Session 1aAA

Architectural Acoustics: Design, Simulation, and Perception of Architectural Acoustics

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Contributed Papers

8:00

1aAA1. Sound absorption of different green roof systems. Ilaria Pittaluga, Corrado Schenone, and Davide Borelli (DIPTEM, Univ. of Genova, Via all'Opera Pia 15/A, I 16145, Genova, Italy)

Experimental data on acoustical performances, in particular on sound absorption, of several green roof systems were evaluated and discussed. Measurements were performed on samples of three green roof systems, different for maintenance, plant setting and containment criteria, and categorized in extensive green roof (sample A), semi-intensive green roof (sample B), and common soil (sample C). Experimental values of normal incidence acoustic absorption coefficient and acoustic impedance were evaluated for each sample in one-third octave frequency bands from 160 to 1600 Hz by using a standing wave tube. Then, diffusive sound absorption coefficients and normal and diffusive weighted sound absorption coefficients were calculated in the same frequency range. Results show that green roofs provide high sound absorption, mostly if compared with the typical performances of traditional flat roofs. Curves of sound absorption coefficients result strongly dependent on the stratigraphy. Comparison between the different systems performed on the base of weighted sound absorption coefficients shows a better behavior for the sample B. Results obtained suggest that green roof technology, in addition to energy and environmental benefits, can contribute to noise control in urban areas by means of high sound absorption performances in relation to the size of the surface area.

8:15

1aAA2. Acoustic properties of green walls with and without vegetation. V. Kirill Horoshenkov, Amir Khan, Hadj Benkreira (School of Eng., Univ. of Bradford, Bradford, West Yorkshire, BD7 1DP, United Kingdom), Agnès Mandon, and Rene Rohr (Canevaflor, 24, Rue du Docteur Guffon, 69170 Tarare, France)

One substantial issue with the majority of modern methods for noise control is their heavy reliance on man-made acoustic structures which require continuous service and maintenance. In this respect, the use of the inherent noise control properties of vegetation appears particular attractive compared to other street/square treatments for reducing noise such as adding façade absorption and diffusion. A green wall with a carefully selected type of soil substrate provides an alternative to more conventional types of acoustic treatment. This work studies the influence of leaves (foliage) on acoustic absorption of soils, plants, and their combination which are typically used in green (living) walls. It is shown the the presence of plans with a particular type of leaves can result in a considerable (up to 50%) improvement in the absorption coefficient of a green wall with soil at a certain water saturation. The acoustic absorption coefficient of these systems is examined here through laboratory measurements and theoretical prediction models. The plants in this study were chosen to cover a range of possible leaf types, sizes, and densities.

8:30

1aAA3. Analysis of sound propagation in an experimental model using a high resolution scanning system. Aditya Alamuru, Ning Xiang, and Joonhee Lee (Graduate Program in Architectural Acoust., School of Architecture, Rensselaer Polytechnic Inst., Troy, NY)

The aim of this work is to analyze low frequency and mid frequency sound propagation in a coupled volume system for different aperture configurations. The cross sectional areas of the primary room and the secondary room are scanned over high spatial resolution grids using an automated scanning system. This procedure is carried out systematically for different aperture configurations. A dedicated analysis algorithm converts experimentally measured room impulse response data at each grid point into energy distributions and instantaneous sound pressure levels as a function of time. The analysis algorithm provides streams of data for a selected frequency thereby creating an animation of sound propagating through the coupled volume system. This work will demonstrate wave phenomena for different aperture configurations at low frequencies and mid frequencies by using animations to analyze the experimentally measured data.

8:45

1aAA4. Architectural acoustic elements to reduce the decay time in a room. Bonnie Schnitta, Melissa Russo, Greg Greenwald, and Michael Cain (SoundSense, LLC, 46 Newtown Ln., Ste. One, E. Hampton, NY, 11937, bonnie@soundsense.com)

The paradise architectural acoustic devices are sound modifying architectural elements, or structures. The architectural structure can be made to look like any one of the standard architectural structures commonly used in a room, from baseboards to crown moldings or ceiling beams. Depending on the intended outcome, the architectural elements can either be a solid body, or what appears to be a solid element but has internal mathematically determined channels. This allows the architectural elements, or devices, to not only reduce or correct the decay time in the room, but also make certain that the architectural elements do not produce undesirable effects. The mathematical foundation of the various shapes and designs of the architectural acoustic structures, or elements, will be presented for a linear case. This will allow a better understanding of the underlining acoustical effects. An appreciation for a more precise mathematical description of the embodiments will also be discussed by additionally taking into account the nonlinear aspects of the various embodiments. Various views of an acoustic architectural device for reducing or correcting decay time will be presented. Additionally, the improvements to the acoustic environment of the room that result from the paradise architectural elements will be provided.

9:00

1aAA5. Analyzing the auditory nature of architecture. Daniel Butko (College of Architecture, The Univ. of Oklahoma, 830 Van Vleet Oval, Norman, OK 73019, butko@ou.edu)

Architects usually place primary focus on the physical nature of materials and the aesthetic qualities of how those various materials are assembled. Although visual appeal is quite valuable when creating the built environment and specific inhabitable space(s), attention to sound is also vital in making a project successful for its intended use and daily occupants. Third year architecture students at the University of Oklahoma were tasked with a series of analytical studies and experiments that focused on the auditory nature of the built environment. This served as a precursor to the semester design project. The students spent time listening and discovering what sounds and noises were present within various functions. Each student categorized their individual findings of analyzed space into three classifications: (1) What sounds and/or frequencies they deemed successful/helpful to the intended use, (2) What sounds and/or frequencies they deemed unsuccessful/hindrance to the intended use, and (3) What additional sounds or noises they believe could have supported the intended use. The results were presented in class, discussed among the entire group, and ultimately fueled the students' future design decisions. This paper focuses on how simple analytical auditory studies can alter the overall design process to include architectural acoustics.

9:15

1aAA6. Acoustic simulation of renaissance Venetian churches. Braxton B. Boren (Music and Audio Res. Lab., New York Univ., 35 W. 4th St. New York, NY 10012, bbboren@gmail.com) and Malcolm S. Longair (Univ. of Cambridge, Cambridge, CB3 0HE, United Kingdom)

The Venetian Renaissance was a confluence of innovative expression across many artistic disciplines. While architects like Palladio and Sansovino were designing architectural masterpieces in many of the churches built during this period, composers such as Willaert, the Gabrielli, and Monteverdi were composing complex polyphonic works for split-choir ensembles, exploring the tonal and spatial dimensions of musical performance. The large churches built during this period have extremely long reverberation times and provide low clarity for understanding the complex polyphony composed for these spaces. This paper uses modern acoustic simulation techniques to provide insights into the acoustics of large Venetian churches as they would have existed during the Renaissance. In consultation with architectural historians, the authors have collected data on the structure and layout of Palladio's Redentore and San Marco on festal occasions, when large crowds, extra seating, and wall tapestries would have provided extra absorption. Using Odeon, acoustic simulations predict that under festal conditions these churches would have had significant improvements in T30, EDT, and C80. The doge's position in San Marco's chancel has particularly good clarity for sources located in Sansovino's galleries, supporting historian Laura Moretti's hypothesis that these galleries were installed for the performance of split-choir music.

9:30

1aAA7. Temporal modeling of measurement conditions to enhance room acoustical parameter characterization. Stephen Roessner (Dept. of Elec. and Comput. Eng., Edmund A. Hajim School of Eng. and Appl. Sci., Univ. of Rochester, NY 14627), Gang Ren, Mark F. Bocko, and Dave Headlam (Univ. of Rochester, NY 14627)

Forming statistical combinations of the results of repeated acoustical measurements taken under identical conditions is a common practice to reduce the effects of random noise. The most common method is to calculate the arithmetic mean of an ensemble of test results, which is based on the assumption that all experiments were conducted under identical noiseless test conditions. For most room acoustic measurement scenarios, this assumption is not valid, and non-stationary sources of noise often contaminate the results. Traditional statistical averaging methods can be improved by explicitly modeling the ambient interference and noise. Using a signal model for the noise and interference, the proposed parameter estimation procedure provides more accurate results than simple averaging in low signal to noise ratio test scenarios. This method, in which multiple, low volume measurements replace high volume test signals, provides a practical and cost-effective approach for characterizing acoustical spaces.

9:45

1aAA8. Benchmark measurements of noise, reverberation time, and an estimate of speech intelligibility in a representative operating room at Nationwide Children's Hospital in Columbus, Ohio. Richard D. Godfrey, Lawrence L. Feth (Dept. of Speech and Hearing Sci. The Ohio State Univ., 1070 Carmack Rd., Columbus, OH, godfrey.20@osu.edu), and Peter Winch (Nationwide Children's Hospital, Columbus, OH 43205)

Nationwide Children's Hospital was interested in understanding speech communications: in their operating rooms and between the parents/child and the doctor in pre-operative rooms. Long-term hearing loss of the staff was of secondary interest. Before a comprehensive project was proposed, data in a single OR to gain some experience was conducted. A SLM was programmed to measure the following during 15 s intervals: overall A-weighted equivalent energy sound level, A-weighted equivalent energy sound level in octave bands from 16 to 16 kHz, and peak un-weighted level during the interval. Reverberation was also measured by an impulsive method. Measurements were made for 23 consecutive hours. The data were downloaded for analysis. It was concluded that (1) adding some absorption around the top of the walls would improve SI, (2) good SI is only possible with a high vocal effort, and (3) long term hearing loss is very unlikely. Follow up topics before a comprehensive project is proposed were (1) try other reverberation methods, (2) study more rooms while a variety of surgical procedures are performed, (3) identify the source and duration of peaks levels, and (4) investigate other measures of SI.

10:00

1aAA9. Impacts of classroom acoustics on elementary student achievement. Lauren M. Ronsse and Lily M. Wang (Architectural Eng. Prog., Univ. of Nebraska-Lincoln, Peter Kiewit Inst., 1110 S. 67th St., Omaha, NE 68182-0861)

This research investigates relationships between unoccupied classroom acoustical conditions and elementary student achievement. Acoustical measurements were gathered in all of the third and fifth-grade school classrooms (67 total) in a public school district in north-eastern Nebraska, USA. Traditional classroom acoustic parameters, including background noise level and reverberation time, have been correlated to the standardized achievement test scores from students in the surveyed classrooms. Binaural impulse response measurements were also conducted in a subset of the rooms (20 total) and correlated to the student achievement scores. Acoustical metrics calculated from the binaural impulse response measurements include speech transmission index, distortion of frequency-smoothed magnitude, interaural cross-correlations, and interaural level differences. The results from this research indicate that scores on fifth-grade student language and reading subject areas are negatively correlated to higher unoccupied background noise levels. Also, the distortion of frequency-smoothed magnitude, which is a perception-based acoustics metric, was significantly related to the student language achievement test scores.

10:15–10:30 Break

10:30

1aAA10. A survey of residential "speaking tubes." William J. Elliot and John T. Foulkes (Cavanaugh Tocci Assoc., Inc., 327F Boston Post Rd., Sudbury, MA 01776, welliot@cavtocci.com)

The speech transmission index is examined for a system of "speaking tubes" within a home in the Avon Hill neighborhood in Cambridge, Massachusetts. Designed in 1888 by noted Boston architects Henry Hartwell and William C. Richardson, the Shingle Style home was both wired for electricity and outfitted with piping for gas. An electronic paging system was used to summon servants, but when aural communication was necessary, the speaking tube system was used for inter-floor communication. This paper examines the measured STI for the speaking tubes which remain in the home within the context of simple passive waveguide sound propagation. The paper also provides a quantitative evaluation of this pre-electroacoustic technology as it appeared in several fashionable homes of the late 19th and early 20th centuries.

10:45

1aAA11. Comparison of the articulation test and speech transmission index values measured in two different acoustical poor conditions. Jorge Sommerhoff (Acoust. Inst., Universidad Austral de Chile, Independencia 641, Valdivia, Chile, jsommerh@uach.cl) and Claudia Rosas (Universidad Austral, Valdivia, Chile)

In this work, a comparison is made between articulation tests and speech transmission index (STI) values, measured in the same place, in two different acoustically poor room conditions, both with STI values of less than 0.4. In the first room condition, a 200 m^3 reverberation chamber with background noise of less than 32 dBA was used. In the second room condition, pink noise was added to a small room with reverberation time of less than 0.6 s, till values of STI lower than 0.4 were reached. The articulation test corpus consisted in a 1000 phonetically Spanish combination of a consonant, vowel, and consonant (CVC logatoms). The logatoms were recorded in an anechoic chamber. In the articulation test and STI measurement, both signals were emitted in the rooms using a NTI Talkbox with a sound power equivalent to a normal human voice. The STI and articulation was measured at the listener's seats which were located at different distances from the source but within STI values less than 0.4. The articulation test results of both acoustical conditions are correlated separately with the measured STI. The results of the measurements indicate that for the same STI value, the subjective response statistically differs.

11:00

1aAA12. The effect of listener head movement on perceived envelopment and apparent source width. Anthony J. Parks (Program in Architectural Acoust., School of Architecture, Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180)

Current research examining listeners' perceived spatial impression of a concert hall relies on a fixed-head worldview, since the overwhelming majority of listening tests conducted to determine subjective spaciousness [listener envelopment (LEV) and apparent source width (ASW)] has required listeners to keep their heads fixed. Such a worldview is an incomplete one, because listeners make noticeable exploratory head movements while evaluating sonic environments, including the more common task of source localization as well as the more involved task of evaluating the spaciousness of a concert hall. This study investigates the role of listener head movement in the evaluation of perceived LEV and ASW under 15 different concert hall conditions simulated over eight loudspeakers using Virtual Microphone Control. The conditions consist of both varying ratios of front-to-back energy and varying levels of cross-correlated reverberant energy. Head movements are monitored in terms of angular rotation (azimuth, elevation, and roll) using a head tracker while listeners are prompted to give subjective ratings of LEV and ASW ranging from 1 (least) to 7 (most). The listening tests are then repeated while subjects are asked to keep their heads fixed. The head movements are analyzed and results of the tests are compared.

11:15

1aAA13. Applications of a binaural model with contralateral inhibition in room acoustics analysis. Timothy Perez, Jonas Braasch, and Ning Xiang (Grad. Prog. in Arch. Acoust., Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180, perezt2@rpi.edu)

In many cases the conventional, monophonic measures used in analyzing room acoustics show little agreement with real listeners' responses; a binaural perspective provides much-needed spatial and perceptual information that is important in acoustical quality judgments. Traditionally, binaural models extracted information about location and intensity of sound through a relatively simple cross-correlation procedure. This paradigm was extended by Lindemann [J. Acoust. Soc. Am. **80**, 1608–1630 (1986)] with the introduction of a contralateral inhibition process, which applies a time- and intensity-dependent weighting to a pair of binaural signals and accurately reproduces results from psychoacoustical tests where the traditional model fails, such as in the case of the Precedence effect. The model will be used to observe the broadening and splitting of auditory events based on the degree of interaural coherence, providing further validation of its adequacy. Then, applications in architectural acoustics will be investigated by processing binaural room impulse responses and producing a binaural activity pattern, which indicates the location and spatial extent of the resulting auditory events. These will be compared to visualizations drawn from spherical harmonic microphones. Implications of such a model on factors important in acoustical quality assessments, such as apparent source width and listener envelopment, will be discussed.

11:30

1aAA14. The audibility of direct sound as a key to measuring the clarity of speech and music. David H. Griesinger (David Griesinger Acoust., 221 Mt. Auburn St., Cambridge, MA 02138, dgriesinger@verizon.net)

Human ear/brain systems evolved to decode the direction, timbre, and distance of multiple sounds in a complex and noisy environment. In a reverberant space, this information is only available at the onset of a sound, before reflections overwhelm it. But since the time of Sabine acoustic science has concentrated on the decay of sound in a reverberant field, not on the audibility of the onset information. In addition, it is well known that the ability to separate multiple sound sources depends critically on pitch, but acoustic research studies only noise and impulses. This paper proposes that clarity requires the ability to separately analyze multiple sounds (the cocktail party effect) and that the cocktail party effect depends on phase relationships between harmonics of complex tones. These phase relationships are scrambled in predicable ways by reflections and reverberation. Well known properties of human hearing are used to develop both a physical model for the neurology of onset detection and an impulse response measure for localization and clarity in a reverberant field. A C language implementation of the physical model is capable of predicting and perhaps measuring the localizability of individual musicians in a binaural recording of live music.

11:45

1aAA15. Sound metric design based on psychological and physiological acoustics for the analysis of automotive sound. Young Joon Lee, Hong Sug Park, and Sang Kwon Lee (Dept. of Mech. Eng., Inha Univ., 253 Yonghyum Dong, In cheon 402-751, Korea)

This paper presents the correlation between psychological and physiological acoustics for the automotive sound. The research purpose of this paper is to evaluate the sound quality of interior sound of a passenger car based human sensibility. The conventional method for the objective evaluation of sound quality is to use the only sound metrics based on psychological acoustics. This method used not only psychological acoustics, but also physiological acoustics. For this work, the sounds of five premium passenger cars are used for the subjective evaluation. The correlation between this subjective rating and sound metrics based on psychological acoustics is calculated. Finally, the correlated sound metric is used for calculating the correlation between sound metric and the electron cephalogram signal measured on the brain. Throughout these results, the new evaluation system for the sound quality on interior sound of a passenger car has been developed.

Session 1aAB

Animal Bioacoustics: Acoustic Ecology

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Thomas Norris, Cochair
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Chair's Introduction—8:00

Invited Papers

8:05

1aAB1. Marine acoustic ecologies and acoustic habitats: Concepts, metrics, and realities. Christopher W. Clark, Aaron N. Rice, Dimitri W. Ponirakis, and Peter J. Dugan (Bioacoustics Res. Prog., Cornell Univ., 159 Sapsucker Woods Rd., Ithaca, NY 14850, cwc2@cornell.edu)

Whales, dolphins, and porpoises (cetaceans) are adapted to produce and perceive sounds that collectively span 4–6 orders of magnitude along space, time, and frequency dimensions. Two important concepts, acoustic ecology and acoustic habitat, emerge from this perspective: where acoustic ecology is the study of acoustics involved in interactions of living organisms, and acoustic habitat as ecological space acoustically utilized by particular species. Cetaceans are dependent on access to their normal acoustic habitats for basic life functions. Communication masking from anthropogenic sounds that are chronically present can result in measurable losses of cetacean acoustic habitats, especially for low-frequency specialists, baleen whales. A communication masking model, informed by multi-year datasets, demonstrates cumulative influences of multiple vessels on fin, humpback and right whale acoustic habitats at spatial, temporal, and spectral scales matched to ecologically meaningful habitats. Results quantify acoustic habitat spatio-temporal variability over ecologically meaningful scales. In some habitats with high vessel traffic and vessel noise, predicted habitat loss and area over which animals can communicate is dramatically reduced compared to what it would be under non-vessel conditions. From a large-scale, ecological perspective, these acoustic habitat reductions likely represent significant costs for species for which acoustic communication is biologically critical.

8:30

1aAB2. Evaluating the potential spatial extent of chronic noise exposures of sufficient magnitude to raise concerns of wildlife impacts. Kurt M. Fristrup (Natural Sound and Night Sky Div., Natl. Park Service, 1201 Oakridge Dr. Ste. 100, Fort Collins, CO 80525, kurt_fristrup@nps.gov)

Noise is probably the fastest growing pollutant in the United States. Traffic levels for many forms of transportation and recreation are increasing in much faster rates than population size. The consequences of chronic noise exposure for natural ecosystems are numerous and potentially severe. Decreases in pairing success, recruitment, population density, and community diversity have been documented for a variety of taxa. This presentation provide a capsule summary of documented biological impacts. These findings will be used to interpret the results from acoustical monitoring in a variety of National Park units, as well as predictions from noise models.

Contributed Papers

8:55

1aAB3. Endangered Stephen's kangaroo rats respond to road noise with footdrumming. Debra M. Shier, Amanda J. Lea, and Megan A. Owen (San Diego Zoo Global Inst. for Conservation Res., 15600 San Pasqual Valley Rd., Escondido, CA 92027)

On-road vehicles have become a pervasive source of low frequency noise in both urban and protected areas. Because many species rely on low-frequency signals to communicate, they are likely vulnerable to signal masking and other adverse effects of road noise exposure. We recorded and quantified both road noise and low frequency footdrumming signals from endangered Stephen's kangaroo rat (*Dipodomys stephensi*; SKR), and found the two signals to overlap extensively. We then played back footdrumming overlaid with experimental (road noise), as well as positive (crickets) and negative control (no noise) sounds to SKR. SKR showed no response to footdrumming playbacks overlaid with road noise, suggesting that noise may mask conspecific signals. Furthermore, playbacks of road noise alone provoked similar behavioral responses to those of footdrumming controls. It appears that road noise itself may mimic footdrumming and prompt a false response in SKR. Therefore, anthropogenic noise may not only mask signaling, it may also function as a deceptive signal to wildlife. For SKR, the combined effects of communication disruption and signal deception may further tax already endangered populations. Road margins serve as dispersal corridors and refugia for SKR, yet these areas may function as ecological traps if anthropogenic noise negatively affects populations.

9:10

1aAB4. Influence of impulsive sources on the soundscape of under-ice Arctic marine mammals. Juan I. Arvelo, Jr. (Natl. Security Technol. Dept., The Johns Hopkins Univ. Appl. Phys. Lab., 11100 Johns Hopkins Rd., Laurel, MD 20723-6099, juan.arvelo@jhuapl.edu)

The Arctic Ocean exemplifies the danger in using sound propagation and interaction models without a clear understanding of the physics of the problem or weaknesses inherent in these models. The zone-of-influence for under-ice marine mammals should be expected to differ significantly from that of open-sea organisms. However, increasing the effective sound attenuation, to empirically account for sound interactions with keel drafts, may lead to grossly erroneous conclusions from predictive and forensic studies. Ice elasticity and ridges combine to increase water/ice low-frequency sound penetration enabling long-distance transmission along this liquid–solid interface in the form of an evanescent wave. Consequently, sound pressure and exposure levels near the canopy are significantly higher even when the acoustic wavelength is several times longer than the ice thickness. Therefore, these physical mechanisms should also be taken into account in Arctic environmental impact assessment calculations. For example, it is more efficient for under-ice marine mammals to mitigate exposure to subsequent active sonar events by diving just a few meters deeper under the ice cap rather than increasing range by hundreds of meters. Therefore, some under-ice marine mammals are likely to exhibit a stronger preference toward diving avoidance behavior. [Work funded by UAF sub-award under NOAA Grant NA09NOS4000262.]

9:25

1aAB5. Seasonal presence of ringed, ribbon, and bearded seal vocalizations in the Chukchi Sea north of Barrow, Alaska. Joshua M. Jones, Ethan Roth, Bruce J. Thayre, Ian Sia (Marine Physical Lab., Scripps Inst. of Oceanogr. Univ. of California San Diego, La Jolla, CA 92093-0205), Michael Mahoney, Clarissa Zeller, Malorie Johnson, Christine Jackson, Kyle Kitka, Daniel Pickett (Mount Edgecumbe High School, AK 99835-9418), Robert Small (Alaska Dept. of Fish & Game, Juneau, Alaska), Zoe Gentes, Sean Wiggins, and John Hildebrand (Univ. of California, San Diego, La Jolla, CA 92093-0205)

Long-term autonomous acoustic recordings were collected between September and June from 2006 through 2009 in the Northeastern Chukchi Sea along the continental slope 120 km north of Barrow, Alaska. These recordings were analyzed for the presence of vocalizations of ringed seals (*Phoca hispida*), ribbon seals (*Histrophoca fasciata*), and bearded seals (*Erignathus barbatus*). We present detailed descriptions of the acoustic repertoire of each species in addition to three-year time series of seal vocalizations and mean daily sea ice concentration. Ringed seal vocalizations are present throughout each winter and spring, indicating that they both overwinter and breed in offshore pack ice. Ribbon seal calls occur only during the open water period in 2008, but their acoustic behavior is more varied than previously described. Bearded seal vocalizations closely match well-documented calls recorded offshore near Point Barrow but have shorter duration and smaller frequency range, suggesting that demographic or behavioral differences related to breeding habitat selection may exist within the population. Bearded seal calls peak during the breeding season from March through June, but also occur in December and January annually. These long-term autonomous recordings provide details of seasonal distribution and behavior of Arctic seals that previously have not been possible to observe with other methods.

9:40

1aAB6. The acoustic ecology of minke whales in the tropical north pacific. Thomas Norris (Bio-Waves, Inc., 517 Cornish, Encinitas, CA 92024), Steven W. Martin (Space and Naval Warfare Systems Ctr. Pacific, 53560 Hull St., San Diego, CA 92152), Tina M. Yack (Bio-Waves Inc., Encinitas, CA 92024), Len Thomas (Univ. of St. Andrews, Fife KY16 9LZ, Scotland), and Julie Oswald (Bio-Waves, Inc., Encinitas, CA 92024)

The minke whale (*Balaenoptera acutorostrata*) is a ubiquitous but rarely sighted species that occurs in subtropical waters of the North Pacific during winter and spring. It produces a unique vocalization called a boing that is easy to detect and localize. We characterized the acoustic ecology of minke whales by detecting and localizing boings using passive acoustic methods. We conducted passive acoustic line-transect surveys in 2006 for a large area around the Northern Mariana Islands (site 1), and in 2010 for a smaller area off the Pacific Missile Range, Kauai, HI (site 2). We also recorded acoustic data from deep waters using cabled seafloor hydrophones at site 2. Densities of calling animals were estimated from line-transect surveys and will be used to estimate calling rates for use in spatially explicit capture–recapture analysis of fixed seafloor hydrophone data. Spatial analysis of acoustic localizations in relation to bathygraphic and oceanographic variables will be discussed. We provide examples of counter-calling and complex responses to vessel noise. These results provide important information about the acoustic ecology and behavior of minke whales that can be used to improve the conservation and management of this elusive but common whale. [Work sponsored by ONR and NAVFAC.]

9:55

1aAB7. Characterizing the vocalizations of North Atlantic right whales (NARWs) in Florida, with emphasis on mother-calf pairs. Edmund Gerstein (Dept. of Psych., Charles E. Schmidt College of Sci. Florida Atlantic Univ, Boca Raton, FL 33431, gerstein2@aol.com), James Hain (Associated Scientists of Woods Hole, Woods Hole, MA 02543), James Moir (Marine Resources Council, Palm Bay, FL 32905), and Stephen McCulloch (Harbor Branch Oceanograph. Inst., Ft. Pierce, FL 34946)

The repertoire of calls, frequency of occurrence with respect to social composition, and ontogeny of vocal learning is being investigated for NARWs in their southeastern critical habitat of Florida. Small synchronized, GPS-instrumented, digital autonomous recording packages (DARPs) are deployed in the vicinity of photo-identified individuals, mother-calf pairs, and groups. The unobtrusive DARP buoys enable the recording of relatively rare, low-intensity vocal exchanges between mothers and calves. We hypothesize that it may be advantageous to be silent or to call softly to avoid predators or harassment by males in the area. These mother-calf exchanges could also be related to early developmental aspects of vocal communication. Site-specific bathymetry and active propagation measurements are conducted with vertical arrays to estimate source levels, and ranges of detection. Preliminary data indicate that exemplar (up-calls) recorded in northern habitats and used for training detection algorithms for passive auto-detection buoys are likely not appropriate for Florida waters. Social demographics, associated behavior, along with water depth and environmental parameters contribute to differences in call rates, types, source levels and respective propagation characteristics between the southeastern and northern habitats. Critical acoustic data required for selecting more appropriate calls for effective DCL algorithms in Florida waters are currently being collected.

10:10–10:25 Break

Invited Papers

10:25

1aAB8. Environmental influences on acoustic communication in frogs. Peter M. Narins (Dept. of Integrative Biology and Physio., UCLA, 621 Chas. E. Young Dr. S., Los Angeles, CA 90095, pnarins@ucla.edu)

Many species of animals, including man, face the formidable task of communicating in naturally noisy environments. The effects of noise on both the calling behavior of frogs and the temporal, and spectral filtering ability of the amphibian auditory pathway are discussed. Moreover, the role of spectral, temporal, and spatial separation in minimizing background noise masking will be examined. Behavioral evidence is presented suggesting that environmental noise may act as a strong selective force in sculpting the communication

systems of two species of Old World frogs. One torrent frog (*Odorrana tormota*) calls frequently from vegetation along fast-flowing mountain streams in Central China. These streams produce high-level, broadband noise spanning the human hearing spectrum. In addition to the high-pitched audible components, the males' calls contain prominent ultrasonic harmonics. Another frog, *Huia cavitympanum*, lives in a very similar habitat in Borneo. Unlike *O. tormota*, *Huia* can modulate its call spectrum to produce purely ultrasonic calls. It is thought that the upward shift of the call frequencies and the upper limit of sensitivity of both *O. tormota* and *H. cavitympanum* are responses to the selection pressures from their noisy habitats. [Work supported by NIDCD DC-00222, Paul S. Veneklasen Research Foundation, UCLA Academic Senate (3501).]

10:50

1aAB9. Chorussing in delphinids. V. M. Janik (School of Biology, Univ. of St. Andrews, Fife KY16 8LB, United Kingdom), P. Simard (Univ. of South Florida, St. Petersburg, FL), L. S. Sayigh (Woods Hole Oceanograph. Inst., Woods Hole, MA), D. Mann (Univ. of South Florida, St. Petersburg, FL), and A. Frankel (Marine Acoust. Inc., Arlington, VA)

The evolution of communication is strongly influenced by the social structure of animals. Here, we report how a group of offshore bottlenose dolphins in the Gulf of Mexico used chorusing of the same whistle type, while no such behavior was observed in inshore populations of the same species. We recorded 166 whistles from a group of 6 bottlenose dolphins in the Gulf of Mexico, 19 nm from the Florida coast. In an examination of the timing of whistle production, we found nine sequences in which there was considerable overlap (i.e., >50%) between whistles and another eight sequences with almost perfect overlap of the same whistle type produced by two to six animals simultaneously. Such synchrony was not expected by chance. To investigate how unique this behavior was, we also analyzed 300 h of recordings of inshore bottlenose dolphins in Florida and Scotland. In these data we found three non-significant cases of two animals showing >50% overlap. Thus, chorusing appears to be absent in inshore animals. Our data suggest that offshore bottlenose dolphins live in closed social units, which could be the result of enhanced difficulties in maintaining contact if home ranges are large.

Contributed Papers

11:15

1aAB10. Tracking dolphins using long-term autonomous acoustic recorders. Sean M. Wiggins, Martin Gassmann, Kaitlin Fraiser, and John A. Hildebrand (Scripps Inst. of Oceanogr., 9500 Gilman Dr., La Jolla, CA 92093-0205, swiggins@ucsd.edu)

Tracking marine mammals over long periods can provide information on their movement patterns including base-line behavior and responses to natural and anthropogenic stimuli. Autonomous acoustic recorders provide a cost effective and portable means of tracking these sounds over long periods, but until recently these devices have been restricted to tracking low-frequency large whales because of limited recording capabilities. In this paper, we will present long-term, passive acoustic tracking of high-frequency dolphin whistles and clicks using autonomous hydrophone recording arrays with kilometer- and meter-scale apertures.

11:30

1aAB11. High-frequency modulated signals of killer whales (*Orcinus orca*) in the North Pacific. Anne E. Simonis, Simone Baumann-Pickering (Scripps Inst. of Oceanogr., Univ. of California, San Diego, 9500 Gilman Dr. La Jolla, CA 92093-0205), Erin Oleson (NOAA Fisheries, Honolulu, HI 96814), Mariana L. Melcón, Martin Gassmann, Sean M. Wiggins, and John A. Hildebrand (Univ. of California, San Diego, La Jolla, CA 92093-0205)

Killer whales (*Orcinus orca*) use acoustic signals to echolocate and communicate, although there are differences in acoustic behavior among ecotypes. Atlantic resident populations recently have been reported to produce acoustic signals at higher frequencies than previously known. Acoustic recordings from ship-based acoustic and visual surveys and from autonomous acoustic recorders reveal that killer whales across a broad range of the North Pacific Ocean also use similar high frequency modulated signals. The median peak frequency of these signals ranged from 19.6 to 36.1 kHz at different locations, with median durations from each location ranging from 50 to 163 ms. All observed high frequency modulated signals were frequency downswept with no or few inflection points. Killer whales are generally believed to use whistles for close range communication in social contexts; however, these uniform, repetitive, down-swept signals are similar to bat echolocation signals and may have echolocation functionality. The large geographic range of occurrence suggests that these signals are utilized by different killer whale ecotypes. [Work funded by Michael Weise at the Office of Naval Research, Frank Stone at Navy CNO-N45, Bob Haskell at Pacific Life, and Mark Spaulding at the Ocean Foundation.]

11:45

1aAB12. Long-term passive acoustic monitoring of parrotfishes (Scaridae) in the *Hawaiian Archipelago*. Lisa M. Munger (Hawaii Inst. of Marine Biology, Univ. of Hawaii, P.O. Box 1346 Kaneohe, HI 96744, lmunger@hawaii.edu), Pollyanna Fisher-Pool, Kaylyn McCoy, Marc O. Lammers, Timothy Tricas, Whitlow W. L. Au (Univ. of Hawaii, Honolulu, HI 96744), Kevin Wong, and Russell E. Brainard (NOAA Fisheries, Honolulu, Hawaii)

Parrotfishes (family *Scaridae*) are an important component of coral reef ecosystems, and this key functional group plays a major role in algae removal and bioerosion of reef substrate. They are also heavily fished in many locations, which may lead to ecosystem-wide impacts such as increased algal cover. In the State of Hawaii, parrotfish management is a priority for marine resource managers, with an ongoing need for accurate population monitoring that is currently addressed by diver-based visual surveys. However, parrotfishes are highly mobile and somewhat skittish around SCUBA divers, particularly in areas where fishing pressure is high. Because parrotfishes produce frequent audible scraping and crunching sounds associated with feeding, passive acoustic monitoring (PAM) can provide information on parrotfish occurrence without requiring the invasive presence of divers. Here, we present results from analyses of parrotfish foraging sounds in long-term acoustic recordings from 10 shallow reef locations throughout the Hawaiian Archipelago dating back to 2006. Parrotfish sounds are compared spatially across a fishing pressure gradient, from heavily fished areas in the main Hawaiian Islands to protected waters within the Papahānaumokuākea Marine National Monument (Northwestern Hawaiian Islands). Results from PAM are compared when possible with data from adjacent visual censuses conducted by divers.

Session 1aAO

Acoustical Oceanography, Underwater Acoustics, and Animal Bioacoustics: Van Holliday Memorial Session I

Whitlow W. L. Au, Cochair
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Kelly J. Benoit-Bird, Cochair
College of Ocean and Atmospheric Science, Oregon State Univ., 104 COAS Admin Bldg., Corvallis, OR 97331-5503

Michael J. Buckingham, Cochair
Scripps Inst. of Oceanography, Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0238

Timothy K. Stanton, Cochair
Dept. of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Inst., Bigelow 201, Woods Hole, MA 02543-1053

Chair's Introduction—8:15

Invited Papers

8:20

1aAO1. Dale (Van) Holliday was so much more than a scientist. Dorian S. Houser (Natl. Marine Mammal Foundation, 2240 Shelter Island Dr. #200, San Diego, CA 92106)

Dale (Van) Holliday is well known for his acoustic studies of ocean life over a scale from plankton to mysticete whales. Van was a globally acknowledged expert valued for his participation in national and international councils governing ocean issues. Multiple times he was awarded high honors, such as the Prix d'Excellence and the Silver Medal in Acoustical Oceanography. More importantly, Van was a man of faith and no respecter of persons; he unselfishly gave of his time and knowledge and treated both students and career scientists with the level of respect due an individual. I was professionally mentored by Van and worked alongside him as a church deacon. As a deacon, I observed Van's compassion—the numerous hospital trips to visit the sick, the visitations of the home bound, and the phone calls to just "check in." His interest in people spilled into his professional relationships, particularly with young and emerging scientists whom Van joyfully assisted and advised. I, and numerous others, have and continue to benefit from our friendship and professional relationship with Van. He was truly unique. He will be missed, but not forgotten, as his science and investment in people will remain impactful for decades to come.

8:40

1aAO2. Van Holliday: Ocean acoustician and biological oceanographer. Richard E. Pieper (Fish Harbor Marine Lab., 820 S. Seaside Ave., Terminal Island, CA 90731)

I first met Van Holliday in 1970 at the International Symposium on Biological Sound Scattering in the Ocean. We were both graduate students, Van at Scripps and I was at the UBC. Two of us were interested in higher frequency acoustics and scattering from zooplankton. In the Working Group on Bioacoustics Recommendations, Brooke Farquhar and Van Holliday wrote "By using acoustic techniques over large frequency ranges (100 Hz to 10 mHz), the distribution of nekton and plankton could be obtained." I moved to USC after graduation and began to meet Van at ONR site reviews. We received funding from ONR and NSF in mid 1970. I bought a plankton pump and Van put together a four-frequency acoustic array (0.5, 1.16, 1.80, and 3.08 MHz). The program began and continued for over 30 yr. With the success of our four-frequency system, we obtained a recently de-classified Shadowgraph system from the Navy and Van built a 21-frequency array (100 kHz to 10 MHz) which was used in many ocean environments. The uniqueness of scattering from zooplankton led Van to develop an inversion algorithm to calculate zooplankton size spectra from the acoustic data. The four-frequency TAPS was designed and is used by many today.

9:00

1aAO3. Van Holliday: A lifetime of contributions to acoustical oceanography. David M. Farmer (The Graduate School of Oceanogr., Univ. of Rhode Island, 215 South Ferry Rd., Narragansett, RI 02882)

Van Holliday's achievements have transformed the acoustical study of marine biology. Working closely with colleagues from fisheries and marine biology, he brought his keen understanding of acoustics and lively curiosity to the solution of many challenging problems. In reviewing his accomplishments one is struck by their range and by the special way in which he reached out to the fields to which he contributed. For example, when he solved a problem such as acoustical scattering by fish schools, he quickly saw the possibilities of exploiting his new understanding to study schooling behavior. He explored the characteristics of ice noise, he was the first to track the movement of whales acoustically and he made major contributions to our understanding of the scattering of sound by zooplankton. His work on plankton acoustics led to the important new sub-discipline of spectral acoustic determination of zooplankton populations and their behavior. His profound contributions to biology, biophysics, and other marine topics display an intellectual breadth, an enthusiasm for crossing disciplinary boundaries, and a deep curiosity that serve us well as a model for achievement in the field of acoustical oceanography.

Contributed Papers

9:20

1aAO4. On Van Holliday's shoulders. Orest Diachok (Johns Hopkins Univ. Appl. Phys. Lab., Laurel, MD 20723-6099)

The year was 1992. The Cold War was over, and funding for resolving deep water issues was fading. I was at the NATO Undersea Research Centre, simultaneously searching for a new research challenge that I could sink my teeth into, and formulating a research program for the Centre, which would be appropriate for the post-Cold War era. I stumbled onto Van's classic paper on resonance scattering by fish, discussed it with him by telephone, and within an hour became a convert to marine bioacoustics. I became familiar with David Weston's work, discussed it with him, and soon thereafter started my research in bioacoustics. Van and David made important contributions to the design of my bioacoustics experiments. After I returned to the USA, I often met with Van to discuss a broad spectrum of fundamental and applied topics in bioacoustics. He was always generous with his time, knowledge, and insights. His explanations of seemingly complex phenomena were always readily understandable, concise, and precise. Standing on Van Holliday's shoulders, greatly expanded my vision of what is possible through technical innovation, interdisciplinary collaboration, dedication, and perseverance. I, along with many others, miss and will continue to miss this amazing and unique individual.

9:35

1aAO5. Acoustics as a tool to answer fundamental marine ecological questions: Thanks Van! James E. Eckman (California Sea Grant Prog., Scripps Inst. of Oceanogr., Univ. of California San Diego, 9500 Gilman Dr. 0232, La Jolla, CA 92093, jeckman@ucsd.edu)

Van Holliday was an acoustician with a sound appreciation (apologies) of the complexity, importance, and beauty of marine animals and plants. His bio-acoustical work, motivated initially by an interest in the significant impacts of fish on acoustic backscatter, rapidly led to studies that addressed the value of that backscatter in answering scientific questions about fish. His research and interests expanded rapidly to provide us with new tools capable of detecting and mapping zooplankton. Moreover, his later efforts contributed to an appreciation of the dynamics and importance of the productivity of benthic microalgae in shallow sediments. While many appreciate the value of his contributions to acoustics, and to the basic detection and mapping of planktonic and nektonic life forms, fewer scientists appreciate that the tools (hardware and software) he developed have helped open a door that enables us to address fundamental biological and ecological questions regarding plankton dynamics and benthic-pelagic couplings: questions that still remain inadequately explored. From my perspective as a former program manager at ONR, I will discuss some of Vans contributions that provide a gateway to asking, and answering, a wide-range of ecologically important questions.

9:50

1aAO6. Broadband active acoustic sensing of fish and zooplankton in the kilohertz to megahertz range: Pursuing Van Holliday's vision. Timothy K. Stanton (Dept. Appl. Ocean Phys. and Eng., Woods Hole Oceanograph. Inst., Woods Hole, MA 02543-1053, tstanton@whoi.edu), Dezhang Chu (NOAA Natl. Marine Fisheries Service, Seattle, WA 98112), and Andone C. Lavery (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543-1053)

Van Holliday had a vision for sensing marine organisms with active acoustics over a very wide range of frequencies. This inspired us at the Woods Hole Oceanographic Institution, Woods Hole, MA, to conduct a series of measurements, both in the laboratory and in the ocean, and associated modeling, over the range of 1.5 kHz to 3 MHz over the past 23 years. The organisms were as small as millimeter-size copepods and as large as 20-cm herring and squid. Broadband acoustic scattering measurements were conducted in the laboratory as a function of frequency (24 kHz 3 MHz) and angle of orientation (0–360 deg) of many species. Instruments were developed to measure broadband acoustic scattering in the ocean over the range 1.5 kHz 1.2 MHz with some gaps. Scattering models, based on the laboratory data, were also developed for several major anatomical groups of organisms and spanned a range of complexity, from low-resolution models that account only for length, width, and general shape to high resolution models that account for shape of the body and heterogeneities within the body in three dimensional at fine scale as well as including roughness. In this presentation, we review the laboratory measurements and scattering models, as well as development of the broadband ocean instruments and their use at sea.

10:05–10:20 Break

10:20

1aAO7. Planktonic layers: New insights stimulated by Van Holliday. Timothy J. Cowles (Consortium for Ocean Leadership, 1201 New York Ave. NW, Washington, DC 20005, tcowles@oceanleadership.org) and Kelly Benoit-Bird (Oregon State Univ., Corvallis OR 97331, kbenoit@coas.oregonstate.edu)

During the late 1980s and early 1990s, initial evidence for persistent thin layers of phytoplankton (less than 1 m in thickness) in the upper ocean was obtained with optical instrumentation. These observations were inconsistent with the existing understanding of small-scale vertical mixing processes and raised questions about the ecological consequences of such structures, should they prove to occur on a regular basis. Dr. D. Van Holliday quickly saw the need for new approaches in acoustical oceanography to address these important ecological questions. Over a period of a few years, Dr. Holliday developed new acoustical tools that could be deployed in concert with other sensors. His moorings with customized high-frequency transducers allowed acoustical resolution over scales of centimeters, sufficient to capture the acoustic signature of marine zooplankton and their spatial relationship to their food supply. The insights provided by Van's work, and his constant encouragement to his colleagues, have led to significant breakthroughs in our understanding of upper ocean physical, biological and chemical processes. This presentation will incorporate recent observations and build upon Van's observations to illustrate the importance of his contributions to ocean science.

10:35

1aAO8. Parsing the prose of D. V. Holliday. Kenneth G. Foote (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543)

The published works of D. V. Holliday have been praised as exemplifying the scientific method [K. G. Foote, J. Acoust. Soc. Am. **115**, 2521 (2004)]. They also exemplify a direct writing style that embodies some elements of a physical theory. Paraphrasing P. Duhem in The Aim and Structure of Physical Theory (Princeton University, 1954), these works, by Holliday, communicate "as simply, as completely, and as exactly as possible, a whole group of experimental" findings. These stylistic features are illustrated by reference to three papers published in JASA under Holliday's name, one with a coauthor, during the period 1972–1980.

10:50

1aAO9. Active acoustic examination of the diving behavior of murres foraging on patchy prey. Kelly J. Benoit-Bird (College of Oceanic and Atmospheric Sci., Oregon State Univ., 104 COAS Admin Bldg., Corvallis, OR 97331, kbenoit@coas.oregonstate.edu)

Van Holliday used sound to study nearly every type of organism living in the ocean, contributing to our understanding of acoustics as well as marine ecological processes. To honor Van, I will talk about the one animal group that I could not find in his long publication list—seabirds. We combined visual observations of murres with active acoustics, fish trawls, zooplankton net tows, and hydrographic measurements in the area surrounding breeding colonies in the southeastern Bering Sea. We detected thousands of unique acoustic targets that were strongly correlated with the number of visually detected murres, providing a new tool for quantitatively studying the foraging ecology of diving birds. Diving murre abundance was related to the combined availability and vertical accessibility of squid, krill, and pollock. Individual krill patches targeted by murres had higher krill density and were shallower than mean values but were similar in total krill abundance and overall size. Murres found outside of krill showed a depth distribution similar to that of juvenile pollock. The high proportion of diving murres in aggregations and their consistent inter-individual spacing support the hypothesis that intra-specific local enhancement may facilitate foraging in these predators.

11:05

1aAO10. Zooplanktivory of fishes measured with a dual wide band sonar/optical imaging system. Amatzia Genin (Hebrew Univ. and Interuniversity Inst. Mar. Sci. Eilat 88203, Israel), Jules Jaffe (Scripps Inst. of Oceanogr., La Jolla, CA 92093-0238), Yoav Lindemann (Hebrew Univ. and Interuniversity Inst. Mar. Sci. Eilat 88203, Israel), Paul Roberts (Scripps Inst. of Oceanogr., La Jolla, CA 92093-0238), and Yonathan Guttel (Hebrew Univ. and Interuniversity Inst. Mar. Sci. Eilat 88203, Israel)

Recent experiments in several near shore habitats in Eilat, Israel, were performed to measure various aspects of predation on zooplankton. Toward this goal, two sets of (4) wide band echo-sounders that can identify echoes from individual sub-millimeter copepods in liter-sized volumes were deployed. The echo sounders were augmented with an underwater optical shadowgraph imaging system that concurrently imaged a 100 ml volume with 25 μm resolution that provided many usable *in-situ* images of the animals that were producing the acoustic reflections. Sonars were located both upstream and downstream from a group of zooplanktivorous fish, allowing measurement of zooplankton abundance in water parcels before and after they passed through the fish group. Information on fish abundance and movements was obtained with concurrent video records. Together with ancillary environmental measurements of flow rate and light level, zooplanktivory rates of: animals consumed per cubic meter per fish were computed from the differential concentration of animals as inferred from the two sets of four echo-sounders. The results permit the estimate of important environmental features of the ecosystem such as the dependence of predation rate on prey abundance, their size, and flow speed.

11:20–11:40 Panel Discussion

MONDAY MORNING, 31 OCTOBER 2011 SUNSET, 8:15 TO 11:25 A.M.

Session 1aSA

Structural Acoustics and Vibration: Multifunctional Composite Structures

Gopal P. Mathur, Cochair
The Boeing Company, 5301 Bolsa Ave., Huntington Beach, CA 92647

Noureddine Atalla, Cochair
Dept. of Mechanical Engineering, Univ. de Sherbrooke, Sherbrooke QC J1K 2R1, Canada

Chair's Introduction—8:15

Invited Papers

8:20

1aSA1. Multifunctional composite materials and structures: A brief review. Ronald F. Gibson (Dept. of Mech. Eng., MS-312, Univ. of Nevada-Reno, Reno, NV 89557)

Recent advances in the area of multifunctional materials and structures are reviewed. Interest in this area has been driven by the need for systems that simultaneously perform structural and nonstructural functions. Multifunctional materials are by nature composite materials and new nanoreinforcements, in particular, have made it possible to achieve simultaneous improvements in properties such as stiffness, compression strength, damping, electrical conductivity, and fracture toughness. For example, among the most important nonstructural functions that a structure may need is electrical conductivity, but many composites have poorly conducting polymer matrix materials. However, very small concentrations of carbon nanotubes or other conducting nanoreinforcements in polymers lead to disproportionately large improvements in the electrical conductivity of the nanocomposite. Recently developed composites with piezoelectric structural fiber reinforcements are capable of vibration control, damping, energy harvesting/storage, or structural health monitoring. Recent research has also demonstrated the feasibility of self-healing polymers and polymer composites based on the use of a microencapsulated healing agent and a catalyst for polymerizing the healing agent. Structurally integrated electronics such as batteries for energy storage are another recent application of multifunctional structure design. Other important nonstructural functions in multifunctional composite structures include electromagnetic interference shielding, optical transparency, and thermal conductivity.

8:40

1aSA2. Multifunctional acoustic metamaterial composites. Christina J Naify and Steven Nutt (Dept. of Mater. Sci., Univ. of Southern California, 3651 Watt Way VHE 402, Los Angeles, CA 90089)

Composite structures used in aerospace applications are designed to optimize high bending stiffness to weight ratio. Acoustical performance of composite structures, however, is notoriously poor due to decreased mass law performance and decreased coincidence frequency. Efforts to improve the acoustic properties of composite structures have included optimization of material selection as well as addition of acoustic treatments. Additionally, development of composite structures to include multifunctional properties has increased. In this study, two types of multifunctional approaches were examined using acoustic metamaterials. Locally resonant acoustic metamaterials (LRAM), which have sound insulation performance of 500% increase over the mass law prediction, were integrated into a high-strength sandwich structure array to provide increased acoustic performance without increase in mass. LRAM were constructed of thin, tensioned membranes with centrally located masses in the form of small magnets. Varying the geometry of the metamaterial to tune effective frequencies optimized acoustic performance. Acoustic excitation of the central magnet was used to harvest energy by positioning a wire coil around each cell such that the displacement of the magnet induced a voltage. Combination of energy harvesting and array configurations produced multifunctional materials with three applications: increased stiffness, optimal acoustic performance, and harvesting of acoustic energy.

9:00

1aSA3. Wave number and damping characterization for sound and vibration mitigation in sandwich composite structures. James J. Sargianis and Jonghwan Suhr (Dept. of Mech. Eng., Univ of Delaware, 130 Acad. St., Newark, DE 19716, James.Sargianis@gmail.com)

With the rising demand for high performance composite materials, there is a great interest for multi-functional materials. Our research focuses on materials with high noise mitigation and passive structural damping with minimal sacrifice in bending stiffness. Specifically, we seek to understand the vibrational properties of carbon-fiber face sheet sandwich beams, with interest in wave number and damping characteristics. Both experimental and analytical methods were applied to characterize the wave number response of sandwich beams, from which coincidence frequencies were obtained. From the same frequency response function, structural damping ratios were calculated using the half-power bandwidth method. Results showed that for low frequency applications, decreasing bending stiffness has the greatest effect on increasing the coincidence frequency. However for higher frequency applications, an improvement in coincidence frequency can be seen if one reduces the core's shear modulus. Moreover it may be concluded that the high amplitudes seen in the wave number domain may be contributed to the lower structural damping values at low frequencies. With both wave number and damping properties being frequency dependent, one can optimize design parameters pertaining to a certain frequency range which will improve damping and acoustic properties while maintaining necessary flexural stiffness.

9:20

1aSA4. Overview of cumulative results of characterization studies of composites. Bernhard R. Tittmann (Dept. Eng. Sci. & Mech., Penn State, University Park, 212 EES, PA 16802)

After an introduction into design concepts of composites, this paper presents a survey of material characterization investigations of a variety of composites ranging from graphite/epoxy, to metal-matrix, to carbon/carbon to CF/PEEK, and to biological material such as plant cell walls. Discussed are the results of a series of studies in anecdotal form, which include the characterization of soft-body impacts with gelatin projectiles as simulation due to bird strike, the healing of impact damage as imaged and followed by increasing temperature (5000 °C) in acoustic microscopy, finite element simulations of embedded piezoelectric element transducers, acoustic shear velocity measurements during the curing of graphite/epoxy; acoustic emissions during carbonization of carbon/carbon by the use of guided wave techniques inside an autoclave; and acoustic microscopy imaging in the characterization of metal-matrix composites. Always a factor is the resolution requirement. At the extreme end of the resolution capability of current instrumentation is the sub-nanometer resolution of the atomic force microscope which has been demonstrated by the imaging of plant cell walls (onion skin), which are a form of nature's composite structure. These topics have given insight into the many facets of problems as well as opportunities for the use of the characterization of composites.

9:40

1aSA5. Transmission loss of curved sandwich-composite panels with attached noise control materials. Noureddine Atalla (Dept. of Mech. Eng., Univ., de Sherbrooke, Sherbrooke (QC), J1K 2R1, Canada) and Franck Sgard (Inst. de recherche Robert-Sauvé en santé et en sécurité du travail, Montréal (QC), H3A 3C2, Canada)

This paper discusses the modeling of the transmission loss of curved sandwich-composite panels with attached noise control treatments using both analytical and numerical methods. Special attention is devoted to the modeling using the Transfer Matrix Method (TMM) and Statistical Energy Analysis (SEA) of these structures in various mounting conditions (single wall and double wall) under diffuse acoustic field excitation with a systematic comparison with an efficient FEM/VBEM formulation of the problem. Classically, in SEA models the sound package is unwrapped and the TMM is used to calculate its effects in terms of added damping, absorption, and insertion loss. Examples are presented to examine the validity of this practice and demonstrate its range of applicability and usefulness.

10:00–10:15 Break

10:15

1aSA6. Active control of a composite panel utilizing piezoelectric patches connected to negative capacitance shunts. Kenneth A. Cunefare, Benjamin S. Beck (The Georgia Inst. of Technol., School of Mech. Eng., Atlanta, GA 30332, ken.cunefare@me.gatech.edu), and Francisco Mariano Badea Romero (Madrid Polytechnical Univ., INSIA, Carretera de Valencia, 28031 Madrid)

Many industries are implementing the use of thin, lightweight carbon fiber panels to increase stiffness and decrease weight. Yet, vibrations of the panels can reach large amplitudes causing an increased acoustic noise field. The use of piezoelectric actuators bonded on or within the

composite panels can be used to decrease the vibration. Negative capacitance shunts have been shown to decrease flexural vibrations over a broadband frequency range. By using the negative capacitance shunts connected to piezoelectric patches, the noise field can be reduced. Yet, the effect of the control may also cause increased acoustic coupling causing more of the flexural modes to create propagating acoustic waves. The acoustic effects of the control system on a clamped carbon fiber composite panel are analyzed by investigating the flexural amplitude and wave number decomposition. The results of the numerical model of the panel are experimentally validated.

10:35

1aSA7. Resonant frequencies of rectangular plates immersed in fluids. Kai Ming Li (Dept. of Mech. Eng., Purdue Univ., 140 S. Martin Jischke Dr., West Lafayette, IN 47907-2031)

The response of a fluid-loaded structure is a subject of considerable interests in many areas of engineering. This includes applications in aerospace industry for composite structures, design of offshore and building structures partially immersed in water, and the design of rectangular micro-plates for bio-sensing devices. For many decades, it has been well recognized that the resonant frequencies of structures in contact with fluid decrease significantly if the fluid-loading on the structure is very heavy. For somewhat lighter fluid-loading, the structural properties are important, and the in vacuo resonant frequencies are usually needed in determining the response due to an external driving force. This paper exploits a simple empirical model to estimate the effect of fluid-loading on the resonant frequency of a rectangular plate. Simple formulas were developed to rapidly compute the natural frequencies of rectangular plates loaded with different fluids on both sides. The rectangular plates with simply supported or clamped edges were considered in the present analysis. Particularly, a square plate with a general boundary condition varying from simply supported to clamped edges was examined. Empirical formulas were derived to calculate the change in the resonant frequencies for baffled plates in all cases.

Contributed Papers

10:55

1aSA8. Acoustic radiation from finite bilaminar submerged plates: Three-dimensional elasticity solution. Sabih I. Hayek (Dept. of Eng. Sci. and Mech., Penn State Univ., University Park, PA 16802) and Jeffrey E. Boisvert (NAVSEA Div. Newport, Newport, RI 02841)

The vibration and radiation of a submerged baffled finite rectangular bilaminar plate is obtained analytically using the three-dimensional equations of elasticity. The plate is composed of two perfectly bonded finite layers of identical size. The boundary conditions on the perimeter of the plate are free of shear stresses and pinned on the in-plane displacements. The plate is coupled to acoustic media on both sides and is baffled by an infinite rigid plane. The solution for the vibration response due to normal surface forces is found in terms of the bilaminar plate eigenmodes. The vibratory response and the associated near- and far-field radiated acoustic pressures are computed for various ratios of thickness to plate dimensions over a broad frequency range. [Work supported by the ASEE Summer Faculty Research Program.]

11:10

1aSA9. Vibrational characteristics of wood, aluminum, and composite hockey sticks. Linda J. Hunt (Dept. of Phys., Kettering Univ., 1700 W. University Ave., Flint, MI 48504) and Daniel A. Russell (Penn State Univ., University Park, PA 16802)

The stick used by ice hockey players consists of a long straight shaft attached to a curved blade. Composite materials have replaced wood and aluminum shafts for the vast majority of current professional and amateur players. The stiffness of the shaft plays a crucial role in the amount of potential energy that can be stored and released during a slap shot. Shafts are available in a wide range of stiffness and flex ratings in order to match player preference. Several wood, aluminum, and composite shafts were tested using a roving hammer experimental modal analysis with and without their blades. Mode shapes of the shaft tested alone were found to be those of a free-free beam. For shafts of similar lengths, aluminum shafts had the highest resonance frequencies and the lowest damping coefficients, while wood shafts had the lowest frequencies and the highest damping. Vibrational characteristics of whole sticks, including one-piece, two-piece sticks (shaft and blade from same material), and hybrid (shaft and blade of different materials) show that the presence of the blade significantly lowers the frequencies of the torsional modes of vibration. These results, especially damping coefficients, suggest reasons for the anecdotally preferred "feel" provided by composite sticks.

Session 1aSP

Signal Processing in Acoustics, Noise, Underwater Acoustics, Acoustical Oceanography, and Animal Bioacoustics: Sampling Methods for Model-Based Parameter Estimation

Ning Xiang, Cochair
Dept. of Architecture, Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180

Paul M. Goggans, Cochair
Electrical Engineering Dept., Univ. of Mississippi, University, MS 38677

Chair's Introduction—8:00

Invited Papers

8:05

1aSP1. Using the Markov chain Monte Carlo method to estimate model order. Paul M. Goggans and Chung-Yong Chan (Dept. of Elec. Engr., Univ. of Mississippi, Anderson Hall Rm. 302B, University, MS 38677, goggans@olemiss.edu)

Markov chain Monte Carlo (MCMC) methods are widely used in the solution of parameter estimation problems arising in acoustics and other applications. The use of MCMC to estimate the parameters of a single model is well established. However, in many applications, there is not a single model for the data but rather a number of competing models. A common method of dealing with multiple models is to use MCMC to compute the posterior probability and estimate the parameter values of each model in turn. However, for problems with many models, it is more efficient to combine the parameter spaces of all models into a single space and use MCMC to perform across-model sampling of the joint space. Although the development of an MCMC algorithm of this sort is sufficiently difficult so as to be unprofitable for the non-specialist, the acoustician wishing to solve their multi model parameter estimation problem using MCMC can still do so using an existing algorithm. This presentation gives an overview and brief tutorial of MCMC for parameter estimation and then discusses and gives an example of using the open source computer program BayeSys [Skilling, 2004] to determine the model order of a simple atomic model.

8:25

1aSP2. Bayesian inversion of seabed reverberation and scattering data via parallel tempering. Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria BC, Canada, V8W 3P6) and Charles W. Holland (The Penn. State Univ., State College, PA 16804-0030)

This paper describes Bayesian inversion of reverberation data for seabed scattering and geoacoustic parameters using the method of parallel tempering. The seabed is modeled as a sediment layer over a semi-infinite basement, with interface scattering occurring at the rough upper and lower boundaries of the sediment and volume scattering within the layer. The scattering mechanisms are considered to be independent and are modeled using perturbation theory and the Born approximation. Unknown parameters include seabed geoacoustic properties (sediment thickness and sound speeds, densities, and attenuations for the sediment and basement) and scattering properties (roughnesses and scattering strengths for upper and lower layer boundaries and volume scattering strength for the sediments). The reverberation inversion problem is found to be strongly nonlinear with a highly multi-modal posterior probability density (PPD). Standard Markov-chain Monte Carlo (MCMC) methods, such as Metropolis–Hastings sampling, are ineffective at sampling the complicated parameter space. However, parallel tempering, which runs multiple MCMC chains at a series of increasing temperatures with probabilistic transitions between chains, effectively samples the multi-modal PPD. Methods to increase efficiency using multiple parallel chains at each temperature and exploiting improved mixing with temperature are considered.

8:45

1aSP3. Trans-dimensional strategies for geoacoustic posterior probability estimation. Jan Dettmer and Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria BC, Canada V8W 3P6)

Choosing appropriate model parametrizations is a fundamental aspect of Bayesian parameter inference. Trans-dimensional inference is based on a hierarchical Bayesian model, where the number of unknowns in the problem is itself unknown. The methodology extends the state-space to the union of subspaces of a group of models of interest. This allows the data to estimate the support for the parametrizations under consideration while accounting for the limited knowledge about the parametrization in the posterior probability density estimate. Algorithms, such as reversible-jump Markov chain Monte Carlo, can be used to sample from the trans-dimensional posterior by proposing and accepting/rejecting dimensional transitions (jumps) according to a generalized Metropolis-Hastings criterion. Several challenges exist for the efficient application of trans-dimensional methods to geoacoustic inference including defining proposal distributions for efficient transitions between dimensions and within dimensions, and specifying (or quantifying) data errors distributions (or statistics). Example1109; of applying the trans-dimensional approach are demonstrated for several geoacoustic inverse problems, using trans-dimensional partition modeling and hierarchical data-error models.

9:05

1aSP4. Estimation of the conditional variance of a broadband source signal employing a repetition code through shallow water waveguides. Michael Pfetsch and Paul Gendron (Maritime Systems Div. SSC-Pacific, 53560 Hull St., San Diego, CA 92152)

A repetition code can be employed as a computationally fast suboptimal means to exploit available time-bandwidth product for improved bit error rate performance. Applications include synthetic aperture communications. Underwater acoustic response functions can vary over the duration of the transmission and thereby degrade system performance. A measure of precision of estimation of the source signal is the source posterior variance given the receiver pressure field time series. Presented here is the computation of the covariance of a source signal accounting for the covariance of the acoustic response function. A Gibbs sampling scheme is employed as a computational method to computing these variances to an acceptable precision. The resulting posterior variance as a function of SNR gives insight into the contributing phenomena that impart ambiguity in synthetic aperture communications through underwater acoustic channels. The method is tested on the very shallow water environment of Keyport WA at a center frequency of 20 kHz.

9:25

1aSP5. Comparison of particle filtering and extended Kalman filtering for acoustic-based tracking of low-flying aircraft. Wm. Garth Frazier (Natl. Ctr. for Physical Acoust., Univ. of Mississippi, 1 Coliseum Dr., University, MS 38677, frazier@olemiss.edu) and Chad Williams (Hyperion Technol. Group, Tupelo, MS 38804)

This presentation summarizes a comparative study of particle filtering and extended Kalman filtering applied to acoustic-based tracking of high-speed, low-flying aircraft. A distributed network of small acoustic arrays, each reporting real-time azimuthal bearings and elevation angles to acoustic sources to a central processing unit, are synthesized into real-time three-dimensional tracks. The primary challenge of the problem is the significant propagation delay between the source and the receivers. Both tracking methods are applied to simulated and field test data and reveal nearly equivalent tracking performance in all cases as along as a sufficient number of particles are utilized. Computational requirements of the extended Kalman filter are significantly less than the particle filters.

9:45

1aSP6. Sequential Bayesian filtering for a varying model-order passive fathometer problem. Caglar Yardim (Marine Physical Lab., Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093, cyardim@ucsd.edu), Zoi-Heleni Michalopoulou (New Jersey Inst. of Technol., Newark, NJ 07102), and Peter Gerstoft (Univ. of California, San Diego, CA 92093)

Sequential model selection is demonstrated for a drifting passive fathometer case. It has been shown that, by processing noise data at a specific array location, a reflector sequence can be extracted, consisting of a summation of sinc pulses. The center of each pulse identifies the depth of a reflector in the ocean environment at that location. Extracting the number and peak/depth locations of these pulses in the reflector sequence provides insight in the sediment structure of the medium. Collecting data in multiple ranges, a process facilitated by the drifting array, allows the study of multiple reflector sequences. Similarly to spatial time delay tracking with Bayesian filters that sample from posterior density functions, we treat sequences obtained at different ranges as data arriving sequentially into a particle filter that extracts at every range (state) the number of pulses and their corresponding depths using an observation equation. A state equation then predicts reflectors at the next range and updates estimates accordingly. The number of pulses varies with range, following changes in sediment layering. Probability density functions of the number of layers and their depths are calculated and demonstrate the successful tracking of changes in the structure of the ocean environment and the uncertainty therein.

10:05–10:30 Break

10:30

1aSP7. Passive sonar tracking using sequences of received signal amplitude fluctuations: Dependence on environmental sampling. R. Lee Culver, Brett E. Bissinger, and Alex W. Sell (Appl. Res. Lab, Penn State Univ., P.O. Box 30, State College, PA 16804)

We have developed a passive sonar tracking algorithm that makes use of variations in the amplitude of the signal received from a source in motion. Originally the likelihood function (probability density function (pdf) of received signal amplitude for a given source location) was calculated by Monte Carlo sampling of the environmental variables and running the acoustic propagation model to predict transmission loss (TL). For each possible source location, the pdf of TL was constructed. To calculate the posterior pdf using received signal amplitude data, Bayes' rule was used sequentially such that for each possible source location, the likelihood function evaluated at the value of the new received amplitude was multiplied by the prior probability associated with that source location. This approach depends fundamentally on how the environment is sampled and on the acoustic propagation model. More recently, the likelihood function has been expanded into the joint pdf of sequences of received signal amplitudes. The environment sampling and use of the acoustic propagation model are the same, but now the likelihood functions are multidimensional. Implications for environmental sampling and selecting the proper model order are discussed. Work supported by the Office of Naval Research Undersea Signal Processing.

10:50

1aSP8. Sequential Bayesian filtering for seismic tremor location. Caglar Yardim, Peter Gerstoft, William S. Hodgkiss (Scripps Inst. of Oceanogr., Univ. of California, San Diego, La Jolla, CA 92093, gerstoft@ucsd.edu), and Eliza Michalopoulou (Univ. Heights, Newark, NJ 07102-1982)

Sequential filtering provides a suitable framework for estimating and updating the unknown parameters of a system as data become available. The foundations of sequential Bayesian filtering with emphasis on practical issues are first reviewed focusing on particle filtering and particle smoothing. Filtering is demonstrated to be a powerful estimation tool, employing prediction from previous estimates and updates stemming from physical and statistical models that relate seismic measurements to the unknown parameters. Particle filtering and particle smoothing are discussed for tracking multiple tremor locations.

Contributed Paper

11:10

1aSP9. Importance-based sampling for porous material physical parameter estimation. Cameron Fackler and Ning Xiang (Graduate Program in Architectural Acoust., School of Architecture, Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180, facklc@rpi.edu)

Bayesian inference is applied to the problem of determining the physical parameters of a rigid-frame porous material. Such materials may be characterized by the parameters of flow resistivity, porosity, and tortuosity. The Biot-Allard and Attenborough models predict the propagation of sound in rigid-frame porous materials by modeling the characteristic impedance and propagation coefficient of the material in terms of these physical parameters and a shape factor. In this work, model-based Bayesian analysis is formulated to estimate the values of these parameters from experimental measurements of the characteristic acoustic impedance or propagation coefficient of a material under test. Importance sampling and related methods are used in the parameter estimation procedure as Monte Carlo approaches to characterize the posterior probability distribution which is used to represent the likelihood of parameter values. To increase the efficiency of the sampling, adaptive strategies are employed to extend the classical importance sampling. This analysis provides quantitative estimates of the parameter values as well as estimates of the uncertainty associated with each parameter and the interrelationship between parameters.

MONDAY MORNING, 31 OCTOBER 2011 PACIFIC SALON 3, 8:00 TO 11:45 A.M.

Session 1aUW

Underwater Acoustics and Structural Acoustics and Vibration: Finite Element Modeling of Acoustic Scattering from Objects in a Heterogeneous Medium

Ahmad Abawi, Cochair
Heat Light and Sound Research, Inc., 3366 Torrey Pines Ct., La Jolla, CA 92037

David S. Burnett, Cochair
Naval Surface Warfare Center, 110 Vernon Ave., Panama City, FL 32407

Invited Papers

8:00

1aUW1. Azimuthal Fourier mode decomposition of generic incident fields in the frequency domain: Computational model and results. Mario Zampolli (TNO, Sonar Group, Oude Waalsdorperweg 63, 2597 AK The Hague, The Netherlands, mario.zampolli@tno.nl), Aubrey L. Espana, Kevin L. Williams (Univ. of Washington, Seattle, WA 98105), and Philip L. Marston (Washington State Univ., Pullman, WA 99164)

The 3-D scattering from axisymmetric objects illuminated by nonaxisymmetric incident acoustic fields can be computed efficiently using finite element models, in which the field variables are decomposed via azimuthal Fourier series expansions. The number of azimuthal modes needed is determined by the convergence of the decomposition of the incident field. For simple cases, the field decomposition can be described analytically. For more complex incident fields, however, a closed form azimuthal Fourier series representation of the incident field is often not possible. A pre-processing step is presented, in which the incident field is decomposed numerically at the Gauss points on the wet surface of the target. This approach makes it possible to treat general cases, such as scattering from objects included inside heterogeneous media, at shallow grazing angle, when the symmetry axis of the object is not perpendicular to the interface between the two media. Other applications include decomposing the boundary scattered field re-incident on an object. The model is applied to scattering from a 2:1 aluminum cylinder, included in a fast fluid medium above a slow fluid medium, with the source in the slow medium, and the results are compared to ultrasonic tank measurements. [Work supported by ONR/ONRG.]

8:20

1aUW2. Acoustic scattering from unexploded ordnance in contact with a sand sediment: Mode identification using finite element models. Aubrey L. España, Kevin L. Williams, Steven G. Kargl (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, aespana@apl.washington.edu), Mario Zampolli (TNO Defense, Security and Safety, The Hague, Netherlands), David S. Burnett (Naval Surface Warfare Ctr., Panama City, FL 32407-7001), and Philip L. Marston (Washington State Univ., Pullman, WA 99164-2814)

Previous work has illustrated the potential benefit of using low frequency sound as a means for detecting and classifying objects in contact with a sand sediment. In these situations, the wavelength of sound is on the order of the object dimensions, thus coupling to the objects resonant modes. This leads to an acoustic signature rich in physical phenomena unique to the object shape and elastic properties. Hybrid 2-D/3-D finite element models have been developed for unexploded ordnance in contact with a sand sediment. Previous work has demonstrated these models are in good agreement with data collected during experiments conducted in a test pond in 2010 [A. L. España *et al*., J. Acoust. Soc. Am. **129**, 2685 (2011)]. In this paper, the finite element models are used as a means for mode identification and physical interpretation. These modes are visualized through plots of the pressure amplitudes and displacements along the UXO exterior and are explained using insights derived from physical acoustics. Finally, a full 3-D finite element model was developed to investigate the changes to the acoustic response in situations where the symmetry of the problem is broken and the hybrid 2-D/3-D method is no longer viable. [Research supported by ONR and SERDP.]

8:40

1aUW3. Time-domain finite element modeling of interaction of heterogeneous solids with acoustic waves. Petr Krysl (Dept. of Structural Eng., Univ. of California, San Diego, 9500 Gilman Dr., #0085, La Jolla, CA 92093, pkrysl@ucsd.edu)

The vibroacoustic finite element toolkit (VATK) utilizes a Lagrangian finite element method specifically developed for analyzing the interaction of biosolids immersed in fluids with acoustic waves. It employs a superposition principle to separate the incident acoustic wave from the scattered and radiated waves in a displacement-based finite element model. An absorbing boundary condition is applied to the perturbation part of the displacement. Linear constitutive equation allows for inhomogeneous, anisotropic materials, both fluids and solids. Displacement-based finite elements are used for all materials in the computational volume, which can be fluids, solids, and voids in arbitrary combination. Robust performance for materials with limited compressibility is achieved using incompatible-mode brick elements. A centered-difference time-stepping algorithm is formulated to handle general damping accurately and efficiently. The VATK uses a voxel-based modeling scheme for complex geometries. The modeling methodology comes with some challenges. Here we discuss the issues of verification and validation, convergence and error control, and performance of the present technique in application areas for which it was not originally intended. [Work supported by the Office of Naval Research and the Chief of Naval Operations, Environmental Readiness Division.]

9:00

1aUW4. New strategies for full-wave simulations of large acoustic models. Tomi Huttunen (Dept. of Appl. Phys., Univ. of Eastern Finland, P.O. Box 1627, FI-70211 Kuopio, Finland, tomi.huttunen@uef.fi)

The simulation of large acoustic models using conventional low-order finite element or boundary element (BE) methods can be computationally demanding due to the requirement of wavelength dependent mesh density (5-10 elements per wavelength is a typical rule of thumb). A recent improvement of finite element type methods has focused on the efficient parallelization of problems to even thousands of processors. The discontinuous Galerkin (DG) methods, in time- and frequency-domain, have been particularly popular since DG methods retain the geometric flexibility of FE methods while allowing a more flexible choice of basis functions. The locality of DG basis makes them ideal for large-scale parallelization and the choice of basis can be easily extended to non-polynomial functions such as plane waves or Bessel functions. This study focuses on the three new strategies for solving large acoustic problems. First, the non-polynomial basis functions are used with the DG method in frequency-domain problems. Second, from element to element varying polynomial order is used for the wave equation in the time-domain. And third, cloud computing is utilized for efficient resource allocation with a fast multipole BE method for the acoustic Helmholtz equation.

9:20

1aUW5. Scattering by an elastic object in the time domain for underwater acoustic applications by means of the spectral-element method. Paul Cristini and Dimitri Komatitsch (CNRS-LMA, 31 Chemin Joseph Aiguier, 13009 Marseille, France)

The increase in computational power which has been occurring during the past years makes it possible to consider the full wave simulation in the time domain of the propagation of acoustic waves in more and more complex configurations in underwater acoustics. Among the various derivations of the finite element method, the spectral-element method has proven to be an efficient and robust tool in seismology. This method combines the accuracy of the pseudospectral method and the flexibility of the finite element method. Its intrinsic properties lend itself very well to numerical simulations on parallel computers, which nowadays is a very big advantage. We will present some results obtained by means of the SPECFEM software, a freely available code which implements the spectral-element method. Its use in underwater acoustics is natural since all types of media which can be encountered in the oceanic environment have already been implemented: fluid, elastic, viscoelastic, anisotropic, and poroelastic. Some illustrative examples of the diffraction of an acoustic wave by an elastic object in various situations will be presented. In particular, a special attention will be paid to the nature of the medium in which the object is embedded.

9:40

1aUW6. Finite-element modeling of sound transmission blocking materials realized using pancake voids in a soft elastomer. David C. Calvo, Abel L. Thangawng, and Christopher N. Layman Jr. (Acoust. Div. Naval Res. Lab., Washington, DC 20375)

The fact that gas-filled voids in a soft elastomer acoustically resemble gas bubbles in a liquid (both having strong low-frequency monopole resonances) was pointed out by analysis and experiment by V. Leroy *et al*. [Appl. Phys. Lett. **95** (2009)]. The present work reports on the modeling, design, fabrication, and testing of specially designed voids in the soft elastomer polydimethylsiloxane (PDMS) with the aim of creating high performance sound transmission blocking materials. The techniques of soft lithography allow the microfabrication of custom cavity shapes in PDMS to obtain desired microstructural resonances. Results of a finite-element modeling analysis are reported that determine the monopole resonance frequencies of what we term pancake voids embedded in layers of PDMS. Because of the high aspect ratio of these voids, the low-frequency monopole (Minnaert) frequencies are between 3 and 6 times lower than that for a spherical cavity of equivalent volume inside PDMS. In terms of the potential for thin sound blocking slabs, this allows a lowering of the frequency at which blocking begins to take place. We also present modeled transmission loss results for normal incidence on an infinite array of pancake voids (a sonic crystal). [Work sponsored by the Office of Naval Research.]

10:00–10:15 Break

10:15

1aUW7. Design of inhomogeneous pentamode metamaterials for minimization of scattering. Jeffrey Cipolla, Nachiket Gokhale (Weidlinger Assoc., Inc., 375 Hudson St, New York, 10014), Andrew Norris, and Adam Nagy (Rutgers Univ.)

Acoustic metamaterials use sub-wavelength, anisotropic, and inhomogeneous microstructures. Macroscopic properties can be related to the microstructure using homogenization theory Hassani and Hinton [Comput. Struct. **69**, 719–738 (1998), which allows an analyst to confirm the extent to which a candidate metamaterial microstructure meets the requirements for a pentamode cloaking material. Norris [Proc. R. Soc. Ser. A, **464**, 2411–2434 (2008)] presented a theory of transformation acoustics that enables the realization of inhomogeneous pentamode acoustic materials having anisotropic elastic tensors, isotropic density and finite mass. This theory describes the spatially varying material properties in terms of a mapping, which for separable geometries may be generated using a scalar function. This function, the constraints on its behavior implicit in the Norris theory, and the material equations constitute the defining relations for pentamode transformation acoustics. Previously, analytic work in transformation acoustics developed the material properties after having fixed a transformation. By reversing the process, we create a number of new families of pentamode cloaking materials. We validate the concept with three-dimensional explicit transient finite element simulations.

10:30

1aUW8. Modeling of offshore wind turbine noise radiation and propagation. Huikwan Kim, Gopu R. Potty, James H. Miller, and Christopher Baxter (Dept. of Ocean Eng., Univ. of Rhode Island, Narragansett, RI 02882, hkkim524@my.uri.edu)

Noise generated by offshore wind turbine and support structure can radiate and propagate through the air, water, and sediment. Predicting noise levels around wind turbine structures at sea is required for the estimation of effects of the noise on marine life. To predict radiated noise, we used a finite element analysis (FEA) of a cylindrical shell model of a monopile structure. In the finite element modeling, transient modal dynamic analysis and steady state dynamic analysis (direct and modal) were implemented to simulate both construction and operational noise. The effect of various sediment types and foundation designs are investigated. The FEA package used was ABAQUS version 6.10. The output of the FEA analysis is used as starting field for acoustic propagation models such as PE to produce long range predictions. We present predictions of particle velocity at the structure-acoustic medium interface and sound pressure level as function of frequency at various distances from the structure. Laboratory experiments using scale models of the cylindrical shell have been carried out to verify the noise predictions. Comparison of the FEA model results and experimental data will be presented.

10:45

1aUW9. Acoustic scattering from a metallic pipe: Mode isolation and visualization via finite element analysis. Aubrey L. España, Kevin L. Williams (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, aespana@apl.washington.edu), Philip L. Marston (Washington State Univ., Pullman, WA 99164-2814), and Mario Zampolli (TNO Defense, Security and Safety, The Hague, Netherlands)

Understanding how sound couples to, and radiates from targets, aids in finding frequencies and angles advantageous for target detection and classification. Finite element models, coupled with physical acoustics models, have been used to identify resonant modes of truncated, solid cylinders [D. B. Thiessen *et al*., J. Acoust. Soc. Am. **129**, 2686 (2011)]. This technique is extended here to an aluminum pipe. Scattering from the pipe in the freefield is studied with a finite element model based on the decomposition of the elastic displacements and fluid pressure in a series of azimuthal Fourier modes. To facilitate elastic mode identification, the calculations for the scattered pressure from a nearly rigid pipe of identical size are subtracted coherently from the elastic model results. Plotting these "subtracted" pressure amplitudes and particle displacements on the wet surface of the pipe allows for visualization of the elastic modes. Subsequently, the model is extended for the pipe in contact with sand, via a superposition of freefield results along with the water/sand reflection coefficient. The method is used to study the modal scattering in the presence of the interface. Where applicable, finite element results are validated by predictions from ray theory and experimental results. [Work supported by ONR.]

11:00

1aUW10. High frequency scattering properties of focused acoustic beams helpful for finite element research. Philip L. Marston (Phys. and Astronomy Dept., Washington State Univ., Pullman, WA 99164-2814)

It can be helpful to understand apparent anomalies in the scattering when developing or testing finite element computations for the scattering of sound by objects in water with the wavenumber-radius product ka of approximately 10 or greater. In the case of focused acoustic beams incident on a sphere centered in the axis of the beam, analytical results are available using the method of superposition of Bessel beams [P. L. Marston, J. Acoust. Soc. Am. **129**, 1773–1782 (2011)]. High ka analytical results can manifest an unusually large forward scattering lobe when the focal width of the beam becomes similar to the size of the sphere. (This is in contrast to the examples of scattering at relatively small ka illustrated in the aforementioned reference.) This new behavior can be understood by considering the definition of the total wave field as the superposition of the incident and the scattered fields combined with reasoning based on geometry, the localization principle, and other high frequency approximations. It is likely that high ka finite element computations of the scattering by narrowly focused beams for other shapes of objects will manifest a correspondingly enhanced scattering lobe. [Research supported by ONR.]

11:15

1aUW11. Numerical model of nonlinear acoustic wave propagation in seabed. Rana Arslan A. Khan and Grant A. Ellis (Dept. of Elec. Eng., Univ. Teknologi PETRONAS, 31750 Tronoh, Perak, Malaysia, rarslana@gmail.com)

In this study, a combination of two fundamental frequencies $f_1 = 485$ KHz and $f_2 = 515$ KHz. The source transducers are placed on the surface of the sand 25 cm above the bottom and 20 cm below the water surface in the tank of dimension $74 \times 47 \times 43.5$ cm simulating a seabed with sand of maximum particle size of 5 mm. Burger's equation is the simplest model for describing the second order nonlinear effects in the propagation of high amplitude plane waves and, in addition, the dissipative effects in media. Typically, the interactions of two acoustic waves at a discontinuity in a dispersive but homogeneous medium will generate harmonics and intermodulation terms. This is numerically modeled in MATLAB using the finite difference time domain method with Neumann boundary conditions and practically verified with measurements from the tank. The measured and simulated results have shown significant agreement with the theory. For instance, second order intermod term show 2 dB decreases in amplitude for 7 mm increase in thickness at constant density of plywood. Also if the thickness is kept same, e.g., 5 mm, there is 10 dB drop in same intermod term for change in density from plywood 550 kg/m^3 to copper 8930 kg/m^3.

11:30

1aUW12. Characterization of scattered acoustic intensity fields of finite cylinders in the resonance region. Robert J. Barton III, Geoffrey R. Moss (Naval Undersea Warfare Ctr., code 1522, 1176 Howell St., Newport, RI 02841, robert.barton@navy.mil), and Kevin B. Smith (Naval Postgrad. School, Monterey, CA)

The properties of the scattered acoustic vector fields generated by infinite-length and finite rigid and elastic cylinders are investigated. Analytical solutions are derived from general acoustic pressure scattering models and analyzed for wave numbers in the resonance region. The separable active and reactive components of the acoustic intensity are used to investigate the structural features of the scattered field components. Numerical results are presented for the near and transition regions. A finite element model is

developed for a rigid cylinder and compared to measured results in-air using an anechoic chamber and acoustic vector sensor probes to measure the scattered acoustic vector field. The finite cylinder model and analysis is then extended to include an evacuated thin-walled elastic shell. The vector properties of the time-independent complex intensity components and their relations to field energy density quantities are summarized.

MONDAY AFTERNOON, 31 OCTOBER 2011 SUNRISE, 1:15 TO 5:20 P.M.

Session 1pAA

Architectural Acoustics and Psychological and Physiological Acoustics: Architectural Acoustics and Audio I

K. Anthony Hoover, Cochair
McKay Conant Hoover, Inc., 5655 Lindero Canyon Rd., Westlake Village, CA 91362

Alexander U. Case, Cochair
Fermata Audio & Acoustics, P.O. Box 1161, Portsmouth, NH 03802-1161

Chair's Introduction—1:15

Invited Papers

1:20

1pAA1. Bollywood sound stages. K. Anthony Hoover (McKay Conant Hoover, Inc., 5655 Lindero Canyon Rd., Ste. 325, Westlake Village, CA 91362)

Sound for bollywood films is rarely recorded live on location, but is looped or added later, in large part because of poor ambient acoustics. Several new sound stages in Film City, Mumbai, India, were intended for "Hollywood" quality acoustics, but construction ceased shortly after starting. Then, after several years' hiatus, the project was renewed with the directive that the existing fragmentary construction be used in the new design and as the foundation for subsequent construction. This paper will discuss the background, site conditions, encroaching hutments, design issues, concerns for local materials and methods, and the results of post-construction acoustical testing.

1:40

1pAA2. Case study: Active acoustics at the Barbara Streisand scoring stage. Steve Ellison (Meyer Sound Labs., 2832 San Pablo Ave., Berkeley, CA 94702, ellison@meyersound.com), Shawn Murphy, and David R. Schwind (Charles M. Salter Assoc., Inc., San Francisco, CA 94104)

Scoring stages are recording studios large enough to accommodate an orchestra, and typically used to record music sound tracks for films. The acoustic properties and goals of scoring stages are reviewed, and compared with other venue types. Recently, an active acoustics system was installed in the Barbara Streisand scoring stage on the Sony lot in Culver City, California. The system was used to electronically vary the reflected sound and reverberation during the recording of several film scores. The objectives, design, and performance of the system in the room is reviewed. The range of settings and controls provided to the scoring mixer are described as well as the process used to select parameters for different aspects of the score. These had implications on the artist performance as well as the recording and mixing process. The resultant reverberation times achieved are compared with archetypical orchestral performance venues as well as other scoring stages.

2:00

1pAA3. Case study: Multipurpose venue at Berklee College of Music. Raunak Mukherjee and Eric Reuter (Music Production and Eng./Liberal Arts Dept., Berklee College of Music, Boston, MA 02215, rmukherjee@berklee.net)

This 90 m^2 square meter multipurpose venue was intended to host a variety of programs, including musical performance, lecture, yoga, and dance instruction, etc. Most of these employ a built-in sound reinforcement systems. However, since its construction, the room has suffered from excessive reverberation, making it unsuitable for most of these intended uses, even with reinforcement. Venues of this type demand a balance between speech clarity and a level of reverberation sufficient to support musical performance. The authors will present a detailed acoustical analysis of the room at the start of the project, the goals of the design, and specific recommendations for acoustical treatment.

2:20

1pAA4. Design guidelines for rooms used for music, speech, and teaching. Peter D'Antonio (RPG Diffusor Systems, Inc., 651-C Commerce Dr., Upper Marlboro, MD 20774, pdantonio@rpginc.com) and Christian Nocke (Akustikbüro Oldenburg, Oldenburg, DE D-26121)

Good architectural acoustic design requires an appropriate combination of absorptive, reflective and diffusive surfaces, providing attenuation, redirection, and uniform scattering. Since the terms acoustical and absorptive have become synonymous in common parlance,