Session 2pAA

Architectural Acoustics: Computer Auralization

Robert C. Coffeen, Chair
School of Architecture and Urban Design, Univ. of Kansas, Lawrence, KS 66045

Chair's Introduction—1:00

Invited Papers

1:05

2pAA1. Auralization–audibility of changing scattering coefficients for audience areas in different size venues. Sarah Rollins (Sparling, Inc., 720 Olive Way, Ste. 1400, Seattle, WA 98101, srollins@sparling.com)

Auralizations in computer modeling are affected by many different variables, such as absorption coefficients, scattering coefficients, and the complexity of the model. However, scattering coefficients are often determined by the best guess of the consultant. In order to isolate the changes due to the scattering coefficient for comparison with measured data, a simple rectilinear room was measured and modeled. This paper will show how changing the architectural surface and audience scattering coefficients affects the auralizations for this room. For comparison, the effects of changing these same coefficients in a larger venue will also be presented.

1:25

2pAA2. Comparison of modeled versus measured room acoustic parameters in the recently completed Shaghoian Concert Hall in Clovis, California. Bill Dohn (Dohn and Assoc., Inc., 630 Quintana Rd. 312, Morro Bay, CA 93442, bill.dohn@gte.net) and Richard H. Campbell (Bang-Campbell Assoc., Falmouth, MA 02536)

The Shaghoian Concert Hall in Clovis, CA is a popular new variable acoustic music venue in the greater Fresno, CA area. The design process for this hall included CATT-Acoustic (TM) modeling for analysis and verification of essential room acoustic parameters based upon the settings of the variable acoustic devices. The model of the final design produced parameters that were closely in line with ideal values for a hall of this size and use. Model results will be compared to measured parameters in the completed hall.

1:45

2pAA3. From toy to tool—advanced auralization procedure in daily design work. Wolfgang Ahnert and Stefan Feistel (AFMG, Arkonastr. 45-49, 13189 Berlin, Germany)

Since more than 20 years simulation procedures are more and more common, but the auralization procedure is considered mainly as a toy. The reason for this relates partially to the efforts needed to get real auralized sound files. In a previous paper the authors reported about a method to produce high end auralization files. This method allows to use normal head phones to get the right spatial impression without in-head localization. The main reason not to use an auralized sound impression in the daily design work is the time-consuming procedure to calculate true impulse responses (IR) especially in large halls. In this paper new algorithms are reported to calculate IRs in multithread mode with one computer or better via a network with a set of CPUs working in parallel. So calculations in large halls maybe be reduced from 8–10 h with one CPU to 10–20 min with multicore computers. The paper explains the way from the model to high-end auralized files. Some examples demonstrate the quality of these derived binaural files.

2:05

2pAA4. The spatial perception of a large pipe organ in various locations in a church computer model is investigated using multiple sources properly spaced within an organ chamber, with each source representing an organ stop. Richard Campbell (Bang-Campbell Assoc., 26 G Chilmartk Dr. East Falmouth, MA 02536)

It is surmized that the auralization of a large pipe organ should use multiple sources properly spaced in the organ chamber with each source representing a stop. But at some point in the acoustic environment of the listener, the advantage of such spatial sourcing disappears. A MIDI sequencer is used to generate audio files of a Buxtahuda fugue in six parts using six different stops. The sources are properly spaced within an organ chamber in a large church. Binaural recordings are evaluated at various locations in the church.

2:25

2pAA5. Comparison of auralized and measured sound in moderately reverberant spaces. Robert C. Coffeen, Jonathan Birney, Stephanie Hoeman, Shane Kanter, Hannah Schultheis (School of Architecture and Urban Planning, Univ. of Kansas, 1465 Jayhawk Blvd., Lawrence, KS 66045, coffeen@ku.edu), Lauren M. Ronsse, and Lily M. Wang (Univ. of Nebraska-Lincoln, Omaha, NE 68182-0681)

This research performs an in-depth comparison of sound from computer auralizations with measured binaural room impulse responses and recordings taken in actual spaces. Binaural measurements and recordings have been gathered in two church naves with midfrequency reverberation times of about 1.5 and 2.5 s. The results from these measurements are compared with auralizations from computer models of the spaces in two different room acoustic modeling programs. The source and receiver positions used for the auralizations are the same as those measured in the real spaces. One of the naves was previously investigated [R.C. Coffeen and G. Caunt, J. Acoust. Soc. Am. **105**, 1174 (1999) (A)] with results from computer auralizations compared to measured binaural recordings in the space. As numerous advancements have been made to computer modeling programs since that time, this project revisits and expands the previous research using updated modeling and measurement techniques. The results of this research not only portray the developments in computer modeling that have occurred over the past decade, but also depict the relationship between current computer auralizations and actual sound in moderately reverberant spaces.

2:55

2pAA6. Using computer auralization to help prevent major problems relating to room acoustics and electroacoustic sound reinforcement. Robert C. Coffeen (Sch. of Archit. and Urban Plan., Univ. of Kansas, 1465 Jayhawk Blvd., Lawrence, KS 66045, coffeen@ku.edu)

Computer modeling and computer auralization will produce comparative listening experiences for architects, building owners, and building users based on selected interior surface shapes, interior finish materials, and electroacoustic sound distribution. Auralization can be a significant tool in helping building designers, owners, and users understand potential acoustical problems and the need for proper acoustic and electroacoustic design.

Contributed Papers

3:15

2pAA7. Diffraction culling for virtual-acoustic simulations. Paul Calamia (Dept. of Comp. Sci., Princeton Univ., 35 Olden St., Princeton, NJ 08540, pcalamia@cs.princeton.edu), Benjamin Markham (Acentech Inc., Cambridge, MA 02138), and U. Peter Svensson (Norwegian Univ. of Sci. and Technol., NO-7491 Trondheim, Norway)

Acoustic simulations of complex virtual environments typically are created with geometrical-acoustics techniques. Such simulations can be augmented with edge diffraction modeling for improved accuracy, but not without a significant increase in processing time due to the additional propagation paths which must be considered and the computational complexity of the diffraction calculations. However, for a given modeling scenario, the contribution of a diffracted path to the overall impulse response can vary over a large range, suggesting that certain diffracted paths can be ignored, or culled, to reduce processing time with a limited effect on the accuracy of the simulation. In this talk, we first analyze the effects of diffraction culling through a precomputed, amplitude-based ranking scheme. We then describe a simple procedure for identifying and culling insignificant diffraction components during a virtual-acoustic simulation which approximates the performance of the precomputed ranking. Through numerical and subjective analysis, we show that a significant percentage of diffracted paths can be ignored if the retained paths are those which lead to the highest-amplitude diffraction components, although the audible effects of such diffraction culling are dependent on the input signal.

3:30

2pAA8. Singers' preferences for acoustical characteristics of performing spaces. Kathleen Stetson (Arup Acoust., 155 Ave. of the Americas, New York, NY 10013, kathleen.stetson@arup.com) and Jonas Braasch (Rensselaer Polytechnic Inst., Troy, NY 12180)

Classical singers, whose instruments' close proximity to their ears makes them unique among musicians, require particular attention from acousticians addressing musician support in performance space design. This study expands upon the few previous analyses of acoustics for singers by exploring what is most basic about solo voice self-perception in halls used for concerts and recitals. A questionnaire was given to a number of professional classical singers and their numerical and narrative responses were analyzed. Five concert halls were measured from the singer's perspective on stage, utilizing a head and torso simulator with a mouth speaker to mimic the proximity of a singer's voice and ears. The resulting impulse responses were utilized in preference tests featuring real-time binaural auralization of singers' vocalizations. The correlations between the subjective results, existing objective parameters, and physical hall characteristics were explored. A strong connection was found between increasing preference and increasing reverberation time. Additionally, test subjects indicated a statistically significant dislike of or preference for a hall, regardless of the singing location on stage or the classical genre being sung. Further developments of this study are discussed in the context of ongoing opera house design utilizing computer model simulations.

3:45

2pAA9. Thirteen findings in ten minutes. Michael Ermann, Nate Crawford, Braden Field, Jessica Green, Sky Kim, Julia Mitchell, Steve Smith, Matthew Van Wagner, John Samuel Victor, and Amanda Massengill (School of Architecture and Design, Virginia Tech, 201 Cowgill Hall, Blacksburg, VA 24061-0205, mermann@vt.edu)

Nine architecture students in an architectural acoustics course studied the influence of design on the acoustic response of spaces. Thirteen of their projects will be presented, rapidly, with time to delve into some of them more deeply in response to questions from attendees. Areas of focus include: room shaping and balcony composition; ceiling and canopy height; canopy design; perception and preference of double sloped decays; side wall angle and orientation; room length; very tall ceilings; room width; side wall diffusion; mapping background noise levels; and frequency content of noise.

Session 2pAB

Animal Bioacoustics and Acoustical Oceanography: Autonomous Remote Monitoring Systems for Marine Animals II

Kathleen C. Stafford, Chair
Applied Physics Lab., Univ. of Washington, Seattle, WA 98105

Invited Papers

1:00

2pAB1. Validating acoustic monitors for marine animals: Field experience with beaked whales and digital acoustic monitors (DMONs). Mark Johnson, Tom Hurst (Woods Hole Oceanograph. Inst., 86 Water St., Woods Hole, MA 02543, majohnson@whoi.edu), Anton Arias, and Natacha Aguilar de Soto (Univ. of La Laguna, Tenerife, Spain)

Passive acoustic monitoring (PAM) is a promising tool for improving the effectiveness of visual surveys for marine animals and for stand-alone persistent monitoring. Nonetheless, significant data gaps make it difficult to predict PAM performance for many species. Detection functions are only beginning to be formed for some vocalizations and detectors. Statistical models for calling rates, as a function of behavior, are needed to translate acoustic detections into abundance estimates, or lack of detections into decisions about absence of animals. Finally, ambient noise levels and spectra are unavailable in most of the world's oceans, complicating the application of results from one area to another. Although some of these gaps are being addressed by a growing group of researchers, there is an urgent need to develop standards for measuring and reporting results, and to foster the interchange of data. To exemplify the form such standards might take, and the potential pitfalls, we present results from a series of field experiments designed to assess the performance of an acoustic monitor for beaked whales. The experiments made use of a freely available reference design for an acoustic detector, called the DMON, which may provide a basis for standardizing and validating real-time implementations.

1:20

2pAB2. Screening large data sets and real-time data streams for bioacoustic signals. Holger Klinck (Cooperative Inst. for Marine Resour. Stud., and NOAA Pacific Marine Environ. Lab., Oregon State Univ., 2030 SE Marine Sci. Dr., Newport, OR 97365, Holger.Klinck@oregonstate.edu), Lars Kindermann (Alfred Wegener Inst. for Polar and Marine Res., 27568 Bremerhaven, Germany), David K. Mellinger (Oregon State Univ., Newport, OR 97365), and Olaf Boebel (Alfred Wegener Inst. for Polar and Marine Res., 27568 Bremerhaven, Germany)

This presentation will discuss a major challenge of passive-acoustic monitoring systems: the analysis of large data sets to identify the occurrence of bioacoustic signals of interest. Triggered by the rapid development of digital audio technology and the increasing capacity of memory devices, it has become easier than ever to produce large, long-term acoustic data sets. However, analyzing these data sets is challenging, as suitable automated detection and classification systems are needed to perform the analysis in a reasonable amount of time. One such large data set is currently produced by the Perennial Acoustic Observatory in the Antarctic Ocean. This passive acoustic observatory has been operated by the Alfred Wegener Institute since January 2006 and has generated more than 10,000 hours of data to date. The observatory features a data link via satellite, which allows analysis of the recorded hydroacoustic data in real time in Germany. However, to be able to run custom algorithms over the entire data set in several times real-time speed, a distributed computing system was developed and applied. Here we provide a detailed description of this system and discuss further possible applications.

1:40

2pAB3. Acoustic sampling for marine mammals in the Beaufort Sea July 2007–March 2008. Kathleen Stafford (Appl. Phys. Lab, Univ. of Washington, 1013 NE 40th St., Seattle WA 98105, stafford@apl.washington.edu), Sue Moore (Alaska Fisheries Sci. Ctr., Seattle WA 98115), Catherine Berchok (Natl. Marine Mammal Lab, Seattle WA 98115), and David K. Mellinger (Oregon State Univ., Newport OR 97365)

As climate change is driving rapid, unprecedented warming of the Arctic, there is increasing interest in how such change will impact Arctic marine mammals. Impacts are anticipated from from habitat alteration, including increasing ambient noise levels from shipping, seismic exploration for oil and gas and geophysical research, and (potentially) commercial fishing. In order to monitor natural and anthropogenic sources of noise, four autonomous recorders were deployed along the 100-m isobath between Cape Halkett and Barrow and recorded data from July 2007–March 2008. The instruments sampled at 8192 Hz on a schedule of 10 min on, 20 min off. Marine mammal sounds recorded included pinnipeds (walrus and bearded seals) and cetaceans (bowhead and beluga whales), while anthropogenic sources included shipping and air gun sounds. Seasonal and geographic patterns for these sounds will be presented. These data form part of a broader-scale international, year-round monitoring program in the Arctic that we hope will eventually span the entire Arctic and provide a basin-wide acoustic observatory.

Contributed Papers

2:00

2pAB4. Integration of automated detection methods into NOAA Southwest Fisheries Science Center (SWFSC) acoustic marine mammal monitoring protocol. Tina M. Yack, Jay Barlow, Shannon Rankin (Natl. Marine Fisheries Svce., Southwest Fisheries Sci. Ctr., 3333 N. Torrey Pines Court, La Jolla, CA 92037, tina.yack@noaa.gov), and Douglas Gillespie (Univ. of St. Andrew, Fife KY16 8LB, Scotland)

Southwest Fisheries Science Center (SWFSC) has used combined visual and acoustic techniques to monitor marine mammal populations for the past 8 yrs. Currently, SWFSC passive acoustic surveys of cetaceans require specially trained personnel to monitor hydrophone signals in real-time. While effective, this method is time-consuming and costly. Automated detection of cetacean vocalizations would be a valuable tool during SWFSC surveys, allowing for detection when experienced technicians are unavailable. This technique is advantageous because it significantly reduces effort and removes sources of human error and bias in detection ability. PAMGUARD 1.0 CORE software was evaluated for use in automated detection of cetacean acoustic signals. Three different detector configurations of PAMGUARD were evaluated. This work shows that the majority of whistle and click events can be detected using PAMGUARD software. All of the PAMGUARD trials were capable of detecting whistles and clicks of cetacean species with varying success. These techniques were field-tested at sea during a recent SWFSC marine mammal survey. Automated detection of beaked whales and Dall's porpoise during this survey will also be discussed. It is our goal to integrate automated detection methods into SWFSC's acoustic marine mammal monitoring protocol and this work is an important step in doing so.

2:15

2pAB5. Tracking fin and blue whales above the Juan de Fuca Ridge with a local seafloor seismic network. William S. D. Wilcock, Dax C. Soule (School of Oceanogr., Univ. of Washington, Box 357940, Seattle, WA 98195, wilcock@u.washington.edu), and Richard E. Thomson (Inst. of Ocean Sci., Sidney, BC, V8L 4B2 Canada)

The Endeavour segment of the Juan de Fuca mid-ocean ridge hosts several high-temperature hydrothermal fields. Previous analysis of bioacoustical data shows that zooplankton are enhanced at all depths above the hydrothermal vent fields compared with sites $\geqslant$10 km away. From 2003–2006, a seafloor seismic network was deployed around the hydrothermal vent fields to monitor earthquakes and it also recorded an extensive data set of fin and blue whale calls. As part of an investigation of a potential correlation between whale tracks, enhanced zooplankton concentrations, and hydrothermal vents above the Juan de Fuca Ridge, an automatic algorithm is being developed to track vocalizing whales that swim near the network. Events are detected by triggering with the ratio of short-term to long-term running RMS averages and whale calls are distinguished from earthquakes based on their spectra. For fin whales each 1-s arrival is identified based on its instantaneous amplitude and frequency and a pick is made at the mid-energy point. A grid search method is used to localize calls using direct and multipath arrivals. The algorithm and preliminary results will be presented. [The Keck Foundation supported the seismic network and the Office of Naval Research is supporting this study.]

2:30

2pAB6. Frequency quantiles and dual harmonic tracking for detection and classification of killer whale calls. Val Veirs (The Whale Museum, Friday Harbor, WA 98250, Colorado College, Colorado Springs, CO, val @beamreach.org)

The Salish Sea Hydrophone Network, www.OrcaSound.net, is operating five streaming hydrophones in the critical habitat of the endangered Southern Resident orcas. Software is being developed that allows each site to sift through the approximately 10 Gbytes of information that are produced each day at each site in order to detect killer whale calls and related sounds. Detection of calls is accomplished via triggering on three time dependent features extracted in real-time from sequential power spectra. One of these three features is derived from the bandwidth between quartiles of the filtered power spectrum. The other two quantify the degree to which the power spectrum has one or two harmonic structures. Features are extracted into feature sets that save the details of each feature: amplitudes; durations; and time variations. A metric has been devised that measures the similarity of different sequences of feature sets. With this metric an unsupervised learning algorithm builds a tree structure that classifies sounds by their similarity. As new calls come in, they either fall into pre-existing groups or create new branches. Automatic reports are made via the Web and e-mail.

2:45

2pAB7. Tracking multiple sperm whales with widely spaced bottom-mounted hydrophones. Eva-Marie Nosal (Dept. of Ocean and Resources Eng., Univ. of Hawaii, 2540 Dole St., Honolulu, HI 96816)

One dataset from the 2nd Int. Workshop on Detection and Localization of Marine Mammals Using Passive Acoustics Data featured multiple clicking sperm whales recorded for 20 min. Data were recorded on five widely spaced bottom-mounted hydrophones at the Atlantic Undersea Test and Evaluation Center. This dataset is used to develop and apply a model-based time difference of arrival (TDOA) method that is capable of simultaneously tracking multiple animals. Clicks on all hydrophones are detected. For every receiver pair, all possible time-differences of arrival (within reasonable time limits) are formed from the detected clicks. A scatterplot of TDOAs versus time, although noisy due to many false TDOAs formed from incorrectly associated clicks, reveals clear "tracks" of slowly varying TDOAs. These tracks are extracted and input to a TDOA tracking algorithm that gives 3-D likelihood surfaces of whale position. Local maxima in the likelihood surfaces are extracted and clustered to give estimated whale tracks.

3:00—3:20 Break

Invited Paper

3:20

2pAB8. The Acousonde: A miniature autonomous wideband recorder. William C. Burgess (Greeneridge Sci. Inc., 6060 Graham Hill Rd., Fl. 2 Stop F, Felton, CA 95018, burgess@greeneridge.com)

The Acousonde™ is a newly designed miniature acoustic/ultrasonic recording tag incorporating several improvements over its predecessor, the Bioacoustic Probe. Design trade-offs for its acoustic data paths targeted acquisition of both near and distant odontocete echolocation clicks with minimal distortion while preserving general-purpose utility and low-power operation. Two acoustic channels are available: a low-power channel for long-term recording of signals up to 9 kHz and a high-frequency channel for signals up to 100 kHz. Each channel has its own dedicated hydrophone. For antialiasing, the low-power channel uses an adjustable switched-capacitor elliptic filter, while the high-frequency channel uses a fixed-frequency linear-phase filter; both filters may be bypassed if raw acquisition is desired. "Ping-pong" alternating sampling may be used to acquire samples from both channels concurrently, possibly to assess time-of-arrival differences between the two hydrophones. The controlling microprocessor, an ARM 9 with vector floating point accelerator, can digitally filter and downsample acoustic data during acquisition to reduce storage requirements. Other sensors include a 3D accelerometer, a 3D compass, a depth transducer, and a temperature monitor. Eight gigabytes of data storage are available, with data offload via a MicroUSB connector. Initial tests with captive animals are planned shortly. [Work supported by ONR.]

3:40

2pAB9. Validated reef fish sound scans of passive acoustic monitors on Hawaiian coral reefs. Timothy C. Tricas and Kelly Boyle (Dept. of Zoology and Hawaii Inst. of Marine Biol., Univ. of Hawaii at Manoa, Honolulu, HI)

Monitoring of fish sounds on coral reefs is a valuable potential technique for fisheries managers to remotely assess local fish populations and their behaviors. However, the species identity of most fish sounds on shallow coral reefs is not known. We have deployed two ecological acoustic recorders (EARs) at 20 m deep on two shallow reefs on the island of Hawaii. In order to validate which fish species produce these acoustic behaviors we used closed circuit rebreather diving, which produces almost no ambient acoustic noise, to record video and sonic behaviors of fish near the recording sites. From the videos we have identified 37 putative acoustic species many of which produce multiple sounds that include behaviors associated with intra- and interspecific aggression, feeding, courtship, and spawning. Cluster analysis was used to identify acoustic clades among and within species. Acoustic waveform average templates were constructed for different species clades and used in XBAT to screen the long-term recordings from the EAR. The use of these species-specific sound templates confirms the potential to detect diel, lunar, and longer-term rhythmicity for several species. This technique also shows promise for characterizing seasonal and annual periods of activity of sounds associated with context-specific behaviors.

3:55

2pAB10. Beaked whale density estimation from single hydrophones by means of propagation modeling. Elizabeth T. Küsel, David Mellinger (NOAA/PMEL, Hatfield Marine Sci. Ctr., Oregon State Univ., Newport, OR 97365, elizabeth.kusel@noaa.gov), Len Thomas, Tiago A. Marques (Univ. of St. Andrews, Scotland), David J. Moretti, and Jessica Ward (Naval Undersea Warfare Ctr., Newport, RI 02841)

Passive acoustic sonar systems offer many advantages to the study of marine mammals. For density estimation studies, it is important to evaluate the probability of detecting an animal as a function of its distance from the receiving sensor. In this work, acoustic propagation modeling is used to estimate the transmission loss as a function of depth and range between a source whale and a single-hydrophone receiver. The computed transmission loss is compared to ambient noise levels and source level distributions to estimate the detection probability as a function of range. Results will be compared to beaked whale data recorded on bottom-mounted sensors in the Atlantic Undersea Test and Evaluation Center (AUTEC) in the Bahamas, where the location of clicks is relative to one hydrophone. Source level and beam pattern extracted from digital acoustic tags (DTags) applied to a sample of animals at the same location will also be used in the detection model, and beaked whale spatial density will be estimated. The detection probability function will provide a relevant comparison to the detection function derived empirically from the DTag data by Marques *et al.* [Marques *et al.*, J. Acoust. Soc. Am. (submitted).]

4:10

2pAB11. Passive acoustic monitoring of fish activity in the Hawaiian Archipelago. Pollyanna Fisher-Pool, Marc O. Lammers (Joint Inst. for Marine and Atmospheric Res., NOAA-CRED, 1125B Ala Moana Blvd., Honolulu, HI 96814, Pollyanna.Fisher-Pool@noaa.gov), Kevin Wong, Russell E. Brainard (NOAA Fisheries, Honolulu, HI 96814), and Whitlow W. L. Au (Univ. of Hawaii, Kailua, HI 96734)

Fish are an important component of coral reef ecosystems and can be valuable indicators of ecological change on reef environments. Many species of fish produce sounds and are therefore well suited for passive acoustic monitoring. Since 2006, NOAA has been using Ecological Acoustic Recorders (EARs) to monitor coral reef habitats in the main and Northwestern Hawaiian Islands in an effort to develop multi-year time series of biological activity at these locations. Sixteen EARs are presently deployed on reef habitats ranging in depth from 2 to 23 meters. Preliminary results reveal that each site is characterized by a unique composition of acoustically active fish . Many sounds are also common at multiple sites. Different species show considerable variability in their diet and seasonal patterns of activity. The results indicate that long-term acoustic monitoring of fish at these sites is likely to yield useful information about changing patterns of fish presence, behavior, and relative abundance. These metrics can be used to gauge the relative stability of ecosystems and be related to physical, oceanographic, and anthropogenic variables affecting them.

4:25

2pAB12. Using moored passive acoustic recorders to assess seasonal occurrence and movements of southern resident killer whales in the coastal waters of Washington State. M. Bradley Hanson, Candice K. Emmons (NOAA/NMFS/Northwest Fisheries Sci. Ctr., 2725 Montlake Blvd. E, Seattle, WA 98112, brad.hanson@noaa.gov), Jeffrey A. Nystuen (Univ. of Washington, Seattle, WA 98105-6698), and Marc O. Lammers (Oceanwide Sci. Inst., Honolulu, HI 96839)

Designating critical habitat is mandated for species listed under the U.S. Endangered Species Act. This task has only been partly accomplished for southern resident killer whales (SRKWs) because winter distribution is poorly understood due to a variety of factors limiting visual sightings within their known central California to northern British Columbia range. To capitalize on the unique vocal behavior of resident killer whales, including pod-specific dialects, two types of acoustic recorders were deployed at strategic locations that span the Washington coast. Between 2005 and 2008 recorders were deployed in early winter for an average of 175.5 days at up to four sites. These functioned for an average of 114.8 days and collected a total of 47 SRKW detections. This exceeds the number of visual sightings during the same time period (15). Additionally, northern resident, transient, and offshore killer whales were recorded as well as Pacific white-sided dolphins, and humpback and sperm whales. SRKW were detected by both types of recorders and in all areas. Detections were made between Jan. and July with the majority of these detections in Mar., Apr., and May. This new information will be of key importance to managers in meeting recovery goals.

Session 2pAO

Acoustical Oceanography and Underwater Acoustics: Environmental Inferences in Inhomogeneous Ocean Environments I

David P. Knobles, Chair
Applied Research Labs., Univ. of Texas at Austin, Austin, TX 78713

Chair's Introduction—1:00

Invited Papers

1:05

2pAO1. Environmental influences on low-frequency, shallow-water acoustic propagation and inversion. George V. Frisk (Dept. of Ocean Eng., Florida Atlantic Univ., 101 N. Beach Rd., Dania Beach, FL 33004, gfrisk@seatech.fau.edu)

Historically, the seabed has been considered to play the dominant role in shallow-water acoustic propagation at low frequencies. As a result, propagation models have focused on the incorporation of accurate values of bottom properties, while inversion techniques have concentrated on the determination of geoacoustic properties of the seabed. In recent years, however, the assumption of a benign water column has increasingly come under scrutiny in addressing both the forward and inverse problems. This paper addresses these issues as they relate to a measurement and inversion methodology in which acoustic data are acquired on synthetic radial apertures that are created using a moving source/receiver configuration in concert with precision navigation. These data can be transformed into the horizontal wavenumber domain to obtain an estimate of the propagation characteristics of the waveguide; namely, its modal content. The modal spectra can then be inverted using a variety of techniques to determine estimates of the waveguide parameters, specifically the geoacoustic properties of the seabed. The issues associated with the successful implementation of this modal mapping method in a highly variable shallow-water environment are discussed. [Work supported by ONR.]

1:25

2pAO2. The impact of ocean sound speed variability on the uncertainty of geoacoustic parameter estimates. Ross Chapman and Yongmin Jiang (School of Earth and Ocean Sci. Univ. of Victoria, Victoria, BC V8W 5C2, Canada, chapman@uvic.ca)

This paper investigates the influence of water column variability on the estimates of geoacoustic model parameters obtained from matched field inversions. The acoustic data were collected on the New Jersey continental shelf during the Shallow Water 2006 experiments. The oceanographic variability was evident when the data were recorded. To quantify the uncertainties of the geoacoustic parameter estimates in this environment, Bayesian matched field geoacoustic inversion was applied to multi-tonal continuous wave data. The spatially and temporally varying water column sound speed was parametrized in terms of empirical orthogonal functions and included in the inversion. Its impact on the geometric and geoacoustic parameter estimates was then analyzed by the inter-parameter correlations. Two different approaches were used to obtain information about the variation of the water sound speed. One used only the profiles collected along the experimental track during the experiment, and the other also included observations from a larger area and a greater time period. The geoacoustic estimates from both the large and small sample sets were consistent. However, due to the diversity of the oceanic sound speed, more empirical orthogonal functions were needed in the inversion when more sound speed profile samples are used. [Work supported by ONR.]

1:45

2pAO3. Observed temporal statistics of acoustic travel time and intensity in the South China Sea. Ching-Sang Chiu and Christopher W. Miller, D. Benjamin Reeder, Justin M. Reeves, Steven R. Ramp (Dept. of Oceanography, Naval Postgraduate School, 833 Dyer Rd., Monterey, CA 93943, chiu@nps.edu)

The coupled ocean and acoustic variability in the Northeastern South China Sea basin was monitored using moored oceanographic and acoustic sensors during the 2005-2006 Windy Island Soliton Experiment (WISE). The temperature and current records captured prominent ocean variability at multiple scales, induced by mesoscale eddies, internal tides, and large amplitude internal waves. The latter two were transbasin, propagating from near the Luzon Strait, through the deep basin, onto the northeastern shelf. The concurrent acoustic measurements were attained from the transmission of a 400 Hz, phase-modulated signal along a 166 km path every 15 min. The receptions were processed to give the arrival structure of a pulse and its temporal change over a nine-month period. The observed temporal variability in the statistics of the acoustic travel time and intensity were analyzed using time-series techniques and models with emphasis to elucidate the connection and sensitivity to the observed ocean variability. Results from the analysis are discussed, as they pertain to the ocean processes and those parameters that can potentially be inferred from these types of acoustic transmissions. [The research is sponsored by the Office of Naval Research.]

2:05

2pAO4. Phase front fluctuations due to internal waves in shallow water 2006 experiment. Boris Katsnelson (Voronezh State Univ., Voronezh, Russia), Mohsen Badiey, Jing Luo (Univ. of Delaware, Newark, DE 19716), and James Lynch (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543)

Experimental results and theoretical analysis of the sound phase front fluctuations measured by Vertical and Horizontal Line (VHLA) array (or L-shaped array) are presented. Low frequency broadband signals were radiated by the source (Miami Sound Machine) placed at the distance of ~25 km from the VHLA. During the time period 18:00–22:00 GMT on Aug. 17, 2006, a train of internal solitons traveled across the acoustic track and initiated fluctuations of the sound field. In an earlier paper [J. Acoust. Soc. Am. **124**, EL66–EL72 (2008)], it was shown that intensity of these fluctuations results from the horizontal refraction of the sound waves due to internal solitons. Here we show the acoustic phase front fluctuations for separate waveguide modes for the same period. To obtain phase fronts for the individual modes, a special approach using an L-shaped receiver array is used. The vertical part of the array was used to obtain modal amplitudes. Using the measured sound field based on the perturbation theory, modal phases at the HLA can be calculated. Results of data processing are compared with theoretical calculations. [Work supported by ONR, CRDF, and RFBR.]

2:20

2pAO5. Signal intensity fluctuations in Shallow Water 2006 (SW06) experiment during Event 50. Mohsen Badiey, Jing Luo (College of Marine and Earth Stud., Univ. of Delaware, Newark, DE 19716), Boris Katsnelson (Voronezh State Univ., Voronezh, Russia), and James Lynch (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543)

During the Shallow Water 2006 (SW06) experiment, several internal wave (IW) events were recorded by moving and stationary instruments simultaneously with the acoustic propagation tests. More than 50 IW events were recorded using the University of Delaware's R/V Sharp's radar. On this ship, a J15 sound source transmitted various acoustic signals at different bearings and ranges to the Woods Hole Oceanographic Institution's vertical and horizontal hydrophone arrays. During one of the IW events, the acoustic source was kept at a constant water depth while moving in horizontal plane with the advancing internal wave front. This internal wave packet, named Event 50, was also recorded by R/V oceanous radar a few kilometers away. The reason for placing the sound source on the advancing IW front was to examine the effects of azimuthal variability of the waveguide on the acoustic propagation. A detailed transition of the waveguide as the internal wave progressively occupied the acoustic propagation track between the source and receiver is reported. It is shown that the intensity peaks at small angles between the acoustic track and the internal wave front where sound intensity focusing and defocusing occurs. [Work supported by ONR 321OA and CRDF, and RFBR.]

2:35

2pAO6. Intensity measurements and fluctuations of acoustic transmissions from the Research Vessel Sharp during Shallow Water 2006. Georges A. Dossot, James H. Miller, Gopu R. Potty (Dept. of Ocean Eng., Univ. of Rhode Island, Narragansett Bay Campus, Narragansett, RI 02882), James F. Lynch, Aurthur E. Newhall (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543), and Mohsen Badiey (Univ. of Delaware, Newark, DE 19716)

During the Shallow Water 2006 (SW06) experiment, the University of Delaware's R/V Sharp transmitted various acoustic signals at several different bearings and ranges to the Woods Hole Oceanographic Institute's vertical and horizontal hydrophone line array. The array was strategically positioned near the shelfbreak front, and in an area where internal waves are known to occur. During several of the R/V Sharp's acoustic transmissions, internal waves passed through the sound field. The internal waves and the shelfbreak front can cause complex multimode and multipath interference patterns which result in intensity variations of received acoustic signals. This presentation provides an overview of the R/V Sharp's transmissions, and the corresponding intensity fluctuations of received signals at the array. These fluctuations are compared to internal wave events that were recorded at both the transmission and reception locations. These internal wave events were also imaged by the R/V Sharp's radar and satellite-based radar. Following the work of Fredricks *et al.* [J. Acoust. Soc. Am. **117**, 1038 (2005)], statistical distributions are fit to the calculated intensities for different transmission directions, distances, and times. These distributions are compared to modeled data with and without the internal wave field. [Work sponsored by the Office of Naval Research.]

2:50

2pAO7. Time-frequency pattern of the sound intensity fluctuations of midfrequency signals in presence of internal waves in Shallow Water 06 experiment. Boris Katsnelson, Valery Grigorev, and James Lynch (Woods Hole Oceanograph. Inst., 98 Water St., Woods Hole, MA 02543, jlynch @whoi.edu)

In given paper fluctuations of intensity of sound signals, radiated by the midfrequency source (R/V Knorr) during ~5 h were studied. Broadband signals (2–8 KHz) were received by four single hydrophones fixed at the bottom (SHRUs) placed at different distances from the source (from 4 to 12 km). These four acoustic tracks have different directions relative direction of propagation of the train of intensive internal waves (the corresponding angles in horizontal plane are from ~5 to ~15 deg). Time-frequency diagrams were constructed using frequency filtering of the spectrum of broadband signals with sliding narrow window. Temporal dependences of intensities of received signals within frequency window were constructed for period 14:00 until 19:00 GMT for experiment carried out on 13 August. During this time train of internal solitons was registered, propagating toward the coast. Mentioned time-frequency diagrams demonstrate specific features of influence of internal waves on the temporal variations of the sound intensities at four SHRUs. More exactly variations of predominating frequency in spectra correspond to variations of positions of the solitons at the acoustic tracks. Results of experimental data are compared with theoretical estimations. [Work was supported by RFBR and CRDF.]

3:05

2pAO8. Acoustic ducting, refracting, and shadowing by curved nonlinear internal waves in shallow water. James F. Lynch, Ying-Tsong Lin, Timothy F. Duda, Arthur E. Newhall, and Glen Gawarkiewicz (Woods Hole Oceanograph. Inst., Woods Hole, MA 02543, jlynch@whoi.edu)

Nonlinear internal waves are common on continental shelves and have been shown to have strong effects on acoustic propagation and scattering. Transmissions from previous field work performed in an along-shelf geometry show very strong ducting of low-frequency (50–500 Hz) sound between nonlinear waves. This strong ducting effect is acoustically important. Most all of the acoustic propagation studies of internal waves have used straight line internal wave fronts for individual waves or packets. In our work, we implement a theoretical analysis using the Weinberg-Burridge horizontal rays and vertical modes formalism to study the acoustic ducting, refracting and shadowing of low-frequency sound due to curved internal waves, which seem to dominate in shelf break regions. A three-dimensional parabolic-approximation sound propagation model is also used with consideration of realistic environmental conditions, and the modeling results provide a clear depiction of the underlying physical processes. The oceanographic origin of the internal wave curvature is discussed, as this affects the predictability of the sound speed field. [This work is sponsored by the Office of Naval Research.]

Session 2pBB

Biomedical Ultrasound/Bioresponse to Vibration: Biomedical Applications of Standing Waves

Armen Sarvazyan, Cochair
ARTANN Laboratories, 1459 Lower Ferry Rd., Trenton, NJ 08618

Martin Wiklund, Cochair
Dept. of Applied Phyiscs, Royal Inst. of Tech., SE-10691, Stockholm, Sweden

Chair's Introduction—1:15

Invited Papers

1:20

2pBB1. Ultrasonic manipulation in microfluidic chips for accurate bioparticle handling. M. Wiklund, O. Manneberg, J. Svennebring, B. Vanherberghen, B. Onfelt, and H. M. Hertz (Dept. of Appl. Phys., Royal Inst. of Technol., SE-10691 Stockholm, Sweden)

Micro-manipulation of cells or other bioparticles has important applications in biological and biomedical research. Dielectrophoresis and optical tweezers are the classical tools in this field. Ultrasonic standing wave (USW) technology is presently emerging as powerful alternative, especially in microfluidic chips and other miniaturized systems. In this contribution we will review our present activities in USW-based particle manipulation in microfluidic chips. Recent experiments and simulations allow us to tailor the spatial distribution of the USW force field by multi-frequency actuation and appropriate microchannel/transducer resonance design. We introduce the concept of ultrasonic micro-cages for single-cell or single-particle 3-D ultrasonic manipulation. It is shown that these manipulation tools can be combined with high-resolution optical microscopy, thereby allowing state-of-the-art characterization of individual cells. Frequency-modulation is shown to stabilize the manipulation performance as well as allowing flow-free transport of particles and cells. Environmental control inside the channels has been achieved and proliferation and viability studies are promising. Finally, for bio-analysis, we demonstrate potential for femtomolar bio-analytical sensitivity in bead-based assays using USW enrichment.

1:40

2pBB2. Acoustofluidics: Theory and simulation of streaming and radiation forces at ultrasound resonances in microfluidic devices. Henrik Bruus (Dept. of Micro- and Nanotechnology, Tech. Univ. of Denmark, DTU Nanotech, Bldg. 345 East, DK-2800 Kongens Lyngby, Denmark, Henrik.Bruus@nanotech.dtu.dk)

During the past few years, there has been an increasing interest in applying ultrasound waves to manipulate biological particles and liquids in microfluidic devices. To obtain optimized designs and functionalities of the acoustofluidic devices, more detailed theoretical studies and numerical simulations are called for. The basic second-order perturbation theory is presented for acoustic fields applied at ultrasound frequencies in silicon/glass systems containing water-filled microfluidic channels and chambers. For various specific device geometries, the resonance frequencies and corresponding modes of the acoustic fields are calculated numerically to first order. At these frequencies, the largest possible acoustic powers are obtained in the microfluidic system. The first order fields are then used as source terms in the equations for the time-averaged second order pressure and velocity fields, which are directly related to the acoustic radiation force on single particles and to the acoustic streaming of the liquid. For the radiation pressure effects, there is good agreement between theory and simulation, while the numeric results for the acoustic streaming effects are more problematic. Possible improvements in the latter case are discussed.

2:00

2pBB3. Transient processes in acoustic resonators. Armen Sarvazyan (Artann Labs., 1753 Linvale-Harbourton Rd., Lambertville, NJ 08530, armen@artannlabs.com) and Lev Ostrovsky (Zel Technologies/Univ. of Colorado, Boulder, CO 80305)

The use of ultrasound in resonators for manipulating particles in various biomedical applications is a relatively well studied topic. These studies were mostly concerned with steady-state processes. However, in certain important applications, such as stirring and mixing fluids in microfluidics and biosensors, the time scale of a process plays a crucial role. In this presentation we consider some of these applications. In particular, the radiation force-induced motion of microparticles and microbubbles in a swept-frequency ultrasonic resonator is considered. The particles are forced to move due to switching the resonance modes in a resonator cell, thus providing effective stirring of the fluid. Another field of medical application of standing waves, where transient processes are of crucial importance, is ultrasonic treatment of tissues. In this new field of ultrasonic therapy, standing waves are used for producing lesions in the tissue with simultaneous monitoring the formation of the lesion by automatic controlling parameters of the standing wave field. The spatial and temporal distribution of ultrasound energy in the resonator containing treated tissue portion is theoretically analyzed. Dynamics of temperature changes in the tissue, which is important for optimizing tissue treatment regimes, is evaluated. Experimental data illustrating theoretical results are presented.

2:20

2pBB4. Current applications of ultrasonic resonators to biomolecular studies. Tigran Chalikian (Faculty of Pharmacy, Univ. of Toronto, 144 College St., Toronto, ON M5S 3M2, Canada, chalikan@phm.utoronto.ca)

The most versatile family of instruments providing the highest precision of acoustic measurements in the lowest sample volumes utilizes the method of fixed-path interferometer. The speed of sound in a medium is a simple function of its density and compressibility. Both parameters are determined by and, therefore, reflect the entire spectrum of intra- and intermolecular interactions within the system. In addition, compressibility probes the pressure response of these interactions. Current resonator-based instruments provide reliable measurements in diluted solutions of biological compounds with solute concentrations on the order of 1 mg/mL and solution volumes of 1 mL. They require less than 1 mg of sample, a range acceptable for the majority of biochemical and biophysical investigations. Ultrasonic velocimetric measurements have been employed to study a range of biologically relevant reactions, including the folding /unfolding transitions of proteins and helix-to-coil transitions of nucleic acids, as well as drug-DNA, ligand-protein, protein-protein, and protein-DNA association events. The limiting factor in such investigations is the need to rationalize the measured properties (volume, compressibility, and their derivatives) in terms of microscopic events, such as solute-solvent interactions. This presentation reviews biomolecular applications of acoustic measurements and discusses the development of approaches for microscopic interpretation of macroscopic volumetric observables.

2:40

2pBB5. Cylindrical standing wave resonator for liquid food quality control. Aba Priev (Hebrew Univ.-Hadassah Med. School, Jerusalem 91120; NDT Instruments Ltd., 56 Anilevich St., Jerusalem, Israel, abbap@ekmd.huji.ac.il) and Armen Sarvazyan (ARTANN Labs., Inc., Lambertville, NJ 08530)

In this paper, an innovative technology based on the use of ultrasonic cylindrical standing waves for continuous monitoring of quality of various liquid food products, such as milk, juices, beer, wine, and drinking water is described. A proprietary unique feature of the developed ultrasonic analyzer is that it employs a combined mode of operation using both high-intensity and low-frequency (10 W/cm^2, 1 MHz) waves for separation and concentration of the high-molecular-weight particles (fat globules or cells) and low-intensity and high-frequency (0.5 W/cm^2, 10 MHz) waves for compositional analysis. High accuracy for ultrasound velocity measurements (up to 0.001%) and ultrasound attenuation (of about 1%) and rapid testing time (2–20 s) have been achieved. Comparative analyses of the ultrasonic method with standard reference techniques have produced linear calibration curves for major components with correlation coefficients higher than 0.95. It is thus possible to monitor total protein and fat content, and somatic cell count in raw milk in cowsheds, or salinity, turbidity, specific gravity, and particles (bacteria) in drinking water directly. Advantages of the proposed technology include the reagent-free nature, no need for sample pretreatment, ease-of-use, and low cost.

3:00—3:30 Break

Contributed Papers

3:30

2pBB6. Movement of liquids and solid particles on multiwall acoustic plates. Jeremy J. Hawkes (School of Chem. Eng. and Analytical Sci., The Univ. of Manchester, MIB 131 Princess St., Manchester, M1 7DN, UK), Rito Mijarez-Castro (Instituto de Investigaciones Elctricas, Morelos, Mexico, rmijarez@iie.org.mx), and Peter R. Fielden (The Univ. of Manchester, Manchester, M1 7DN, UK)

Well-defined vibration modes are used to form acoustic wells on flat plates. Within these dynamic traps, acoustic streaming continually stirs the contents. Traps can be used to hold liquids in separate heaps on a surface or to hold particles in levitated arrays. A protocol for creating trap patterns will be described, where FE modelling is used to select modes and then maneuver the modes to the desired frequency.

3:45

2pBB7. Nonlinear ultrasonic standing waves in bubbly liquid: A numerical study. Vanhille Christian (Escet, Univ. Rey Juan Carlos, Tulipán s/n, 28933 Móstoles, Madrid, Spain, christian.vanhille@urjc.es) and Campos-Pozuelo Cleofé (Inst. de Acústica, CSIC, 28006 Madrid, Spain)

This study deals with the behavior of nonlinear ultrasonic standing waves in a bubbly liquid. A water air mixture is considered. The SNOW-BL numerical code gives the solution of a differential system coupling the nonlinear bubble equation with the linear wave equation. Several kinds of high power standing waves which may be useful in biomedical applications are considered here: pulses propagating in water with air bubbles clouds or layers, harmonic waves in a bubbly resonator, non-resonant standing waves in a fluid with bubbles. Conclusions about acoustic pressure distributions, waveforms, and frequency content, as well as mean and rms pressures, are given. Particular acoustical effects induced by the dynamics of the air-bubbles on the pressure standing wave are commented. Comparisons with results in homogeneous fluids are also presented. [Work supported by DPI2008-01429.]

4:00

2pBB8. Use of resonator method for body fluids composition assessment. Viktor Klemin (BIOM, 3 Veterinarnaya Str., Nizhny Novgorod, 603098, Russia, klemina@rf.unn.ru)

Ultrasonic resonator method of body fluids composition evaluation is described. The experimental data on assessment of whole blood, blood serum, gastric juice, and saliva are presented. The developed method is based on the assumption of additivity of the contributions of major components of fluids in their acoustic characteristics. The acoustic characteristics measured by the ultrasonic resonator method include the speed and absorption of ultrasound and their frequency and temperature dependences. The device for evaluation of body fluid composition comprises differential ultrasonic resonator cells with the volume of 80 mkl each, operating at about 8 MHz, mounted in a micro-thermostat, and a compact electronic unit. The method allows for simultaneous determination of total protein, Na+ and K+, in saliva and gastric juice, lipid components (cholesterol total, cholesterol of high and low density, and triglycerides), the total protein and protein fractions in blood serum within a very short period of time, on the order of minutes, in contrast to conventional time consuming tests. Other advantages of the proposed technology include the reagent-free nature, no need for sample pretreatment, ease-of-use, and low cost. The accuracy of ultrasonic method for body fluid composition assessment is comparable to that of conventional time-consuming and expensive assays.

4:15

2pBB9. Ultrasound standing wave fields control the spatial distribution of cells and protein in three-dimensional engineered tissue. Kelley A. Garvin (Dept. of Biomedical Eng., 205 Goergen Hall, Univ. of Rochester, Rochester, NY 14627, garvin@bme.rochester.edu), Denise C. Hocking, and Diane Dalecki (Univ. of Rochester, Rochester, NY 14627)

The application of ultrasound standing wave fields (USWFs) to cell suspensions results in the radiation force-mediated movement of cells to areas of the field separated by half-wavelength intervals. In this study, USWF-induced cellular arrangements were maintained after removal of the sound field by polymerization of a collagen type-I solution around the organized cell bands. Using a water tank setup, cell suspensions of varying concentrations were exposed to a 1-MHz, continuous wave USWF for 15 min, during which time collagen polymerization occurred. An acoustic pressure amplitude of 0.2 MPa was used to achieve the USWF-induced cell organization. Compared to sham samples with a random cell distribution, cell viability was not adversely affected by USWF exposure. The organization of cells into a banded pattern within the collagen gels resulted in a significant two-fold increase in cell-mediated gel contraction, suggesting that USWF-induced cell organization leads to differential extracellular matrix remodeling. Protein organization within the tissue constructs was further controlled by USWF-mediated collocalization of soluble fibronectin to cell bands. These technologies have applications to the fabrication of tissue analogs with desired tissue characteristics for the repair or replacement of diseased or injured tissues and organs in the field of tissue engineering.

4:30

2pBB10. Two-dimensional numerical simulations for the time-averaged acoustic forces acting on a rigid particle of arbitrary shape in a standing wave. Jingtao Wang (Ctr. of Mech., Dept. of Mech. and Process Eng., ETH Zurich, 8092 Zurich, Switzerland, wang@imes.mavt.ethz.ch) and Jurg Dual (ETH Zurich, 8092 Zurich, Switzerland)

The time-averaged acoustic force can be applied to many practical fields such as contactless particle manipulation in biomedicine. It is necessary to accurately predict the mean forces on suspended obstacles to design ultrasonic particle manipulators. Although there have been many analytical solutions on this topic, it is difficult to determine the acoustic forces on obstacles under more complex system conditions such as proximity to the chamber wall, complex viscous function, acoustic streaming, and complicated particle shapes. Therefore, the numerical modeling may become a powerful tool. In this paper, the time-averaged forces, which act on rigid 2-D particles with different shapes in ideal and viscous fluids exerted by a standing sound wave field, are computed by solving the Navier-Stokes equations directly using the finite volume method (FVM) technique. The cylinder results agree well with Haydock's theoretical prediction and his lattice Boltzmann simulations. Then, the force and torque acting on a needle shaped particle in a standing wave are calculated and discussed in detail. Furthermore, the viscous effects of the host medium are also investigated. Our program with the FVM algorithm proves to be quite suitable for calculating the acoustic forces in standing waves.

4:45

2pBB11. Time reversal of monochromatic signals in elastic media. Brian E. Anderson, Robert A. Guyer, Timothy J. Ulrich, and Paul A. Johnson (Geophys. Group EES-17, Los Alamos Natl. Lab., Los Alamos, NM 87545)

A set of experiments has been conducted to show that time reversal of steady state monochromatic signals can produce spatial focusing in a reverberant elastic cavity when multiple channels are used. The transient portion of the received signals is not used. A single channel does not produce spatial focusing as it only drives the system according to its modal distribution. The amplitude of the energy at the focal location increases as the square of the number of channels used, while the amplitude elsewhere in the medium increases proportionally with the number of channels used. This work has importance in the field of medical ultrasound where the use of a long duration monochromatic excitation may be used for lithotripsy or other ultrasonic therapy. [This work is supported by Institutional Support (LDRD) at Los Alamos National Laboratory.]

TUESDAY AFTERNOON, 19 MAY 2009 — COUNCIL SUITE, 1:00 TO 3:30 P.M.

Session 2pEAa

Engineering Acoustics: Emerging Transduction Devices

Fletcher Blackmon, Chair

Naval Sea Systems Command Division Newport, Newport, RI 02841

Contributed Papers

1:00

2pEAa1. The piezoelectric thickness mode hydrophone using tonpilz structure for deep-sea application. Min Sung, Haksue Lee, and Wonkyu Moon (Dept. of Mech. Eng., Pohang Univ. of Sci. and Tech., PIRO, Rm. 416, san31 hyja-dong, nam-gu, Pohang-si, kyungsangbuk-do, Korea)

A piezoelectric thickness mode hydrophone for deep-sea application using tonpilz structure was designed, and its macroprototype was made as a preliminary for the micromachined version. Several types of micromachined thin-diaphragm sensors for hydrophone application have been reported. They have two issues in deep-sea applications. One is a sensitivity problem. To enhance the sensitivity, a cone structure for sound pressure amplification was placed between the clamped diaphragm and the piezoelectric square plate. To evaluate the effect of the cone structure on sensitivity, which was motivated by tonpilz structure, an air-backed prototype was made using aluminum and piezoelectric ceramic square plate of 700 μm length and 400 μm thickness. A lumped parameter model was used in the design procedure. The measured sensitivity of the prototype was −249.60 dB ref. One volt per micropascal without a preamplifier, and the measured resonant frequency was 30 kHz, which agreed with the prediction. The other is an endurance problem due to high hydrostatic pressure. To develop the endurance for the high hydrostatic pressure in deep-sea, PZT thickness mode and oil-backing on the diaphragm backside were proposed. The comparison of oil-backing and air-backing is to be presented as an evaluation of the endurance development. [Research supported by MRCnd.]

1:15

2pEAa2. Rapid identification of candidate materials for tonpilz head-mass design. Scott P. Porter, Douglas C. Markley, David J. Van Tol, and Richard J. Meyer, Jr (Appl. Res. Lab., The Pennsylvania State Univ., P. O. Box 30, State College, PA 16804, scott.porter@psu.edu)

Optimum performance of a tonpilz transducer head-mass section is often achieved when the mass is minimized and the stiffness is maximized. High stiffness keeps head-mass modes away from the band of interest with minimal material; low mass maximizes the motor section aspect ratio and re-

duces the stored energy in the head-mass, raising the electromechanical coupling coefficient. Therefore, the material selected for the head-mass construction plays an integral role in transducer performance. In the practical design of tonpilz radiating heads, a tool which can rapidly identify the materials best suited for a given design is desirable. The figure of merit, $E\rho^3$, has traditionally been used. This figure of merit, however, is based on thin-plate approximations. Most actual tonpilz head-masses require thick-plate theory for accurate analysis. In this paper, the authors use a numerical routine to rapidly assess the thick-plate behavior of various materials and rank their suitability for a given head-mass geometry. These results are corroborated with finite element modeling. Finally, the thick-plate ranking scheme is compared to the traditional figure of merit. The results of this comparison challenge established assumptions about the best materials for head-mass design and identify ceramic materials as strong candidates for future designs.

1:30

2pEAa3. Investigation of single crystals for U.S. Navy standard electro-acoustic transducer applications. Jeffrey A. Szelag and Thomas R. Howarth (Naval Sea Systems Command Div. Newport, Newport, RI)

The Underwater Sound Reference Division (USRD), Naval Sea Systems Division in Newport, RI, is the U.S. Navy's primary source for the provision of standard underwater electro-acoustic reference transducers. USRD has over 40 years of traceable and repeatable historic data for each transducer that is currently available for underwater calibrations and experiments. As such, USRD's primary focus is on the continuous development of new reference transducers incorporating the latest technologies available. Requirements for these standards include repeatability over extended time, traceability, and ease of maintenance. This presentation covers an on-going USRD investigation to feature single crystal PMN-PT as the active substrate in the current F41 program transducer. In addition, lossy rubber substrates are being examined to replace the legacy corprene passive materials in order to extend the operating depths of the transducer. Our presentation will begin with an overview of the fabrication techniques followed by experimental underwater data comparing the new active and passive materials with the traditional F41.

1:45

2pEAa4. A generalized differential effective medium model of piezoelectret foams. Michael R. Haberman (Appl. Res. Labs., The Univ. of Texas at Austin, 10000 Burnet Rd., Austin, TX 78758)

Piezoelectrets are closed-cell foams consisting of a continuous polymer matrix containing preferentially oriented and electrically polarized ellipsoidal voids. These materials display low density, low characteristic impedance, thicknesses on the order of 100 μm, and potential to act as conformal transducers on complex geometries. They therefore provide an intriguing alternative to piezoelectric ceramics and piezopolymers for applications such as air-coupled ultrasonics or underwater receive elements. Unfortunately, some fundamental attributes of piezoelectret behavior, such as their non-monotonic change in receive sensitivity with increasing ambient pressure, remain unexplained by physical modeling or experiment. To explain this and other behavior, this work develops a fully coupled multiscale microelectromechanical model which captures the void-scale physics and predicts macroscopically observed piezoelectric properties. The model employs volume averaged Green's function solutions of the three-dimensional stress equilibrium equations and Gauss's Law. The resulting model approximates the effective stiffness, dielectric permittivity, and piezoelectric coupling tensors as a function of the constituent material properties, void fraction, shape, and orientation, as well as the deposited charge density. Strain localization tensors of the model are then employed to approximate piezoelectret dependence and external pressure. Model results show good agreement with experimental results and data from the literature.

2:00

2pEAa5. A micromachined piezoelectric flexural mode hydrophone for audible frequency application. Haksue Lee, Sungjoon Choi, and Wonkyu Moon (Dept. of Mech. Eng., Postech, South Korea, wkmoon@postech.ac.kr)

A micromachined hydrophone is designed for audible frequency application (20 Hz–20 kHz). The basic structure is a flexural unimorph consisting of a clamped silicon diaphragm and a piezoelectric film. Two design approaches can enhance its sensitivity. One is a unimorph with unequal radii between the piezoelectric film and the diaphragm, which increases electromechanical coupling. The other is an air-backed chamber, which reduces mechanical impedance in the flexural vibration and, consequently, enhances sensitivity. To predict the effects of these approaches on sensitivity, an equivalent transduction model is composed and used for calculations. In the case of oil backing, compared to air backing, a reduction in sensitivity of about 40 dB is expected. The dimensions of the micromachined diaphragm (piezoelectric film) are 630 μm (400 μm) radius and 15 μm (3 μm) thick. A fabricated microsensor is constructed as a hydrophone by using a rubber housing filled with castor oil. The measured sensitivity is −228.3 dB at 1V /μPa without a preamplifier. A flat frequency response within ±1 dB deviations were measured in the 100 Hz–5 kHz band. Based on the simulation, it can resist the hydrostatic pressure of 100 m depth, without pressure balancing, while decreasing in sensitivity. The results of a larger model having a higher sensitivity of −207.6 dB will also be presented. [Research supported by MRCND and R0A-2007-000-20042-0.]

2:15

2pEAa6. Advantages of piezoelectric microelectromechanical systems (MEMS) microphones. Robert Littrell and Karl Grosh (2250 GG Brown Bldg., 2350 Hayward St., Ann Arbor, MI 48109)

Microphones fabricated using microelectromechanical systems (MEMS) technology are one of the fastest growing applications of MEMS. Capacitive sensing has been the dominant form of transduction in both traditional and recently commercialized MEMS microphones. Models and experiments, however, indicate that the thin layers and fine spatial resolution made possible by MEMS technology lend themselves more appropriately to piezoelectric microphones. Although piezoelectric MEMS microphones have typically been shown to have a relatively high noise floor, this limitation can be overcome with appropriate design and high quality piezoelectric material. Models indicate that piezoelectric MEMS microphones can achieve a comparable noise floor to capacitive MEMS microphones of similar size and bandwidth while achieving 1000 times greater dynamic range. A piezoelectric MEMS microphone utilizing aluminum nitride (AlN) will be presented. Previously experienced film quality issues have been addressed. This microphone is designed to have a noise floor below 40 dB (A), a dynamic range greater than 160 dB SPL, a 10 kHz bandwidth, and a sensing area of less than 1 mm^2.

2:30

2pEAa7. Infrasonic microphone. Timothy Marston and Thomas B. Gabrielson (Grad. Prog. in Acoust., Penn State Univ., PO Box 30, State College, PA 16804, tmm357@psu.edu)

The high cost of many infrasonic transducers can be a setback for universities interested in performing research in the field of infrasound. Reasonably effective infrasonic transducers can be constructed in the laboratory, however, and for a fraction of the cost. A simple, inexpensive infrasonic microphone that operates on the principle of carrier demodulation has been constructed. Noise analysis of the microphone demonstrates its potential usefulness for cost-effective field research and deployment in temporary infrasonic arrays. [Research funded by the Penn State Applied Research Laboratory Educational and Foundational Fund.]

2:45

2pEAa8. Mechanical characterization of capacitor microphones for analysis and study. YuFan Chuang (Master Program of Electroacoustics, Feng Chia Univ., 100 Wenhwa Rd., Seatwen, Taichung, Taiwan 40724, ROC, yufan420@gmail.com), S. J. Pawar, and Jin H Huang (Feng Chia Univ., Taichung, Taiwan 40724, R.O.C.)

An attempt is made to investigate the mechanical properties of the diaphragm of capacitor microphone using MTS Tytron 250 micro-force testing machine. The compliance of the diaphragm is calculated from the force-displacement diagram. The simulation of the microphone is carried out using equivalent circuit method. The mechanical parameters like mass (measured), compliance (measured and calculated), and resistance (assumed from literature) are being used to formulate mechanical domain of microphone in equivalent circuit model. The sensitivity curve of microphone is being plotted. Simultaneously, the experimental measurement has been carried by PULSE Electroacoustics with the software Sound Check in an anechoic chamber. The simulation and experimental results for sensitivity are found to follow each other within a wide frequency range. The characteristic investigation is carried out using validated equivalent circuit model for parametric study of microphone. [Work supported by Contract Nos. NSC 95-2221-E-035-013-MY3 and 95-2221-E-035-087. The authors would like to thank Leo Liao and Jack Wei of Merry Electronics Co. Taiwan and Listen Inc. for supplying Sound Check measurement.]

3:00

2pEAa9. Head related transfer functions for KEMAR. Gunnar Rasmussen (G.R.A.S. Sound & Vib., Skovlytoften 33, 2840 Holte, Denmark, gr@gras.dk)

The head related transfer functions (HRTFs) for KEMAR for a number of ear pinnas of different sizes and hardnesses have been measured. Right and left ear differences on KEMAR as well as change in HRTFs over the last 40 years will be reported along with data for the ITU - Type 3 and the IEC 60959 standardized pinna. The influencing factors on the uncertainty budget will be discussed.

3:15

2pEAa10. A transfer matrix method for estimating the dispersion and attenuation of plane waves in the standing wave tube. Kang Hou and J. Stuart Bolton (Herrick Lab, Purdue Univ., West Lafayette, IN)

In this paper, an iterative method based on the transfer matrix approach is described for evaluating the sound speed and attenuation constant of air in a standing wave tube. The procedure is based on transfer matrix, the four-microphone method for measuring the transmission loss of acoustical materials. In the latter procedure, a sample is placed between two pairs of microphones, where the sample is exposed to an incident plane wave field. In the present case, the air inside the standing wave tube is treated as the sampled material. Since the knowledge of the dispersion characteristics of plane waves within the tube is required to perform this measurement, an iterative method must be applied at the postprocessing step to estimate the complex wave numbers in the sample section. The result from the experiments showed that the air temperature within the tube has a significant impact on the results. The measured results were found to be in good agreement with the Temkin formula for attenuation in tubes. In addition, the approach may be extended to the accurate measurement of viscosity and sound velocity of liquids and gases.

TUESDAY AFTERNOON, 19 MAY 2009 — COUNCIL SUITE, 3:30 TO 4:40 P.M.

Session 2pEAb

Engineering Acoustics: Piezoelectric Energy Harvesting

Thomas R. Howarth, Chair
Naval Sea Systems Command Division Newport, Newport, RI 02841

Chair's Introduction—3:30

Invited Papers

3:35

2pEAb1. Bridging the gap between macro- and microdevices for manufacture of piezoelectric energy harvesters. Arthur L. Chait (EoPlex Technologies, Inc., 3698-A Haven Ave., Redwood City, CA 94063, achait@eoplex.com)

In this presentation, materials engineer and entrepreneur, Arthur L. Chait will show why there is a gap at the miniature scale when building complex devices with multiple materials. He will explain why few technologies can handle several materials, with complex geometries, in small parts. Miniature piezoelectric (PZ) energy harvesters are an example of this challenge. Mr. Chait will describe his piezoelectric energy harvester, designed for tire pressure sensor systems. This tiny device uses PZ materials to convert some of the vibration of the tire into electricity. The electric current is stored in a capacitor and used to power the system. Audiences will learn why it is difficult and costly to build a small, rugged system to power a tire sensor. The anatomy of this device includes at many diverse materials and five basic design elements. These are bonded into a strong package about the size of a contact lens. Building this energy harvester would be almost impossible with conventional manufacturing techniques. Mr. Chait will share a relatively new solution; i.e., a print deposition technique that produces thousands of parts simultaneously from many different materials. Active elements like circuits, catalyst beds, mixing chambers, capacitors, and piezoelectric actuators are produced all in one step.

4:00

2pEAb2. Acoustic energy harvesting using an electromechancal Helmholtz resonator. Fei Liu (Dept. of Mech. and Aerosp. Eng., Univ. of Florida, Gainesville, FL 32611-6250), Alex Phipps , Stephen Horowitz, Louis Cattafesta , Toshikazu Nishida , and Mark Sheplak (Univ. of Florida, Gainesville, FL 32611-6250)

This talk presents the development of an acoustic energy harvester using an electromechanical Helmholtz resonator (EMHR). The EMHR consists of an orifice, cavity, and a piezoelectric diaphragm. When the acoustic wave is incident on the EMHR, a portion of acoustic energy is converted to electrical energy via piezoelectric transduction in the diaphragm of the EMHR. Moreover, the diaphragm is coupled with energy reclamation circuitry to increase the efficiency of the energy conversion. Two power converter topologies are adopted to demonstrate the feasibility of acoustic energy reclamation using an EMHR. The first is comprised of only a rectifier, and the second uses a rectifier connected to a flyback converter to improve load matching. Experimental results indicate that approximately 30 mW of output power is harvested for an incident sound pressure level of 160 dB with a flyback converter. Such power level is sufficient to power a variety of low power electronic devices.

Contributed Paper

4:25

2pEAb3. Theoretical study of thermoacoustic power conversion with a piezoelectric transducer. Carl Jensen and Richard Raspet (Natl. Ctr. for Physical Acoust., Univ. of MS, Univ., MS 38677)

A heat-driven thermoacoustic engine prototype has been designed with a piezoelectric transducer as an electroacoustic transformer. The design under consideration uses a bending, unimorph transducer placed between two identical thermoacoustic engines operating out of phase such that the transducer is driven in a push-pull fashion. The thermoacoustic engine is modeled using a one-dimensional low amplitude simulation. The piezoelectric unimorph is modeled by an electroacoustic equivalent circuit aimed at capturing the first order resonant behavior of the transducer; loss mechanisms from hysteretic behavior of the dielectric or elastic properties are not considered by the model. Issues in optimizing the geometry of the model will be presented as well as comparisons to other forms of waste heat power harvesting such as thermoelectric.

TUESDAY AFTERNOON, 19 MAY 2009 STUDIO SUITE, 1:00 TO 4:00 P.M.

Session 2pMUa

Musical Acoustics: Wind Instruments II

R. Dean Ayers, Chair
624 Valley View Dr., Medford, OR 97504-6356

Invited Papers

1:00

2pMUa1. Evaluation of two control parameters of trumpet players as function of sound features. Rene Causse (Ircam, 1 place Igor Stravinsky, F-75004 Paris, France) and Vincent Freour (McGill Univ., Montréal, PQ Canada.)

Experiments were performed by five trumpet players with the same trumpet and mouthpiece. For each subject, two control parameters are measured: mouth-pressure and force applied by the lips on the mouthpiece. The sound is also recorded. The players are asked to play sustained notes at different pitch and sound levels. We calculate fundamental frequency, sound pressure level, and some spectral features: noisiness, spectral roll-off, etc. Although little mouth-pressure variability as function of pitch and dynamic appears between subjects, clear differences were obtained in terms of the force applied on the mouthpiece. Therefore, we suggest to focus on the link between sound features and the ratio of these two control parameters measured, sort of "gesture estimator." The representation of the ratio as function of the sound features shows a good classification of musicians. Moreover, in some specific cases such as noisiness, the relation seems independent from the players. These observations suggest that these two control parameters could be efficient to characterize players' embouchure and to access some sound characteristics without knowledge of the mechanical characteristics of the lips. These results will be described and discussed, and direction for future works suggested. [Consonnes project, supported by the French Research Agency.]

1:30

2pMUa2. Does a brass-instrument's timbre depend on the alloy from which it is made? Robert W. Pyle, Jr. (11 Holworthy Pl. Cambridge, MA 02138, rpyle@post.harvard.edu)

Most brass players with a few years experience would give an affirmative answer to the question posed in the title. In the past, audible differences have proven elusive when pursued through spectral analysis of sustained tones, perhaps because the right question was not asked. This talk will examine several attributes of trombone spectra. The trombone used has a "modular construction" so that different bells can easily be installed on an otherwise unchanged instrument. A clear difference, consistent with the player's and listener's perception of the tone quality, emerges between yellow brass (70% Cu, 30% Zn) and red brass (90% Cu, 10% Zn). Transient behavior, particularly during the attack, is at least as important to the performer as sustained sounds. Here, too, differences are attributed to the alloy. Yellow brass is characterized by "crisp" attacks, red brass by "rounded" attacks. This talk will also analyze attack transients, even though attacks that are perceived as similar appear quite variable when examined in detail.

2:00

2pMUa3. Comparison of the mechanics of the brass players' lips during slurred note transients. John P. Chick and Shona M. Logie (SEE, Univ. of Edinburgh, Kings Bldgs., Edinburgh EH9 JL, UK, john.chick@ed.ac.uk)

When sounding a note on a brass instrument, a strong coupling is established between the vibrating lips of the player and the air column resonance. In moving between notes as smoothly as possible, or "slurring," there is a transition from one strongly coupled, steady-state, regime of the lip/air column to a different steady-state coupling of the lip/air column. To the listener, there are sometimes subtle differences in the sound of the transition between notes depending on how this transition is achieved: by lip slur, valve slurs, and, in the case of the trombone, slide slurs. This paper uses data collected from high speed video capture of the players' lips, synchronized with microphones in the mouthpiece and the bell of the instrument, to investigate and compare the motion of the brass players' lips for different types of slurred internote transients.

2:30

2pMUa4. Acoustical history of the tuba. Arnold Myers (Univ. of Edinburgh, Reid Concert Hall, Bristo Square, Edinburgh EH8 9AG, U.K.)

Low-pitched valved brass wind instruments are often described generically as tubas. In fact, the term "tuba" covers a broad family of instruments, with sounding lengths ranging from the 8 ft C of the classic French orchestral tuba to the 18 ft Bb of the brass band and orchestral contrabass. The first instrument designated as a tuba was introduced in 1835, and since then a variety of models differing in bore profile as well as in nominal pitch have been used. This paper explores the the historical development of the tuba family from an acoustical perspective, presenting and discussing measurements of bore profile and input impedance for a number of representative instruments from different periods and musical traditions.

3:00—3:15 Break

Contributed Papers

3:15

2pMUa5. The double bell descant euphonium. Frederick J. Young (Div. of Com. and Arts, Univ. of Pittsburgh, 800 Minard Run Rd., Bradford, PA)

A euphonium is presented that has better intonation and is easier to play in the extreme registers. It is a complete double horn having five double valves in contrast to the incomplete normal double French horn having only three double valves. The valves descend 2, 1, 3, 4, and 5 semitones from the open tones. The large bell is for the B♭ standard part of the instrument. A switch valve activates the smaller alto bell in the key of high E ♮ and sends the air through the five shorter valve slides and out the small bell. The fundamental frequency of the E side is 82.4 Hz or six semitones above the fundamental of the B♭ euphonium. The key of E rather than F or E♭ enables all notes in the complete range (about 29–988 Hz) to be played with a single tunable valve slide. Either of the other keys would introduce a need for one additional valve or compromise the intonation.

3:30

2pMUa6. Optimization of valve tube lengths for brass instruments. Frederick Young (Div. of Com. and Arts, Univ. of Pittsburgh, 800 Minard Run Rd., Bradford, PA 16701, youngfj@youngbros.com)

The intonation deviations from the well-tempered scale are presented for valve brass wind instruments. Compensating and full double instruments are considered. Systems including descending valves and less popular ascending valves are studied. The lengths of the valve tubes are optimized by minimizing the overall root mean squared (rms) intonation error using the method established in 1967 [R. Young, J. Acoust. Soc. Am. **42**, 224–235 (1967)]. Open note detuning is considered in each case and improves the overall intonation. The worst three valve instrument without open note detuning has an rms deviation 24 cents The best of the three and four valve instruments is a three valve compensating euphonium tuned 3 cents sharp on the open notes and flat on valves 2, 1, and 3 by 3, 3, 10 cents, respectively. It exhibits only 2 cents rms deviation on single valves and less than 3 cents on combinations of valves. The comparisons also include several new three, four, and five valve systems. Included is a double horn with only two double valves and a switch valve.

3:45

2pMUa7. The input impedance of an alphorn including an Alexander mouthpiece. Frederick J. Young (Div. of Com. and Arts, Univ. of Pittsburgh, 800 Minard Run Rd., Bradford, PA 16701, youngfj@youngbros.com)

The alphorns built and sold by the late Joseph Littleton of Hammondsport, NY are used in this study. His dimensions of bore as a function of position are used in solution of the Webster equation for impedance solved numerically earlier [F. J. Young, Acustica, **10**, 91–97 (1960)]. The musical notation for the frequencies of the impedance peaks are given below. Here the subscripts refer to the harmonic number. The fundamental, rarely used, is 13 cents flat from A at 55 Hz. The intonations errors for. C_1, C_2, G_3, C_4, E_5, G_6, B^b_7, C_8, D_9, E_{10}, F_{11}, G_{12}, A_{13}, B^b_{14}, B_{15}, C_{16}, $C^\#_{17}$, and D_{18} are 287, 58, 195, 28, 1.5, 0.83, -28, -0.85, -2.63, 1.5, 40, 14, -49, 1, -3, 16, 24 and 28 cents.

Session 2pMUb

Musical Acoustics: Wind Instruments III and Mini Concert

D. Murray Campbell, Chair
School of Physics and Astronomy, Univ. of Edinburgh, Edinburgh EH9 3JZ, U.K.

Invited Paper

4:15

2pMUb1. Imitating the human voice: The renaissance cornett and sackbut. Murray Campbell (Sch. of Phys. and Astron., Univ. of Edinburgh, Edinburgh EH9 3JZ, U.K., d.m.campbell@ed.ac.uk)

In the 16th century the lip-reed instruments most commonly used in sacred and chamber music were the cornett (Italian “cornetto”) and the sackbut (Italian “trombone”). The sound ideal described by contemporary writers for these instruments was clearly distinguished from the ceremonial and often military splendor of the trumpet ensemble: the cornett and the sackbut were expected to produce dynamic levels and timbres comparable to those of human singers. The acoustical features, which make it much easier to approach this ideal on the renaissance instruments than on modern trumpets and trombones are explored through measurements on original instruments and modern reproductions.

4:45—5:30 Mini Concert

TUESDAY AFTERNOON, 19 MAY 2009 BROADWAY III/IV, 1:00 TO 4:55 P.M.

Session 2pPA

Physical Acoustics and Biomedical Ultrasound/Bioresponse to Vibration: Numerical Methods for Weak Shock Propagation

Andrew A. Piacsek, Chair
Dept. of Physics, Central Washington Univ., Ellensburg, WA 98926-7422

Invited Papers

1:00

2pPA1. Numerical modeling of weak shock propagation: Past, present, and future. Andrew Piacsek (Dept. of Phys., Central Washington Univ., 400 E. University Way, Ellensburg, WA 98926, piacsek@cwu.edu)

This presentation provides an overview of the subject of numerical modeling of weak shock propagation, with the aim of providing context for subsequent talks in this session. First is a brief history of analytical approaches to the problem of weak shocks in both one and two dimensions, emphasizing the characteristic physical behavior of the solutions. This leads to a discussion of the physical processes that must be modeled, including the Rankine-Hugoniot conditions at the shock interface, nonlinear steepening, and self-refraction, refraction and diffraction due to an inhomogeneous medium, dissipation, relaxation, and heating of the medium. Next is a summary of paraxial numerical methods, specifically the NPE and KZK equations, and their recent applications, followed by a description of efforts to develop “wide-angle” versions of these codes. Computational challenges, and possible approaches, to extending these methods to three dimensions are also presented. Last, a brief introduction to new approaches to 3-D modeling will be given, along with a discussion of the applicability of computational improvements such as adaptive meshing and parallel processing.

1:20

2pPA2. Numerical simulation of acoustical shock waves: Beyond the parabolic approximation. Franck Dagrau, Mathieu Renier, François Coulouvrat, and Regis Marchiano (Univ. Pierre et Marie Curie, Institut Jean Le Rond d’Alembert (UMR CNRS 7107), 4 place Jussieu, 75005 Paris, France)

The KZK equation is the reference equation for the modeling of finite amplitude diffraction effects. It has been applied with success to many applications in various domains. Nevertheless, the parabolic approximation underlying the KZK equation limits the validity of this one to narrow-angle propagation. A new formulation of the Kuznetsov equation enables us to go beyond the parabolic approximation for the diffraction effects in the homogeneous case, the parabolic approximation being now limited only to the heterogeneous perturbation which is one order of magnitude smaller. This method formalizes and generalizes to the weakly heterogeneous case the

previous work of Christopher and Parker [J. Acoust. Soc. Am. **90**, 488–499 (1991)]. Special attention is paid to the implementation of boundary conditions (such as absorbing or perfectly matched layers). Several validation tests will illustrate the potential of the method, such as nonlinear focusing or scattering. Applications to sonic boom propagation in a turbulent atmosphere will finally be discussed.

1:40

2pPA3. Extension of the iterative nonlinear contrast source method to nonlinear media exhibiting tissue-like attenuation. Martin Verweij, Jacob Huijssen (Lab. of Electromagnetic Res., Fac. of Elec. Eng., Mathematics and Comput. Sci., Delft Univ. of Technol., Mekelweg 4, 2628 CD Delft, The Netherlands, m.d.verweij@tudelft.nl), and Nico de Jong (Erasmus Medical Ctr., Rotterdam, The Netherlands)

Recently, the Iterative Nonlinear Contrast Source (INCS) method has been developed to compute the pulsed acoustic pressure field in a nonlinear and lossless medium that extends over a very large, 3-D domain. This method solves the nonlinear wave equation by considering the nonlinear term as a distributed contrast source in a linear background medium. The full nonlinear wave field follows by convolving the background Green's function with successive estimates of the contrast source. It has been shown that by spatiotemporal filtering of the convolution factors, the method yields accurate field predictions even for a discretization approaching two points per smallest wavelength or period. The current paper discusses how attenuation, in particular tissue-like power law losses, may be incorporated into the method through the introduction of a causal compressibility relaxation function. The latter gives the background the desired loss behavior. Fields in nonlinear media with different power law losses are presented, as computed by the extended INCS method. Moreover, the ability of both the lossless and the extended INCS method to evaluate fields at the shock formation distance is shown. Especially the latter results show the significance of using a proper, tissue-like power law. [Work supported by STW and NCF.]

2:00

2pPA4. Weak shock propagation in the ocean and marine sediments. B. Edward McDonald (Acoust. Div. Naval Res. Lab, Washington DC 20375, mcdonald@ccs.nrl.navy.mil)

The nonlinear progressive wave equation (NPE) [B. E. McDonald and W. A. Kuperman, JASA 81, 1406 (1987)] was initially developed to model weak shock waves in a refracting medium (specifically, ocean acoustic convergence zones). It has been refined to include high-angle and two-way propagation. Inclusion of two-way propagation improves agreement with empirical power laws for peak pressure from an explosive as a function of range and explosive charge. The NPE is currently being used to examine weak shock propagation into marine sediments for studies related to mine countermeasures. An intriguing behavior results from the stress-strain relation for Hertzian granular media, in which stress is proportional to the 3/2 power of strain rate. Numerical and analytic solutions with the Hertzian nonlinearity reveal its most nonlinear behavior (shock formation) near zero stress, whereas in a fluid, shock formation results from high stress. Numerical experiments are presented to determine whether shocks resulting from Hertzian nonlinearity can be observed with nominal values of frequency-linear attenuation common to granular media. [Work supported by the Office of Naval Research.]

2:20

2pPA5. Modeling weak shocks produced by high-intensity focused ultrasound. Vera A. Khokhlova (Ctr. for Industrial and Medical Ultrasound, Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105/ Moscow State Univ., Moscow 119991, Russia), Olga V. Bessonova (Moscow State Univ., Moscow 119991, Russia), Michael S. Canney, Michael R. Bailey (Univ. of Washington, Seattle, WA 98105), Joshua E. Soneson (Food and Drug Administration, Silver Springs, MD 20993), and Lawrence A. Crum (Univ. of Washington, Seattle, WA 98105)

Shock waves of up to 100 MPa may form at the focus of high-intensity focused ultrasound (HIFU) transducers at clinically reported *in situ* intensities of up to 30,000 W/cm^2. The heating due to shocks is sufficient to boil tissue in milliseconds, which dramatically alters the treatment. Quantification of enhanced heating from shocks is therefore critical to treatment planning. In this work, several approaches and temporal grids of different resolutions were used to simulate HIFU fields. Peak positive pressure, which determines the shock amplitude, and thus the heating rate were found to be the most sensitive to the parameters of the numerical scheme. Heating rates calculated in modeling and estimated using weak shock theory from the measured and modeled waveforms were compared. Time to boil measured in tissue phantoms and tissue was used as a metric of the heating efficiency of shocks. It is shown that the bandwidth limitations in the waveform measurements result in underestimation of the heat rates, although boiling onset predicted in modeling agreed well with the experimental data. An experimentally validated numerical model thus can be an effective tool in both laboratory and clinical HIFU setting. [Work is supported by NIH EB007643 and NSBRI SMST01601.]

2:40

2pPA6. Numerical simulation of the propagation of three-dimensional helical shock waves in a weakly heterogeneous medium. Regis Marchiano, Francois Coulouvrat (Univ. Pierre et Marie Curie, Institut Jean Le Rond d'Alembert (UMR CNRS 7107), 4 place Jussieu, 75005 Paris, France), and Jean-Louis Thomas (Univ. Pierre et Marie Curie, 75005 Paris, France)

A numerical method for the simulation of 3-D acoustical shock wave propagation through a homogeneous or weakly heterogeneous medium is presented. It is based on a generalization of the KZ equation taking into account weak heterogeneities. The algorithm is based on a spectral treatment of the linear diffraction (angular spectrum), coupled with quasianalytical solutions for the heterogeneous part and for the nonlinear one. This last one solves Burgers' equation with the so-called Burgers-Hayes method using the potential instead of the pressure field. The combination of these several algorithms lead to the development of an efficient software, allowing to solve full 3-D problems for standard personal computers. This software is used to study the dynamics of helical shock waves also called acoustical vortices (AVs) which are the acoustical equivalent of optical vortices. The 3-D helical spatiotemporal wave field is characterized by azimuthal shocks. The dynamics of the so-called topological charge, an intrinsic property of AVs, is studied in the nonlinear regime through different focusing lenses.

3:00—3:20 Break

3:20

2pPA7. Numerical methods for weak shock propagation and diffraction around a microphone. Victor W. Sparrow (Penn State, Grad. Program in Acoust., 201 Appl. Sci. Bldg., University Park, PA 16802, vws1@psu.edu)

There are two interrelated goals for this presentation. The first goal is to give an overview of available numerical approaches for weak shock propagation. There are multiple approaches available, including formulations based on the Burgers equation, KZK or NPE equations, the second-order equations of nonlinear acoustics, the Navier-Stokes equations, or the Boltzmann equation. There are also multiple numerical techniques for discretizing each of underlying equations, and while some approaches give special treatment to weak shocks others handle the shocks automatically. The second goal of this presentation is to show recent simulation results for an explosion shock interacting in two dimensions with a microphone. The diffraction of the weak shock around the microphone housing does turn out to be amplitude dependent. It is only a modest effect, increasing for higher amplitudes. This knowledge is important for precise, close-range blast source characterization. In the future, the nonlinear diffraction of weak shocks around transducers also should be investigated for finite amplitude biomedical ultrasound, since the mechanisms for nonlinear diffraction are almost identical for ultrasound and explosion waves. [Work supported by U.S. Army ERDC-CERL.]

Contributed Papers

3:40

2pPA8. Simulations of converging shocks in water. Veronica Eliasson (Graduate Aerosp. Lab., Caltech, 1200 E. California Blvd., Pasadena, CA 91107, vero@caltech.edu), William D. Henshaw (LLNL, Livermore, CA 94551), and Paul E. Dimotakis (Caltech, Pasadena, CA 91125)

Numerical simulations of weak shocks in water traveling through a convergent geometry were performed. The convergent geometry is surrounded by an elastic solid, which is deformed by the fluid, thereby, generating elastic waves in the solid, which in turn affect the liquid, thus creating a coupled fluid-structure problem. Here, we use the Overture suit, which is a code for solving partial differential equations on curvilinear overlapping grids using adaptive mesh refinement. In particular, we use a multiphysics solver to solve the fluid-structure problem. The Euler equations with a stiffened equation of state are used in the fluid domain and the linear elasticity equations are used in the solid domain. The solutions at the interface between the fluid and the solid are matched using continuity of normal velocities and forces. Preliminary results indicate that the wave speed of the material has a large influence on the behavior of the converging shock. The numerical simulations are also compared to schlieren photographs and pressure measurements obtained from experiments. Results can enhance the design of marine structures with convergent sections subjected to dynamic loading events. [Work supported by ONR.]

3:55

2pPA9. Comparison of time and frequency domain approaches to simulate propagation of weak shocks. M.V. Averiyanov, P.V. Yuldashev (Faculty of Phys., Moscow State Univ., Moscow 119991, Russia, misha@acs366.phys.msu.ru), Ph. Blanc-Benon (LMFA, UMR CNRS 5509, Ecole Centrale de Lyon, 69134 Ecully Cedex, France 5509), and V.A. Khokhlova (Univ. of Washington, Seattle, WA 98105)

Simulations of acoustic fields using finite-difference methods are performed either in time or frequency domains. A method of fractional steps with an operator splitting procedure is frequently applied to solve nonlinear equations of the evolution type. Either time or frequency domain solvers can be used to calculate different terms in the equation over a propagation grid step. In this work, several algorithms that have been used to simulate quadratic nonlinear term in the Burgers or KZK-type evolution equations are applied to model the propagation of weak shocks. Shock capturing schemes of Godunov type, exact analytic solution with further extrapolation of the waveform over a uniform temporal grid, time-domain conservative schemes, direct modeling in the frequency domain, and asymptotic spectral approach are compared. The parameters of the schemes that would provide the results of the same accuracy, an artificial absorption necessary for stability of the schemes, resolution of shocks, and internal viscosity of the algorithms are discussed. It is shown that the Godunov-type algorithm is better suited to model weak shocks with sufficient accuracy achieved with only three temporal grid points per shock. [Work supported by the RFBR and NIH EB007643 grants.]

4:10

2pPA10. A shock-fitting method for general nonlinear progressive waves. Francois Coulouvrat (Univ. Pierre et Marie Curie, Institut Jean Le Rond d'Alembert (UMR CNRS 7107), 4 place Jussieu, 75005 Paris, France)

Many physical phenomena are concerned with the propagation of weak nonlinear waves that can be modeled under the form of a generalized Burgers equation. Physical examples include nonlinearities that can be either quadratic (nonlinear acoustical waves in fluids or longitudinal waves in solids), cubic (nonlinear shear waves in isotropic soft solids), or nonpolynomial (Buckley-Leverett equation for diphasic fluids, models for car traffic, Hertz contact in granular media). A new weak shock formulation of the generalized Burgers equation using an intermediate variable called "potential" is proposed. This formulation is a generalization to nonquadratic nonlinearities of the method originally proposed by Burgers himself in 1954 for his own equation, and later applied to sonic boom applications by Hayes et al. (1969). It is an elegant way to locate the position of a shock. Its numerical implementation is almost exact, except for an interpolation of Poisson's solution that can be performed at any order. It is also numerically efficient. As it is exact, a single iteration is sufficient to propagate the information at any distance. It automatically manages waveform distortion, formation of shock waves, and shock wave evolution and merging. The theoretical formulation and the principle of the algorithm are detailed and illustrated by various examples of applications.

4:25

2pPA11. A nonlinear computational method for the propagation of shock waves in ducts: Application to buzz-saw noise. Rasika Fernando, Yann Druon (Airbus France, Acoust. Environment Dept. Turbomachinery Acoust. (EDEA3), 316 route de Bayonne, 31060 Toulouse Cedex 03), Regis Marchiano, and Francois Coulouvrat (Univ. Pierre et Marie Curie, 75005 Paris, France)

A numerical method to compute shock wave propagation in uniform waveguides in 2-D and 3-D is presented. The solution is searched under the form of a modal solution of the Kuznetsov equation for which the modal amplitudes of the analytical linear modes are supposed to vary along the duct axis due to nonlinear interactions between the different modes and frequencies. This finally yields to a differential system on the mode amplitudes, which is solved numerically using a standard Runge-Kutta algorithm for ordinary differential equations after numerical truncation of the modal series. Examples are presented of the nonlinear evolution of the pressure field for a 2-D waveguide. One important 3-D application is the so-called "buzz-saw" noise occurring for high-bypass-ratio turbofan engines, when fan blade tip relative flows exceed the sound velocity. First results on 3-D simulations for nonlinear propagation of a saw-tooth waveform spiraling inside a hard-walled cylindrical will be presented. Extensions of the model to ducts with uniform flows or with liners (walls with impedance) will finally be discussed.

4:40

2pPA12. Evaluation of a wave vector frequency domain method for nonlinear wave propagation. Yun Jing and Greg Clement (Dept. of Radiology, Harvard Med. School, Brigham and Women's Hospital, Boston, MA 02155)

In this paper, a wave vector frequency domain method is presented to describe both forward and backward nonlinear wave propagations in acoustic media. A frequency domain nonlinear wave equation is first derived based on the Westervelt equation by taking the Fourier transform in the temporal and spatial domains. Since the model works directly in the frequency domain, arbitrary dispersion relations can be elegantly considered. The nonlinearity is further evaluated by multidimensional autoconvolution of the Fourier transform of the sound pressure. An implicit solution of the equation is proposed by employing the Green's function, and is solved numerically. Comparisons between the numerical simulations and the Burger's solution show good agreements within the shock formation distance. Error study is also carried out to test the efficiency of the model. It is found that the error grows as the initial pressure increases and the spatial resolution decreases. Finally, the present model is compared with a time-domain approach for a practical case, where the diameter of the transducer is 100 mm, the fundamental frequency is 1 MHz, and the focus range is 150 mm.

TUESDAY AFTERNOON, 19 MAY 2009 FORUM SUITE, 2:00 TO 4:40 P.M.

Session 2pSA

Structural Acoustics and Vibration: Emerging Applications of Structural Acoustics

Sean F. Wu, Chair
Dept. of Mechanical Engineering, Wayne State Univ., Detroit, MI 48202

Invited Papers

2:00

2pSA1. Intrinsic damping models and their role in predicting structural response. Allan D. Pierce (Dept. of Mech. Eng., Boston Univ., Boston, MA 02215, adp@bu.edu) and Adnan Akay (Bilkent Univ., Ankara, Turkey)

In many industries, it is often desired to estimate whether a structure can withstand severe broad-band high-frequency loads. Because the structures have many natural frequencies within the band of interest, the response is critically affected by the damping within the structure. One typically performs finite element model computations with the elastic modulus replaced by a complex number, the ratio of imaginary to real parts being the loss factor, this taken as frequency independent. The crudity of such a model invariably leads to designs that are either overly conservative or not inspiring confidence. The present paper revisits the topic of internal damping from a fundamental standpoint and adopts the viewpoints of [J. J. Thomson (1888), Clarence Zener (1948)], in which "all anelastic phenomena are regarded as the superposition of elementary processes in which the stress relaxes exponentially." The resulting general model involves a continuous distribution over relaxation times. Lumped parameter realizations require that the configuration of the structure be described by the positions of all the mass points, and also by those of a large number of "hidden variables" connected to the mass points by Maxwell elements (spring and dashpot is series). General implications of the model are derived and explained.

2:20

2pSA2. Measurement methodologies for the analysis of influence of surface panels and their vibrations on interior cabin noise. Sean Wu (Dept. of Mech. Eng., Wayne State Univ., 5050 Anthony Wayne Dr., Detroit, MI 48202, aa3199@wayne.edu) and Allan Pierce (Boston Univ., Boston, MA 02215)

In the design of quiet automobile compartments, one analyzes the influence of individual panels and enclosure surface leaks on noise received in a specific region (the location of the driver's ear position). Two recent papers [Hald *et al.*, Internoise (2006); Wolff, Internoise (2007)] suggest the needed measurement process can be shortened using a sound source at the typical listener position, taking measurements over the enclosure surface, and then invoking the principle of reciprocity. The present paper clarifies the analytical discussions of these earlier papers with improved and more nearly rigorous derivations and suggests improved measurement methodologies. One exemplary model considered is that of an arbitrarily shaped cavity with sound absorbing walls that are also moving due to external influences. The boundary condition on the pressure field inside the cavity is shown to be well approximated such that the normal component of the pressure gradient is a superposition of a constant times the pressure itself (locally reacting surface with finite impedance) plus a constant times the portion of the surface velocity that is due to the external sources. The pressure inside the cavity can be solved by Green's function techniques, and the Green's function can be proven to rigorously satisfy reciprocity.

2:40

2pSA3. Using structural acoustics methods to study new materials. J. D. Maynard (Dept. of Phys., The Pennsylvania State Univ., University Park, PA 16802)

In structural acoustics it is usually necessary to know the vibration properties of the structure under study, and this requires knowing the elastic constants of the materials involved. A relatively recent and powerful method for measuring elastic constants is resonant ultrasound spectroscopy (RUS). Very new and exotic materials for structures often require RUS; the reason is that new materials, when first fabricated, are often available only in very small samples (a few hundred micrometers) or as thin films on substrates, and RUS is the best method for handling such samples. On some occasions samples are fragile or chemically reactive so that they cannot be polished into the shapes required by conventional RUS. Thus, it has been necessary to develop a RUS analysis for arbitrarily shaped samples. This has been accomplished by borrowing a method from structural acoustics: the finite element method (FEM). The discussion of the application of FEM to RUS for arbitrarily shaped samples will include bridging the gap between theory (involving matrices as boldfaced symbols without indices in textbooks on FEM) and actual lines of computer code. Applications of the RUS method for materials will also be discussed.

3:00—3:20 Break

3:20

2pSA4. Spatial maps of modal damping from frequency response measurements. J. Gregory McDaniel, Craig Boucher, and Hande Öztürk (Mech. Eng. Dept., Boston Univ., 110 Cummington St., Boston, MA 02215)

A method is proposed for constructing spatial maps of modal damping for viscously damped structures. These maps are intended to be useful in assessing the effectiveness of spatially distributed damping, particularly in complex structures that are damped by a variety of mechanisms. The method uses frequency response measurements and modal analysis to determine the natural frequencies and mode shapes of the damped structure. The damping matrix is estimated directly from the frequency response measurements and is expressed as a sum over connectivity matrices weighted by dashpot constants. This sum is substituted into the well-known approximation for the modal loss factor that results by neglecting off-diagonal elements of the modally transformed damping matrix. The resulting expression quantifies the contribution of local dashpot properties to the modal loss factor, and may be visually presented as a spatial map of damping. A significant advantage of this approach is its independence from a detailed model of the structure or its damping, allowing it to be used for complex structures. The resolution of the map is directly correlating to the number of measurement locations, as will be illustrated by examples. [Work supported by ONR under Grant No. N000140810531.]

2p TUE. PM

3:40

2pSA5. A three-dimensional Wiener-Hopf technique for general bodies of revolution, Part II: Substructuring and implementation. Rudolph Martinez and Carina Ting (CAA-Alion Corp., 84 Sherman St., Cambridge, MA 02140)

This paper begins with a brief review of Part I's main ideas and conclusions regarding: (a) Operator-induced symmetry and reciprocity leading to compatibility of the halfplanes of analyticity between the integral equation's non-translational kernel and those of the Fourier-transformed displacements and pressures on the surface of a scattering or vibrating body of revolution; and (b) subsequent spectral factorizations in juxtaposition to those of the classical Wiener–Hopf case for the planar geometry. The spatial and spectral domains in question refer to the arclength variable along the body's generator and to its transform wavenumber, respectively. The analysis described in this Part-II paper brings out some of the additional positive consequences of the pre-symmetrization of the integral equation that governs the response of the coupled fluid and structure. It then applies standard substructuring schemes to extend Part I's formulation to include departures from axisymmetry resulting from generic appendages as discontinuities along the shape's circumferential coordinate. The presentation ends with sample applications of its new 3-D Wiener–Hopf technique to canonical shapes of revolution, and with a summary of the physical insights made possible by the new approach relative to numerical results by boundary elements.

4:00

2pSA6. Surface wave testing of pavements. Nils Ryden (Eng. Geology, Faculty of Eng., Lund Univ., Box 118, SE-22100 Lund, Sweden)

Pavements are constructed using several layers of materials, and their durability depends on the quality of all of these strata. It is, therefore, valuable to be able to determine the properties of the layers nondestructively. A method is presented for evaluating the thickness and stiffness of multilayered pavement structures from guided waves measured at the surface. In this type of layered structure, the interaction of leaky Lamb waves in the embedded layers generates surface waves corresponding only to certain portions of the guided wave dispersion curves and branches measurable at the pavement surface. To resolve the different mode branches, the wavefield is measured at the surface by using a light hammer as the source and an accelerometer as receiver, generating a synthetic receiver array. The recorded data are transformed to a phase velocity spectrum, which is then inverted to give the layer properties using a global inversion algorithm. The theoretical background along with experimental results of the application to nondestructive testing of pavements will be presented. Ongoing research on noncontact air-coupled measurements is also demonstrated. This opens up the possibility for faster on-the-fly surface wave testing of pavement layers, since surface contact is no longer required.

4:20

2pSA7. Innovative structural acoustic strategies to reduce sound transmission through lightweight flexible structures. Donald Bliss, Qinxian He, Linda Franzoni, and Cassidy Palas (Mech. Eng. and Mater. Sci., Duke Univ., Durham, NC 27708, dbb@duke.edu)

This paper describes research utilizing structural acoustics in novel ways to cancel the transmission of sound and vibration through multielement flexible barriers. Configurations analyzed include panels with different thickness and elastic modulus in different regions and layered structures connected by an elastic suspension. The purpose of the research is to demonstrate that flexibility and controlled resonant behavior can be used to block sound transmission even when structural damping is very low. Strategies are considered to alter vibrating surface wavenumber spectra to reduce coupling between the structure and the acoustic field. Another approach that can be employed is the utilization of structural wave cutoff with multielement multipath (MEMP) structures. Finally, multiple differentially tuned subsidiary elements acting as resonators can be used to greatly reduce the structural response. Examples of acoustic transmission

loss through panel barriers using different strategies are presented, and the potential advantages and possible shortcomings of various approaches are evaluated. Possible configurations for layered sound reduction materials are proposed. The work has particular application to the reduction of vehicle interior noise and addresses the need for good acoustic performance of the lighter weight flexible structures that will be used in the future.

TUESDAY AFTERNOON, 19 MAY 2009 EXECUTIVE SALON I/II/III, 2:00 TO 5:30 P.M.

Session 2pSC

Speech Communication and Psychological and Physiological Acoustics: Exploring the Relationship Between Cognitive Processes and Speech Perception (Lecture/Poster Session)

Amee P. Shah, Chair
Dept. of Speech and Hearing, Cleveland State Univ., Cleveland, OH 44115

Chair's Introduction—2:00

Invited Papers

2:05

2pSC1. Perceptual learning and expectations: Cognitive mechanisms in speech recognition. Howard Nusbaum (Dept. of Psych., The Univ. of Chicago, 5848 S. University Ave., Chicago, IL 60637, h-nusbaum@uchicago.edu)

There is substantial plasticity in adult perceptual processing of speech that cannot be accounted for by most theories. Even 1 h of training on low-intelligibility synthetic speech can improve recognition by 20 percentage points for novel words. Whether speech perception is based on auditory properties or articulatory properties, few theories acknowledge the role of cognitive processes, and some explicitly exclude these mechanisms. Evidence will be examined suggesting perceptual learning of phonetic information in adult listeners involves processes such as attention and working memory. In addition, evidence will be examined that speech perception can be influenced, if not typically guided, by listeners' expectations about speech. In some cases, expectations may be derived by explicit instruction to listeners, and in others, from contextual information. For example, research on talker normalization and perception of sinewave speech has demonstrated that listeners' expectations about the speech signal change perceptual processing. Evidence will be discussed suggesting mechanisms that mediate this effect of expectations and compare this to mechanisms involved in perceptual learning. Perceptual learning may depend on the same kinds of cognitive mechanisms involved in the top-down guidance of perception by expectations and these mechanisms may be necessary for stable phonetic perception. [Research supported by NIDCD.]

2:25

2pSC2. The role(s) of capacity limitations in speech perception. Alexander L. Francis (Speech, Lang., and Hearing Sci., Purdue Univ., 500 Oval Dr., West Lafayette, IN 47907, francisa@purdue.edu)

This paper reviews some current research exploring the role that capacity limitations play in recognizing speech, particularly in the presence of competing speech. Load theory [Lavie, Trends Cogn Sci **92** (2005)] suggests that perceptual capacity limits the number of objects (or features) that can be processed simultaneously, while cognitive capacity limits rejection of irrelevant information. Functional imaging studies show increased cognitive (working memory) load corresponding to failure of inhibition of (increased activity in) brain regions associated with processing distractor stimuli [de Fockert *et al.*, Science **291** (2001)], whereas increased perceptual load results in decreased activity in distractor-related areas [Rees *et al.*, Science **278** (1997)]. However, all of these studies were carried out in the visual modality, and it is unclear whether the same predictions were obtained in audition or speech perception. A series of experiments in which perceptual and working memory load were varied as listeners identified words produced by one talker while ignoring another provides qualified support for the predictions of load theory and lays the groundwork for subsequent studies of the effects of hearing impairment, cognitive deficits, and perceptual and cognitive training on the perception of speech in competing speech. [Work supported by NIDCD R03DC006811.]

2:45

2pSC3. Hearing the forest despite the trees: Perceptual learning of systematic variation in speech. Lynne C. Nygaard (Dept. of Psych., Emory Univ., Atlanta, GA 30322)

A fundamental problem for the understanding of spoken language processing is listeners' robust perceptual constancy in the face of enormous variability in the instantiation of linguistic form. On the one hand, listeners are sensitive to the fine-grained structure of linguistic segments that signal differences among talkers and speaking styles. On the other hand, listeners tolerate large discontinuities in this same fine structure forming robust, perceptually constant linguistic categories. Data from a perceptual learning paradigm addressing both the limits and flexibility of speech perceptual mechanisms will be presented and discussed in light of evidence for perceptual learning of accented speech. In a series of studies, listeners were exposed to accented English under learning conditions in which

the opportunity to compare across instances varied. At test, generalization and long-term retention of perceptual learning were evaluated. The results suggest that adaptation to lawful variation in speech is fundamentally influenced by the character and structure of the learning experience. These findings suggest cognitive constraints on behavioral and representational plasticity in speech perception and spoken language processing.

3:05

2pSC4. The nature and time course of the relationship between surface variability and linguistic processing. Amee Shah (Dept. of Health Sci., Cleveland State Univ., 2121 Euclid Ave., MC 429, Cleveland, OH 44115) and Conor McLennan (Cleveland State Univ., Cleveland, OH 44115)

It is becoming increasingly prevalent to study and understand the role of surface information in the process of speech perception and to attempt to accommodate these variables in theories of speech perception. Indeed, theories of speech perception increasingly require an account of the precise circumstances under which surface details affect the ease with which listeners access spoken words. To date, the majority of studies have focused on manipulating various components of surface information (e.g., speaking rate, talker differences, dialect difference, and so on) to determine whether these manipulations matter to the processing task. The present set of studies in our laboratory represents the converse component of this relationship in order to determine whether linguistic complexity can affect or modulate listeners' overt subjective impressions of the surface information. Two different methodologies, including semantic priming and repetition priming, were used manipulate ease of lexical access and determine the role on listeners perception of surface details (foreign accent). Additionally, the time course of the effect of linguistic context on accent rating judgments was studied as it manifested itself differently at different points during perceptual processing. Overall, these studies help understand the complex nature of the relationship between surface variability and linguistic processing.

3:25

2pSC5. Influences of auditory object formation on speech perception. Barbara G. Shinn-Cunningham and Dali Wang (Boston Univ. Hearing Res. Ctr., Auditory Neurosci. Lab., 677 Beacon St., Boston, MA 02215)

In common social settings, our ears receive a jumbled mixture of sound coming from different sources in different directions. A normal hearing listener is adept at using the low-level acoustic structure in the sound mixture to organize this cacophony into auditory objects, each corresponding to a distinct talker (i.e., performing auditory scene analysis). Typical listeners are also proficient at focusing on the talker of interest and ignoring distracting objects (i.e., directing selective attention to the desired object). Often, despite the efficacy of object formation and selective attention, portions of an attended object are inaudible, masked by sources that overlap the attended source in time and frequency. In such situations, listeners "fill in" the missing speech and extract a meaningful, whole message from the sound mixture, a process known as "phonemic restoration." This talk will review some recent studies demonstrating that the process of phonemic restoration, which relies on high-level, acquired knowledge about speech structure and meaning, is directly impacted by low-level acoustic attributes that influence auditory grouping. These results demonstrate the inter-connected nature of the high-level processes that allow listeners to communicate in challenging settings.

3:45—3:55 Break

3:55—4:25 Panel Discussion

4:25—4:30 Break

Contributed Papers

All posters will be on display from 4:30 p.m. to 5:30 p.m. To allow all contributors an opportunity to see other posters, contributors of odd numbered papers will be at their posters from 4:30 p.m. to 5:00 p.m. and contributors of even numbered papers will be at their posters from 5:00 p.m. to 5:30 p.m.

2pSC6. The learning of lexical tones. Sunjing Ji (Dept. of Linguist., Univ. of Arizona, Douglass Bldg., Rm. 200E, Tucson, AZ 85719, sunjing@email.arizona.edu)

Our understanding of speech perception suggests that categorization is an essential task of our cognitive system. Based on previous research on segment perception, this study explores the questions of what mechanism is involved in the acquisition of lexical tones and whether contour tones are decompositional in the process of cognitive learning. An experiment adopting the statistical training method from Maye *et al.* (2002) and Hayes-Harb (2007) was conducted on the learning of lexical tones by adult naive tone learners. The results show that statistical distribution of stimuli along a pitch continuum in training affects naive tone learners' formation of level lexical tone categories. In addition, the perception of level tones behaves more like the perception of vowels rather than consonants. Moreover, exposure to statistical training on a level tone continuum alone affects participants' performance in contour tone discrimination. This indicates that participants were able to apply level tone categories to generate new mental categories of contour tones, providing psychological evidence for the auto-segmental argument that contour tones are composed of a sequence of multiple level tones.

2pSC7. Effects of differences in fundamental frequency on cross-formant grouping in speech perception. Robert J. Summers, Brian Roberts (Psych., Sch. of Life and Health Sci., Aston Univ., Birmingham B4 7ET, UK, r.j.summers@aston.ac.uk), and Peter J. Bailey (Dept. of Psych., Univ. of York, Heslington, York YO10 5DD, UK)

In isolated syllables cross-formant perceptual grouping can be promoted by a common fundamental frequency (F0), but this effect is relatively weak [Darwin, Q., J. Exp. Psychol. **33A**, 185–207 (1981)]. Few studies have explored the role of F0 in cross-formant grouping using sentences. Three-formant (F1+F2+F3) analog of almost continuously voiced natural utterances were synthesized using a monotonous glottal source (F0=150 Hz). Perceptual organization was probed by presenting stimuli dichotically (F1+F2C+F3; F2), where F2C is a competitor for F2 that listeners must resist to optimize recognition. Competitors were created using time-reversed

amplitude and frequency contours of F2, and F0 was manipulated ($\Delta F0 = \pm 8$, ± 2, or 0 semitones relative to the other formants). Adding F2C reduced intelligibility for most utterances, and this reduction was greatest overall when $\Delta F0 = 0$. However, as for isolated syllables, the effect of $\Delta F0$ was quite small. Competitor efficacy was also somewhat dependent on absolute F0. Manipulation of relative F2C level indicated that competitor efficacy was not due primarily to energetic masking. The modest effect of $\Delta F0$, both for sentences and isolated syllables, suggests that cross-formant grouping depends more on other factors, for example common patterns of modulation. [Supported by EPSRC]

2pSC8. The perceptual organization of sine-wave speech under competitive conditions. Brian Roberts, Robert J. Summers (Psych., Sch. of Life and Health Sci., Aston Univ., Birmingham B4 7ET, UK, b.roberts@aston.ac.uk), and Peter J. Bailey (Univ. of York, Heslington, York YO10 5DD, UK)

Speech comprises dynamic and heterogeneous acoustic elements yet is heard as a single perceptual stream, even when accompanied by other sounds. The relative contributions of grouping primitives and of speech-specific factors, for example modulation patterns, to the perceptual coherence of speech are unclear, and the critical acoustical correlates of the latter remain unknown. The parametric manipulations possible with simplified speech, such as sine-wave analogs, make them attractive experimental stimuli to explore this issue. Given that the factors governing perceptual organization are generally revealed only where competition operates, the second-formant competitor (F2C) paradigm was used, in which the listener must resist competition to optimize recognition [Remez et al., Psychol. Rev. 101, 129–156 (1994)]. Three-formant (F1+F2+F3) sine-wave analogs were derived from natural utterances and presented in a dichotic configuration (one ear = F1+F2C+F3; opposite ear = F2). Different versions of F2C derived from F2 by manipulating its amplitude and frequency contours were effective at reducing intelligibility except when the frequency contour was constant. Manipulation of relative F2C level indicated that competitor efficacy was not due primarily to energetic masking. The findings suggest that modulation of the frequency, but not the amplitude, contour is critical for cross-formant grouping. [Work supported by EPSRC.]

2pSC9. Developing audio-visual associations in infancy. Francisco Lacerda, Eeva Klitfors, and Ellen Marklund (Dept. of Linguist., Stockholm Univ., SE-106 91 Stockholm, Sweden, frasse@ling.su.se)

To investigate how possible biases in matching of object sizes with sound intensities may be influenced by the ecological relevance of the potential associations, three groups of Swedish infants (4, 6, and 8 months of age) are being tested in their preferences to match speech or nonspeech sounds of different intensities with visual stimuli showing faces or unanimated objects of different sizes. The infants' audio-visual matching preferences are measured by the cumulative time that the infants' gaze vector was directed to each of the faces and objects simultaneously displayed on the screen, in response to the presentation of an acoustic stimulus (either a speech sound or a nonspeech sound). The results appear to suggest a general trend towards matching of visual prominence with sound intensity, when the ecological relevance of the audio-visual associations was high (i.e., matching speech sounds with faces and nonspeech sounds with unanimated objects) but the pattern seems to be disturbed when only nonecologically relevant matches are possible. [Work carried out within grants from The Bank of Sweden Tercentenary Foundation, Grant No. K2003:0867, MILLE, from EU-NEST Project No. 5010, CONTACT, and from the Knut and Alice Wallenberg Foundation, Grant No. KAW 2005.0115.]

2pSC10. Voice familiarity helps infants tackle variability in the speech signal. Marieke van Heugten and Elizabeth Johnson (Dept. of Psych., Univ. of Toronto Mississauga, 3359 Mississauga Rd. N., Mississauga, ON, Canada, L5L 1C6, marieke.vanheugten@utoronto.ca)

The acoustic realization of lexical items produced by different speakers can vary greatly. Current research suggests that infants, unlike adults, struggle to cope with this lack of invariance in the realization of words. Although 7.5-month olds are able to recognize words across different utterances when produced by speakers of the same gender with similar voices, they fail to do so when target words produced in a female voice are subsequently produced in a male voice [Houston and Jusczyk (2000)]. Note that all work in this area has used disembodied unfamiliar voices to test infants. In the current study, we ask whether infants might perform better under more ecologically valid conditions, i.e., when tested on familiar rather than unfamiliar voices. Using the headturn preference procedure, infants were familiarized with passages spoken by their mother. During the test phase, they were presented with their father's voice producing isolated repetitions of familiarized target words. Preliminary results suggest that infants may recognize words across different utterances produced by speakers of different genders if they are highly familiar with both the male and female speakers. In other words, infants may handle variability in the realization of words better when tested on familiar rather than unfamiliar voices.

2pSC11. The development of infants' sensitivity to modified spectral tilt: Fricatives, approximants, and vowels. Elizabeth Beach and Christine Kitamura (MARCS Auditory Labs., UWS, Bdg. 5 Bankstown Campus, Locked Bag 1797, Penrith South DC 1797, NSW, Australia)

In early infancy, speech perception is based on innate psychoacoustic thresholds allowing young infants to discriminate a wide range of speech contrasts. However, as infants accumulate knowledge of their native language, they begin attuning to native speech sounds: first vowels around 6 months; then consonants around 9–12 months. Now that hearing-impaired infants are being diagnosed and fitted with hearing aids early in life, there is a need to investigate how speech is amplified in infant hearing aids. This study examined whether infants would benefit from positive, negative, or unmodified spectral tilt. Spectral tilts of +6dB/octave and −6dB/octave (as found in hearing aids) were applied to three speech contrasts (fricatives, approximants, vowels) and in a third condition the contrasts remained unmodified. Normal-hearing 6- and 9-month-olds were tested using an habituation procedure to determine whether positive, negative, or unmodified tilt aids discrimination of the speech contrasts. The results showed 6-month-olds benefit when relevant frequency information is amplified, i.e., high-frequency for fricatives and approximants, low-frequency for vowels. Nine-month-olds, on the other hand, discriminated all contrasts best when unmodified. The developmental change between 6 and 9 months might be explained by infants shifting from an acoustic to a linguistic mode of speech perception.

Session 2pSP

Signal Processing in Acoustics and Underwater Acoustics: Detection and Classification of Underwater Targets II

Patrick J. Loughlin, Cochair
Dept. of Bioengineering, Univ. of Pittsburgh, Pittsburgh, PA 15261

Jack McLaughlin, Cochair
Applied Physics Lab., Univ. of Washington, Seattle, WA 98105

Invited Papers

1:30

2pSP1. Alternative signal processing models for broadband underwater propeller sounds. Les Atlas, Pascal Clark (Dept. of Elec. Eng., Univ. of Washington, Campus Box 352500, Seattle, WA 98195, atlas@u.washington.edu), and Ivars Kirsteins (Naval Undersea Warfare Ctr., Newport, RI)

Underwater propeller sounds often have audibly rhythmic characteristics. These sounds are commonly modeled as a broadband noise carrier multiplied by a rhythmic modulator, where analysis of the modulator wave form can provide information relating to the speed and identity of the source vessel. A natural assumption is to posit a purely periodic modulator, considering the rotary action of the propeller, which is useful for deriving maximum-likelihood estimates of the shaft rate [Lourens and du Preez, J. Ocean. Eng. **23**, 4, (1998)]. Indeed, recorded propeller data are unmistakably rhythmic, but the assumption of a strictly periodic or cyclical modulator wave form is questionable. A critical analysis of the periodicity assumption is presented and compared to three alternatives. Maintaining the product form in which the modulator wave form multiplies a random broadband carrier, the possible modulator signals are generalized to include: (1) almost-periodic functions expressible by nonharmonic trigonometric series; (2) multiplicative cascades of possibly complex-valued modulator functions; and (3) stochastic processes in which random state transitions constitute a sense of repeatability or rhythm. In this work, three modulator models are contrasted as estimators of periodicity, using actual propeller sound recordings to validate these estimates. [This work is supported by the Office of Naval Research.]

1:50

2pSP2. The propagation of noise in a dispersive medium. Leon Cohen (Dept. of Phys., City Univ. of NY, Hunter Coll., 695 Park Ave., New York, 10021)

If noise is generated at a particular region, it will generally propagate and be nonstationary in position and time. We present a phase space approach to understand the propagation of noise in a dispersive medium and to present methods to ascertain when the noise is stationary or quasi-stationary. The damping case is also discussed. In addition, we present approximate methods that allow one to study the statistical properties of the evolution of the noise field in space and time in a relatively simple way. A number of examples will be presented. [Work supported by ONR.]

2:10

2pSP3. Classification of shallow water passive sonar signals using stochastic channel model. Maya Gupta, Hyrum Anderson, and William Mortensen (Dept. of Elec. Eng., Univ. of Washington, Seattle, WA 98195)

This paper addresses the problem of classifying passive sonar signals propagating in shallow water channels. A key problem is that such signals are corrupted by noise and multipath, which we model stochastically in terms of the expected multipath and noise, and the variance of the multipath and noise. We assume that free-field (e.g., deep water) training signals are available. We show that for classification, the accuracy can be improved by not committing to an estimate of the channel or signal, but rather by marginalizing out the channel and noise uncertainty. Specifically, we propose variants of the quadratic discriminant analysis (QDA) classifier and the support vector machine classifier (SVM) that probabilistically account for the unknown channel effects, and which avoid ill-posed deconvolution. The proposed classifiers can work either directly on a time signal or on subband power features. Results on simulated data and real Bowhead whale vocalizations show that we can significantly improve classification performance over traditional methods over a range of signal-to-noise ratios. In addition, we will discuss the case where the classification decision can be made by multiple cooperating receivers, such as in a sonar network.

2:30

2pSP4. Finding physically motivated classification features using finite element models. Jack McLaughlin and Lane M.D. Owsley (Univ. of Washington, Appl. Phys. Lab., Box 355640, 1013 NE 40th St., Seattle, WA 98105)

Finite element models (FEMs) for simple shapes such as spheres, cylinders and pipes can be used to uncover potential features for classification by sonar systems. Analyses were conducted of the simulated, bistatic returns over a wide range of aspects using FEMs for a solid steel cylinder and a cement pipe all in free space. Salient characteristics noted in this way were then sought in field data collected

from the same or similar objects during the SAX04 experiment and two other data collections conducted in a test pond at the Naval Surface Warfare Center in Panama City, Florida. Characteristics robust enough to appear in both simulated data and field data are candidates to serve as classification features for similarly shaped objects. It is found that FEMs can provide important pointers to classification features that are closely tied to the physics of reflection. As such, the variability of these features in the face of object burial and multipath can be more easily assessed than statistical spectral features. [This work was supported by the U.S. Navy Office of Naval Research.]

2:50

2pSP5. Kirchhoff scattering from underwater targets modeled as an assembly of triangular facets. Ahmad T. Abawi (HLS Res., Inc., La Jolla, CA)

Scattering from underwater targets is a challenging problem, mainly because many of the techniques developed in scattering theory are for radar applications and, therefore, appropriate only in free space. Underwater scattering occurs in a waveguide, which in most cases requires a modification if not a reformulation of the methods developed for scattering from targets in free space. The most accurate solution of scattering from a target in a waveguide can be obtained by solving the wave equation in an environment that contains the waveguide and the target and simultaneously imposing boundary conditions on the boundaries of the waveguide and on the surface of the target. However, this technique is numerically intensive making it impractical in most cases of interest. As a means of offering a more practical solution, we show how to solve the scattering problem from a target in a waveguide by (1) modeling it as an assembly of triangular facets, (2) computing scattering from each facet analytically using the Kirchhoff approximation for each set of incident and scattered plane waves, and (3) combining the solutions coherently. We compare this solution with those obtained using more accurate methods such as the virtual source technique.

3:10—3:20 Break

Contributed Papers

3:20

2pSP6. Change detection deconfliction process for sonar clutter items. John Dubberley and Marlin Gendron (Naval Research Lab. Code 7441, Stennis Space Ctr., MS 39529, john.dubberley@nrlssc.navy.mil)

When resurveying a seafloor area of interest during change detection operations, an automated method to match found bottom objects with objects detected in a previous survey allows the surveyor to quickly sort new objects from old objects. Here we will demonstrate a software system that accomplishes change detection. The change detection system contains modules for automatic object detection by geospatial bitmap technique, object collocation, feature matching using shadow outlining, scene matching by control point matching, and visualization and filtering capabilities. Emphasis will be placed on the new elements of the system, namely, shadow outlining and optional spatial filtering.

3:35

2pSP7. Processing techniques applied to underwater target echoes and their relationships. Brian H. Houston (Naval Res. Lab., Code 7130, 4555 Overlook Ave., Washington, DC 20375-5320, brian.houston@nrl.navy.mil), Joseph A. Bucaro (Naval Res. Lab., Washington, DC 20375-5320), Larry Kraus (Global Strategies (North America), Crofton, MD 21114), Harry J. Simpson (Naval Res. Lab., Washington, DC 20375-5320), and Timothy J. Yoder (Global Strategies (North America), Crofton, MD 21114)

Interest in acoustic scattering from underwater unexploded ordnance (UXO) has been increasing because of the growing need for sonar technology able to detect submerged UXO and to efficiently separate these detections from those due to natural and man-made clutter. Recent efforts range from laboratory and numerical studies seeking to understand the basic structural acoustic echo formation processes and the environmental effects on them to field exercises determining how well a particular detection /identification technology performs. This paper discusses several important scattering-based constructs, which have been utilized in both the basic UXO studies and the technology exercises as well. They include: (1) $\sigma(\omega, \theta)$, the frequency/angle-dependent scattering cross section; (2) standard imagery, oftentimes implemented with synthetic aperture arrays; (3) reflection tomography imaging; and (4) supersonic imaging using holographic techniques. Without a clear appreciation for the differences among the constructs, it is difficult to properly relate the results of the various studies. We have measured the broadband scattering from several underwater UXO targets using laboratory, rail-based, and AUV systems and processed the data using the above constructs. The use of a common, high quality UXO scattering data base in this process helps clarify the differences and relationships among the constructs. [Work supported by SERDP and ONR.]

3:50

2pSP8. Bistatic synthetic aperture sonar images of penetrable cylinders. Christopher Dudley and Philip L. Marston (Phys. and Astron. Dept., Washington State Univ., Pullman, WA 99164-2814)

Bistatic synthetic aperture sonar (SAS) and acoustic holographic images and monostatic backscattering by penetrable tilted cylinders in water were investigated. Refracted rays internally reflected from the cylinder's backside often dominated the scattering. Ray theoretic models predict scattering enhancements for cylinders made of some isotropic and anisotropic materials. Experiments involved solid cylinders and liquid-filled cylindrical shells of polymers and fiberglass. The experiments used transient insonification and ka in the range of $9<ka<40$, where ka is a product of the acoustic wave number and the cylinder radius. Bistatic measurements used a hydrophone scanned along a line. Transversely isotropic fiberglass rods produced rich features in the images and in the backscattering plotted as a function of tilt and time. The timing of some features could be explained from a ray model based on properties of quasi-shear and quasi-longitudinal waves computed from the stiffness matrix measured for the fiberglass. Bright features for solid cylinders and liquid-filled shells were typically associated with refracted waves having phase velocities less than the speed of sound in water. For some tilt angles, radiated wavefronts were relatively flat producing enhanced farfield scattering. [Work supported by ONR.]

4:05

2pSP9. Bistatic synthetic aperture sonar and acoustic holographic imaging of a tilted circular elastic plate. Neil Tuazon and Philip L. Marston (Phys. and Astron. Dept., Washington State Univ., Pullman, WA 99164-2814, marston@wsu.edu)

Circular plates have axial symmetry and are sometimes used as components of items relevant to applications of sonar to detection and classification. Measurements of the backscattering spectrum as a function of tilt angle for an isolated circular plate reveal bright features associated with the excitation of compressional and flexural waves on the plate. Some of the features were previously found relevant to the interpretation of acoustic holographic images based on 2-D hydrophone scans close to a circular plate [B. T. Hefner and P. L. Marston, ARLO **2**(1), 55–60 (2001)]. In the present research, bistatic synthetic aperture sonar (SAS) and holographic images were constructed from line scans of a hydrophone at a large distance from

the plate using a method previously summarized [K. Baik, C. Dudley, and P. L. Marston, J. Acoust. Soc. Am. **121**, 3203 (2007)]. Because of elastic responses, the images are bright even when the receiver scan line does not intersect specular reflections from the plate. The radiation by the transient elastic waves excited on the plate can significantly increase the contrast of SAS and holographic images. [Work supported by ONR.]

4:20

2pSP10. Optical simulation of bistatic specular reflection by a rigid cone on a flat surface. Anthony R. Smith, Matthew D'Asaro, and Philip L. Marston (Phys. and Astron. Dept., Washington State Univ., Pullman, WA 99164-2814, asmith8@mail.wsu.edu)

To gain insight into the high-frequency scattering of sound by cone-shaped objects near flat reflecting surfaces, a small conical mirror was placed on a flat horizontal mirror and illuminated by a tilted laser beam. The symmetry axis of the cone was vertical. Light scattering patterns were recorded by imaging with a camera on a white vertical screen that intersected the scattering. Bright regions on the screen were associated with specular reflections from the cone and from the flat mirror. To determine which contributions depended on the presence of the flat mirror, the screen was also imaged with the cone on a nonreflecting surface. The patterns were recorded with the screen placed sideways relative to the laser beam as well as in front of the cone and behind the cone. The cone half-angle was 45 deg but the grazing angle of the laser beam could be changed. The bright patterns were described by a geometric analysis of bistatic reflection previously summarized [P. Marston, J. Acoust. Soc. Am. **124**, 2584 (2008)] modified so as to allow for images caused by the flat mirror. The pattern for a vertical circular cylinder on a mirror was also studied. [Research supported by ONR.]

4:35

2pSP11. Modelled Doppler and range resolutions of active pulses in simulated environments. Andrew Holden (Dstl Farnborough, Ively Rd., Farnborough, Hampshire, GU14 0LX, UK)

The ability of an active sonar waveform to simultaneously estimate the range and velocity resolution of a target can be predicted by the wideband ambiguity function. Although this gives good insight into the capabilities of different pulse types, it does not replicate a real active sonar where a transmitted pulse is propagated through an environment and the received pulse is cross-correlated with a number of frequency and time shifted replicas of the transmitted pulse. In order to predict this a ray trace model is used to calculate the travel time and received amplitude of each ray path from the transmitting sonar to a target and back to include seabed and sea surface scattering where complex broadband pulse types can be modelled using a sub-band approach. This allows the determination of Doppler and range resolution for a variety of pulse types including pulse trains of LFM pulses in simulated environments, especially highly reverberate shallow water environments.

TUESDAY AFTERNOON, 19 MAY 2009 — PAVILION WEST, 1:00 TO 5:05 P.M.

Session 2pUW

Underwater Acoustics and Acoustical Oceanography: Session in Honor of Ralph Goodman and His Contributions to the Acoustics of Bubbles and Other Works

Jerald W. Caruthers, Cochair
Dept. of Marine Sciences, Univ. of Southern Mississippi, Stennis Space Center, MS 39529

Kenneth E. Gilbert, Cochair
National Ctr. for Physical Acoustics, Univ. of Mississippi, University, MS 38677

Steve Stanic, Cochair
Naval Research Lab., Stennis Space Center, MS 39529

Chair's Introduction—1:00

Invited Papers

1:05

2pUW1. Ralph Goodman, builder of laboratories. Samuel W. Marshall (P.O. Box 668, White Stone, VA 22578, swmiii@yahoo.com)

Ralph had an extraordinarily successful career in building programs and laboratories. He started with an overall vision of what was to be built while determining the principle obstructions. He carefully avoided early details which would most often be overtaken by events. In addition, he was an eminent scientist whose acumen in a number of technical areas permitted him breadth of very constructive technical leadership. Besides a history of how Ralph got into underwater acoustics and his first major position in management, some personal anecdotes will be presented to emphasize how he successfully dealt with people and with some very difficult situations in this and subsequent undertakings.

1:25

2pUW2. The Italian connection: Ralph Goodman's close ties to NATO over 45 years. Finn B. Jensen (NATO Undersea Res. Ctr., 19126 La Spezia, Italy, jensen@nurc.nato.int)

Ralph's enduring and very intense professional relationship with SACLANTCEN (now NURC) in La Spezia, Italy, started in September 1961 when he joined the Centre as a young scientist. He worked in Italy for two years publishing on "convergent zone propagation" and "reverberation from smooth ocean floors." This was also the time of his first sea trial, which on Ralph's watch nearly led to the ship running aground. His love for life in Italy and the NATO Centre as such led to many visits in the coming years. He returned in 1981 to become the first American director of SACLANCEN. His primary task was to plan and undertake the construction of a new NATO research vessel named Alliance, a task which involved many crucial decisions about ship specifications and performance, plus guidance to the in-house ship building team, and excruciating negotiations with NATO agencies to secure the funding. Ralph's broad scientific background and superb people management skills ensured the success, and his "yacht" is still one of the best research vessels around, here 20 years later. Ralph's tenure as director lasted an unprecedented 6 years and he left in 1987 having secured SACLANTCEN a top-rated seagoing capability for years to come.

1:45

2pUW3. Coupled ocean-acoustics studies at Navy and NATO laboratories: The legacy of Ralph Goodman. Steve A. Piacsek, Charlie N. Barron (Oceanogr. Div., Naval Res. Lab., Stennis Space Ctr., MS 39529, piacsek@nrlssc.navy.mil), and Michael Porter (HLS, Inc., La Jolla, CA 92037)

A brief history of collaborations between ocean and acoustic modelers is given under the directorships of Ralph Goodman at NORDA and SACLANT, and of continuing coupled modeling studies at NRL built on previous studies he sponsored. At NORDA the Numerical Modeling Division consisted of an acoustic and an ocean branch, one of the first known instances of such close-knit administrative units for ocean and acoustic modelers. At SACLANT, close collaborations were strongly encouraged by Ralph Goodman and the respective group leaders. The results of these studies eventually appeared among the first published papers on the effects of mixed layer and Gulf Stream properties on surface-duct propagation (*Computational Acoustics: Ocean-Acoustic Models and Supercomputing* (North Holland Press, 1990); *Oceanography and Acoustics: Prediction and Propagation Models* (AIP Press, 1994). At NRL, these studies were restarted recently: evaluation of sonic layer depth relative to mixed layer depth [JGR **113** (2008)]; the acoustic impact on marine mammals [AGU Ocean Sciences Meeting (2006)]; and the acoustic impact of propagating internal solitons [IEEE Journal of Ocean Engineering (2007)]. Examples will be given from some of these studies to show progress in the field.

2:05

2pUW4. Ralph Goodman and Hamiltonian acoustics. W. A. Kuperman (Marine Physical Lab., Scripps Inst. of Oceanogr., UC San Diego, La Jolla, CA 92093-0238)

Much of the underwater acoustic community that has worked with ray theory starts from the eikonal-ray equations. Since these equations, which are solved numerically, can be derived from a high-frequency asymptotic expansion, Fermat's/Hamilton's principle is typically bypassed. Historically, the introduction of the Hamiltonian formulation of underwater acoustics ray has come from scientists with a background in classical physics and/or from researchers whose goals were to study complicated environments, chaos, etc., using the well developed formalism of Hamilton's equations and perturbation theory. Mostly, these latter applications go back to the 1980s. Among Ralph Goodman's earliest work in underwater acoustics is a paper [R. Goodman and R. B. Duykers, J. Acoust. Soc. Am. 34, 960–962 (1961)] in which he derived the Hamiltonian for convergence zone rays in the harmonic oscillator approximation and then solved the equations by inspection. This paper must be one of the earliest applications of the Hamiltonian formulation to underwater ray acoustics and a part of the beginning of an illustrious career in the underwater acoustics community.

2:25

2pUW5. Bubble research with Ralph Goodman at Penn State. Kenneth E. Gilbert (Natl. Ctr. for Phys. Acoust., Univ. of Mississippi, University, MS 38677)

During the years 1992–1998 at Penn State, I collaborated closely with Ralph Goodman on scattering from the near-surface oceanic bubble layer. Ralph's enthusiasm, physical insight, and encyclopedic knowledge of at-sea experiments proved to be invaluable. I will outline the research and discuss Ralph's contributions to graduate theses and scientific papers that were published. I will also give some personal observations on what it was like collaborating with Ralph.

2:45

2pUW6. Extending bubble measuremenets below 20 μm: in memory of Ralph Goodman's contributions. Helen Czerski and David Farmer (The Graduate Sch. of Oceanogr., Univ. of Rhode Island, S Ferry Rd., Narragansett, RI 02882)

No matter which aspect of underwater acoustics we worked on, conversations with Ralph Goodman invariably added insight and often motivated new lines of investigation. This was certainly true of our interest in measuring bubble size distributions. We discuss the extension of acoustical measurement of bubbles to radii below 20 μm, a topic of particular relevance to the study of optical scatter in the ocean. Extending the frequency range of a resonator to 1 Mhz would in principle allow measurement down to $\sim$3 μm, but significant challenges arise due to the confounding effects of geometric scatter from larger bubbles. This problem becomes greater for measurements of smaller bubbles, requiring a careful analysis of the accuracy limits imposed on the inversion procedure. Preliminary steps along this path are discussed with examples drawn from recent field measurements.

3:05—3:20 Break

3:20

2pUW7. Anomalous dispersion and pulse propagation in oceanic bubble clouds. Frank S. Henyey (Appl. Phys. Lab., Univ. of Washington, 1013 NE 40th St., Seattle, WA 98105, frank@apl.washington.edu)

During a planning meeting for the Scripps pier bubble experiment, Ralph Goodman suggested we apply the Kramers-Kronig relations to bubble cloud data. By "we," I assumed he meant that I should do it. I applied the Kramers-Kronig relations to David Farmer's Scripps pier data from his modified Medwin resonators. This allowed a determination on which data had lower accuracy than the rest. Using the high accuracy data, I constructed a model of the complex sound speed. No formula relating bubble size distributions was needed. This model has anomalous dispersion in a frequency band that nearly coincides with a region in which the group speed is higher than the sound speed in bubble-free water. Summerfeld's theorem prohibits any signal from traveling that fast. The consequences for pulse propagation within bubble clouds was determined, using pulses having the same frequency spectrum as transmitted by Jerry Caruthers. The predicted nature of the received pulse is only partially described by Brillouin's studies, done before computers existed.

3:40

2pUW8. Conversations with Ralph about bubbles in the surf zone. Grant B. Deane (Marine Physical Lab., Scripps Inst. of Oceanogr., UCSD, La Jolla, CA 92093-0238, gdeane@ucsd.edu)

Ralph Goodman made many contributions to the field of oceanic bubbles. This talk will focus on conversations with Ralph about bubbles in the surf zone. Questions that Ralph asked about surf zone bubbles included: where are they, and what are their acoustical properties? These fundamental questions will be examined in the light of Ralph's own experimental and theoretical work, with some contributions from the author. [Work supported by the Office of Naval Research.]

4:00

2pUW9. Ralph Goodman's recent contributions on oceanic bubbles. Jerald W. Caruthers (Dept. of Marine Sci. Univ. of Southern Mississippi, 1020 Balch Blvd., Stennis Space Ctr., MS 39529, jerald.caruthers@usm.edu) and Steve Stanic (Naval Res. Lab., Stennis Space Ctr., MS 39529)

Many of us are never too old to have an esteemed mentor such as Ralph Goodman. We have for the past decade and a half had the pleasure and privilege of conducting research on oceanic bubbles with his help and advice. Over this period, bubble research has been his main focus. It is appropriate that we highlight his leadership and contributions with us on oceanic bubbles. This presentation will provide snapshots of a number of publications and presentations on bubbles since 1993. [Work supported by ONR and NRL.]

Contributed Papers

4:20

2pUW10. Shallow water horizontal signal coherence measurements with use of mobile acoustic sources to create synthetic aperture arrays. Philip Abbot, Ira Dyer, and Chris Emerson (OASIS, Inc., 5 Militia Dr. Lexington, MA 02421)

Horizontal signal coherence length was measured in shallow water using a reciprocal synthetic aperture array created from multiple signals radiated by a mobile acoustic source, and a slowly drifting omnidirectional receiver. The tests were conducted in September, 2008, in shallow water (125 m depth) of the South East China Sea. Source and receiver depths were 61 m. Twelve hyperbolic FM slides per minute were transmitted while the source moved horizontally at 2.5 m/s, maintaining a nearly constant range of ~6 km to the receiver. Received signals were matched-filter processed, phase-corrected to form an equivalent linear array, then coherently combined using a synthetic aperture time delay beamformer. The beamformer output signal gain versus the number of elements in the array, N (using $2 \leqslant N \leqslant 512$ transmissions), was compared to the theoretical limit (20 log, N). The coherence length, defined to be L/λ at a point 3 dB down from the limit, was determined. At 900 Hz, the correlation length was $L/\lambda \approx 40$ ($N=7$, over 40 s). At 600 Hz, it was $L/\lambda \approx 10$ ($N=3$ over 8 s). The degradation at 600 Hz is due to substantially smaller signal-to-noise levels at the element level. Partial coherence is observed at both frequencies, even at $N=512$.

4:35

2pUW11. Attenuation measurements across surface-ship wakes and computed bubble distributions and void fractions: A tribute to the contributions by Ralph Goodman on oceanic bubbles. Steve Stanic (Naval Res. Lab., Stennis Space Ctr., MS 39529, Steve.Stanic@nrlssc.navy.mil), Jerald Caruthers (Univ. of Southern Mississippi, Stennis Space Ctr., MS 39529), Ralph Goodman (Deceased), Edgar Kennedy, and Bob Brown (Naval Res. Lab., Stennis Space Ctr., MS 39529)

A series of three CW-pulsed signals were transmitted across a surface ship wake as the wake aged. Each transmission contained a set of four 0.5-ms-long pulses that ranged over frequencies from 30 to 140 kHz in 10-kHz steps. The acoustic attenuation across wakes that were due to varying bubble-size densities within the wakes were determined experimentally. From those data, estimates of the bubble densities as functions of the speed of the wake-generating ship, the wake's age, and acoustic frequency were calculated. From the bubble-density results, power-law fits and void fractions are calculated. The attenuation measurements were taken at 7.5-m intervals behind the wake-generating ship and continued for about 2 km. The experiment was run for wakes generated at ship speeds of 12 and 15 knot wakes. The bubble densities were observed to have power-law forms with varying parameters with the strongest, for early ages, having an exponent of -3.6 and a void fraction of 4×10^{-7}, and with both diminishing for older wakes, as might be expected. This work was Ralph Goodman's last contribution in underwater acoustics. [Work supported by the Naval Research Laboratory Program Element 62435N and the Office of Naval Research Code 321OA.]

4:50

2pUW12. Observations and theory of dispersion in rip currents at the Scripps Pier Bubble Experiment of 1997. Jerald W. Caruthers (Dept. of Marine Sci. Univ. of Southern Mississippi, 1020 Balch Blvd., Stennis Space Ctr., MS 39529, jerald.caruthers@usm.edu), Steve Stanic (Naval Res. Lab., Stennis Space Ctr., MS 39529), Jorge C. Novarini (Planning System, Inc., Long Beach, MS 39560), and Frank Henyey (Univ. of Washington, Seattle, WA 98105)

Two of the authors (Caruthers and Stanic), with help and advice from Ralph Goodman, were instrumental in planning and conducting the 1997 Scripps Pier Bubble Experiment. Ralph's participation was invaluable in making this effort a success. A number of institutions were involved in the

overall experiments, but the main experiments, conducted by the Naval Research Laboratory, centered on what was termed the "delta frame" [Caruthers *et al.*, J. Acoust. Soc. Am., **106**, 617–625 (1999)]. The delta frame was a triangle 10 m on a side with sources at two apexes and eight hydrophones distributed along the arms. Eight frequencies (39 to 244 kHz) were propagated from the two sources. The NRL personnel and other participants in the experiment published a number of detailed measurements and analyses. In the delta frame experiments, a significant amount of the data was relevant to sound-speed-dispersion analyses. Ralph was always keenly interested in dispersion, but we never fully analyzed, nor published those observations. With that oversight and regret in mind that the relevant analyses were not conducted during Ralph's lifetime, we have revisited that data in his honor. [Work supported by ONR and NRL.]

TUESDAY AFTERNOON, 19 MAY 2009 ALEXANDERS LOUNGE, 2:45 TO 3:45 P.M.

Meeting of Accredited Standards Committee (ASC) S1 Acoustics

P. Battenberg, Chair S1
Quest Technologies, Inc., 1060 Corporate Center Dr., Oconomowoc, WI 53066-4828

R. J. Peppin, Vice Chair S1
Scantek, Inc., 6450 Dobbin Road, #A, Columbia, MD 21045

Accredited Standards Committee S1 on Acoustics. Working group chairs will report on the status of standards currently under development in the areas of physical acoustics, electroacoustics, sonics, ultrasonics, and underwater sound, etc. Consideration will be given to new standards that might be needed over the next few years. Open discussion of committee reports is encouraged.

People interested in attending the meeting of the TAGs for ISO/TC 43 Acoustics and IEC/TC 29 Electroacoustics, take note — those meetings will be held in conjunction with the Standards Plenary meeting at 9:00 a.m. on Tuesday, 19 May 2009.

Scope of S1: Standards, specifications, methods of measurement and test, and terminology in the field of physical acoustics, including architectural acoustics, electroacoustics, sonics, and ultrasonics, and underwater sound, but excluding those aspects of which pertain to biological safety, tolerance and comfort.

TUESDAY AFTERNOON, 19 MAY 2009 DIRECTORS ROOM, 4:00 TO 5:00 P.M.

Meeting of Accredited Standards Committee (ASC) S12 Noise

R. D. Hellweg, Chair S12
Hellweg Acoustics, 13 Pine Tree Rd., Wellesley, MA 02482

W. J. Murphy, Vice Chair S12
NIOSH, 4676 Columbia Pkwy., Cincinnati, OH 45226

Accredited Standards Committee S12 on Noise. Working group chairs will report on the status of noise standards currently under development. Consideration will be given to new standards that might be needed over the next few years. Open discussion of committee reports is encouraged.

People interested in attending the meeting of the TAGs for ISO/TC 43 Acoustics and IEC/TC 29 Electroacoustics, take note — those meetings will be held in conjunction with the Standards Plenary meeting at 9:00 a.m. on Tuesday, 19 May 2009.

Scope of S12: Standards, specifications, and terminology in the field of acoustical noise pertaining to methods of measurement, evaluation and control, including biological safety, tolerance and comfort, and physical acoustics as related to environmental and occupational noise.