important as agents of transfer of heat, chemicals, and biological material from the mantle and crust into the ocean in quantitatively significant amounts. High-frequency sonar measurements offer the possibility of inversion to obtain fluxes of central importance in these processes. Long-term time series, obtainable in cabled systems, allow observations of hydrothermal response to tidal, tectonic, and volcanic forcing. Examples will be given of plume bending due to currents, determination of entrainment of ambient water, time variation of diffuse flows, and Doppler determination of volume flux. [Work supported by NSF Grants Nos. OCE-0824612 and OCE-0825088.]


161st Meeting: Acoustical Society of America
Session 1aBA

Biomedical Acoustics: Medical Acoustics in Urology

Michael R. Bailey, Cochair
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Robin O. Cleveland, Cochair
Boston Univ., Dept. of Mechanical Engineering, Boston, MA 02215

Contributed Paper

7:45 1aBA1. Real-time tissue change monitoring during the treatment of prostate cancer using Sonablate 500 with high intensity focused ultrasound. Wo-Hsing Chen, Narendra T. Sanghvi, Roy F. Carlson (Focus Surgery, Inc., 3940 Pendleton Way, Indianapolis, IN 46226, wchen@focus-surgery.com), Georg Schatzl, and Michael Marberger (Medical Univ. of Vienna, Waehringer Guertel 18-20, A-1090 Vienna)

Tissue change monitoring (TCM) during HIFU is an essential required feedback during the HIFU treatment. The Sonablate 500 (SB500) HIFU is enhanced with quantitative, real-time TCM software that estimate changes in tissue properties due to HIFU treatment of prostate cancer. TCM generates energy reading based on spectral analysis of the two-dimensional rf backscattered ultrasound signals acquired during HIFU. These energy changes are correlated to tissue temperature. TCM results are overlaid on the real-time ultrasound image in green, yellow, and orange to represent low, medium, and high degree of change in backscattered energy levels. To validate the TCM process five patients with histologically confirmed, organ confined prostate cancer were enrolled for the study. Needles containing three thermocouples were placed transperineally under TRUS guidance in the prostate to monitor temperatures from focal zone, posterior to the focal zone and on the lateral gland where no HIFU was applied. The measured temperatures in the HIFU treatment zones were from 70–114 °C (average 84 °C). The TCM results, estimated tissue temperatures were from 75 to 100 °C for 83% of treatment sites with an average tissue temperature of 91 °C.

Invited Paper

8:00 1aBA2. Design of dual mode high intensity focused ultrasound transducers for prostate therapy. Chapelon Jean-Yves, Bouchoux Guillaume, and Lafon Cyril (INSERM, LabTAU U556, Univ. of Lyon, 151 cours Albert Thomas, 69424 Lyon Cedex 03, France, jeanyves.chapelon@inserm.fr)

In HIFU applications, either MRI or ultrasound is used for treatment guidance and monitoring. When ultrasound imaging is used, a separate imaging transducer can be confocally aligned with the therapy probe itself. Yet, in endocavitary applications, such as transrectal prostate HIFU treatment, there are significant constraints on the size and geometry of the final probe, and the integration of the imaging transducer with the therapy probe is a significant challenge. One solution to this problem is to use the same transducer elements for both imaging and therapy. Dual-mode transducers meet the specifications for therapy and imaging by taking into account the constraints linked to the features of the therapy transducer different from those of the imaging probe. This presentation discusses the results of simulations undertaken to determine an optimal geometry for a dual-mode probe that can be used both for thermal ablation of the prostate as well as for obtaining ultrasound images of sufficient quality for treatment guidance. A new dual-mode design is presented that allows for a smaller overall device than with separate imaging/therapy transducer designs, and Field II simulated images of prostate show that image quality equivalent to or better than those obtained with dedicated imaging probes can be obtained. [This research is supported in France by ANR Program Tecsan 2010.]

Contributed Paper

8:15 1aBA3. High speed imaging of shockwave-induced dynamics of cavitation bubbles and vessel wall. Hong Chen, Camilo Perez, Andrew A. Brayman, and Thomas J. Matula (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab., Univ. of Washington, Seattle, WA)

High speed optical imaging under a microscope (high speed photomicrography) was used to observe shockwave-induced bubble dynamics and bubble-induced vascular dynamics. Ultrasound contrast agent microbubbles, serving as cavitation nuclei, were injected into the vessels of ex vivo rat mesentery. The bubbles were then insonated by focused shock wave pulses with peak positive pressures of 42 MPa and peak negative pressures of 10 MPa, generated by an electromagnetic shockwave source (Storz Duodith). The recorded images were analyzed to obtain bubble radius-time curves, vessel wall displacement, as well as their corresponding velocities. In general, bubble dynamics induces vessel distention (outward displacement of vessel wall) and invagination (displacement of vessel wall into the lumen). Comparisons of shockwave-induced dynamics with HIFU-induced dynamics will also be presented. [Work supported by NIH EB000350 and AR053652.]
1aBA4. Numerical simulation of bubble dynamics in deformable vessels, Vedran Coralic and Tim Colonius (Div. of Eng. and Appl. Sci., California Inst. of Technol., 1200 E. California Blvd., MC 104-44, Pasadena, CA 91125, vcoralic@caltech.edu)

The growth and collapse of cavitation bubbles has been implicated as a potential damage mechanism leading to the rupture of blood vessels in shock wave lithotripsy (SWL) [Bailey et al., in The Fifth International Symposium on Cavitation, Osaka, Japan (2003)]. While this phenomenon has been investigated numerically, the resulting simulations have often assumed some degree of symmetry and have often failed to include a large number of influential physics, such as viscosity, compressibility, surface tension, phase change, and fluid-structure interactions (FSI). We present here our efforts to explore the role that cavitation bubbles play in the rupture of blood vessels in SWL and to improve upon the current state of the numerical approach. We have developed a 3-D, high-order accurate, shock- and interface-capturing, multicomponent flow algorithm that accounts for the effects of surface tension and FSI. The preliminary results for the case of a bubble collapse, induced by a shock wave lithotripter pulse and occurring inside a deformable vessel, are presented. [This research was supported by the NIH (Grant No. 2PO1DK043881.)

Contributed Papers

8:45

1aBA5. Interface capturing simulations of acoustically driven bubble dynamics in and near tissue, Jonathan Freund, Arpit Tiwari (Univ. of Illinois at Urbana-Champaign, Urbana, IL 61854), Ratnesh Shukla (Indian Inst. of Sci.), and Carlos Pantano (Univ. of Illinois at Urbana-Champaign, Urbana, IL 61854)

Tissue injury during therapeutic ultrasound or lithotripsy is thought, in cases, to be due to the action of cavitation bubbles. Assessing this and mitigating it is challenging since bubble dynamics in the complex confinement of tissues or in small blood vessels are challenging to predict. Simulations tools require specialized algorithms to simultaneously represent strong acoustic waves and shocks, topologically complex liquid-vapor phase boundaries, and the complex viscoelastic material dynamics of tissue. We discuss advances in a simulation tool for such situations. A single-mesh Eulerian solver is used to solve the governing equations. Special sharpening terms maintain the liquid-vapor interface in face of the finite numerical dissipation included in the scheme to accurately capture shocks. A recent enhancement to this formulation has significantly improved this interface capturing procedure, which is demonstrated for simulation of the Rayleigh collapse of a bubble. The solver also transports elastic stresses and can thus be used to assess the effects of elastic properties on bubble dynamics. A shock-induced bubble collapse adjacent to a model elastic tissue is used to demonstrate this and draw some conclusions regarding the injury suppressing role that tissue elasticity might play.

9:00

1aBA6. Stone comminution using histotripsy, Timothy L. Hall, Alex P. Duryea, Charles A. Cain, and William W. Roberts (Univ. of Michigan, 2200 Bonisteel Blvd., Ann Arbor, MI 48109, hallt@umich.edu)

This work explores the use of histotripsy to enhance urinary stone comminution ordinarily accomplished by lithotripsy. Histotripsy is a method of tissue ablation or erosion using high-energy pulsed therapeutic ultrasound to induce and control a cavitation bubble cloud. We have shown previously that histotripsy applied to model urinary stones causes surface erosion producing fine debris, which can be more readily eliminated. In this work, we show that optimal acoustic parameters can yield an effective comminution rate (96 mg/min) similar to a standard lithotripter (111 mg/min). As histotripsy is a surface erosion effect within the cloud of cavitation bubbles and lithotripsy has been shown to be most efficient at initial coarse fragmentation of stones, we propose a combined approach where the lithotripter coarsely fragments the stone, while histotripsy is used to erode these fragments with their greatly increased surface area.

Invited Paper

9:15

1aBA7. Holmium: YAG lithotripsy varies with power settings, Joel M. H. Teichman, Jason Sea, Lee Jonat, Ben Chew (Dept. of Urological Sci., Univ. of British Columbia, Vancouver, Canada), Jinze Qiu, and Thomas Milner (Biomedical Optics Program, Univ. of Texas, Austin, TX)

The holmium:YAG laser fragments stones by photothermal mechanism. Increased pulse energy (PE) produces larger ablation craters, implying faster lithotripsy. However, increased PE increases retropulsion, implying slower lithotripsy. Optimal power settings were studied. Uniform stone phantoms were ablated in water (500 J total energy). Six power settings were tested: ranging from 0.2 to 2.0 at 10–40 Hz. Two conditions were tested: no stabilization vs stabilization devices placed behind the stone. Total fragmentation (TF) and fragment sizes were quantified. In the no stabilization cohorts, retropulsion was measured. Pressure transients were measured by needle hydrophone. Stone crater volumes were quantified by optical computed tomography. With or without stabilization, TF increased as PE increased, p<0.0001; and fragment size increased as PE increased, p<0.05. Without stabilization, retropulsion increased as PE increased, p<0.0001. TF was greater with vs without stabilization, p<0.01. Pressure transients were <30 bars even at 2.0 J. Crater volumes increased as PE increased, p<0.01 but remained symmetric. Increased PE produces more lithotripsy but also larger fragments. Even at high PE (2.0 J) Ho:YAG lithotripsy is photothermal. Low PE produces small fragments but less lithotripsy. Modest PE (0.2–0.5 J) at high-repetition rate produces more fragmentation, small fragments, and less retropulsion. [Work supported by Percsys and Boston Scientific.]
Residual fragments remain in over 50% of treatments for lower pole kidney stones. A second-generation device based on a diagnostic ultrasound system and scanhead has been developed with a unique algorithm for stone comminution and the capability to focus ultrasound to expel residual fragments. Focused ultrasound was applied to a bead on string in a water tank as well as to human stones (<5 mm) implanted in the lower pole of a live porcine model via retrograde ureteroscopy. Histological samples were collected and scored in a blinded fashion for therapeutic exposures and for super-therapeutic levels. The in-vitro bead was visually observed to move under focused ultrasound. Even with progressive manual displacement of the bead, the system continuously tracked and caused bead movement in real time. In the live porcine model, stones were expelled from the lower pole to the ureteropelvic junction in seconds to minutes using pulses at a duty factor of 0.02 and 8 W total acoustic power. Injury was observed no more frequently than in controls. Occurrence of injury rose slightly above control at a duty factor of 0.02 and 80 W and at a duty factor of 1 and 8 W. [Work supported by NIH DK48331, NIH DK086371, and NSBRI through NASA NCC 9-58.]

9:45—10:00 Break

10:00


The effects of respiratory motion on stone comminution produced by an electromagnetic (EM) shock wave lithotripter were evaluated in vitro. Individual spherical BegoStone phantoms (D = 10 mm) were placed in a flat-base tube holder and treated at various radial distances in the lithotripter focal plane. To assess the effects of respiratory motion on stone comminution, the holder was set into translational motions in another series of experiments with various excursion distances (1.5–3.0 cm), breath rates (12–24 bpm), and drift factors for motion randomization. Stone comminution tests were performed using either a newly designed acoustic lens with a wide focal width and a low peak pressure or the original lens under equivalent acoustic energies. The results shows that the new lens produces statistically higher stone comminution (p < 0.01) than the original lens. Moreover, stone comminution at various radial distances will be compared, together with cavitation potential calculated by the Gilmore model based on the pressure waveforms measured by an FOPH.

10:15

1aBA10. Clinical assessment of shockwave lithotripsy accuracy. Anup Shah, Jonathan D. Harper, Jonathan L. Wright, Mathew D. Sorensen (Dept. of Urology, Univ. of Washington School of Medicine, 1959 NE Pacific St., Seattle, WA 98195), Marla Pauw, and Michael R. Bailey (Univ. of Washington, Seattle, WA 98105)

Kidney stone movement primarily due to patient respiration compromises shock wave lithotripsy (SWL) targeting and efficacy. The objective of this study is to describe the use of B-mode ultrasound to evaluate the accuracy of targeting during SWL. Patients undergoing electrohydraulic SWL were enrolled into this institutionally approved research study. A commercial diagnostic ultrasound imaging system, either Philips HDI 5000 or IU-22, was used to intermittently visualize and detect any shockwave-induced motion of the stone during 1–3 min periods. Four patients (mean age 52.7) underwent treatment of seven renal stones with mean individual stone size of 10.41 ± 4.5 mm. A mean of 2937 shocks (range 2750–3000) were delivered at a rate of 1–2 Hz and charging voltage of 14–26 kV. Stone oscillation or jumping at the exact time of individual shock delivery was visualized with ultrasound: no stones completely failed to move. Accurate alignment, as interpreted by positive stone motion, occurred in a mean of 50 ± 20.4% of shockwaves. Ultrasound imaging represents a method of real-time assessment of accuracy in SWL and may provide the basis for devices to control targeting so that shockwaves are only delivered when the stone is in focus. [Work supported by NIH DK43881 and DK086371.]

10:30


Vibro-acoustography (VA) is an ultrasound interrogation and imaging technique with a variety of applications. Here it was used to identify optimal parameters for detecting and imaging kidney stones in phantoms. The parameters varied included the difference frequency and the position in time of the analysis window used for image construction. Experiments in a water tank were conducted using a focused PVDF membrane hydrophone (receiver) placed in a central opening of an annular, dual element transducer (source), itself mounted on a translation stage. Our source consisted of 90-ns pulses with a center frequency of 2.0 MHz and difference frequencies between 50 and 350 kHz, applied both on and off stone. Variations in the amplitude of the measured ultrasound backscatter and acoustic emissions as a function of difference frequency, between signals from stone and phantom, guided the choice of imaging parameters. The results were detailed images of renal stones measuring 10 dB above the background tissue. These findings suggest that spectral information from the scattering and reverberation of VA induced ultrasound can be used to guide the interrogation and imaging of kidney stones. [Work supported by NIH DK43881, NIH DK086371, and NSBRI through NASA NCC 9-58.]

10:45


Twinkling artifact on color Doppler ultrasound is the color labeling of hard objects, such as kidney stones, in the image. The origin of the artifact is unknown, but clinical studies have shown that twinkling artifact can improve the sensitivity of detection of stones by ultrasound. Although Doppler detection normally correlates changes in phase with moving blood, here the effect of amplitude on the artifact is investigated. Radio-frequency and in-phase and quadrature (IQ) data were recorded by pulse-echo ensembles using a software-programmable ultrasound system. Various hard targets in water and in tissue were insomnified with a linear probe, and rectilinear pixel-based imaging was used to minimize beam-forming complexity. In addition, synthesized radio-frequency signals were sent directly into the ultrasound system to separate acoustic and signal processing effects. Artifact was observed both in onscreen and post-processed images, and as high statistical variance within the ensemble IQ data. Results showed that twinkling artifact could be obtained from most solid objects by changing the Doppler gain, yet signal amplitude did not have to be sufficiently high to saturate the receive circuits. In addition, low signal but high time gain compensation created the largest variance. [Work supported by NIH DK43881, DK086371, and NSBRI through NASA NCC 9-58.]

11:00

1aBA13. Autoregressive ultrasound imaging method to enhance kidney stone twinkling and suppress blood flow. John C. Kucewicz, Bryan W. Cunitz, Barbirina Dunnire, Michael R. Bailey, and Lawrence A. Crum (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105)

Twinkling is a widely reported ultrasound artifact whereby kidney stones and other similar calcified, strongly reflective objects appear as turbulent, flowing blood in color and power Doppler. The twinkling artifact has
been shown to improve kidney stone detection over B-mode imaging alone, but its use has several limitations. Principally, twinkling can be confused with blood flow, potentially leading to an incorrect diagnosis. Here a new method is reported for explicitly suppressing the display of color from blood flow to enhance and/or isolate the twinkle signal. The method applies an autoregressive model to standard Doppler pulses in order to differentiate tissue, blood flow, and twinkling. The algorithm was implemented on a software-based, open architecture ultrasound system and tested by a sonographer on phantoms and on stones implanted in a live porcine kidney. Stones of 3–10 mm were detected reproducibly while suppressing blood flow in the image. In conclusion, a new algorithm designed to specifically detect stones has been tested and has potential clinical utility especially as efforts are made to reduce radiation exposure on diagnosis and monitoring. [This work was supported by the National Institutes of Health (NIH Grant No. DK43881) and the National Space Biomedical Research Institute through Grant No. NASA NCC 9-58.]

11:15
1aBA14. Modeling of radiation force imparted to an elastic sphere from an ultrasound beam of arbitrary structure. Oleg A. Sapozhnikov (Dept. of Acoust., Phys. Faculty, Moscow State Univ., Moscow 119991, Russia, olegs@apl.washington.edu) and Michael R. Bailey (Univ. of Washington, Seattle, WA 98105)

The radiation force created by an acoustic wave incident on an elastic sphere is studied theoretically. Elastic spheres with properties similar to kidney stones are considered. An acoustic wave is taken in the form of high-intensity focused ultrasound beam of megahertz frequency, which is typical for transducers proposed for stone therapy. To study radiation force of beams with arbitrary structure, the source excitation is modeled as a sum of plane waves of various inclinations (angular spectrum representation). First, a plane acoustic wave scattering at the stone is modeled using the known solution in the form of a spherical harmonics series. Then superposition of such solutions is used to calculate the scattered field from a focused beam. Once the acoustic field is known, the radiation stress tensor is calculated on a surface surrounding the sphere. Finally, the net force acting on the sphere is calculated by integrating the radiation stress along the surface. Numerical calculations show that the direction and value of the radiation force acting on the sphere depend on the pressure field structure in the region where the scatterer is positioned. [Work supported by NIH DK43881 and DK086371, RFBR, and NSBRI through NASA NCC 9-58.]

11:30
1aBA15. Real-time tracking of renal calculi displaced by the radiation force of focused ultrasound. Paul R. Illian, Jr., Bryan W. Cunitiz, John C. Kuczewicz, Michael R. Bailey, and Peter J. Czaczoski (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab.-Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105-6698, rillian@apl.washington.edu)

An area of active research involves using the radiation force of ultrasound to expel small kidney stones or fragments from the kidney. The goal of this work is real-time motion tracking for visual feedback to the user and automated adaptive pushing as the stone moves. Algorithms have been designed to track stone movement during patient respiration but the challenge here is to track the stone motion relative to tissue. A new algorithm was written in MATLAB and implemented on an open-architecture, software-based ultrasound system. The algorithm was first trained then implemented in real-time on B-mode IQ data recorded from phantom experiments and animal studies. The tracking algorithm uses an ensemble of image processing techniques (2-D cross-correlation, phase correlation, and feature-edge detection) to overlay color on the stone in the real-time images and to assign a color to indicate the confidence in the identification of the stone. Camera images as well as ultrasound images showed that the system was able to locate a moving stone, re-target, and apply a new focused push pulse at that location. [Work supported by NIH DK43881, NIH DK086371, and NSBRI through NASA NCC 9-58.]

11:45

A 3-D time-domain finite-difference solution to the linear elastic equations was applied to investigate the stress and velocity fields of kidney stones subject to lithotripsy shock waves. The kidney stone models were scanned from micro-computed tomography and had diameters from 2 to 5 mm. It was found for these shapes that shear waves induced by interference of the shock wave with stone boundaries dominated the high stress in the stones. The traditional belief of stone comminution mechanism by spall mechanism does not play important role due to the irregular proximal and distal stone surfaces. It was found for natural stones that stone orientation had an impact on the generation of high stress with a smooth convex surface producing the highest internal stresses. The results indicate that lithotritors with a focal width larger than a stone should be able to break a stone more efficiently since the large focal width shock waves result in stronger interaction with stone circumferences and produce larger shear waves.

12:00
1aBA17. Location of coupling defects influences stone breakage in shock wave lithotripsy. Guangyan Li, James A. McAteer, and James C. Williams, Jr. (Dept. of Anatomy and Cell Biology, Indiana Univ. School of Medicine, 635 Barnhill Dr., Indianapolis, IN 46202-5120)

SWL is the most common treatment for kidney stones. However, compared to uroscopy and nephrostolithotomy, SWL is least effective—failing in ~50% of cases. Since stone breakage is highly effective under controlled conditions, acoustic coupling between the lithotripter and patient may be the weak link. Previous in vitro studies determined that air-pockets created in routine coupling reduce SW-amplitude by ~20% and defects occupying only 2% of coupling area reduced breakage 20%–40%. As a step toward determining if the position of defects influences SW delivery to the target we used styrofoam to selectively block portions of the coupling interface between a DoLi-50 and the test tank. Stone breakage was ~three times greater when the entire 13 cm diameter coupling interface was unblocked than when all but the center 6 cm was blocked, consistent with the reduction in surface area. However, the transition was abrupt, with ~70% of the loss in efficacy occurring upon reduction in the aperture from 7 to 6 cm. Reducing the aperture had a greater effect on P- than P+ (P+/P- no aperture ~41/4.3 MPa; 7 cm ~42/3.5 MPa; 6 cm ~37/2.5 MPa). These initial findings begin to identify a region of the overall coupling interface where defects are likely to be problematic. [Work supported by Grant No. NIH-DK43881.]
Session 1aNS

Noise: Indoor Psychoacoustic Response to Outdoor Noise Sources

Alexandra Loubeau, Cochair
NASA Langley Research Center, Hampton, VA 23681

Edward T. Nykasa, Cochair
ERDC-CERL, 2902 Newmark Dr., Champaign, IL 61822

Erica E. Ryherd, Cochair
Georgia Inst. of Technology, Mechanical Engineering, 771 Ferst Dr., Atlanta, GA 30332-0405

Jonathan Rathsam, Cochair
NASA Langley Research Center, Structural Acoustics Branch, Hampton, VA 23681

Chair’s Introduction—8:00

Invited Papers

8:05

1aNS1. Indoor human response to blast noise measured in situ. S. Hales Swift, Dan Valente, Edward T. Nykaza (U.S. Army Corps of Engineers, ERDC-CERL, P.O. Box 9005, Champaign, IL 61826, stephen.h.swift@usace.army.mil), and Kathleen Hodgdon (The Penn State Univ., State College, PA 16804)

As a result of suburban sprawl, the number of people living near military installations is drastically increasing. Coupled with an escalation of military activities and preparedness, the potential for noise generated by an installation to impact the surrounding communities has grown, especially for large amplitude impulsive events such as those generated during artillery training exercises. To assess the effect of blast noise on individuals living near installations, a large scale in situ study has been performed. The homes of study participants were instrumented and outdoor/indoor blast signature pairs of routine installation activities were captured over the course of 1 year. Participants filled out short questionnaires whenever they heard blast noise events. Measurements of single events at subjects’ homes along with their responses present unique data with which to investigate the human response to blast noise on an event-by-event basis. In this presentation, the characteristics of the noise typically experienced by residents in their own homes will be examined and used to create dose-response relationships. Comparison will be made of dose-response curves based on annoyance, interference, and loudness as a function of level-based metrics, and as a function of a variety of psychoacoustic metrics. [Work supported by the Strategic Environmental Research and Development Program.]

8:25

1aNS2. A theory-based model of the prevalence of transportation noise annoyance. Sanford Fidell (Fidell Assoc., Inc., 23139 Erwin St., Woodland Hills, CA, Paul Schomer (Schomer and Assoc., Inc., Champaign, IL 61821, schomer@schomerandassociates.com), and Vincent Mestre (Landrum and Brown, Laguna Niguel, CA 92677)

Dosage-response relationships between cumulative noise exposure and the prevalence of annoyance in communities are generally developed by statistical curve fitting methods. Generic methods of this sort, such as regression, can characterize the central tendency of findings of social surveys, but provide no explanation for the great variability of these data. Further, confidence intervals around a regression curve do not yield prediction intervals appropriate for use in environmental disclosure documents. An alternative approach under consideration by ISO Working Group 45 for inclusion in an updated draft international standard is based on the hypothesis that the rate of growth of the prevalence of annoyance closely resembles that of the rate of growth of effective that is, duration-corrected loudness. A comprehensive database of the findings of 43 aircraft noise annoyance studies provides strong empirical support for the hypothesis.

8:45

1aNS3. A simple method for comparing social survey findings on the annoyance of transportation noise. Vincent Mestre (Landrum & Brown, 27812 El Lazo Rd., Laguna Niguel, CA, 92677, vmestre@landrum-brown.com), Paul Schomer (Schomer and Assoc., Champaign, IL 61821), and Sanford Fidell (Fidell Assoc., Woodland Hills, CA 91367)

Findings of social surveys about the annoyance of transportation noise vary greatly from one community to the next. Popular speculations about the sources of this variability have included situational differences in exposure, methodological differences in interviewing, and errors of measurement. The model described in the prior presentation provides a simple method for summarizing the community-specific variability in a single-valued metric, the community tolerance Index (CTI). Findings of several CTI-based analyzes are discussed in this presentation, along with some of their policy and regulatory implications.
In a subjective test assessing human annoyance to low-amplitude sonic booms, different subjective testing methods were utilized. These included a hybrid categorical line scaling method as well as magnitude estimation with two different reference sounds. The test methods will be discussed, as well as their advantages and disadvantages. Other topics of discussion will include experimental design, data analysis, as well as subject participant preference. [Work sponsored by the NSF and the FAA through the PARTNER Center of Excellence.]

A facility has been constructed at NASA Langley Research Center to simulate the soundscape inside residential houses that are ensoundified by environmental noise from aircraft. The purpose of this facility, the interior effect room, is to examine parameters that affect psychoacoustic response in a controllable indoor listening environment. The single room facility, built using typical residential construction methods and materials, is surrounded on two sides by arrays of loudspeakers. These exterior arrays are used to simulate aircraft noise sources that transmit into a room of a typical house. The exterior sound reproduction system, which consists of 52 subwoofers and 52 mid-ranges in close proximity to the walls of the room, has been designed to enable study of sonic booms transmitted into residential structures and has a usable bandwidth of 3 Hz–6 kHz. In addition to these exterior arrays, satellite speakers placed inside the room are used to simulate rattle and other audible contact-induced noise that can result from low frequency excitation of a residential house. The layout of the facility, operational characteristics, acoustical characteristics, and equalization approaches are summarized. Current research efforts utilizing the facility are described in two companion papers.

A sonic boom simulator at NASA Langley Research Center has been constructed for research on human response to low-amplitude sonic booms heard indoors. Research in this facility will ultimately lead to a psychoacoustic model for single indoor booms that will be validated by future community studies. The first subjective test was designed to explore indoor human response to variations in sonic boom rise time and amplitude. Another goal was to identify variability across listener locations within the facility. Finally, the test also served to evaluate the facility as a laboratory research tool for studying indoor human response to sonic booms. Subjects listened to test sounds and were asked to judge the annoyance relative to a reference boom. Measurements of test signals were conducted for objective analysis and correlation with subjective responses. Results confirm the functionality of the facility and effectiveness of the test methods and indicate that calculated loudness does not fully describe the indoor annoyance.

A sonic boom simulator at NASA Langley Research Center has been constructed to research the human response to low-amplitude sonic booms heard indoors. The facility’s initial goal is the development of a psychoacoustic model for individual sonic booms to be validated by future community studies. The current test assesses the suitability of existing loudness metrics for predicting indoor human annoyance to sonic-boom waveforms. The test signals consist of synthesized and recorded sonic-boom waveforms chosen to systematically vary the low-frequency content. Some waveforms are presented with and without high-pass filtering to examine the effect of low-frequency content on annoyance. Equally annoying presentation levels are determined among the test signals by paired comparison with a reference sonic-boom waveform. A second reference waveform is also used for some signals to examine if results change with the reference sound. Loudness metrics are then calculated for each measured test signal at the subjective-equality level. Loudness metrics are thus evaluated based on their ability to predict annoyance for a wide range of sonic-boom waveforms.

Street canyons are common in modern cities. It is well known that the multiple sound reflections within the canyons tend to increase the noise levels inside the canyons. A scaled model experiment was conducted in the present investigation to study the effect of the inclination of building facade on the sound field. A line source consisted of 100 2-in. aperture loudspeakers was used to simulate the road traffic source. The whole experiment was carried out inside an anechoic chamber. The canyon was 4 m long, 2 m high, and 1 m wide (1:4 scale down ratio). The case of a single facade was used acted as the reference. The reverberation inside the model canyon was strong when the two model facades are vertical (inclination 90 deg) and parallel to each other. However, it was found that such reverberation deteriorated very rapidly as the inclination of one of the model facade was reduced to 80 deg. The sound strength inside the model canyon was also reduced. The sound levels at the top region of the canyon decreased more rapidly. It was also found that the effect of the opposite facade was basically unchanged once its inclination was less than 60 deg.
11:00
1aNS9. A noise mapping study for heterogeneous road traffic conditions considering horn sounds. Kalaiselvi Ramasamy and Ramachandraiah Alur (Dept. of Civil Eng., Indian Inst. of Technol.-Madras, kalaiarchi@gmail.com)

In recent years noise mapping has become an increasingly useful tool for environmental noise assessment. Noise mapping is the process of determining and visualizing noise impact on the environment. The current noise mapping softwares are typically designed for the express and freeways of other countries where the roads are widely open with the homogeneous traffic conditions and speeds of vehicles touching 100 km/h. This situation is not suitable for Indian conditions where heterogeneity of traffic and honking of vehicles are the characteristics in an urban environment. A pilot study in typical areas of a metropolitan city (Chennai city) using soundplan software shows a difference of up to 7 to 10 dB(A) in Lden values between obtained and measured noise levels. A multiple regression model has been developed taking into account the horn aspects and heterogeneity. The statistical parameters such as L10, L50, L90, and Leq are measured along with the vehicle speed. The vehicle count and number of horn events are also observed during the field measurements with the video camera. The developed multiple regression models can be used as a plug-in in any open source GIS softwares such as QGIS, GRASS, etc., for noise mapping purposes. With this background this paper explains a methodology to build 3-D noise models for urban areas to analyze and visualize the 3-D distribution.

11:15
1aNS10. A new metric for the objective determination of steady state noise source measurement validity as affected by extraneous noise. Noel W. Hart, Robert D. Bruce (CSTI acoustics, 16155 Park Row, Ste. 150, Houston, TX 77084-5100, noel@csiacoustics.com), Ralph R. Galetti (Boeing), and Mark Rubino (Industrial Noise Control, North Aurora, IL 60542)

The measured difference between the maximum sound level (Lmax) and the equivalent sound level (Leq) of a steady state source can be used to objectively demonstrate inconsistencies in measurement. This method has particular applications to field measurements made in an uncontrolled environment where extraneous, time-variant noise from wind, animals, people, or machinery often interferes. The method is also straightforward to implement with modern sound level meters, as the necessary data are easily recorded.

11:30
1aNS11. A study of noise mitigation techniques for explosive training scenarios. Michelle E. Swearingen (US Army ERDC-CERL, P.O. Box 9005, Champaign, IL 61826, michelle.e.swearingen@usace.army.mil), Donald G. Albert (US Army ERDC-CRREL, Hanover, NH 03755), and Dan Valente (US Army ERDC-CERL, Champaign, IL 61826)

Utilizing explosives to destroy questionable munitions is a standard procedure in the military. It is critical to have teams trained to perform these activities safely. Often the training involves practice in setting up and detonating relatively small charges of explosives, but these activities can cause annoyance in surrounding civilian populations. A study was performed at one military installation to determine best practices for managing the noise generated by these activities. Three methods were investigated: burying charges with sandbags, covering charges with a rubber blast mat, and spraying water over the charges during detonation. Acoustic and seismic measurements were performed at several distances between 4 and 2500 m in two directions to investigate the relative effectiveness of each method. The study found that covering the charges with sandbags provided a reduction in noise levels of as much as 15 dB in the far field with minimal impact on the training. Use of sandbags was therefore superior to the other methods investigated in maximum reduction, ease of use, and cost. This presentation will provide an overview of the study results.

1aNS12. Directivity and variability characterization of a propane cannon. Tom W. Noble and Dan P. Valente (Construction Eng. Res. Lab., US Army Engineer Res. and Development Ctr., P.O. Box 9005, Champaign, IL 61826, thomas.w.noble@usace.army.mil)

When studying the influence of an environment on blast noise propagation, it is often unrealistic to use typical blast noise sources such as plastic explosives or artillery fire. A propane cannon, designed as a bird scare-away device, is a reasonable surrogate source which produces a loud impulsive sound rich in low frequency energy. In order to confirm the cannon’s utility as a blast surrogate, we examined the directivity of the propane cannon, the variability in received level as a function of distance, and the variability in one-third octave band SEL as a function of distance and direction. The results indicated that the propane cannon has low shot-to-shot variability and is nearly omni-directional within 60 deg of the forward facing direction.

MONDAY MORNING, 23 MAY 2011

WILLOW A, 8:45 TO 11:30 A.M.

Session 1aPA

Physical Acoustics: Interaction of Sound with Sound

Joel Mobley, Chair

Univ. of Mississippi, National Ctr. for Physical Acoustics, 1 Coliseum Dr., University, MS 38677

Contributed Papers

8:45
1aPA1. The acoustic levitation and simultaneous contactless transportation of matter in the third resonance mode (H3-mode) of a line-focused system. Daniele Foresti, Majid Nabavi, and Dimos Poulilakos (Dept. of Mech. and Process Eng., Inst. of Energy Technol., Lab. of Thermodynamics in Emerging Technologies, ETH Zurich, CH-8092, Zurich, Switzerland, dforesti@ethz.ch)

We investigate theoretically herein higher modes of resonance for transportation of matter (particles or droplets) in line-focused acoustic levitation. Contactless transportation was achieved by varying the height between the radiating plate and the reflector. Transportation and levitation of volatile liquids, in particular, involves two limits of the acoustic forces. The lower limit corresponds to the minimum force required to levitate a droplet, i.e., to overcome the gravitational force. The higher limit corresponds to the maximum acoustic pressure before atomization of the droplet occurs. By increasing the size of the droplet, the lower limit increases and the higher limit decreases. Therefore, in order to have large droplets levitated in the device, a relatively flat radiation pressure over the translation distance is needed. In this study, using a finite element model, the Gor’kov potential was calculated for different heights between the reflector and the radiating plate. It was found that the best levitation configuration is the H3-mode, which represents a good compromise between high levitation power and smooth pattern transition. The H3-mode also allows three translation lines in parallel.
We investigate manipulating 5 nm diameter carbon nanoparticles in user-defined patterns on substrates using the acoustic radiation force associated with a bulk acoustic standing wave. Both concentric and rectangular patterns are studied and the experimental results are compared with theoretical predictions. The effect of drag force acting on a nanoparticle is evaluated and limits for particle speed and particle size that can be moved by acoustic radiation force are derived. The near- and far-field acoustic radiation force are determined. The importance of Brownian motion when manipulating nanoparticles is discussed. We found good agreement between our experimental results and existing theoretical models and demonstrate that nano-sized particles can be manipulated effectively by means of bulk wave acoustic radiation force.

9:15
1aPA3. Metamaterial synthesis using the acoustic radiation force and characterization with x-ray microcomputed tomography. F.G. Mitri and D.N. Sinha (Los Alamos Natl. Lab., Los Alamos, NM 87545)

In this research, we demonstrate the manipulation of clusters of ~5 nm diameter carbon nanoparticles using the acoustic radiation force at 1 and 2 MHz. 1-D and 2-D patterns are synthesized and experimental results show the successful synthesis of a nano-composite 3D metamaterial structure. Furthermore, x-ray micro-computed tomography (CT) is used as a tool to characterize each metamaterial. Though not investigated here, the aim is to create finite element models based on the x-ray micro-CTs to study the multiple functionalities of the acoustically-assembled metamaterials. [Work supported by LANL-LDRD X9N9.]

9:30

The arbitrary acoustic scattering of a high-order Bessel vortex beam by a sphere is investigated. It is shown here that shifting the sphere off of the axis of wave propagation induces a dependence of the scattering on the azimuthal angle. Theoretical expressions for the incident and scattered fields from a rigid immovable sphere are derived. The near- and far-field acoustic scattering fields are expressed using partial wave series involving the nth-order spherical harmonics, the scattering coefficients of the sphere, the half-conical angle of the wave number components of the beam, its order, and the beam-shape coefficients. The scattering coefficients of the sphere and the three-dimensional (3-D) scattering directivity plots in the near- and far-field regions are evaluated using a numerical integration procedure. The calculations indicate that the scattering directivity patterns near the sphere and in the far-field are strongly dependent on the position of the sphere facing the incident high-order Bessel vortex beam. In addition to providing physical insight into the off-axis scattering of acoustic Bessel vortex beams, this investigation would potentially assist in the development of the transverse acoustic radiation force and could provide a useful test of finite element codes for the evaluation of the scattering.

9:45
1aPA5. Radiation torque on solid spheres and drops centered on an acoustic helicoidal Bessel beam. Likan Zhang and Philip L. Marston (Dept. of Phys. and Astronomy, Washington State Univ., Pullman, WA 99164-2814)

Somewhat analogous to circularly polarized electromagnetic waves carrying axial angular momentum and generating a corresponding torque, a helicoidal acoustic (vortex) beam also carries axial angular momentum and absorption of such a beam should also produce an axial radiation torque [B. T. Hefner and P. L. Marston, J. Acoust. Soc. Am. 106, 3313–3316 (1999)]. Here the acoustic radiation torque on solid spheres and spherical liquid drops centered on acoustic helicoidal Bessel beams is analyzed. Using a relation between the scattering and the partial wave coefficients for a sphere in a helicoidal Bessel beam, the torque is predicted to be proportional to the ratio of the absorbed power to the acoustic frequency. Calculations suggest that beams with a low topological charge tend to be more efficient for generating torques on solid spheres for all frequencies and on liquid drops in the low frequency regime. Balanced by drag torque, a steady rotation is generated. Calculations of the steady-state angular velocity suggest that the rotation in this type of traveling wave beam could be significant using appropriate frequencies. [Work supported in part by NASA.]

10:00—10:15 Break

10:15
1aPA6. Modal exchange between an elastic mode and an acoustic mode of a fluid-filled spherical shell resonator at an avoided crossing. Joel B. Lonzaga, Joel Mobley (Nat. Ctr. for Physical Acoustics, The Univ. of Mississippi, 1 Coliseum Dr., University, MS 38677, jlonzag@olemiss.edu), and D. Felipe Gaitan (Impulse Devices, Inc., Grass Valley, CA 95945)

High pressure liquid-filled spherical resonators are promising devices for increasing the energy density of a cavitating liquid. Since increasing the static pressure in the liquid also increases the sound speed, it is important to investigate the dependence of the resonances on the sound speed. In this paper, we report on an avoided crossing or repulsion between an elastic mode and an acoustic mode of a fluid-filled spherical shell resonator as the sound speed is varied. Such an avoided crossing is attributed to the fluid-shell interaction and leads to a modal exchange between the acoustic and the elastic modes. Furthermore, the eigenfrequency curves of both the acoustic and elastic modes are discontinuous in the frequency-sound speed phase space in the neighborhood of the avoided crossing. Additional analysis reveals that the elastic mode also forms an avoided crossing with other acoustic mode orders and that this result can be extended to other pairs of modes with different symmetry. The acoustic pressure field in the fluid and the stress field in the shell are shown to take extreme values at this region. [Work supported and funded by Impulse Devices, Inc. ACP7 Contract No. W9113M-07-C-0178.]

10:30
1aPA7. Quasispherical acoustic resonators: The shell-gas interaction. James B. Mehl (P.O. Box 307, Orcas, WA 98280, jmehl@rockisland.com) and Michael R. Moldover (Natl. Inst. of Standards and Technol., Githersburg, MD 20899-8360)

Spherical acoustic cavity resonators are useful tools for high-precision measurements of the speed of sound in gases. Conventionally, the gas-acoustic resonances are corrected for coupling to the shell using analytic expressions valid for isotropic, unsupported, shells of uniform thickness. Practical resonators have nearly spherical inner surfaces but exterior surfaces with non-spherical features and support structures. Finite-element methods have been used to calculate the response of realistic resonator shells that are coupled to support structures. Improved corrections of the gas-mode eigenfrequencies can be obtained in a form that is similar to the usual analytic expression, except that the shell response function must be calculated numerically. It is also shown that the coupling of gas modes through the shell is normally a weak effect proportional to the square of the static pressure and is totally negligible except in very unusual circumstances. The evolution of gas-shell coupling is followed when the speed of sound in the gas is varied so that a radial gas mode eigenfrequency $f_g$ approaches a shell mode eigenfrequency $f_s$. The gas mode becomes unobservable as $f_s$ nears $f_g$ due to an avoided-crossing phenomenon similar to simple coupled oscillators.

10:45
1aPA8. Measurement of the penetration depth for an ultrasonic diffraction grating in contact with a slurry. Margaret S. Greenwood (Appl. Phys., Pacific Northwest Natl. Lab., P.O. Box 999, Richland, WA 99352)

The initial measurements of the penetration depth were presented at the Portland ASA meeting [Proceedings of Meetings in Acoustics, Vol. 6 P045001]. This report describes additional measurements using several gratings with transducer frequencies of 1, 3.5, and 7 MHz. The grating unit (with the grating surface in the horizontal plane) is placed atop a vessel containing a slurry of polystyrene spheres in water. The data acquisition system
was set up to take up to 20 measurements of the FFT amplitude per second. When the magnetic stirrer is turned off, the increasing FFT amplitude shows the transition from a slurry to water as the particles fall to the bottom of the vessel. As the slurry descends it forms a layer which is videotaped to yield the descent velocity. The penetration depth is obtained from the transition time and the descent velocity. The penetration depth varies with frequency and is less than about 4 mm. These measurements were not taken at the critical frequency for which the penetration depth is expected to be very large.

**11:00**

**1aPA9. Attenuation mechanism for slurry in contact with ultrasonic diffraction grating.** Margaret S. Greenwood (Appl. Phys., Pacific Northwest Natl. Lab., P.O. Box 999, Richland, WA 99352)

Attenuation measurements for ultrasonic penetrating a slurry in contact with an ultrasonic diffraction grating were presented at the Paris ASA meeting (Proceedings of Meetings on Acoustics, 4, 045017). Also, the viscous-inertial model was suggested as the mechanism, in which the attenuation is due to the dissipation in the thin boundary layer of liquid surrounding the particle. Further, it was proposed that, in order for the dissipation to occur, the circumference of the particle must be equal to or greater than 1 ultrasonic wavelength. Measurements will be reported for the following slurries in contact with a grating using a 1 MHz transducer: (1) 275-μm diameter polystyrene spheres, (2) 671-μm polystyrene spheres, and (3) 1588-μm acrylic spheres using a diffraction grating with a 1 MHz transducer. Attenuation was observed for slurry cases 2 and 3. However, no attenuation could be observed for the slurry of 275-μm diameter polystyrene spheres in water even at a volume fraction of 0.4; the signal was the same as that for water.

Since the circumference for the 275-μm diameter particles was less than wavelength in water, these data provide confirmation of the proposed mechanism. Also, such measurements provide a method of exploring the viscous-inertial model.

**11:15**


An extended version of the previously developed volumetric integral equation solver is presented, which is based on solving a coupled system of volumetric and surface equations describing, respectively, the inhomogeneous elastic object and the embedded piecewise homogeneous inclusions. The considered method is capable of accurate large-scale numerical simulations involving anatomically realistic models of a human head characterized by complex geometrical details and large density contrasts. The main application of the approach consists in an accurate analysis of interaction of acoustic waves with human hearing system; in this case, precise modeling of the highly intricate structure of middle and inner ears is essential for reliable numerical simulations capable of discerning between different mechanisms of energy transfer to the human ear. The method allows us to treat the inner ear region as a piecewise homogeneous inclusion described by surface integral equations with displacement and traction fields as unknowns. The results of representative calculations will be presented, which were carried out with a realistic detailed geometry model of the middle and inner ear including essential geometry elements needed in simulating energy transfer processes. [This work is supported by the AFOSR.]

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**MONDAY MORNING, 23 MAY 2011**

**GRAND BALLROOM C, 8:15 A.M. TO 12:00 NOON**

**Session 1aPP**

**Psychological and Physiological Acoustics: Cochlear Models and Psychoacoustics of Speech**

Douglas S. Brungart, Chair
Walter Reed Army Medical Center, Washington, DC 20307

**Contributed Papers**

**8:15**

**1aPP1. Four-chamber cochlea box model: Establishing acoustic comfort, illustrating injury and toward therapy.** Luis Ma. T. Bo-ot, Henry V. Lee, Jr., Henry J. Ramos (Natl. Inst. of Phys., Univ. of the Philippines, Diliman, Quezon City 1101, Philippines), and Che-Ming Chiang (Natl. Cheng Kung Univ., Tainan 701, Taiwan)

The unrolled cochlea is modeled using the finite-element software ANSYS with four inner chambers representing the Scala Vestibuli contiguous with the Scala Tympani thru a rounded helicotrema, the Scala Media, the inner and the outer hair cells. The tectorial membrane is represented as a plate in contact with the hair cells. An improvement from previously presented results is the inclusion of a tapered helicotrema. Various geometries are compared, i.e. with straight sides and with tapered sides, and differences in the frequency response of the models are seen. Applying real values for material properties and the human hearing range and using characteristic frequency at certain nodes inside the Scala Media, the tapered model is calibrated to establish the reference comfort sound level. Hearing injury is regarded by subjecting nodes to increased sound pressure levels until the frequency response disappears. This is done at the same time monitoring the change in electrical potential in the inner and outer hair cell regions. The potential change between the normal and the injured conditions is inputted to the Gibbs energy equation for the ATP-ADPase glycolysis to identify a possible route to remedy.

A scale representation of a signal describes its compression or dilation as a function of time or frequency. Because the frequency scaling properties of cochlear mechanics vary slowly at frequencies above 1–1.5 kHz, a frequency-scale representation is of particular interest for auditory filters. An auditory filter is constructed based on the analytic signal with the minimum uncertainty product between frequency and scale. Its spectral and temporal properties are analyzed. The complex spectrum of the filter is completely specified as a function of the frequency relative to the center frequency of the filter, the filter SQ8 and the dimensionless group delay normalized by the number of periods at center frequency. In approximate agreement with basilar-membrane mechanics and human psychophysics, the frequency of peak spectral amplitude decreases by a half octave as tuning broadens, the spectral amplitude gain increases with sharper tuning, and the dimensionless group delay of the filter is independent of frequency. The peak envelope of the filter impulse response occurs at a time inversely proportional to the peak spectral frequency. Results are obtained on auditory phase perception for tones embedded in chirp masakers. A nonlinear filterbank composed of frequency-scale filters has potential applications in auditory research and audio engineering.
Log-scaled sentences with 80- and 112-ms segments replaced by speech-shaped noise. In the context of upward spread of masking and two-tone suppression as scaled and loudness-scaled measures of CSE predict intelligibility very well, scaled measures of speech intelligibility as a function of CSE when amplitude is change over time reported sentence intelligibility to be well-predicted by measures of sensory change over time is observed in real auditory nerve fibers.

Biphasic membrane filtering introduces frequency-dependent cochlear delays. Cochlear models predict that the delay between the peaks in responses to 100-Hz versus 10-kHz tones may be as long as 10 ms. This study investigated the role of across-frequency delays for asynchrony perception. A method of constant stimuli was used to evaluate the perception of delays between two tones, a 250-Hz tone paired with a higher-frequency tone at 1, 2, 4, or 6 kHz for a range of delays between the high- and low-frequency tones. Bandpass noise located between the two tones was used to avoid within-channel cues. Listeners judged whether the tone pairs appeared synchronous or asynchronous. For each pair, the proportion of “synchronous” responses was plotted as a function of the delay between the tones. Since cochlear-filter bandwidths depend on level, the perception of across-frequency delays was evaluated for two levels of the tones, 20 dB SL and 85 dB SPL. Overall, the data support the hypothesis of a higher-level mechanism compensating for cochlear delays, producing audible perception. However, the results do suggest a perceptual asymmetry, with synchronous judgments occurring more often for leading high-frequency tones than vice versa. [Work supported by NIH Grant No. R01DC006804.]

Cochlea-scale entropy predicts speech intelligibility when intensity is scaled as linear amplitude or as loudness, but not when scaled logarithmically. Christian E. Stilp and Keith R. Kluender (Dept. of Psych., Univ. of Wisconsin, 1202 W. Johnson St., Madison, WI 53706, cestilp@wisc.edu) reported sentence intelligibility to be well-predicted by measures of sensory change over time [cochlea-scaled spectral entropy (CSE)] and not consonants, vowels, or duration of signal replaced. As greater amounts of CSE were replaced by noise, intelligibility worsened. They calculated CSE as Euclidean distances between spectra defined by linear amplitude as a function of equal rectangular bandwidth (ERB). The present experiments compare measures of speech intelligibility as a function of CSE when amplitude is measured on a linear scale as before and when log-scaled (dB) or loudness-scaled (sone). Listeners typed all words they understood after hearing sentences with 80- and 112-ms segments replaced by speech-shaped noise. Log-scaled (dB) CSE was a poor predictor of performance. Both linear-scaled and loudness-scaled measures of CSE predict intelligibility very well, replicating Stilp and Kluender. Linear and loudness scales will be discussed in the context of upward spread of masking and two-tone suppression as they relate to speech signals. These perceptual findings suggest that conventional use of spectrograms (linear frequency × dB intensity) could systematically misinform researchers concerning properties of speech signals that are most useful to listeners. [Work supported by NIDCD.]

The neural representation of continuous speech in human auditory cortex was obtained noninvasively via magnetoencephalography. The neural response was recorded from human subjects listening to a spoken narrative, either in clear or in the presence of interfering speech. The cortical neural response to clean speech is demonstrated to precisely track the slow temporal modulations (<10 Hz) of speech in a broad spectral region between 400 Hz and 2 kHz. The neural code is sufficiently faithful to decode acoustic features of speech. To examine the robustness of, and the role of attention in, this neural code, another spoken narrative was presented simultaneously, either to a different ear (dichotically) or to the same ear (diotically), instructing the subjects to focus on only one of the two speech signals. The cortical representation of the attended speech is found to be substantially stronger than that of the unattended speech. This attentional effect is significant during the subjects’ first exposure to the spoken narratives. These results demonstrate that auditory cortex precisely represents the slow temporal modulations of speech and maintains separate neural representations for concurrent speech signals that can be individually and strongly modulated by attention. [Work supported by the NIDCD Grant No. R01-DC-008342.]

Several studies have demonstrated that increasing age leads to a decrease in the ability of the brainstem to phase-lock to periodic stimuli. This frequency following response has additionally been related to several other metrics, including musical training, experience with a tonal language, and ability to understand speech in noise. The current study explored a potential relationship between brainstem responses and large, observed individual differences in the ability of normal-hearing listeners to deploy selective spatial auditory attention. Previously, we reported that the ability to selectively attend varies enormously (from near chance to 90% correct) in normal-hearing listeners, but is uncorrelated with age (ranging from 20–55 years). Here, we recruited a subset of the original listeners and measured the brainstem’s frequency-following response (FFR). Although selective-attention performance was correlated with the strength of the FFR, there was an interaction between the FFR strength and age. For younger listeners, the FFR closely predicted selective attention ability, but the FFR was weak in all older listeners, even those who performed well behaviorally. These results show that the FFR strength decreases with age without necessarily leading to degraded perceptual abilities; however, young listeners with weak FFR cannot effectively deploy selective spatial attention.

In listening environments with spatially separated sources, listeners can often obtain a substantial improvement in performance by implementing a “better ear” listening strategy where they selectively attend to the ear with the more advantageous signal to noise ratio (SNR). However, relatively little is known about the ability of listeners to implement the better ear strategy on a band-by-band basis by focusing attention on a different ear within each frequency band. This experiment examined how efficiently listeners are able to implement a band-by-band better-ear listening strategy by dividing a modified rhyme test speech stimulus into 20 frequency bands of approxi-
chemically equal intelligibility and presenting a subset of those bands either monaurally, with all the bands in one ear, or dichotically, with half the bands assigned to one ear and half assigned to the other ear. The results showed that the listeners were able to integrate information across the two ears on a band-by-band basis, and that this ability was robust in a wide range of within-band and across-band masking conditions. However, there was a slight penalty for dichotic presentation, which was estimated to be roughly equivalent to a 1.2 dB decrease in the SNR of a broadband speech signal in noise.

10:30
1aPP9. The effect of disrupting the continuity of target sentences on the perceptual segregation of competing voices. Nandini Iyer (Air Force Res. Lab., WPAFB, OH 45433), Douglas S. Brungart (Walter Reed Army Medical Ctr.), and Brian D. Simpson (Air Force Res. Lab.)

Relative differences in fundamental frequency and prosodic features have been studied as possible cues that enable listeners to segregate a target talker in multitalker listening tasks. However, little is known about the effects of disrupting the prosody characteristics of a talker within a single phrase. The current experiment measured color-number identification scores with the coordinate response measure (CRM) sentences under two conditions: a “normal prosody” condition, where the target and masker phrases were spoken contiguously by a single talker, and a “disrupted prosody” condition, where the target and masking phrases were generated by concatenating together individual words that were originally spoken in different sentences. The results show that the elimination of normal prosodic cues had the greatest impact on performance when the target sentence was masked by a single CRM masking phrase that was presented at the same level as the target talker. The elimination of prosodic information had only a very slight impact on performance when the target talker was masked by more than one simultaneous talker, suggesting that the use of prosodic cues for segregation may be impaired when more than one interfering talker is present in the mixture.

10:45
1aPP10. Cues above 4 kilohertz can improve spatially separated speech recognition. Sunil Puria, Suzanne Carr Levy, Daniel J. Freed, and Michael Nilsson (Earlens Corp., 200 Chesapeake Dr., Redwood City, CA 94063, spuria@earlenscorp.com)

There are multiple acoustic cues above 4 kHz that may be used to improve speech recognition in noisy environments. This study tests this hypothesis with spatially separated speech maskers. The reception threshold of speech (RTS) was measured in two conditions: (1) asymmetric condition with target speech at −45° and maskers at +45°, and (2) diffuse condition with speech at 0° and one masker at each of four quadrants around the listener (±45°, ±135°). HINT sentences were rerecorded using a male talker and a 22.05 kHz bandwidth while different males were recorded speaking the television and rainbow as maskers. SRTs were measured with all materials low-pass filtered at 4, 6, 8, and 10 kHz for the asymmetric and diffuse conditions. 12 normal hearing subjects (on the way to 24) were tested using free-field loudspeakers in a sound booth. The mean RTSs for the asymmetric condition were −17.43, −19.07, −19.34, and −20.65 dB for 4, 6, 8, and 10 kHz, respectively. For the diffuse condition the mean RTSs were −7.77, −9.00, −9.88, and −10.05 dB for the same frequencies. The results suggest that high-frequency acoustic cues can enhance the ability to segregate spatially separated speech.

11:00
1aPP11. Room reverberation and constancy in sparse noise-vocoded speech. Anthony Watkins, Andrew Raimond, and Simon Makin (Dept. of Psych., Reading Univ., Reading RG6 6AL, United Kingdom)

Speech played several metres from the listener in a room is usually heard to have much the same phonetic content as it does when played nearby, although the different amounts of reverberation at these distances make the temporal envelopes of these signals very different. To study this “constancy” effect, listeners heard natural-speech messages and noise-excited vocoder versions of them. The vocoder used eight auditory-filter shaped noise-bands, each with the temporal envelope arising in that filter when the speech message is played. The center frequencies of the equally log-spaced bands ranged from 250 Hz to 4.24 kHz. An 11-step “sir-to-stir” continuum was formed by amplitude modulation and each step was played in the context, “next you’ll get … to click on.” Listeners identified test words appropriately, even in the eight-band conditions where the speech had a robotic quality. Constancy was assessed by comparing the influence of reverberation on the test word across conditions where the context had either the same level of reverberation (i.e., from the same, far distance), or where it had a much lower level (i.e., from nearby). Constancy effects were obtained with both the natural- and the eight-band speech, with the higher-frequency bands having more importance.

11:15
1aPP12. Predicting speech intelligibility based on the envelope power signal-to-noise ratio after modulation-frequency selective processing. Torsten Dau and Søren Jørgensen (Dept. of Elec. Eng., Tech. Univ. of Denmark, Lyngby, Denmark)

A model for predicting the intelligibility of processed noisy speech is proposed. The model represents a speech-based version of the envelope power spectrum model [Ewert and Dau, 2000] originally developed to account for modulation detection and masking data. The model estimates the ratio of speech-to-noise envelope power, SNRenv, at the output of a modulation filterbank and relates this metric to speech intelligibility using the concept of an ideal observer. Model predictions were compared to literature data, obtained with speech mixed with stationary speech-shaped noise. Furthermore, the model was tested in conditions with noisy speech subjected to reverberation and spectral subtraction. Consistent with new experimental data, the model predicted an increase in SRT as a function of the reverberation time as well as in conditions of spectral subtraction, the latter in contrast to the STI. An analysis of the model’s internal representation of the stimuli processed by spectral subtraction revealed that the decrease of the predicted speech intelligibility was caused by an elevation of the noise envelope power, which exceeded that of the speech envelope power. The results strongly suggest that the signal-to-noise ratio at the output of modulation frequency selective processing represents a critical measure of speech intelligibility.

11:30
1aPP13. Temporal integration of interrupted speech: Effects of time compression and expansion on the intelligibility of words and sentences. Valeriy Shafrir, Stanley Sheft, and Robert Risley (Dept. Comm. Disord. Sci., Rush Univ. Medical Ctr., 1015 AAC, 600 S. Paulina Str., Chicago, IL 60612, valeriy_shafrir@rush.edu)

Temporal integration of interrupted speech was investigated by contrasting the performance on gated to time-compressed/expanded words and sentences. In the control condition, HINT sentences and CNC words were gated at 0.5, 1.2, 4, 8, or 16 Hz using a 50% duty cycle. In the two experimental conditions, stimuli previously gated at each rate were either time-compressed by concatenating the consecutive speech segments or time-expanded by doubling the silent intervals between consecutive speech segments. Across rates, these manipulations thus varied both the size of intact speech intervals and the duration of silence between the intervals. No differences were observed in the rate-intelligibility functions of gated versus time-expanded words and sentences with the overlapping functions monotonically rising with rate. Though intelligibility was similar to the gated control condition at the lower and higher rates, the time-compressed rate-intelligibility function for sentences was nonmonotonic with a minimum at 2-Hz. In contrast, the time-compressed function for words remained similar to the corresponding gated and time-expanded functions. These findings indicate that the temporal integration of interrupted speech takes place on different perceptual time scales for words and sentences and is affected by the size of speech segments being integrated. [Work supported by NIH /NIDCD.]
11:45

1aPP14. Discrimination of acoustic differences improves with greater dissimilarity to experienced covariance. Christian E. Stilp and Keith R. Kluender (Dept. of Psych., Univ. of Wisconsin, 1202 W. Johnson St., Madison, WI 53706, cestilp@wisc.edu)

Stilp et al. [Proc. Natl. Acad. Sci. (in press)] demonstrated efficient coding of correlations between complex acoustic attributes (attack/decay and spectral shape) in novel sounds. Discrimination of differences between sounds that violate correlations (orthogonal) is initially inferior and later comparable to that for sound pairs that respect the correlation (consistent). Subsequent findings [Stilp et al., J. Acoust. Soc. Am. 128, 2455–2456 (2010)] suggest that this effect may depend more on acoustic similarity between consistent and orthogonal sounds than upon probability of orthogonal test trials. Across the present experiments, listeners discriminated (AXB) the same 15 consistent sound pairs and a single orthogonal sound pair of varying similarity to the consistent sounds (distance from the correlation vector in the stimulus matrix). Orthogonal discrimination systematically improves with increasing dissimilarity. With extreme dissimilarity, orthogonal discrimination is significantly better than consistent discrimination across all testing blocks. Results cannot be explained by weighting of individual stimulus dimensions. A principal components analysis network model for extracting covariance structure that successfully predicted listener performance in previous tasks predicts some but not all of these findings. Implications for perception of complex sounds including speech will be discussed. [Work supported by NIDCD.]

MONDAY MORNING, 23 MAY 2011 DIAMOND, 8:00 TO 11:40 A.M.

Session 1aSA

Structural Acoustics and Vibration, Noise, and Engineering Acoustics: Fluid-Structure Interaction, Computational and Experimental

Dean E. Capone, Cochair
Pennsylvania State Univ., Applied Research Lab., P.O. Box 30, State College, PA 16804

Robert L. Campbell, Cochair
Pennsylvania State Univ., Applied Research Lab., P.O. Box 30, State College, PA 16804

Invited Papers

8:00

1aSA1. Fluid-structure interaction and inverse design simulations for highly flexible turbomachinery. Robert L. Campbell (Appl. Res. Lab., The Penn State Univ., P.O. Box 30, State College, PA 16804)

Highly flexible turbomachinery offers substantial advantages for biomedical implantation but can suffer from performance losses due to blade deformations during operation. The objective of this work is to develop a method to define an impeller shape that deforms into the design shape during operation, thereby making feasible a collapsible impeller for medical implantation without incurring performance losses due to blade flexibility. A fluid-structure interaction (FSI) solver is developed and validated for quasi-steady operation, capable of modeling the time-dependent deformation inherent to the impeller polymeric material. The solver is validated using experimental data for a modified NACA 66 fin at various angles of attack. Inverse design simulations are used to define blade geometry that deforms into the design shape after being subjected to quasi-steady flow at prescribed conditions for a specified amount of time. The validated FSI solver is used to confirm performance of the inverse design shape. Evaluation of the FSI solver convergence shows the fluid and structure are nearly fully converged after only a few sub-iterations for these quasi-steady simulations. Performance studies show that the flow solver consumes most of the processing time, with the mesh motion and structure solutions requiring a much smaller fraction of the total processing time.

8:20

1aSA2. Scattering of acoustic quasi-Gaussian beams and Bessel beams by fluid-loaded spheres: Exact solutions and physical interpretation. Philip L. Marston (Phys. and Astronomy Dept., Washington State Univ., Pullman, WA 99164-2814, marston@wsu.edu)

Exact solutions are available for the scattering of sound by spheres placed on the axis of certain types of acoustic beams. In the case of an acoustic Bessel beam the scattering for various elastic spheres is greatly modified relative to the standard case of plane-wave illumination [P. L. Marston, J. Acoust. Soc. Am. 122, 247–252 (2007)]. Symmetry and geometric considerations explain why selected sphere modes can be suppressed in a way that depends on the Bessel beam parameters. The quasi-Gaussian case is treated by an appropriate superposition of zero-order Bessel beams displaying the focal properties of a Gaussian beam [P. L. Marston, submitted]. This superposition, unlike the case of a paraxial Gaussian beam, is an exact solution of the Helmholtz equation. The sphere is centered on the focal point of the beam and the scattering follows by superposition from the Bessel beam case. While not prone to suppress specific modes of the sphere, the quasi-Gaussian case can also modify the scattering for a wide range of beam parameters and frequencies. Mode amplitudes are modified by a function depending on a ratio of incomplete gamma functions and the size of the focus of the beam. [Work supported by ONR.]
Contributed Papers

8:40
1aSA3. Experimental and computational studies of vortex shedding and aerodynamic sound for flow over a square cylinder near a rigid wall. Yatao Hu, Jun Chen, Kai Ming Li (Dept. of Mech. Eng., Purdue Univ., 140 S. Martin Jischke Dr., West Lafayette, IN 47907-2031), Yatao Hu, and Keqi Wu (Huazhong Univ. of Sci. and Technol., 1037 Luoyu Rd., Wuhan 430074, China)

Flow around a bluff body near a solid wall, such as a circular or rectangular cylinder placed in a uniform flow near a solid boundary, is of fundamental importance. The reduction in the aerodynamic sound is a very important issue, for example, flow induced noise in tall buildings, bridges, high-speed trains, windmills, and computer cooling fans. This type of problem has been addressed extensively both experimentally and theoretically in the past. The flow past a long rectangular cylinder is usually associated with vortex shedding, which can be affected strongly by the presence of a nearby wall. Flow past a solid body induces vortices and the vortex acceleration will cause sound. In the present study, the aerodynamic sound generated by flow past a rectangular cylinder of various configurations was investigated experimentally in a low-speed quiet wind tunnel. A numerical study using large scale eddy simulation technique has also been conducted to compute the sound generation due to vortex shedding. Experimental results are compared with the numerical predictions. [Work sponsored by the China Scholarship Council.]

8:55
1aSA4. Sound generated by an elastic wing actuated at its leading edge. Avshalom Manela (Faculty of Aerosp. Eng., Technion, Haifa 32000, Israel)

The sound generated by a thin elastic plate, subject to uniform low Mach flow and to leading-edge pitching and heaving motions, is studied. The linearized plate motion is analyzed under conditions where the unforced plate (in the absence of leading-edge actuation) is stationary. When the frequency of applied forcing coincides with an eigenfrequency \( \omega_{el} \) of the unforced plate, a resonance motion is excited and the plate oscillates at the corresponding eigenmode. The sources of sound in the problem include the plate velocity and fluid vorticity. Acoustic radiation of dipole type is calculated and discussed in the limit of an acoustically compact plate. It is found that plate elasticity has two opposite effects on sound radiation: close to \( \omega_{el} \), the elasticity results in the generation of high sound pressure levels; however, far from \( \omega_{el} \), elasticity tends to reduce the amplitude of plate deflection (compared to that of a rigid plate), leading to reduced sound levels. It is also shown that the release of trailing-edge vortices is the main source of sound, dominating the radiation from the direct plate motion. The present theory is suggested as a simple tool for analyzing insect-flight sound and predicting the acoustic signature of flapping micro-air-vehicles.

9:10
1aSA5. SALINAS: A massively parallel finite element code for structural dynamics and acoustic analysis. Jerry W. Rouse, Timothy F. Walsh, and Garth M. Reese (Sandia Natl. Labs., P. O. Box 5800, 87185-0346, jwrouse@sandia.gov)

This talk shall present an overview of SALINAS, a massively parallel finite element code for structural dynamics and acoustic analysis that is being developed at Sandia National Laboratories. SALINAS allows for prediction of both the time and frequency domain responses of complex structural, acoustic, and fully coupled structural acoustic systems having millions of degrees of freedom. An overview of SALINAS capabilities shall be presented including development history, solver and element types, quadratic eigenanalysis and frequency response, direct frequency response, nonlinear acoustics, implicit transient dynamic analysis, and infinite elements with focus given to structural acoustics capabilities. The application of SALINAS to structural acoustics problems shall also be presented as well as future directions of research for the development of the code.

9:25

The resonance frequencies of a spherical aluminum shell (radius 3.0 in., thickness 1/8 in.) filled with water have been measured for several different values of static water pressure. It is found that a pressure increase of 100 psi causes resonance frequencies associated with axisymmetric bending modes to shift higher by about 0.15%, consistent with predictions of elastic shell theory [DiGiovanni and Dugundji, Air Force Office of Scientific Research Report No. 65-0640 (1965)]. The shell is suspended by elastic cords attached to an inlet valve and is excited acoustically with a swept sine wave; the vibrational response is measured with small accelerometers mounted on the shell surface. Techniques for identifying frequency shifts associated with very small pressure changes (less than 1 psi) will be discussed. The effect reported here may have an application in the development of noninvasive methods for measuring intracranial pressure changes. [Work supported by National Science Foundation STEM program and Central Washington University.]

9:40

A finite-element model of the vibrational response of fluid-filled shells with arbitrary shape and composition has been developed using the comsol, multi-physics modeling package. The user can specify the properties of the fluid inside the shell including the static pressure. The shell is surrounded by air, which is enclosed by a perfectly matched layer boundary, and an acoustic source is positioned just outside the shell. The frequency response of the shell due to a swept sine acoustic excitation can be recorded at multiple locations. Model results for a spherical aluminum shell filled with water at different static pressures are compared with experiment. Results are also shown for a shell with geometry and material properties similar to a human skull. The goal is to apply this model to predict vibrational response due to changes in intracranial pressure. [Work supported by Central Washington University Science Honors Program.]

9:55—10:10 Break

10:10
1aSA8. Coupled structural-acoustic computations for interior problems using a modal solution for the structural vibrations and a direct solution for the acoustic pressure field. John B. Fahnline (Garfield Thomas Water Tunnel, University Park, PA 16802)

Structural-acoustic computations involving enclosed volumes of fluid using finite elements are often performed by coupling _in vacuo_ structural modes with acoustic modes derived assuming rigid-wall boundary conditions, sometimes referred to as Dowell’s method. This approach works well for problems with “light” fluid coupling, but is very slow to converge for problems with “heavy” fluid coupling. Several authors have suggested methods to derive terms to add to the acoustic basis set to account for the residual contributions of truncated modes. Another possibility, which will be the focus of this paper, is to directly compute the acoustic field in terms of nodal pressure variables rather than as a modal summation. Despite the relative simplicity of this approach, it does not appear to have explored previously in the literature. As will be shown, the coupled structural-acoustic equation system closely resembles that for coupled finite element/boundary element problems because both are written in terms of the structural variables only. The main goal of the presentation will be to demonstrate that using a direct
solution for the acoustic field alleviates the slow convergence difficulties encountered with Dowell’s method for coupled structural-acoustic analyzes.

10:25
1aSA9. On the use of a variational boundary element/finite element approach to predict the vibroacoustic response of structures. Franck Sgard, Kamel Amichi (Service de la recherche, IRSST, 505 Boulevard de Maisonneuve O, Montréal, PQ H3A3C2, Canada, frasga@irsst.qc.ca), Noureddine Atalla (Univ. of Sherbrooke, Sherbrooke, PQ J1K2R1, Canada), and Hugues Nlisse (IRSST, Montréal, PQ H3A3C2, Canada)

This paper deals with the application of a variational boundary element/finite element approach to predict the vibroacoustic response of structures. First, the theoretical formulation is presented. Then two specific examples are considered and numerical results are presented. The first case concerns the calculation of the sound transmission through a curved orthotropic sandwich panel. The blocked pressure field acting on the structure is first calculated and then used as a loading in the computation of the forced response of the panel. The second case consists of the calculation of the sound radiation of an assembly of plates at different angles excited by uncorrelated point forces. This configuration is of special interest to evaluate the accuracy of analytical Leppington’s radiation efficiency correction factors related to baffle angles to predict the acoustic power radiated by a box-shaped acoustic enclosure.

10:40
1aSA10. Analysis of results of numerical calculations of sound scattering by inhomogeneous elastic shells aiming to create a physical model of the scatterer. Mikhail B. Salin (Inst. of Appl. Phys., Russian Acad. of Sci., 46 Uljanov St., Nizhny Novgorod 603950, Russia, mikesalin@hydroappl.sci-nov.ru)

Determining vibration and acoustic characteristics of elastic bodies in water (especially elastic shells) is a challenging problem that becomes more complicated if non-homogeneities of various types are present or a finite length object is considered (~1–10 wavelengths). Scattering by such bodies is considered here. This paper describes methods of analysis of results of numerical calculations that allow one to find the scattering mechanisms that make the greatest contribution to the scattered directivity pattern. The method allows one to distinguish the following factors: scattering as if it were a rigid body and excitation of an eigenmode, whose form can also be roughly estimated. The scattering object is replaced virtually by a discrete receiver-transmitter array whose transmitted signal is defined as the product of the received signal and the scattering matrix. Elements of the scattering matrix are found in such way that calculated scattered field values in the far field are close to the real ones. The results of this research can help in such areas as design of structures with required scattering characteristics, solving inverse problems and in classification and remote sensing. [The author gratefully acknowledges the generous support of the U.S. Office of Naval Research, ONRG.]

10:55
1aSA11. An efficient back-scattering model for arbitrarily shaped objects. Edward Pees (Naval Undersea Warfare Ctr., 1176 Howell St., Newport, RI 02841, edward.pees@navy.mil)

A method is presented for efficiently computing the propagating pressure field back-scattered from arbitrarily shaped, 3-D objects. This is accomplished by drawing upon a previously reported relationship between the boundary condition on a 2-D radiating aperture and the pressure propagating along an axis normal to the aperture, and the diffraction slice theorem, which relates the Fourier transform of an object function to its scattered pressure field. Together, these two results allow for the derivation of an integral formula that expresses the pressure field back-scattered from an object as a 1-D Fourier transform of its scattering amplitude. Use of this formula is demonstrated for computing the back-scattered pressure field from a uniform sphere in the first Born approximation (weak scatterer) and with a Kirchhoff boundary condition (rigid scatterer); the results of which are compared to the corresponding rigorous partial wave expansions.

11:10
1aSA12. Low-wavenumber turbulent boundary layer wall-pressure measurements from vibration data on smooth and rough cylinders in pipe flow. Neal D. Evans (Graduate Program in Acoust., Penn State Univ., 201 Appl. Sci. Bldg., University Park, PA 16802, nue110@psu.edu), Dean E. Capone, and William K. Bonness (Penn State Univ.)

The vibration response of a thin cylindrical shell excited by a fully-developed turbulent boundary layer is measured and used to extract the fluctuating pressure levels generated by the boundary layer. Parameters used to extract the turbulent boundary layer pressure levels are determined via experimental modal analysis of the water-filled pipe and measured vibration levels from flow through the pipe at 6 m/s. Hydrostatic head from a large reservoir provides the low-noise source of steady flow for measuring the low-wavenumber fluctuating pressure levels. Measurements are reported for smooth, transitionally rough, and fully rough conditions and are compared to the turbulent boundary layer pressure models of Chase, Smol’yakov, and Howe.

11:25
1aSA13. Determination of pipe interior pressures using external accelerometers. Alexandra R. Salton, Dean E. Capone, and William K. Bonness (Graduate Program in Acoust., Penn State Univ., 201 Appl. Sci. Bldg., University Park, PA 16802, ars328@psu.edu)

A non-invasive method utilizing a ring of accelerometers to measure pipe interior pressures is presented. The internal acoustic pressure of the fluid inside a cylindrical pipe is directly related to the vibrations at the surface due to the coupling of the fluid and structure. The $n=0$ breathing mode provides the basis for this relation and is extracted from operational data using a circumferential modal decomposition routine. The measurement of pipe interior pressures can be useful in determining the integrity of a piping system by detecting high pressures, which may lead to the fatigue or failure of the system. Within the field, a non-invasive method for measuring these pressures is more practical in comparison to the intrusive but more direct method of using hydrophones. Measurements using the ring of accelerometers are compared to hydrophone measurements to determine accuracy.
Session 1aUW

Underwater Acoustics and Acoustical Oceanography: Sediment Acoustics and Geological Processes I

Charles W. Holland, Cochair  
*Pennsylvania State Univ., Applied Research Lab., P.O. Box 30, State College, PA 16804*

Allen Lowrie, Cochair  
*U.S. Naval Oceanographic Office, Balch Blvd., Stennis Space Center, MS 39522-5001*

Chair’s Introduction—8:25

Invited Papers

8:30  

1aUW1. Low-frequency geoacoustic modeling in shallow water sediment environments. N. Ross Chapman (School of Earth and Ocean Sci., Univ. of Victoria, 3800 Finnerty Rd., Victoria, BC V8P5C2, Canada)

The goal in geoacoustic modeling is to develop realistic geophysical models of the ocean bottom that can be used in numerical calculations of the acoustic field in the ocean. The ocean bottom is assumed to be a layered structure of different types of sediment material that have been deposited over geological times. However, in shallow water the bottom is generally much more complex. The sediment material is variable on different spatial scales horizontally and is inhomogeneous in depth below the sea floor. Despite this complexity in realistic bottom environments, there has been considerable success using the simplified approach of a layered, range-independent geology in low-frequency (20–500 Hz) applications with inversion techniques that provide estimates of geoacoustic model parameters and their uncertainties. This paper reviews some of the most effective inversion techniques and compares their performance in estimating realistic and effective geoacoustic profiles in applications with data from the recent Shallow Water ’06 experiments on the New Jersey continental shelf. Conditions are discussed that limit the performance of present day inversion techniques. These include rough interfaces on and below the sea floor, consolidated material that supports shear wave propagation, and range variation of sub-bottom structure.

8:50  


The degree of compaction in marine sediments has a direct effect on their velocity and density, components in the Navy’s geoacoustics databases. Acoustic transmission through sediments necessitates grain-to-grain contact. Such a conceptual model coincides with geology of sediments settling onto seafloor to consolidation as generally continuous. However, such continuity may not be justified. Understanding of global/regional/local processes and impacts suggests that sediment grains are jostled, causing rearrangement/breaking/damaging/retarding contact between grains, reducing rigidity, and intergranular fluids “flushed” by passing ocean waves. Resultant of these processes is that sediments remain unconsolidated to unexpected depths. Improved knowledge of global/regional/local stress-fields reveals heretofore unappreciated complexity maintaining individual grains apart with retardation of contact. Meteor impacts and major earthquakes and volcanic eruptions form “instantaneous” stress-waves that can jostle sediments globally, forcing high-frequency intergranular motions, rupturing, and interstitial fluid movements. Dynamic sedimentation episodes from glacial-lake releases and continental margin collapses provide lower frequency stress-waves causing lateral motions among sediments, re-forming grain arrangements. Wave migration over seafloor and de-watering fluctuates inter-granular fluids, maintaining interstitial spaces open. Tectonics form faults/breakages along with movements and fluids and material flowage, creating differing domains/units within sediments. These dynamic inputs within a complex-geographic-matrix assist in maintaining sediments unconsolidated.

9:10  

1aUW3. Measurement and modeling of high frequency sound speed and attenuation in sandy sediments since the Sediment Acoustics Experiment 1999. Brian T. Hefner (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, hefner@apl.washington.edu)

During the Sediment Acoustics Experiment in 1999 (SAX99), measurements were made of the sound speed and attenuation in a sandy sediment, supplemented by detailed environmental characterization. While the dispersion was consistent with Biot theory, the attenuation at high frequencies had a linear frequency dependence that was consistent with models based on losses at grain contacts. These results led to the development of a number of competing models of sound propagation in sand sediments. Subsequent to SAX99, measurements of sound speed and attenuation have been made in several ocean sediments as well as in a number of laboratory sediments composed of either sand or glass beads. Many of these experiments have been accompanied by careful measurements of the sediment properties and, in some cases, these properties have been varied to assess their impact on sound propagation. An overview of these results will be given and the implications of these measurements for high frequency sediment acoustics modeling will be discussed. [Work supported by the Office of Naval Research.]
Two seabed properties that control high-frequency (greater than 10 kHz) acoustic scattering from and propagation into the sea floor are interfacial roughness and sediment inhomogeneities. Geological processes that affect the statistical distribution of these properties include sediment transport and sediment diagenesis. Sediment transport is a hydrodynamic process driven by waves and currents, which are results of storms and tides. Seafloor features that are significant for acoustic scattering and are created by sediment transport include sand waves, ripples, ripple-scour depressions, lag layers, flasers, and sand lenses. Scattering from these features can be predicted from the statistical characterization of interface roughness and sediment inhomogeneities. Sediment diagenesis is a physical, chemical, and sometimes biological process that affects the sediment bulk density through processes of dewatering, consolidation, precipitation, or cementation. Sediment diagenesis affects the gradient and fluctuations in bulk density and thus the speed and attenuation of sound. Scattering model inputs related to these features are derived from measurements of vertical fluctuations of sediment bulk density and sound speed. Examples of how sediment transport and diagenetic processes affect high-frequency acoustic bottom-interactions are presented.

10:10—10:30 Break

Contributed Papers

10:30


Measurements of the sound speed characteristic of the high porosity Dodge Pond mud were found to have a sonic speed less than that observed by Wood and Weston [Acustica 14, (1964)], a compressional speed 3% less than that of water. Other experiments performed on muddy sediments at frequencies greater than 1 kHz are consistent with the Dodge Pond observations when microbubbles are present. The presence of bubbles is known to be an important factor in decreasing the sound speed. A theoretical treatment of “muddy sediments,” the card house theory [Pierce and Carey, POMA 5, 7001, (2009)], estimated the slow sound speed and frequency dispersion proportional to mud porosity, \( C_{\text{mud}} \sim (0.91–0.97)C_w \). The presence of microbubbles can lower the sound speed consistent with the Mallock–Wood equation when the bubble size distribution and mean bubble separation are less than the wavelength of the propagating wave. Since measurement of the bubble size distribution within the mud is difficult; theoretical limits on the size distribution in the complex card house structure can be useful in interpreting measurements on muddy sediments and provide a basis for acoustic distribution measurement. [Work partially supported by the ONR OA and the NSWC PCD.]

10:45


Principal constituents of mud ocean sediments are small platelets of minerals such as smectite and kaolinite. Isomorphous substitution produces negative charges on platelets, and salt water ions rearrange to cause an effective quadrupole moment per unit area of platelet. A card-house structure results, where an edge of one platelet is bonded to the face of another and where each platelet is in a state of electrostatic equilibrium. Platelets are idealized as elastic plates, with a bending modulus proportional to \( Eh^2 \). The elastic modulus \( E \) can be estimated from chemical physics principles as a dimensionless constant times \( h^3/(m_0 \alpha_0) \), where \( \alpha_0 \) is the Bohr radius. When an elastic platelet is perturbed from its equilibrium position, the restoring forces near a contact point (joined edge) are exceptionally large so that an appropriate boundary condition is that the platelet is cantilevered. Shearing forces cause the platelet to bend like a cantilevered beam with distributed electrostatic restoring forces. Solution for the platelet deformation leads to estimates of the shear modulus and shear speed, which compare favorably with existing data. [Work partially supported by the ONR and NSWC PCD.]

11:00

1aUW8. Compressional and shear wave modeling in underwater granular media. Nicholas P. Chiotiros and Marcia J. Isakson (Appl. Res. Labs., The Univ. of Texas at Austin, P.O. Box 8029, Austin, TX 78713-8029)

A model of attenuation and sound speed in water-saturated granular media, based on a combination of the Biot–Stoll and contact squirt and shear drag model (BICSQS) [Chiotiros and Isakson, J. Acoust. Soc. Am. 116(4), 2011–2022, (2004)] and the frame virtual mass (FVM) model [Chiotiros and Isakson, J. Acoust. Soc. Am. 121(2), EL70 (2007)] is reconciled with the physical dimensions of the area and thickness of the fluid film at the grain–grain contact. The results are consistent with recent experimental observations of enhanced viscosity in nanometer-scale interfacial water films due to
The exact nature of sound propagation in water-saturated granular sediments, across the range of frequencies of interest in underwater acoustics, remains insufficiently understood. Well-controlled laboratory measurements are useful for validation and continued development of predictive models. Toward this end, a time-of-flight technique operating in the 250 kHz–750 kHz range was used to determine the sound speed and attenuation in a variety of artificial sediments including sand and glass beads of varying grain size and varying levels of homogeneity. Measurements will be presented and compared to existing model predictions.

## Contributed Papers

### 1PAa1. Psychoacoustic limitations of discrete infinite impulse response and finite impulse response auralizations

Ioan W. Mooney (Acoust. Team, KJWW Eng. Consultants, 623 26th Ave., Rock Island, IL 61201, mooneyjw@kjww.com)

Auralizations based on discrete infinite impulse response (DIIR) filters having coefficients derived from statistical reverberation type analyzes are relatively quick and easy to produce but have limitations. Auralizations of very small rooms, or very large rooms having little acoustic treatment, or rooms having dissonant eigenmodes may sound less than real. Auralizations based on discrete finite impulse response (DFIR) filters having coefficients derived from finite element type analyzes can avoid these effects. In both DIIR and DFIR methods, filter coefficient spacing and polarity has a large effect on simulation quality. In this study, auralizations of a test room are created from recorded impulses, derived DFIRs and calculated DIIRs. Sound clips produced by each method are rated using audition and psychoacoustic measures of roughness, fluctuation and sharpness. This paper addresses (1) the derivation of DIIR based auralization from statistical reverberation analysis, (2) the derivation of DFIR based auralization from finite element analysis, (3) psychoacoustic limitations imposed on auralizations, and (4) DIIR/DFIR auralization limits indicated by audition and psychoacoustic rating of a limited number of simulation comparisons.

### 1PAa2. Practical applications and limitations for analog auralizations

Richard A. Vedvik (Acoust. and Vib. Team, KJWW Eng. Consultants, 623 26th Ave., Rock Island, IL 61201, vedvikra@kjww.com)

Developing auralizations of irregularly shaped or small spaces proves to be a challenge for computer software to achieve a natural representation of the original recording. Analog auralizations are discussed using scaled wavelengths, high-bandwidth loudspeakers, and high-bitrate and high-bandwidth measurement equipment, effectively capturing the sound of the analog room. This paper discusses the practical applications and limitations of scale model analog acoustic auralizations. Impulse responses and auralizations of anechoic musical performances in a 1.5 scale music practice room are presented to demonstrate the fine tuning capability of the technique. Interference from outside sources such as ultrasonic emissions of modern electronics is also discussed.