Session 1aAA

Architectural Acoustics: Sound Systems in Large Rooms and Stadia

David S. Woolworth, Cochair
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Invited Papers

8:45

1aAA1. Acoustical and sound system design considerations in large venues and stadia. Jack Wrightson, Ron Baker, and Kevin Day (WJHW, Inc., 4801 Spring Valley Rd, #113, Dallas, TX 75244, rbaker@wjhw.com)

Large, spectator seating facilities provide unique challenges for the sound and acoustical system designer. The challenges are equally daunting, but different for indoor and outdoor facilities. This presentation provides empirical data of existing facilities in regard to speech intelligibility, uniformity of sound reinforcement coverage, maximum loudness, etc., along with a review of predicted modeling and auralization techniques. Design guidelines for acoustical treatment, loudspeaker configuration, predictive calculation of speech intelligibility, and other aspects will be discussed. Difference or variations in design practice between more conventionally sized spaces and very large environments will be presented.

9:10

1aAA2. The implications of scale on sound systems in large spaces. Bob McCarthy (Alignment and Design Inc., 204 Falling Leaves Ct., Creve Coeur, MO, 63141, bob.mccarthy@charter.net)

The symphonic concert hall is a well documented reference point for matters of scale in the musical side of architectural acoustics. Larger spaces may have comparable shapes, and yet the matters of scale require vastly different approaches in regard to the sound system and architectural acoustics. The causes and consequences of scalar expansion will be discussed as well as the shifting balance between the roles of the sound system and the architectural acoustics. Sound system and acoustical designs must adapt to those aspects which are modified by scale (power, distance, wavelength, etc.) along with those that remain constant, regardless of the size (angular aspects, echo perception, the spacing between and size of audience members, etc.). Expanded room scale requires the sound system to use increasingly effective methods of controlling the direct sound field to tailor its response to the highly asymmetric shapes presented for coverage. The methods of control and their implication on the hall acoustics will be discussed. Scalar independent methods for sound system designs which can be form-fitted into a space will be discussed in the context of a variety of large room examples.

9:35

1aAA3. Stadium acoustics-design challenges and solutions. David Marsh (PMK Consultants, 1420 W. Mockingbird Ln., Ste. 400, Dallas, TX 75247, David.Marsh@pmkconsultants.com)

Large stadiums, whether enclosed or open-air, present many acoustical design challenges including excessive reverberation, echoes from surfaces distant from the sound system loudspeakers, sound absorption by air, refraction, difficulty achieving acceptable speech intelligibility, and synchronization of the sound reinforcement system to the video boards. This paper is an overview of how these challenges have been met in several professional sports facilities. Reverberation times for these large venues are normally underpredicted on the order of -20% by conventional methods. Low frequency reverberation times (down to 63 Hz) tend to be extremely long—about 15 s on average. A novel approach will be described to estimate these values (within a wide range of possibilities) based on *in situ* measurement data. It will be shown that after exhausting all possibilities of acoustical treatments, the most effective way of achieving acceptable speech intelligibility is to use a distributed sound system with no seat being more than about 80 ft from the nearest loudspeaker.

10:00–10:20 Break

10:20

1aAA4. Purpose built sound systems for large rooms. Neil A. Shaw (Menlo Sci. Acoust., Inc., P.O. Box 1610, Topanga, CA 90290-1610, menlo@ieee.org) and John Monitto (Meyer Sound Labs., Inc., Berkeley, CA 94702)

Sound systems for sports facilities have improved over the years with the development of better loudspeaker systems with increased headroom and reduced distortion at high sound levels. Today's loudspeaker systems can produce cleaner sound with less interference between the devices, when installed either temporarily or permanently in these often very reverberant venues. Two basic design philosophies for football, baseball, and soccer stadiums are the point source and the distributed system. Smaller basketball,

hockey and other sports typically have sound systems flanking scoreboards in a point source design with the option of distributed delayed speakers. In some new facilities that are designed for multipurpose use, the use of electronic processing systems enables these rooms to be designed with lower reverberation times, which is typically the preferred acoustic environment for live amplified concerts. For games and other events a variable acoustic system provides additional reverberation as needed, also enhancing natural crowd and court sounds, such as a ''puck'' sound, and increases the intimacy of applause and cheering between the fans and the game itself.

10:45

1aAA5. Signal-to-noise ratios in sound system design. Marshall Long (Marshall Long Acoust., 13636 Riverside Dr., Sherman Oaks, CA 91423, mlacoustics@sbcglobal.net)

An important consideration in sound system design is intelligibility, and the most common measure of intelligibility is some sort of signal-to-noise ratio. Intelligibility can be expressed in terms of a goodness ratio (high signal-to-noise) or a badness ratio (high noise-to-signal), or a modified badness ratio (noise x reverberation time)/signal such as %ALcons. The trick is how to calculate signal, how to calculate noise, and how to design systems with what we calculate. Three types of solutions: Cabinets (horns), distributed loudspeakers, and line arrays are discussed.

11:10

1aAA6. Live sound measurements in stadia. Wolfgang Ahnert, Stefan Feistel, Alexandra Radu Miron, and Enno Finder (Ahnert Feistel Media Group, Arkonastr. 45–49, D-13189 Berlin, Germany, wahnert@ada-acousticdesign.de)

In this presentation, the authors introduce the software-based measuring system EASERA SysTune to be used for measurements by excitation with music or speech signals. It investigates the use of standard signals supplied from a sound system in a stadium in real-time. Using a newly developed program module, live-sound recordings or speech and music signals from a microphone input and from the mixing console can be utilized to obtain impulse response data for further evaluation. New noise suppression methods are presented that allow these impulse responses to be acquired in full-length, even in occupied venues. As case studies, acoustic measurements based on live sound supply are discussed for a soccer stadium. Required measuring conditions and limitations are derived as a result.

TUESDAY MORNING, 27 NOVEMBER 2007 GRAND COUTEAU, 8:00 TO 10:05 A.M.

Session 1aAO

Acoustical Oceanography: Marine Sediment Properties and Inversions

Jon M. Collis, Chair
Woods Hole Oceanographic Inst., Bigelow Bldg, Woods Hole, MA 02543

Chair's Introduction—8:00

Contributed Papers

8:05

1aAO1. The effect of grain shape on the porosity of marine sediments. David R. Barclay and Michael J. Buckingham (Marine Physical Lab., Scripps Inst. of Oceanogr., Univ. of California, San Diego, 9500 Gilman Dr., La Jolla, CA 92093-0238)

The porosity of marine sediments increases as the mean grain diameter decreases. In contrast, the close-packing structures (including random packing) of uniform-size spheres all show a porosity that is independent of sphere size. Hamilton suggested that, in sediments, the shape of the grains is instrumental in determining the porosity. To investigate this idea, experiments have been performed on a variety of sand samples (marine sediments, beach sands, and desert sands) with mean radii within the range 30 mm–200 mm. The macroscopic properties (porosity and bulk density) are measured in simple tabletop experiments, while the microscopic details of grain shape are quantified using an optical microscope and image-analysis software. For each grain in, typically, a sample of several hundred, the boundary is traced and various geometric parameters are returned, including the perimeter, the cross-sectional area, the centroid, and the best-fit ellipse. Also, a Fourier decomposition yields the radius as a function of angle, and the higher-order coefficients are then combined to provide a description of grain shape (i.e., deviation from sphericity). An attempt is being made to interpret the observed porosities in terms of the measured grain shapes. [Research supported by ONR.]

8:20

1aAO2. Shear waves and the discrepancy between perceived and ideal frequency power laws for sediment attenuation. Jon M. Collis, Allan D. Pierce, and William M. Carey (Boston Univ., Boston, MA 02215, jcollis@bu.edu)

Inverse techniques based on data for long-range propagation in shallow water have recently inferred that the attenuation in certain marine sediments varies at low frequency as the 1.8 power. Idealized models predict the exponent to be exactly 2.0. The inverse inferences usually assume the bottom is a fluid, and this is ordinarily a good approximation, because the shear wave speed in bottom sediments is typically very small. Direct numerical simulation [J. M. Collis et al., Proc. Oceans 2007, Aberdeen (2007)] indicates that shear waves make a sufficient contribution to shallow water attenuation that could account for the small discrepancy in exponents. To better assess whether this is the case, the present paper analyzes the effect of shear waves on modal attenuation. The Pekeris model with a lower elastic half-space is used with the shear wave speed taken to be substantially less than the sound speed in water. The derived dispersion relation has complex roots for the horizontal wave number, and the imaginary part, found by a perturbation analysis, predicts that the shear wave contribution to the modal attenuation is proportional to the cube of the ratio of the shear wave to water sound wave speeds. [Work supported by ONR.]

8:35

1aAO3. Complex-density, equivalent-fluid modeling of acoustic interaction with the seafloor. Michael Vera (Univ. of Southern Mississippi, 118 College Dr., #5046, Hattiesburg, MS 39406, michael.vera@usm.edu)

Acoustic interaction with the seafloor can generate both compressional and elastic shear waves in the solid. Accurate models of shear propagation are often computationally expensive and difficult to apply to long-range propagation. When the sound field in the water is of primary interest, an equivalent-fluid model of the seafloor, with parameters chosen to match the reflection coefficient of the actual elastic solid, can sufficiently characterize the effect of the bottom on energy in the water. The effective density of the seafloor material in this approach can be a complex number. Prior methods for generating equivalent fluids were intended for low shear speeds and low grazing angles. Recent developments in the technique were intended to extend its validity to higher shear speeds and a wider range of angles. These efforts were initially motivated by the need to simulate bottom-interacting arrivals for the broadband Kauai source in the North Pacific Acoustic Laboratory experiment at megameter ranges. The work to be presented involves a more detailed examination of the performance of the method, including comparisons to benchmark models and to shorter range data from this Kauai source collected as part of the Basin Acoustic Seamount Scattering Experiment.

8:50

1aAO4. A direct inversion scheme to obtain sediment sound speed and density in shallow water. Kyle M. Becker (Penn State Univ./Appl. Res. Lab., P.O. Box 30, State College, PA 16804-0030)

A simple inversion scheme is described for estimating the sound speed and density in the seabed for Pekeris-type waveguides. At a fixed frequency, input data to the inversion algorithm are discrete values of the phase of the plane wave reflection coefficient at the water/bottom interface. Above the critical angle, the input data are derived from estimates of the horizontal wave numbers for propagating modes in the wave guide. For two or more propagating modes, a linear system of equations is solved directly to determine sound speed and density in the bottom. The approach is strictly only valid for determining properties of the lower half-space in a Pekeris Wave guide. However, in certain circumstances, the approach can be applied to determine properties of the topmost sediment in layered media. The method is demonstrated on a synthetic data set and then applied to data collected at sea. [Work supported by an ONR Ocean Acoustics Entry-Level Faculty Award.]

9:05

1aAO5. Analysis of the effect of water column sound speed variation on geoacoustic inversion. Yong-Min Jiang and N. Ross Chapman (School of Earth and Ocean Sci., Univ. of Victoria, PO Box 3055, Victoria, BC V8W 3P6, Canada)

Bayesian matched field inversion has been applied on multi-tonal data sets acquired on the New Jersey continental shelf in the SW06 experiment in August, 2006. Since the data sets were collected in a range-dependent environment due to water column sound speed variation, sound speed profile (SSP) was decomposed in terms of empirical orthogonal functions and also inverted in the inversion. This presentation examines the sensitivity of the geoacoustic and geometrical parameters to the shape and the gradient of the sound speed in the thermocline by the interparameter correlation from the inversion. The effects of the SSP on the geoacoustic inversion and source localization are studied through the inversions of measured data at different ranges with/without prior information about geometric parameters in the inversion. Further investigations on the variation of SSP to the sediment sound speed, density, and attenuation at different ranges are carried out by simulations. It is found that the geometric parameters are more sensitive to the SSP than are the geoacoustic parameters in this shallow water environment. [Work supported by ONR.]

9:20

1aAO6. Geoacoustic information content of bottom-moored horizontal line array data. Dag Tollefsen (Norwegian Defence Res. Establishment (FFI), Box 115, NO3191 Horten, Norway) and Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria BC, Canada V8W 3P6)

This paper considers geoacoustic information content in matched-field inversion of acoustic data from bottom-moored horizontal line arrays. Bayesian geoacoustic inversion is applied to low-frequency multi-tone data in a synthetic shallow water environment under realistic signal-to-noise ratios and for frequency bands relevant to both controlled-source experiments and ship-noise inversion. The information content is quantified in terms of widths of marginal a posteriori probability densities of model parameters obtained by fast Gibbs sampling. The information content dependence on factors such as array length and sensor configuration, source range and bearing (from endfire to broadside), and frequency content is studied.

9:35

1aAO7. Bayesian geoacoustic inversion of ship-noise data from a bottom-moored horizontal line array. Dag Tollefsen (Norwegian Defence Res. Establishment (FFI), Box 115, NO3191 Horten, Norway) and Stan E. Dosso (School of Earth and Ocean Sci., Univ. of Victoria, Victoria BC, Canada V8W 3P6)

This paper presents results from matched-field geoacoustic inversion of low-frequency (40–150 Hz) ship-noise data recorded on a horizontal array deployed at the seafloor. Data are taken from an experiment conducted by FFI in shallow waters of the Barents Sea. Estimates of sediment parameters were obtained by inversions of narrowband data from a relatively quiet surface ship at source-array ranges of 1–6 km. The fast Gibbs sampler was used to estimate posterior probability densities of model parameters. Estimates of sound speed and density of quaternary sediment are compared with results from inversion of data from a towed source collected along the same track, and with reference values from other geophysical data collected in the area.

9:50

1aAO8. Improved perturbative inversion schemes for obtaining bottom geoacoustic properties in shallow water. Megan S. Ballard and Kyle M. Becker (Penn State Univ., State College, PA 16802, msd200@psu.edu)

Perturbative schemes using modal wave numbers are used to obtain sound speed in the sediment as a function of depth [S. D. Rajan, et. al., J. Acoust. Soc. Am. **82**(3), 998–1017 (1987)]. The inversion algorithm involves solving an ill-posed problem, with regularization and singular-value decomposition used to stabilize the solution, resulting in a smoothed version of the true sound speed profile. However, owing to geological processes, sediments are often better described by layers having distinct properties and are not well represented by a smooth profile. In this work, two new methods are applied to stabilize the solution of the inverse problem, making it possible to resolve discontinuities in the sound speed profile of the sediment. Piecewise polynomial truncated singular value decomposition (PP-TSVD) is used in place of traditional stabilizing methods and is demonstrated to yield better results when a layered model is a reasonable assumption. The results can be further improved using qualitative regularization if prior knowledge of the location of sound speed discontinuities is available. These methods are shown to yield very accurate estimates of the sound speed profile deep into the sediment using very few perturbations to the forward model. [Work supported by NDSEG and ONR.]

Session 1aUW

Underwater Acoustics: Propagation Modeling

Josette Paquin Fabre, Chair
Acoustics Division, Naval Research Lab., Stennis Space Center, MS 39529

Chair's Introduction—10:25

Contributed Papers

10:30

1aUW1. Integrated signal excess as a metric for environmental acoustic assessment. J. Paquin Fabre (Naval Res. Lab., 1005 Balch Blvd., Stennis Space Ctr., MS 39529)

Signal excess (SE) is often used as a metric for determining acoustic performance through a waveguide or over an area. This quantity can limit the capability to assess the environment because SE is computed given a single acoustic source, receiver and frequency, and is a function of range from the source, thereby limiting the scenarios for which the environment can be assessed as well as the ability to visualize it over an area. Integrated SE (ISE) with phase tracking is proposed as an improved metric for evaluation of acoustic performance. For a given source location (in latitude and longitude), the SE is integrated over all possible source depths, a band of frequencies, and bands of ranges. Additionally, the phase variations across the regions are tracked. This metric is compared to various traditional SE fields and is shown to provide a better representation of the overall acoustic properties of a waveguide and an area. The ISE and the original SE are also examined across an ensemble of sound speeds and the variations of the acoustic environment are characterized. [The author appreciates and acknowledges the funding support from the Naval Research Laboratory Base Program.]

10:45

1aUW2. Modeling surface duct precursors for Littoral Acoustic Demonstration Center 2003 (LADC03) seismic calibration experiment. Arslan M. Tashmukhambetov, George E. Ioup, Juliette W. Ioup (Dept. of Phys., Univ. of New Orleans, 2000 Lakeshore Dr., New Orleans, LA 70148, atashmuk@uno.edu), and Natalia A. Sidorovskaia (UL Lafayette, Lafayette, LA 70504-4210)

In summer 2003, LADC conducted a seismic calibration experiment for a 3190-in3 21-element seismic exploration array. After calibration, absolute broadband (up to 25 kHz) pressure-time dependencies for a wide range of offsets and arrival angles were produced. A computational workflow, combining the upgraded version of the Navy standard acoustic propagation model RAM and industry airgun modeling packages, was developed to model the calibrated experimental data. Experimental and modeled data have demonstrated good agreement in absolute pressure amplitudes and large-scale frequency interference pattern for the frequencies up to 1,000 Hz. The results of the application of the developed workflow for investigation of the effect of a seasonally-formed surface duct on seismic array energy distribution is presented. The presence of the surface duct is experimentally confirmed to be responsible for the generation of a unique set of modes forming the precursor arrivals, first systematically observed from a point source on a near-bottom hydrophone by DeFerrari and Monjo. The influence of a range-dependent environment on precursor stability is addressed. An attempt to identify precursors in the LADC03 experimental data is discussed. [Research sponsored by the Industry Research Funding Coalition and the Joint Industry Project.]

11:00

1aUW3. Efficient modeling of range-dependent seismo-acoustics problems. Michael D. Collins, Woo-Yeol Jung (Naval Res. Lab., Washington, DC 20375), Elizabeth T. Kusel (Northeastern Univ., Boston, MA 02115), and William L. Siegmann (Rensselaer Polytechnic Inst., Troy, NY 12180)

The parabolic equation method is the most effective approach for solving range-dependent problems in ocean acoustics. During the past three decades, many difficulties have been encountered while attempting to generalize this approach to problems involving elastic layers. With the development of an improved single-scattering solution [J. Acoust. Soc. Am. **121**, 808813 (2007)], a large class of range-dependent seismo-acoustics problems can now be solved accurately and efficiently. Previous single-scattering solutions for seismic problems were based on an iteration formula, and limited by convergence problems. Since the improved solution does not require iteration, it provides the efficiency of the energy-conserving solution that has proved to be very useful for acoustics problems. The application of this approach to problems involving fluid layers is currently being investigated. [Work supported by ONR.]

11:15

1aUW4. Mode formulas for shallow water waveguides using a modified asymptotic approximation. Stephen V. Kaczkowski, William L. Siegmann (Dept. of Mathematical Sci., Rensselaer Polytechnic Inst., 110 8th St., Troy, NY 12180-3590, kaczks@rpi.edu), Allan D. Pierce, and William M. Carey (Boston Univ., Boston, MA 02215)

Sound speed profiles in shallow water waveguides are small deviations from isospeed and often decrease monotonically with depth. Approximation formulas for the propagating modes are found using a modified form of the classical WKBJ method. The ocean bottom is taken as homogeneous. The approach is accurate for modes with phase speeds greater than, and even slightly less than, the maximum water sound speed. The validity and accuracy of the approximations over frequency and mode number are illustrated using benchmark numerical calculations. Comparisons with approximations from other methods, including previous WKBJ approaches, are described. The formulas here are typically more compact and convenient. The results demonstrate how changes in parameters, such as frequency, bottom sound speed, and water sound speed profile quantitatively affect the mode functions. Applications for representative waveguide profiles are provided. [Work supported by the Office of Naval Research.]

11:30

1aUW5. Modeling underwater sound propagation from an airgun array using the parabolic equation method. Alexander MacGillivray (JASCO Res. Ltd., 4464 Markham St., Victoria, BC, Canada)

A technique for modeling sound propagation from an airgun array using the parabolic equation (PE) method is presented that takes into full account the far-field, angle-dependent directionality pattern of the array. This is achieved by generating a PE starting field for the array by summing together shaded, phase-shifted replicas of the PE self-starter. The