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Monday, 7 September 2009

Room 1 10:00-10:45	Keynote lecture: Manfred Kaltenbacher: Computational Acoustics in Multifield Problems
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Coffee break

Room 1 11:30-12:15	Keynote lecture: Phil Shorter, Robin Langley: Recent Advances in Mid-Frequency Noise and Vibration Modeling
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Lunch

	Room 2	Room 3	Room 4	Room 5
14:00-14:30	R. Piscova: Diffraction baffled plate	M. Charnotskii: Monte-Carlo	M. Berezin: Dielectrophoresis	A. Pierce: Theoretical corrections
14:30-15:00	N. Gorenflo: Explicit representations	P. Blanc-Benon: Nonlinear ray theory	T. Sakuma: Sound transmission loss	Y. Sun: Elastic modeling
15:00-15:30	M. Kumik: Hard & soft screen	O. Marsden: High-fidelity techniques	A. Boufermel: Acoustic streaming	M. Austin: Computational Grid Design
15:30-16:00	A. Shamin: Sommerfeld-type problems		K. Kazhan: Entropy noise modelling	P. Borejko: Scholte waves

Coffee break

16:30-17:00	D. Givoli: High-Order Absorbing Boundaries	O. Godin: Gas-solid interfaces		C. Chen: Numerical Backscattering
17:00-17:30	P. Gamallo: PML and infinite element	S. Wanda: Acoustic & gravity waves		R. Evans: Basin scale computation
17:30-18:00	S. Fuß: Modal Analysis	V. Kopiev: Resonant sound scattering		V. Burov: Ocean acoustic tomography

Tuesday, 8 September 2009

	Room 2	Room 3	Room 4
09:00-09:30	A. Bonner-Ben Dhia: Non-orthogonal PMLayers	E. Blanc: Infrasound monitoring (I)	Y. Teng: Source Simulation Elastodynamics
09:30-10:00	R. Anderssohn: Identification of Admittance Condition	E. Blanc: Infrasound monitoring (II)	Ö. Demirkan: Numerical experimentation
10:00-10:30	T. Abboud: DG & retarded potentials	P. Campus: IMS Infrasound Network	L. Liu: Shear wave velocity
10:30-11:00	H. W eisbecker: Galbrun equation	L. Evers: Remote sensing	Y. Xu: Wavelet transform

Coffee break

Room 1 11:30-12:15	Keynote lecture Timothy Leighton: From pencil to pc to product: taking ideas through experiment and simulation to the ocean and the operating theatre
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Lunch

14:00-14:30	G. Seriani: Seismic Wave Modelling	S. Kulchikov: Atmospheric turbulence	H. Tsuru : Impulse response prediction
14:30-15:00	D. Komatitsch: Seismic wave propagation	E. Privitera: Eruption Mt. Etna	M. Sadrasab: Waves in Persian Gulf
15:00-15:30	N. Glinesky-Olivier: 3D elastic wave propagation	V. Pasko: Electrostatic Mechanism	M. Vermet : Multiple diffractions
15:30-16:00	C. Tsogka: Data filtering		V. Tcheverda: Finite-difference simulation

Coffee break

16:30-17:00	M. Schanz: Efficient BEM	E. Sullivan: Buried Object Detection	C. Klorz: Railway wheelsets
17:00-17:30	B. Bergen: Wave Based Method	C. Capus: Wideband Sonar	M. Makarenko: Optimal passive control
17:30-18:00	S. Lui: Expressive music	N. R. Cerruti: Burial depth dependence	J. Lee: Fluid-valve system

Wednesday, 9 September 2009

	Room 2	Room 3	Room 4	Room 5
09:00-09:30	P. Jordan: Nonlinear acoustic phenomena	D. Hewett: Bangs and reverberations	M. Taroudakis: Statistical characterization	J. Santos: Fluid-saturated porous media
09:30-10:00	B. Kalenbacher: Well Posedness	D. Albert: Urban environment	A. Tolstoy: Low frequencies	E. Deckers: Trefftz based method
10:00-10:30	S. Bargmann: Second sound in solids	D. Hutchins: Road vehicle cargo	Z. Liu: Reconstruction Algorithm	N. Joly: Thermoviscous fluid
10:30-11:00	C. Escudero: Generalized Hydrodynamics	Y. Païffas: MIMO Sonar	D. Blanchet: FE/SEA Coupled	R. Christensen: Perforated plates

Coffee break

Room 1 11:30-12:15	Keynote lecture Jeong-Guon Ih: Simulation Techniques for Auralization and Visualization of the Transient Vibro-acoustic Field of Machinery and Space			
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Lunch

14:00-14:30	A. Warn-Varnas: Shock formation	S. Wu: Panel contributions	W. Kreuzer: Anisotropic layered media
14:30-15:00	R. Field: Stratified Turbulent Flow	N. Zhu: Incoherent sound sources	H. Jang: TD acoustic BEM
15:00-15:30	G. Norton: Dispersive moving media	J. de Villiers: Material properties	Y. Yasuda: Fast multipole BEM
15:30-16:00		K. Sepahvand, S. Marburg, H.-J. Hardtke: Uncertain parameter identification	J. López: Adaptive Box

Thursday, 10 September 2009

	Room 2	Room 3	Room 4
09:00-09:30	E. Sullivan: Broadband Reverberation	A. Ziemann: Meteorological influence	T. Atrakinen: Active noise control
09:30-10:00	L. Hörchens: Flexural waves	N. Aouzale: PSPICE Modelling	H. Barucq: IPDQG formulation
10:00-10:30	V. Pozdaniakov: Collector capacity estimation	M. Mironov: Transversal vibrations	C. Agot: Heterogeneous Media
10:30-11:00	H. Jalsjoudi: Ultrasound		N. Noe: Ray-tracing solution

Coffee break

Room 1 11:30-12:15	Keynote lecture Roland W. Freund: Krylov Subspace-Based Model Reduction Techniques and Some Applications in Large-Scale Matrix Computations
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Lunch

14:00-14:30	E. Rudnyi: Fluid-Structure Interaction	M. Braun: Seismic wave equation	G. Keshetova: Anisotropic media
14:30-15:00	K. Meerbergen: Multiple right-hand sides	I. Rekanos: Elastic Waves	R. Iwatsu: Symplectic integration method
15:00-15:30	R. Gärtner: Hearing research	F. Zyserman: Electroacoustics	M. Isaksson: Interface Roughness
15:30-16:00	R. Srinivasan Puri: Krylov-Arnoldi Projection	V. Burov: Hydrodynamic equations	

General information

Ding Lee - U.S.A.

Steffen Marburg, Chairman - Technical University Dresden, Germany

Alexandra Tolstoy Co-Chair - Atolstoy Sciences, U.S.A.

Er-Chang Shang Co-Chair - CIRES, Univ. of Colorado, Boulder, CO,  
U.S.A.

Yu-Chiung Teng Co-Chair - Femarco, Inc., U.S.A.

Sean Wu - Wayne State University, U.S.A.

Mandy Scheffler

Thomas Kopprasch

Bjorno, L. - Denmark Technical University, Denmark

Bradley, D. - Pennsylvania State University, U.S.A.

Buckingham, M. - University of California, San Diego, U.S.A.

Chapman, N.R. - University of Victoria, Canada

Lee, Ding - U.S.A.

Liu, G. D. Inst. of Geology and Geophysics, Chinese Academy of Sciences

Livingston, E. - US Office of Naval Research (ONR), U.S.A.

Papadakis, J.S. - FORTH/IACM, Greece

Pierce, A.D. - Dept. of Aerospace & Mechanical Eng., Boston Univ., U.S.A.

Robinson, A. R. - Harvard University, U.S.A.

Seriani, G. - Inst. Nazionale di Oceanografia e di Geofisica Sperimentale  
(OGS), Italy

Taroudakis, M. - University of Crete, Greece

Blanc-Benon, P. - Ecole Central de Lyon, France

Chen C-F - National Taiwan University, Taiwan

Chiu, C-S - Naval Postgraduate School, U.S.A.

Chiu, J-M - The University of Memphis, U.S.A.

Dosso, S. - University of Victoria, Canada

Dougalis, V. - University of Athens, FORTH/IACM, Greece

Givoli, D - Dept. Aerospace Eng., Technion-Haifa, Israel

Godin, O. - CIRES, University of Colorado, Boulder, CO, U.S.A.

Hanyga, A. - Inst. of Solid Earth Physics, Univ. of Bergen, Norway

Herman, J-P - Universite Libre de Bruxelles, Belgium

Hovem, J - Norwegian University of Science and Technology, Norway

Jensen, F - NURC, Italy

Marburg, S. - T.U. Dresden, Germany

Michalopoulou, E - New Jersey, Inst. Technology, U.S.A.

Tian, J. - Inst. Of Acoustics, China

Trochidis, A. - University of Thessaloniki, Greece

Special sessions

Wave Modelling: Algorithms and Their Implementation

Dan Givoli and Geza Seriani

Low Frequency Acoustic Detection and Identification of Complex Objects and Events

Duncan P. Williams

Mathematical Aspects of Acoustical Diffraction Problems for the Helmholtz Equation

Norbert Gorenflo and Martin Ochmann

Infrasound: Generation, Propagation, and Applications to Remote Sensing of the Environment

Philipp Blanc-Benon and Oleg Godin

Reduced Order Models and Optimization

Srinivasan Puri and Denise Morrey

Acoustic and Second-Sound Phenomena in Linear and Nonlinear Media

S. A. Chin-Bing and Pedro M. Jordan

Orientation plan



## 9th International Conference on Theoretical and Computational Acoustics

Program	Monday, 7 September 2009
Opening ceremony	09.45–10.00 Room 1
Keynote lecture Manfred Kaltenbacher: Computational Acoustics in Multifield Problems	10.00–10.45 Room 1
Coffee break	
Keynote lecture Phil Shorter, Robin Langley: Recent Advances in Mid- Frequency Noise and Vibration Modeling	11.30–12.15 Room 1
Lunch	
Mathematical aspects of acoustical diffraction problems for the Helmholtz equation	Room 2
Chair: Martin Ochmann, Norbert Gorenflo	
Piscoya R., Gorenflo N., Ochmann M.: Comparison of half-analytical and numerical solutions for the diffraction by a slit in a baffled plate	14.00–14.30
Gorenflo N.: Explicit representations of solutions for the diffraction by a slit	14.30–15.00
Kunik M., Gorenflo N.: On the acoustical diffraction problem for a slit in a hard and a soft screen	15.00–15.30
Shanin A.: Sommerfeld-type problems and results related to them	15.30–16.00
Infrasound: Generation, propagation, and applications to remote sensing of the environment	Room 3
Chair: Philipp Blanc-Benon, Oleg Godin	
Charnotskii M., Godin O.: Monte-Carlo modeling of the Green's function emergence from noise	14.00–14.30
Blanc-Benon P., Gainville O.: Analysis of infrasound propagation in realis- tic atmosphere using nonlinear ray theory.	14.30–15.00
Marsden O., Bogey C., Bailly C.: Infrasound propagation studies with high- fidelity numerical techniques	15.00–15.30
Multifield problems	Room 4
Chair: Manfred Kaltenbacher	
Berezin M., Mozhaev V., Zyryanova A.: Dielectrophoresis Driven by Acou- stic Pulses on Piezoelectric Substrates	14.00–14.30
Sakuma T., Yasuda Y., Egawa K.: Modeling of edge support of a glass pane for simulating sound transmission loss	14.30–15.00
Boufermel A., Joly N., Lotton P.: Numerical computation of acoustic strea- ming in annular resonators	15.00–15.30
Kazhan K., Tokarev V.: The optimal entropy noise modelling in the airport vicinity	15.30–16.00



Tuesday, 8 September 2009

<b>Wave modelling: Algorithms and their implementation</b>	<b>Room 2</b>
<b>Chair: Dan Givoli</b>	
Bonnet-Ben Dhia A., Goursaud B., Hazard C., Prieto A.: Non-orthogonal Perfectly Matched Layers for time-harmonic scattering problems	09.00–09.30
Anderssohn R., Marburg S., Hardtke H.-J.: Global Identification of Admittance Boundary Conditions for Closed Three-Dimensional Spaces using a FE-based Inverse Algorithm	09.30–10.00
Abboud T., Joly P., Rodríguez J., Terrasse I.: Coupling discontinuous Galerkin methods and retarded potentials for transient wave propagation on unbounded domains	10.00–10.30
Weisbecker H., Rodríguez R., Marburg S.: Spurious modes in mixed finite element formulation for Galbrun equation	10.30–11.00
<b>Infrasound: Generation, propagation, and applications to remote sensing of the environment</b>	<b>Room 3</b>
<b>Chair: Philippe Blanc-Benon</b>	
Blanc E., Le Pichon A., Ceranna L., Farges T.: Infrasound monitoring for the study of the atmospheric dynamics (I)	09.00–09.30
Blanc E., Le Pichon A., Ceranna L., Farges T.: Infrasound monitoring for the study of the atmospheric dynamics (II)	09.30–10.00
Campus P.: The IMS Infrasound Network: detections of man-made and natural events around the world and contribution of the Network on geophysical hazard monitoring	10.00–10.30
Evers L.: Passive acoustic remote sensing with infrasound	10.30–11.00
<b>Seismoacoustics and acoustic propagation in fluids and solids</b>	<b>Room 4</b>
<b>Chair: Yu-Chiung Teng and Mehmet Çaliskan</b>	
Teng Y.: Three Dimensional Finite Element Source Simulation in Elastodynamics	09.00–09.30
Demirkan Ö., Çaliskan M., Özgüven H.: Numerical experimentation on effectiveness of passive and reactive means on acoustic field shaping inside enclosed spaces	09.30–10.00
Liu L., Dong H.: Characterization of shear wave velocity in seafloor sediments with noise-generated seismoacoustic interface waves	10.00–10.30
Xu Y., Hao T., Li Z., Huang S.: Wavelet transform for potential field anomaly separation	10.30–11.00

Coffee break

- 11.30–12.15 Room 1      **Keynote lecture Timothy Leighton: From pencil to pc to product: taking ideas through experiment and simulation to the ocean and the operating theatre**
- Lunch
- Room 2**      **Wave modelling: Algorithms and their implementation**  
**Chair: Martin Schanz**
- 14.00–14.30      Seriani G.: Computational Issues of Seismic Wave Modelling
- 14.30–15.00      Komatitsch D., Martin R., Labarta J.: Simulation of seismic wave propagation in a complex 3D geological model based upon an unstructured MPI spectral-element method: a non-blocking communication strategy
- 15.00–15.30      Glinisky-Olivier N., Delcourte S., Fezoui L. : A Discontinuous Galerkin method for 3D elastic wave propagation : analysis and applications
- 15.30–16.00      Tsogka C., Borcea L., Papanicolaou G., Gonzalez del Cueto F.: Data filtering for array imaging in heavy clutter
- Room 3**      **Infrasound: Generation, propagation, and applications to remote sensing of the environment**  
**Chair: Oleg Godin**
- 14.00–14.30      Kulichkov S.: Effects of atmospheric turbulence on azimuths and grazing angles estimation at the long distances from explosions
- 14.30–15.00      Privitera E., Cannata A., Montalto P., Gresta S., Nunnari G., Patanè D.: Infrasound radiation of May 13, 2008 eruption at Mt. Etna: source modelling and monitoring implication
- 15.00–15.30      Pasko V.: Electrostatic Mechanism of Lightning Associated Infrasonic Pulses from Thunderclouds
- Room 4**      **Numerical methods for wave propagation**  
**Chair: Hideo Tsuru and Masoud Sadrinasab**
- 14.00–14.30      Tsuru H., Iwatsu R.: Efficient impulse response prediction by finite difference method
- 14.30–15.00      Sadrinasab M.: Modelling of sound waves in the Persian Gulf
- 15.00–15.30      Vermet M., Noe N.: Multiple diffractions by close edges applied to creeping waves in a ray-tracing simulation
- 15.30–16.00      Tcheverda V., Lisitsa V., Reshetova G.: Finite-difference simulation of waves' propagation within multiscale elastic media
- Coffee break

<b>Wave modelling: Algorithms and their implementation</b>	<b>Room 2</b>
<b>Chair: Luis Hervella-Nieto</b>	
Schanz M.: Efficient Boundary Element Method for wave propagation problems	16.30–17.00
Bergen B., Vandepitte D., Desmet W.: An efficient Wave Based Method for three-dimensional acoustic scattering and transmission problems	17.00–17.30
Lui S.: Producing expressive music by training and retargeting acoustic parameter	17.30–18.00
<b>Low frequency acoustic detection and identification of complex objects and events</b>	<b>Room 3</b>
<b>Chair: Duncan Williams</b>	
Sullivan E., Xiang N., Candy J.: Buried Object Detection/Localization using Noisy Laser Doppler Vibration Measurements	16.30–17.00
Capus C., Pailhas Y., Brown K.: Detection of Buried and Partially Buried Objects Using Wideband Sonar	17.00–17.30
Cerruti N.R., Espana A.L., Marston T.M., Osterhoudt C.F., Thiessen D.B., Marston P.L.: Burial depth dependence of scattering of evanescent waves by cylinders	17.30–18.00
<b>Structural acoustics and aeroacoustics</b>	<b>Room 4</b>
<b>Chair: Christian Klotz and Vitalii M. Makarenko</b>	
Klotz C., Quarz V., Koch S., Beitelshmidt M., Kohrs T.: Simulation based prediction of the sound radiation of railway wheelsets	16.30–17.00
Makarenko V., Marburg S., Tokarev V.: An optimal passive control of beam vibration	17.00–17.30
Lee, J.: Noise Reduction Design of Fluid-valve System in Linear Compressor using CAE	17.30–18.00

Wednesday, 9 September 2009

- Room 2**                      **Acoustic and second-sound phenomena in linear and nonlinear media**  
**Chair: S.A. Chin-Bing**
- 09.00–09.30                  Jordan P.: Nonlinear acoustic phenomena in viscous, thermally relaxing fluids: shock bifurcation and the emergence of diffusive solitons
- 09.30–10.00                  Kaltenbacher B.: Well Posedness and Optimization in Nonlinear Acoustics, with Application to High Intensity Ultrasound Focusing Mid-frequency range and uncertainties
- 10.00–10.30                  Bargmann S.: An approach to model second sound in solids
- 10.30–11.00                  Escudero C.: Dynamics of Generalized Hydrodynamics
- Room 3**                      **Low frequency acoustic detection and identification of complex objects and events**  
**Chair: Duncan Williams**
- 09.00–09.30                  Hewett D., Ockendon J., Allwright D.: Bangs and reverberations - sound propagation in an urban environment
- 09.30–10.00                  Albert D., Liu L.: Acoustic source location in an urban environment
- 10.00–10.30                  Hutchins D., Davis L., Diamond G., Zimmerman P., Peter J.: Acoustic inspection of road vehicle cargo
- 10.30–11.00                  Pailhas Y., Petillot Y., Capus C.: Time Reversal Techniques for Broadband MIMO Sonar Systems
- Room 4**                      **Inverse problems**  
**Chair: Sean Wu**
- 09.00–09.30                  Taroudakis M.: Statistical characterization of an underwater acoustic signal with applications in ocean acoustic tomography and geoacoustic inversions
- 09.30–10.00                  Tolstoy A.: Using low frequencies for geoacoustic inversion
- 10.00–10.30                  Liu Z., Liu L.: A Novel Reconstruction Algorithm for Thermo Acoustic Tomography Imaging by Kirchhoff Migration
- 10.30–11.00                  Blanchet D.: Full Frequency Transmission Loss modelling using FE, SEA and FE/SEA Coupled
- Room 5**                      **Numerical methods for wave propagation**  
**Chair: Nicolas Joly and René Christensen**
- 09.00–09.30                  Santos J., Ravazzoli C., Picotti S., Carcione J.: A finite element method to model attenuation and dispersion effects in highly heterogeneous fluid-saturated porous media
- 09.30–10.00                  Deckers E., Vandepitte D., Desmet W.: An efficient Trefftz based method for acoustic porous material modelling
- 10.00–10.30                  Joly N.: Finite element modeling of acoustics in thermoviscous fluid
- 10.30–11.00                  Christensen R.: Acoustic modeling of perforated plates

Coffee break

**Keynote lecture Jeong-Guon Ih: Simulation Techniques for Auralization and Visualization of the Transient Vibro-acoustic Field of Machinery and Space** 11.30–12.15 Room 1

Lunch

**Acoustic and second-sound phenomena in linear and nonlinear media** Room 2

**Chair: Pedro Jordan**

Warn-Varnas A., Chin-Bing S., Piacsek S., Lamb K.: An analogue to shock formation of internal bore slope increases. 14.00–14.30

Field R., Gallacher P., Hebert D., Jarosz E.: High Frequency Acoustic Propagation in a Stratified Turbulent Flow 14.30–15.00

Norton G.: The numerical solution of a modified wave equation that incorporates a causal propagation operator to describe acoustic propagation through dispersive moving media 15.00–15.30

**Inverse problems**

Room 4

**Chair: Michael Taroudakis**

Wu S., Pierce A.: Analysis of panel contributions to sound pressure field inside an enclosure 14.00–14.30

Zhu N., Wu S.: Locating multiple incoherent sound sources in a non-ideal environment 14.30–15.00

de Villiers J., Braun M.: Recovery of material properties via minimization for the seismic wave equation in 1, 2 and 3 dimensions. 15.00–15.30

Sepahvand K., Marburg S., Hardtke H.-J.: Uncertain parameter identification from experimental modal analysis using polynomial chaos expansion 15.30–16.00

**Numerical methods for wave propagation**

Room 5

**Chair: Wolfgang Kreuzer and Tetsuya Sakuma**

Kreuzer W., Rieckh G., Waubke H.: BEM in anisotropic layered media 14.00–14.30

Jang H., Ih J.: Boundary condition at low frequencies in time-domain acoustic BEM for the interior problems 14.30–15.00

Yasuda Y., Sakuma T., Oshima T.: Comparison of computational performance of the fast multipole BEM based on different translation theories 15.00–15.30

López J., López-Portugués M., Taboada J., Rice H., Obelleiro F.: Adaptive Box Parallel Implementation of the Multipole Method for Acoustic Scattering 15.30–16.00

Thursday, 10 September 2009

<b>Room 2</b>	<b>Scattering</b>
	<b>Chair: Edmund Sullivan and Lars Hörchens</b>
09.00–09.30	Sullivan E., Godoy C., Greenbaum H.: High-Fidelity Real-time Broadband Reverberation Model for Range and Cross-Range Dependent Environments
09.30–10.00	Hörchens L., de Vries D.: Imaging using scattering of flexural waves
10.00–10.30	Pozdniakov V., Tcheverda V.: Scattering waves as reliable tool for collector capacity estimation
10.30–11.00	Jakjoud H., Chitnalah A., Aouzale N., Kourtiche D.: Ultrasound Harmonic Scattered by Fluid Spheres

<b>Room 3</b>	<b>Propagation modelling</b>
	<b>Chair: Astrid Ziemann and Noureddine Aouzale</b>
09.00–09.30	Ziemann A., Fischer G.: Meteorological influence on the simulation of sound propagation in urban areas
09.30–10.00	Aouzale N., Chitnalah A., Jakjoud H.: PSpice Modelling Ultrasonic Transducer's Effect on Modulated and Coded Excitation
10.00–10.30	Mironov M., Gladilin A.: Transversal vibrations of specially tapered rod

<b>Room 4</b>	<b>Numerical methods for wave propagation</b>
	<b>Chair: Julien Diaz and Cyril Agut</b>
09.00–09.30	Airaksinen T., Toivanen J., Heikkola E.: Active noise control in a stochastic domain based on a finite element model
09.30–10.00	Barucq H., Diaz J., Duprat V.: New Absorbing Boundary Conditions for the acoustic wave equation approximated by an IPDG formulation
10.00–10.30	Agut C., Diaz J., Ezziani A.: Fast High-Order Method for Solving the Acoustic Wave Equation in Heterogeneous Media
10.30–11.00	Noe N., Vermet M.: A general ray-tracing solution to reflection on curved edges and diffraction by their bounding edge

Coffee break

11.30–12.15 Room 1	<b>Keynote lecture Roland W. Freund: Krylov Subspace-Based Model Reduction Techniques and Some Applications in Large-Scale Matrix Computations</b>
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Lunch

<b>Reduced order models and optimization</b>	<b>Room 2</b>
<b>Chair: Roland Freund</b>	
Rudnyi E., Landes H., Moosrainer M.: Efficient Simulation of Acoustic Fluid-Structure Interaction Models by Means of Model Reduction	14.00–14.30
Meerbergen K., Bai Z.: The solution of parametrized linear systems with multiple right-hand sides	14.30–15.00
Gärtner R., Fleischer M., Baumgart J., Schmidt R., Hardtke H.-J.: Application of a subspace method using the ARNOLDI-Algorithm to problems in hearing research.	15.00–15.30
Puri R.S., Morrey D.: A Review of Krylov-Arnoldi Projection Framework Techniques For Interior Structural Acoustic Analysis and Optimization	15.30–16.00
<b>Wave propagation</b>	<b>Room 3</b>
<b>Chair: Moritz Braun and Fabio I. Zyserman</b>	
Braun M.: The seismic wave equation expressed in terms of longitudinal and transverse components for non-constant Lamé parameters	14.00–14.30
Rekanos I., Trochidis A., Papadopoulos T., Terzidou A.: Analytical and Numerical Investigation of Intermodulation Phenomena in Nonlinear Longitudinal Propagation of Elastic Waves	14.30–15.00
Zyserman F., Gauzellino P., Santos J.: Electroseismics of gas hydrate-bearing sediments: numerical modeling	15.00–15.30
Burov V., Dmitriev K., Sergeev S.: Calculations of acoustical fields on base of the hydrodynamic equations system	15.30–16.00
<b>Numerical methods for wave propagation</b>	<b>Room 4</b>
<b>Chair: Reima Iwatsu and Marcia Isakson</b>	
Reshetova G., Lisitsa V., Lys E., Pissarenko D., Tcheverda V.: Finite-difference simulation of sonic log for anisotropic media with attenuation	14.00–14.30
Iwatsu R., Tsuru H.: Trigonometrically fitted symplectic integration method	14.30–15.00
Isakson M.: Quantifying the Effects of Interface Roughness on Reverberation using Finite Elements	15.00–15.30
Conference diner	20.00–23.00 Blockhaus

## Computational Acoustics in Multifield Problems

Manfred Kaltenbacher

Applied Mechatronics, Institute of Smart Systems Technologies, University of Klagenfurt

**Monday, 07.09.2009**

**Room 1**

**10:00–10:45**

Many design problems in acoustical engineering are based on multifield interactions. Clearly, the final task is either to generate a defined acoustic field (e.g., sound generation by electrodynamic loudspeakers) or to reduce noise (e.g., noise emitted by electric power transformers). Since modern design processes more and more rely on CAE (Computer Aided Engineering) tools, the demand for efficient numerical simulation schemes, precisely computing the acoustic field based on solving multifield problems, strongly increases. We will present latest numerical schemes based on the Finite Element Method (FEM) being capable of efficiently solving multifield problems. Since for many applications the standard FEM needs enhancements, we will discuss GEFM (Generalized FEM) for homogenization strategies, Mortar FEM for obtaining the freedom of non-conforming grids and mixed spectral FEM for solving acoustic conservation equations. To demonstrate the applicability and the necessity of such enhanced computational schemes, we will discuss in detail the numerical computation of the following three practical applications: noise emitted from electric power transformers, vibration control using piezoelectric patches and the generation process of the human phonation.

## Recent Advances in Mid-Frequency Noise and Vibration Modeling

Philip Shorter<sup>1</sup>, Robin Langley<sup>2</sup>

<sup>1</sup>ESI US R&D Inc., <sup>2</sup>University of Cambridge

**Monday, 07.09.2009**

**Room 1**

**11:30–12:15**

The analysis of mid-frequency noise and vibration is a severe computational challenge. Many degrees of freedom are needed to describe the detailed response of the system, and furthermore the computed response can be very sensitive to small changes in the system properties that might fall within manufacturing tolerances. Ideally, the statistics of the response of an ensemble of random manufactured systems is required, but the direct computation of the response statistics using a combination of the finite element method and Monte Carlo simulations is often unfeasible. Here an alternative approach is described in which the finite element method (FEM) is combined with statistical energy analysis (SEA) within a single computational model. This has the advantage of massively reducing the number of degrees of freedom within the model, while also allowing the response statistics to be calculated without recourse to Monte Carlo simulations. This approach has recently been adopted by a range of automotive, aerospace and other manufacturers; here the basis behind the method is described and a number of practical applications are presented.

From pencil to pc to product: taking ideas through experiment and simulation  
to the ocean and the operating theatre

Timothy G. Leighton

Institute of Sound and Vibration Research, University of Southampton

The classical route from idea to successful product is often a long and difficult one, particularly if the criterion for success is based on wealth creation. Other criteria are however important, such as establishing a service or a pioneering dataset, or advancing and disseminating knowledge sufficient to support innovation in the years to come. The trend by some sponsors who claim to support of basic, adventurous research, to grant funds predominantly to projects which they believe will lead directly to wealth creation by the end of the grant, is nonsensical: such a criterion begs the question of who will support the decade or more of research and development that many innovations must undergo before wealth is created, and the reality that if a body of research projects is truly adventurous, a proportion will not lead to the expected output.

This paper reports on two studies, following them from the initial idea through to their current status. They are linked by the fact that both of the technologies rely on nonlinear scattering of incident acoustical energy by gas bubbles in liquids. Such bubbles are probably the most potent naturally occurring acoustical entities in liquids, and are highly nonlinear when they pulsate in response to a driving sound field. The first example describes a passive acoustical sensor which is placed on the skin of a patient undergoing shock wave lithotripsy (SWL). During SWL, thousands of shock waves are directed into the patient at a rate of about one per second, in order to fragment kidney stones or reduce them to a size whereby they can subsequently be dissolved using drugs. With current equipment the clinician is ill-equipped to determine in-theatre whether the treatment has been successful, with the result that 30-50% of patients need to return for re-treatment, and an unknown number receive a greater exposure to shock waves than is necessary for stone fragmentation. The new passive acoustic sensor is placed by a nurse on the patient's skin, and passively monitors the scattering and reverberation of the SWL pulse in the body. In the clinical trials, a nurse operating the device during treatment could correctly predict successful treatments 94.7% of the time, compared to the 36.8% per cent scored by the clinician in theatre using the best currently-available equipment. Development of the device required theory, CFD simulation, laboratory and human tests, and clinical trials with the associated issues of patient safety and confidentiality.

The second project described the development of a sonar system which can function in bubbly waters, where dolphins are able to echolocate but where the best currently-available man-made sonar cannot. Although gas bubbles in the ocean confound man-made sonar, some cetaceans must deal

Tuesday, 08.09.2009

Room 1

11:30-12:15

with bubbles as a result of their location (for example as occurs with those species restricted to coastal regions): others actively generate bubbles to aid their feeding. Data is scarce as to what extent, if any, cetaceans have exploited the acoustical effects of bubbles, or undertake tactics to compensate for their deleterious effects. The absence of data provides a fruitful opportunity for hypothesis. Having evolved over tens of millions of years to cope with the underwater acoustic environment, cetaceans may have developed extraordinary techniques from which we could learn. The second project describes how the idea was developed through modelling, laboratory and sea trials to develop practical sonar technology for use in bubbly waters.

### Simulation Techniques for Auralization and Visualization of the Transient Vibro-acoustic Field of Machinery or Space

Jeong-Guon Ih

Center for Noise and Vibration Control (NoViC), Department of Mechanical Engineering,  
KAIST (Korea Advanced Institute of Science and Technology), Daejeon

Wednesday, 09.09.2009

Room 1

11:30–12:15

Numerical simulation is very important in the design of machinery and acoustic space in the early and refinement stages of the development target to have a desirable acoustic performance.

Nowadays, auralization of a transient acoustic event is one of major purposes of the acoustic simulations. Auralization as an output of the simulations is important for the subjective evaluation of the sound quality radiated by the design object. Also, visualization of the sound and/or vibration field of the target space is needed for the people to actually see what acoustical and dynamical characteristics happen and change in time at the design target space. Although these two presentation methods of the output data do not usually require a very high precision, but, sometimes, those responses should show detailed vibro-acoustic behavior in specific time and space. Efforts have been made to predict the realistic vibro-acoustic responses of the design target, but the computation methods are still on the way to be employed in the analysis and design of actual complicated applications. In this presentation, a review introduction on some numerical methods for the auralization and visualization of the vibro-acoustic field of machinery and space will be given briefly with some examples: transient BEM, FDTD, phased beam tracing technique, transient holography technique, and characteristic method. The problems to be solved in future will also be discussed along with their potential application areas.

## Krylov Subspace-Based Model Reduction Techniques and Some Applications in Large-Scale Matrix Computations

Roland W. Freund

Department of Mathematics, University of California, Davis

Krylov-subspace methods, most notably the Lanczos algorithm and the Arnoldi process, have long been recognized as powerful tools for large-scale matrix computations, in particular for the iterative solution of large systems of linear equations and for large-scale eigenvalue computations. In recent years, Krylov-subspace algorithms have also emerged as the methods of choice for reduced-order modeling of large-scale linear dynamical systems. While much of the development of these model reduction techniques was driven by applications in the simulation of integrated electronic circuits, the resulting algorithms are much more general and have found use in many other application areas.

In this talk, we explain why and how Krylov-subspace methods are employed to generate reduced-order models of large-scale multi-input multi-output linear dynamical systems. We discuss various desirable and in part conflicting properties of the reduced-order models, such as high approximation accuracy, stability, and passivity. We review the use of Krylov subspace-based model reduction techniques in various application areas, with special focus on applications in computational acoustics.

**Thursday, 10.09.2009**

**Room 1**

**11:30–12:15**

Poster sessions

- Möbius F., Or D.:** Acoustic emissions from fluid front displacement in porous media
- Zakupin A., Kachesova G.:** Effect of physical fields on structurally heterogeneous medium and the problem of seismic process control
- Demin I., Gurbatov S., Pronchatov-Rubtsov N.:** Theoretical and Computational Aspects of Propagation of High-Intensity Modulated Noise
- Milosic Z.:** Model of vibration of medium with concentrated mechanical parameters as a starting point of analyses of receive sensitivity of hydroacoustical transducer
- Montalto P., Cannata A., Privitera E., Nunnari G., Patanè D.:** Infrasound investigation as a tool to recognise active vent and volcanic activity: Mt. Etna, September-November 2007
- Smirnov A., Kunakov V., Le Pichon A., Guilbert J., Ponceau D.:** Infrasound monitoring in Kazakhstan: source localization and characterization

Comparison of half-analytical and numerical solutions for the diffraction by a slit in a baffled plate

R. Piscoya, N. Gorenflo, M. Ochmann  
TFH Berlin

For various incident waves the diffracted wave behind a thin baffled plate with a slit has been computed by using recently developed basis functions. Each basis function describes a special wave field for which the wave itself as well as its normal derivative in the slit can be expressed explicitly. The diffracted waves obtained by using this basis functions are compared with the diffracted waves that result from a numerical calculation. For the numerical approach, the space is divided in two regions, above and below the baffle. The diffracted field in each region is defined by a Rayleigh integral. The normal derivative of the wave field at the slit is obtained by requiring the appropriate boundary conditions. Analogous results for diffraction by finite apertures will be discussed.

**Monday, 07.09.2009**

**Room 2**

**14:00–14:30**

Explicit representations of solutions for the diffraction by a slit

N. Gorenflo  
TFH Berlin

We consider the two-dimensional time harmonic problem of acoustical diffraction by a slit in a rigid plane screen. First we give a short survey of some earlier approaches for solving this problem. Then we propose a new method for solving the underlying boundary integral equation. This method is based on special right-hand sides for which the boundary integral equation can be solved in closed form. There are finite linear combinations of this special right-hand sides, with explicitly given coefficients, which together with a sequence of further concrete functions constitute a biorthogonal system. Thus, for an arbitrary right-hand side the boundary integral equation can be solved explicitly by performing a biorthogonal expansion.

**Monday, 07.09.2009**

**Room 2**

**14:30–15:00**

### On the acoustical diffraction problem for a slit in a hard and a soft screen

M. Kunik<sup>1</sup>, N. Gorenflo<sup>2</sup>

<sup>1</sup>Otto-von-Guericke Universität, Magdeburg, <sup>2</sup>TFH Berlin, Berlin

**Monday, 07.09.2009**

**Room 2**

**15:00–15:30**

We present a new and self-contained theory for mapping properties of the boundary operators for acoustical slit diffraction problems with a hard and soft screen, respectively.

This theory is entirely developed in the context of the boundary operators with a Hankel kernel and not based on the corresponding mixed boundary value problem for the Helmholtz equation.

For a logarithmic approximation of the Hankel kernel we also study the corresponding mapping properties and derive explicit solutions together with certain regularity results.

This is a common work with Dr. Norbert Gorenflo from the TFH Berlin.

### Sommerfeld-type problems and results related to them

A. Shanin

Moscow State University

**Monday, 07.09.2009**

**Room 2**

**15:30–16:00**

A class of „Sommerfeld“ problems is introduced. These problems are 2D scalar stationary diffraction problems that can be reduced to propagation problems on branched multi-sheet surfaces by applying the method of reflections. It is assumed that the number of sheets and the number of branch points is finite.

We represent some results common for all Sommerfeld problems. First, we formulate and prove the embedding formula, which represents the diffraction coefficient related to the problem in terms of the directivities of the so-called edge Green functions, i.e. the fields generated by point sources located at the branch points. Second, we prove that the vector composed of the directivities of the edge Green's function obeys a „spectral equation“, which is an ordinary differential equations using the scattering angle as a variable. Third, we prove that the edge Green functions as the functions of geometrical coordinates obey the system of „coordinate equations“, i.e. a two-dimensional ordinary differential equation.

### High-Order Absorbing Boundaries: Recent Extensions and Improvements

D. Givoli<sup>1</sup>, T. Hagstrom<sup>2</sup>, E. Becache<sup>3</sup>, A. Mar-Or<sup>1</sup>

<sup>1</sup>Technion, Haifa, <sup>2</sup>Southern Methodist University, Dallas, <sup>3</sup>INRIA, Paris

Recently new finite element formulations have been proposed which involve high-order Absorbing Boundary Conditions (ABCs) for the solution of exterior time-dependent wave problems. In the first part of this talk the general subject will be briefly reviewed and the proposed approach will be discussed and contrasted with other approaches, such as the Perfectly Matched Layer (PML). In the second part of the talk the high-order Hagstrom-Warburton (HW) ABCs will be presented, and recent extensions and improvements related to them will be discussed and demonstrated. These include, among other things, the application of the ABCs to stratified and anisotropic media, their use in one-way nesting schemes, and their incorporation in spectral-element schemes. Difficulties that are encountered in extending these ideas to elastic waves will also be discussed.

**Monday, 07.09.2009**

**Room 2**

**16:30–17:00**

### A numerical comparison between PML and infinite element methods in the frequency domain

P. Gamallo<sup>1</sup>, L. Hervella-Nieto<sup>2</sup>, A. Prieto<sup>3</sup>

<sup>1</sup>Tecnologías Avanzadas Inspiralía SL, Madrid, <sup>2</sup>Universidad de A Coruña, <sup>3</sup>Universidad de Santiago de Compostela

The Helmholtz problem over an unbounded domain is considered for the propagation of harmonic acoustic waves. The radiation condition is tackled numerically by two different ways: the exact Perfectly Matched Layer (PML) and Infinite Element (IE) methods. More precisely, the exact PML consists in using non-integrable absorbing functions so that a PML of finite thickness is sufficient to represent exactly the acoustic propagation in an unbounded domain without generating spurious reflections.

From the discretization point of view, both the exact PML technique and the Infinite Element method have been combined with a standard piecewise linear finite element discretization and implemented by using commercial computing software. Several 2D and 3D scattering and radiation test problems are considered.

The numerical results for the two methods are analyzed by comparing their accuracy and efficiency.

**Monday, 07.09.2009**

**Room 2**

**17:00–17:30**

## Modal Analysis of a Fluid inside and around a Recorder

S. Fuß, S. Hawkins, S. Marburg

Technische Universität Dresden

**Monday, 07.09.2009**

**Room 2**

**17:30–18:00**

In this talk the numerical simulation of the sound spectrum and the propagation of the acoustic noise inside and around a three-dimensional recorder model is presented.

The fluid inside and close to the recorder is meshed by Lagrangian tetrahedral finite elements. Complex conjugated Astley-Leis infinite elements are used to obtain results in the far field of the recorder. For the application of these infinite elements the finite element domain has to be meshed either in a spherical or an ellipsoidal shape. Specific characteristics of both shapes regarding the recorder will be shown in this talk. Results of the modal analysis of the fluid for different tones will also be presented.

## Monte-Carlo modeling of the Green's function emergence from noise

M. Charnotskii<sup>1</sup>, O. Godin<sup>2</sup>

<sup>1</sup>Zel Technologies, LLC, NOAA/Earth System Research Lab., Boulder, Colorado, <sup>2</sup>Univ Colorado, CIRES., NOAA/Earth System Research Lab, Boulder, CO

**Monday, 07.09.2009**

**Room 3**

**14:00–14:30**

We present a simple Monte-Carlo model imitating the generation and propagation of diffuse ambient noise in a moving homogeneous fluid. The model does not rely on high-frequency approximations such as geometrical acoustics and represents a first step toward a computational study of passive tomography of the atmosphere through interferometric measurements of infrasonic noise. Acoustic signals received by an array of point receivers are calculated for our model noise, and simple correlation signal processing is performed. Acoustic travel-time between given receivers emerges as a peak of the envelope of the cross-correlation function of noise.

We analyzed the required averaging time for the correlation peak to exceed the pseudo-noise level as a function of the recording bandwidth and central frequency, geometry of the source distribution, and the distance between the receivers. In the case of the moving fluid, our model shows the theoretically predicted asymmetry in the position of the correlation peaks at positive and negative time delays, which reflects acoustic non-reciprocity and enables determination of the flow speed. For a two-dimensional flow, three-receiver array allows the measurement of the velocity vector.

We have analyzed the width of the envelopes of the correlation functions, which ultimately determines the accuracy of the velocity measurements, and found it to depend linearly on the signal bandwidth. We discuss straightforward generalizations of our full-wave model that include rigid or pressure-release boundaries, and some simple vertical profiles of the sound speed.

Analysis of infrasound propagation in realistic atmosphere using nonlinear ray theory.

P. Blanc-Benon<sup>1</sup>, O. Gainville<sup>2</sup>

<sup>1</sup>Ecole Centrale de Lyon, Centre Acoustique, <sup>2</sup>CEA, DAM DIF, Arpajon

Using ray theory, long range propagation of infrasound through the atmosphere is modeled in the framework of the Comprehensive Nuclear-Test-Ban Treaty. In atmospheric propagation, the high frequency hypothesis is based on the assumption that space and time scales of atmospheric properties (temperature, wind, density) are much larger than acoustic wave scales. An operational 3D nonlinear ray tracing code is developed to compute the temporal pressure signature at receivers. The global pressure signature at the receiver is the sum of eigenray contributions that link the source to the receiver. They are obtained by solving a generalized Burgers equation along each eigenray taking into account nonlinear effects, shear and bulk viscosity absorption and molecular vibrational relaxation mechanisms. This equation is solved using a Fourier Galerkin spectral scheme. Specific developments are performed to pass through caustics and take into account ground reflection. The propagation of infrasound emitted by a motionless point source in a realistic atmosphere will illustrate the analysis. To quantify the validity limits of our approach we investigate effects of the wind, atmospheric absorption, nonlinearity, refraction and scattering by small atmospheric scales on observed phase kinds, their travel time and their waveform. To estimate the nonlinearity effects relative to the linear dissipative effects we evaluate the Goldberg number.

We note that nonlinear mechanisms are quite important to model the waveform signature evolution of infrasound. The N and the U measured waveform shape of thermospheric and stratospheric paths respectively are associated with nonlinear mechanisms. Nonlinearities are weak but the development of nonlinear models is necessary in the goal to characterize the source energy. Comparisons will be made with results available in the literature and recent numerical simulations based on Navier-Stokes equations.

**Monday, 07.09.2009**

**Room 3**

**14:30-15:00**

### Infrasound propagation studies with high-fidelity numerical techniques.

O. Marsden, C. Bogey, C. Bailly

LMFA Ecole Centrale de Lyon, ECULLY

**Monday, 07.09.2009**

**Room 3**

**15:00–15:30**

The numerical study of atmospheric infrasound propagation has long been possible only via the use of parabolic equations and ray tracing, and has thus been limited in terms of the physical effects that could be examined.

Recently, with the combined improvement of computer processors and high-precision numerical methods, atmospheric infrasound studies are becoming possible with the Navier-Stokes equations, which do not suffer from the physical limitations inherent to other methods.

This work illustrates the use of high-performance numerical schemes for studying infrasound propagation. High-order finite differences are coupled with a wave-number optimized Runge-Kutta integration scheme Bogey03b, Berland07 to solve the full Navier-Stokes equations.

A non-linear filtering technique Bogey09 is implemented which combines shock-capturing properties with zero dissipation away from discontinuities. The test case used in this work involves a realistic atmosphere including temperature gradient effects Gainville06, Marsden08c.

Its mean structure is constructed from an experimental temperature profile which has been fitted by a high-order polynomial function of altitude.

This function is integrated to obtain pressure as a function of altitude, and subsequently, density. A low-frequency source is used to emit two periods of the main frequency of interest, fixed at  $f_s=0.1$  Hz.

In first part, the effect of the non-linear filter is examined. In simulations where the filter is not applied, dispersion effects around shock fronts are shown to have a significant effect on shock front propagation velocities. These effects are in large part removed by the application of the non-linear filtering technique.

In a second part, the source amplitude is varied, and time signatures recorded 400 km away from the source are compared.

Non-linear effects, including signal steepening, time stretching and N-wave - caustic interaction, are observed for the different acoustic arrivals for strong acoustic sources.

Transmission of infrasound through gas-solid interfaces

O. Godin

NOAA/ESRL, Boulder, Colorado

It was found recently [Godin O. A. Anomalous transparency of water-air interface for low-frequency sound, Phys. Rev. Lett., 97, No. 16, 164301 (2006)] that gas-liquid interfaces, which are usually almost perfect reflectors of acoustic waves because of a very large impedance contrast, become anomalously transparent and the power flux in the wave transmitted into the gas increases dramatically, when a compact sound source in the liquid approaches the interface within a fraction of wavelength.

In this paper, we study the effects of shear rigidity on sound transmission through an interface with a large mass density contrast. It is found that, as in the case of gas-liquid interface, acoustic power flux into the gas increases greatly when a compact source located within the solid approaches the interface. The ratio of power fluxes into gas from shallow and deep sources proves to be significantly larger when the sources are located within solid rather than within liquid. The physics behind the increase of the power flux into gas, when the source depth decreases, is shown to be rather different in the gas-liquid and gas-solid cases.

Depending on values of the quality factors of compressional and shear waves in the solid, leaky interface waves supported by the gas-solid interface can be responsible for the bulk of acoustic power flux into the gas. Implications of the theoretical findings for understanding infrasound radiation by volcanoes and detection of underground explosions will be discussed.

**Monday, 07.09.2009**

**Room 3**

**16:30-17:00**

## Radiation of acoustic and gravity waves in the stratified fluid from a time-varying bottom boundary

S. Watada

University of Tokyo, Earthquake Research Institute

**Monday, 07.09.2009**

**Room 3**

**17:00–17:30**

Energy flow and radiation of linearized acoustic-gravity waves and propagation of boundary waves in a gravitationally stratified isothermal compressible inviscid semi-infinite fluid from a time-varying bottom boundary are investigated in the frequency-wavenumber domain. Impedance  $Z$ , the ratio of the bottom vertical displacement to the fluid pressure above it, is a function of the frequency and horizontal wavenumber  $(\omega, k)$  of the bottom boundary undulation. The amplitude and phase of  $Z$ , at the bottom boundary divide the  $(\omega, k)$  coordinates into wave-type regimes. In contrast to the pure acoustic or gravity wave case, the phase of  $Z$  is continuous, but changes quickly across the regime boundaries between the propagating waves and trapped waves at the bottom, except for the Lamb wave branch along which the amplitude is infinite and across which the phase jumps by  $\pi$ . The phase of  $Z$  determines the efficiency of the work against the fluid by the deforming bottom boundary, showing reduced upward wave-energy flow from the bottom near the regime boundaries in which the phase of  $Z$  approaches  $\pi/2$ . For precise modeling of pressure waves and the energy flow of acoustic and gravity waves in the fluid originating from a time-dependent bottom-surface deformation with an apparent phase velocity comparable to the speed of sound in the fluid, it is necessary to include the dependency on  $(\omega, k)$  of impedance  $Z$ .

## On the destroying of atmospheric vortices due to resonant sound scattering

V. Kopyev, I. Belyaev

TsAGI, Moscow Branch

**Monday, 07.09.2009**

**Room 3**

**17:30–18:00**

The well-known two-dimensional problem of sound scattering by a Rankine vortex at small Mach number is considered. Despite its long history, the solutions obtained by many authors still are not free from serious objections. The common approach to the problem consists in the transformation of governing equations to the d'Alembert equation with right-hand part. It was recently shown [1] that due to the slow decay of the mean velocity field at infinity the convective equation with nonuniform coefficients instead of the d'Alembert equation should be considered, and the incident wave should be excited by a point source placed at a large but finite distance from the vortex instead of specifying an incident plane wave (which is not a solution of the governing equations). We use the new formulation to obtain the correct solution for the problem of resonant sound scattering and the result is found that unifies earlier solutions in the literature [2,3].

Sound scattering may cause resonant excitation of oscillations, and the scattered field (re-emission by excited degrees of freedom) may increase by many times. In this case, eigenfrequencies of the system become poles of the scattering amplitude. Thus, resonant scattering results in the faster decaying of the vortex. Therefore this physical process can be the mechanism being looked for atmospheric vortex destroying. Note that the resonant frequency could occur in infrasound region. The conditions, under which it is reasonable to assume that the resonant sound scattering can be an effective tool in destroying the atmospheric vortices is considered.

The work was partly supported by the Russian Foundation for Basic Research under grant 08-01-00697.

### Dielectrophoresis Driven by Acoustic Pulses on Piezoelectric Substrates

M. Berezin, V. Mozhaev, A. Zyryanova  
Moscow State University, Faculty of Physics,

Traveling-wave dielectrophoresis (TWD) is a promising method for manipulating micro- and nanoparticles, as well as biological cells. A quasi-wave distribution of electric field instead of true waves is used in the common TWD scheme. Such a distribution is produced near an electrode array with individual phase shifts of alternating voltage at every electrode. An interesting feature of TWD is a backward movement of single particles observed sometimes in experiments and numerical simulations (Masuda, 1987; Gartshtein, 1999). In spite of the attempts to give various interpretations of the backward transport (Schmidlin, 1995), this puzzling property remains incompletely understood. The idea of implementation of TWD driven by true wave, like surface acoustic waves (SAW) propagating on piezoelectric substrates, was suggested by two of us in 2004. The consideration of pure harmonic spatial wave field distribution, natural for the acoustic drive, simplifies the theory and makes it easier to interpret and to explain the particle backward transport. The aim of the present study is to develop an analytical 2D theory of pulsed TWD transport and to present the results of numerical simulation in the case of pure harmonic in space, but limited in time, wave drive of the acoustic type. We are looking for the solution to 2D equations of motion describing the movement of a small particle placed in a fluid near the surface of piezoelectric substrate under the action of electric fields accompanying SAW pulses propagating in the substrate. On the basis of analytical solution obtained which is free of numerical errors, pointed out previously as a pseudo-reason for the backward transport, we conclude that the single parameter controlling the direction of particle transport in TWD with no collisions is the carrier-wave phase with respect to the leading edge of wave pulses. Collisions of particles with the substrate are computationally revealed as a new reason for the backward TWD transport.

**Monday, 07.09.2009**

**Room 4**

**14:00–14:30**

### Modeling of edge support of a glass pane for simulating sound transmission loss

T. Sakuma, Y. Yasuda, K. Egawa  
University of Tokyo, Kashiwa

**Monday, 07.09.2009**

**Room 4**

**14:30–15:00**

Sound transmission loss of a glass pane strongly depends on the edge support condition in addition to its properties. For building windows, putty and silicone are often used around the glass pane as sealing material, which brings some amplifying effect. In this paper, modeling of the edge support is investigated for numerical simulation of sound transmission loss, where vibro-acoustic coupling analysis is done with structural FEM and acoustic BEM. Firstly, a simple edge model assuming translational and rotational springs with damping factors is theoretically discussed, formulating the energy absorption coefficient of the edge in the semi-infinite vibration field. Through a parametric study concerning the properties of glass pane and sealing material, it is seen that the translational spring is dominant in most cases, and in addition, a multi-mass-spring system is necessary at higher frequencies. Next, based on the edge model, numerical simulation of sound transmission loss is performed for some combinations of glass panes and sealing materials. Calculated results of random-incidence sound reduction index are compared with theoretical and measured results, and the validity of the edge model is discussed.

### Numerical computation of acoustic streaming in annular resonators

A. Boufermel, N. Joly, P. Lotton  
Laboratoire d'Acoustique de l'Université du Maine, Le Mans

**Monday, 07.09.2009**

**Room 4**

**15:00–15:30**

The acoustic streaming, or acoustic wind, is a slow mean fluid flow created by an acoustic wave, stationary or propagative. The streaming is excited inside the viscous and thermal boundary layers of the thermo-viscous fluid, due to momentum transfer by nonlinear processes. An accurate modeling of such non-linear phenomena is required in thermo-acoustic devices, because their performance is limited by the convective heat transfer of the streaming. Acoustic streaming may also have applications in microfluidics for pumping fluids in microchannels. The formulation used is based on the mass and momentum conservation equations for the streaming, and the energy conservation equation for heat transfer, where the variables are chosen such that usual numerical methods can be used for the streaming flow. The governing equations for streaming are presented as a standard form of weak compressible flow based upon the velocity of mass transport vector, where the driving forces are set in the right-hand side. The nonlinear effects of acoustics are considered as averaged exciting sources for the streaming

flow. The Finite Element computation of the unsteady streaming flow is presented for a propagative wave in annular resonator. The transfer of momentum and the time evolution for streaming flow profiles are illustrated, and the effect of the curvature of the waveguide is discussed.

### The optimal entropy noise modelling in the airport vicinity

K. Kazhan, V. Tokarev

National Aviation University, Kiev

An approach for maximizing airport noise capacity, based on entropy method with the use of analytical models, was proposed in the investigation. An airport is considered as the complex system, which exists and develops according to constraints, including operational and noise ones. The entropy noise model also includes possibility of implementation of noise abatement procedures for increasing noise capacity (such as flight route optimization in the airport vicinity; continuous descent approaches, etc.) The probable distribution of aircraft  $T_{kij}$  for  $l$  points of noise control is defined by the relative extremum of Lagrangian functions with additional constraints:

$$T_{kij} = A_i B_j Q_l D_j \exp(-\sum_l \beta_l P_{kij})$$

It should be noted that:

$P_{kij} = T_0^{-1} (100.1L_{(kij)} - 0.1Leq_{(l)})$  where  $T_0 <sup></sup>$  - time period;

$L_{(kij)}$  - noise level for aircraft type  $i$  on the route  $j$  and operational regime  $k$  in critical zone  $l$ ;  $Leq_{(l)}$  - normative noise level in critical zone  $l$ ; the multipliers  $\beta_l$  are Lagrangians defined from the initial restrictions;  $A_i$  and  $B_j$  - are balancing multipliers.

The method, algorithm and application software were obtained for short- and long-term forecasting of aircraft noise for operational aircraft fleet and were verified on the base of operational data of the civil aviation international airport Borispol (Ukraine).

The results of short-term forecasting show that optimization of aircraft distribution of the aircraft among the routes allows to reduce equivalent noise to the normative levels in control points without application of noise abatement procedures for day and night time: increase noise airport capacity on 9% (day time) and 13% (night time). Such aspects as perspective aircraft fleet and maximum airport capacity were analyzed during long-term forecasting.

The proposed approach allows to: estimate the airport capacity, taking into account noise requirements; minimize noise impact on the airport vicinity; forecast daily and monthly flights schedule; and make long-term forecasting prediction.

**Monday, 07.09.2009**

**Room 4**

**15:30–16:00**

## Theoretical corrections to the sediment attenuation inferred via geoacoustic inversion from long range shallow water transmission data

A. Pierce, W. Carey  
Boston University

Monday, 07.09.2009  
Room 5  
14:00–14:30

In shallow water propagation, the decrease in the undulating amplitude with horizontal range is primarily due to the sediment's intrinsic attenuation. A indirect method uses a known source and measures the acoustic pressure at a given depth along a horizontal distance extending out to great ranges. Such data judiciously considered yields an estimate of the intrinsic attenuation of the sediment. What typically results from measurements at different frequencies is a power law, where the sediment intrinsic attenuation  $\alpha$  in, say, decibels per meter, varies with the frequency  $f$  raised to some power  $n$ . The reported values of  $n$  are always somewhat less than 2 and distinctly higher than 1 [Carey et al., JASA. November 2008]. Theory predicts that the exponent is 2.0. The explanation [Carey, Evans, Collis, and Piercel is that all such geoacoustic inversions have proceeded with the assumption that the sediment bottom can be modeled as a fluid. The premise is that, if the possibility of shear waves in the bottom were properly taken into account, then the sequence of geoacoustic inversions would yield 2.0. Specific numerical calculations based on a model of the bottom as being an elastic solid tend to support this premise.

The present paper reexamines the premise making use of an appropriate perturbation theory, whereby the first approximation to the bottom is a fluid, and where shear enters in as a perturbation. The disturbance in the bottom is represented as a sum of compressional (acoustic) and shear wave fields, which are weakly coupled through terms that arise because of gradients of environmental parameters with depth. Both shear and compressional waves are generated at the sediment-water interface, but the shear waves are much weaker.

The details of this perturbation theory provide strong support for the supposition that the existing long range propagation data is consistent with an attenuation in the bottom that varies as the square of the frequency.

### Full-waveform elastic modeling and analysis of multi-component ocean bottom seismic data in shallow-water environment of the Arabian Gulf

Y. Sun<sup>1</sup>, K. Berteussen<sup>2</sup>

<sup>1</sup>Texas A&M University, USA, <sup>2</sup>The Petroleum Institute, Abu Dhabi, United Arab Emirates

The Arabian Gulf where some of the world's most important oil and gas fields reside has an average water depth about 5-15 m. Shallow water environment typical of the Arabian Gulf presents unique challenges and opportunities to multi-component ocean bottom cable (OBC) seismic data acquisition, processing and analysis. Besides strong surface waves (e.g. Scholte waves) and multiples, conversion of acoustic energy in the water column to shear wave energy in the seabed is substantially enhanced when the sea bottom is hard as in the coral reef area. Full-waveform elastic modeling of a 2D 4-Component (4C) OBC data set acquired in the Arabian Gulf suggests that acquisition of 4C OBC seismic data should consider long time delay between shots, small spacing interval and other parameter modifications so that severe signal contamination and spatial aliasing can be avoided. Importantly, a combination of shallow water depth and hard bottom can result in efficient conversion of acoustic energy to downward point-source-like shear-wave energy at the water/seabed interface that is more than thousand times stronger than in deep-water environments. Further analysis of Scholte wave characteristics reveals the variation of the elastic properties of seabed in the studied area as confirmed by sonar data and direct observation.

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### Computational Grid Design for Efficient 3D PE Modelling

M. Austin<sup>1,2</sup>, R. Chapman<sup>1</sup>, D. Hannay<sup>2</sup>

<sup>1</sup>School of Earth and Ocean Science, University of Victoria, <sup>2</sup>JASCO Research Ltd, Victoria BC

One class of very accurate computer models that can be used to predict underwater acoustic fields is based on solutions of the parabolic form of the acoustic wave equation.

The spatial variability of the ocean and seafloor properties is fully accounted for using three-dimensional (3D) parabolic equation (PE) models that contain differential operators in both depth and azimuth. These 3D solutions are very computationally intensive, but strategic definition of the model grid can save computation time. A 3D PE model (MONM3D) has been developed that incorporates techniques that reduce the required number of model grid points. The concept of tessellation is used to optimize the radial grid density as a function of range, reducing the required number of grid points in the horizontal.

The model marches the solution out in range along several radial propagati

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on paths emanating from a source position. Since the arc-length separation between radial paths increases as does the range away from the source, a greater number of radial paths are required at longer ranges to maintain a sufficient grid density to accurately sample the field. Using a fixed number of radial propagation paths either oversamples the field close to the source, or under-samples the field at long ranges. Tessellation, as implemented in MONM3D, allows the number of radial paths in the model grid to depend on range from the source. In addition, the model incorporates a higher-order azimuthal operator which allows a greater radial separation and reduces the required number of radial propagation paths. The efficiency and accuracy of the MONM3D model will be presented by demonstration of a test case.

### On the significance of Scholte waves in long-range propagation in a shallow-water wedge

P. Borejko

Vienna University of Technology

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The acoustic fields may be determined from the asymptotic solutions of wave equations at high frequencies, the theory known as geometrical acoustics or ray acoustics. Note that the fields may differ significantly from the geometrical-acoustics approximation if either the source or receiver is near the interface (in acoustic wavelengths) or if the ray path is near the critical angle. It is for this reason that the full wave-theory solutions (the general solutions) must be considered, including those components of the field that vanish with increasing frequency. Without the application of asymptotic analysis the general solutions for the fields may be derived by applying the theory of generalized ray which involves construction of integral representations for such solutions. In the literature they are known as ray integrals, but they are quite different from ray integrals of the geometrical acoustics. In this paper, we investigate acoustic propagation from a point source in a wedge of fluid supported by an elastic solid, a subject of interest in shallow water acoustics. Although others tackled this problem, the effect of a sloping slow-speed elastic bottom on the field within the wedge was not considered in detail. We thus concentrate on the interpretation of this effect in terms of the generalized ray theory and, in particular, our emphasis is on the role that the Scholte waves play in the field. The theory is applied to compute in a shallow-water wedge the time records of the pressure received at distances which are much greater than the fluid depth at the source location. These records exhibit three phases: the early time response composed of the critically refracted longitudinal waves, the intermediate time response composed of the multi-reflected spherical waves, and the late time response composed of the Scholte waves which is the most prominent phase in the records even at the receivers that are not near the sloping bottom.

### A Robust Numerical Backscattering Model

C. Chen<sup>1</sup>, D. Lee<sup>2</sup>

<sup>1</sup>National Taiwan University, Taipei, <sup>2</sup>2603 Ayala Way, The Villages, FL

This paper presents a robust numerical method to compute the acoustic backscattering field in the ocean.

We first introduce the formulation of the problem into a numerical marching scheme, then present some stable numerical methods to obtain the solution computationally. We also demonstrate the application of a family of stable numerical methods, such as the Generalized Adams Methods (GABM), to solve the representative wave equation, and evaluate the results.

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### Basin scale computation of vertical and horizontal directivity characteristics of underwater ambient noise, due to shipping and wind

R. Evans, W. Carey

Boston University

Two methods are described for simulating the directivity of underwater ambient noise, at low frequency. Both methods are based on the use of a parabolic equation propagation code on a radial-by-radial basis to compute the noise field. The directional characteristics are estimated with a spatial plane-wave transformation. The noise field at the vertical array from many near surface sources of sound can be obtained by starting at a large range and marching toward the array using a parabolic equation propagation model. Each near surface source is added to the acoustic field as it is encountered. Alternatively the array can be treated as a set of sources. The field at the near surface receivers from each array source is obtained by starting at the array location and marching out in range. These near surface fields may be superimposed and the use of reciprocity yields the noise field at the vertical array. The latter method has the advantage of not having to specify the phase and amplitude of each of the near surface sources during calculations. The second method is used to demonstrate the calculation of vertical and horizontal directivity of underwater noise for an ocean basin with a radius of 1000 km. The parabolic equation calculations are based on environmental databases of bathymetry and sound speed profiles. The geo-acoustic characteristics of the ocean bottom are chosen to represent two extremes: fast or slow. Vertical directivity of shipping noise at 50 Hz is computed based on a database of historical shipping densities and associated source levels. Wind noise vertical directivity at 200 Hz is based on wind speed data and computed source level densities. Horizontal directivity is calculated, in both cases, by displaying vertical directivity on a radial-by-radial basis.

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## Robust and easy to implement ocean acoustic tomography scheme

V. Burov, S. Sergeev, A. Shurup

Moscow State University

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Nowadays the practical implementation of ocean acoustic tomography is greatly restricted by the technical difficulties such as deployment of long vertical arrays, complexity of precise determination of hydrophones positions in space, problems of low frequency sound radiation and others. All these aspects considerably increase the cost of experiments and complicate its realization.

The new scheme of ocean acoustics tomography was developed in order to overcome these difficulties. The scheme involves:

- 1) Different approaches to the parametric description of the ocean inhomogeneities of both refraction and kinetic types. In addition to bases commonly used in oceanological problems a new basis, presumably, more convenient for solving tomographic problems is considered. The abilities of different bases to reconstruct the ocean inhomogeneities are compared with the use of special theoretical approach. The quality of reconstruction is investigated.
- 2) The realization of passive ocean tomography based on the relation between the Green's function and ambient noise cross-correlation is discussed;
- 3) The mode structure of acoustic field is determined from the cross-correlation matrix of the noise field received by the hydrophones of short vertical arrays bent by the ocean currents and covering only the part of the sound channel. The proposed algorithm allows a compensation of antenna declination from the vertical profile and takes into account of the finite length of antenna aperture, that ordinary takes place in ocean experiments.
- 4) The positions of the vertical antenna hydrophones are unknown (except the sea surface element) due to the underwater currents. The proposed scheme solves that problem due to the measuring signal arrive angles distortions. Corresponding questions such as an accumulation time are discussed. The scheme is illustrated by the computer reconstruction of the ocean combined (both refractive and velocity) inhomogeneities.

Non-orthogonal Perfectly Matched Layers for time-harmonic scattering problems

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During the last two decades, Perfectly Matched Layer (PML) technique has demonstrated to be an accurate numerical tool for dealing with numerical simulation of wave motion problems in unbounded domains. Most of the work has been focused on the construction of PML models in different spatial coordinate systems and for several physical models involving Cartesian, spherical or cylindrical system of coordinates.

In the framework of time-harmonic scattering problems, since a local orthogonal system of coordinates can be defined from any convex obstacle, a PML model can be derived by using a complex stretching based on these orthogonal coordinates. Moreover theoretical results on the convergence of general orthogonal PML models (see Lassas-Sommersalo 2001) can be stated in convex geometries. However these results cannot be extended to scattering problems where the obstacle is not convex, and moreover the potential utility of non-orthogonal PML technique in non-convex domains has been remained improperly answered.

The main goal of this work focuses on the construction of a non-orthogonal PML model in Cartesian and radial coordinates for the Helmholtz equation, analysing the numerical advantages and drawbacks, and their theoretical restrictions to obtain the existence and uniqueness of solution for the coupled physical-PML problem and the required assumptions to recover theoretical convergence results similar to those proved for the standard orthogonal case.

To illustrate the numerical performance of the non-orthogonal PML method, we have used two time-harmonic problems (a closed waveguide and a star-shaped scattering problem). Moreover, a comparison of the non-orthogonal PML and the standard orthogonal PML technique has been done, analyzing the numerical error and the computational cost of both techniques. Additionally, a numerical algebra application based on the non-orthogonal PML is sketched to construct a preconditioner for high-frequency scattering problems.

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## Global Identification of Admittance Boundary Conditions for Closed Three-Dimensional Spaces using a FE-based Inverse Algorithm

R. Anderssohn, S. Marburg, H.-J. Hardtke  
Technische Universität Dresden

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Knowledge about damping and elasticity of walls enclosing any kind of spaces is highly significant to determine, predict and optimize acoustical behavior. These properties may be quantified in terms of the acoustical boundary impedance or boundary admittance, respectively. The authors aim to approximate a decent number of discrete admittance values distributed on the entire wall enclosing cavities with arbitrary geometries. In order to achieve this, sound pressure measurements are simulated and a FEM-based inverse algorithm was set up. The 3D-FEM is based on the Helmholtz equation together with the Robin boundary condition. The inverse problem leads to a non-linear optimization process. Results will be shown for three-dimensional numerical examples and discussed with respect to accuracy, efficiency and practicability.

## Coupling discontinuous Galerkin methods and retarded potentials for transient wave propagation on unbounded domains

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In many applications in engineering we are faced to the simulation of wave propagation on locally heterogeneous unbounded media. This arises the important question of artificially bounding the computational domain without introducing spurious reflections. In this work we propose to combine a discretization based on a discontinuous Galerkin method in space and explicit finite differences in time on a interior (bounded and eventually heterogeneous) domain with a Galerkin retarded potential method to account the unbounded nature of the whole domain. This approach has the main advantage of not introducing any modeling error, being able to handle non convex domains for example. The coupling formula enforces a discrete energy identity (that mimics the classical energy conservation associated to the wave equation) ensuring the stability under the usual CFL condition on the interior domain. The global discretization allows to use a surface mesh that is non-conforming with the volume mesh and a smaller time step in the interior domain, yielding to quasi-optimal discretization parameters for both methods. The aliasing phenomena introduced by the local time stepping is reduced by a post-processing by averaging in time which provides a stable and second order consistent coupling algorithm. The method has been implemented (using Sledge++ DG library and Sonate retarded

potential code) and used to solve the 3D scalar wave equation on unbounded (convex and non convex) domains. The numerical results show the feasibility of the whole discretization procedure. The method can be extended to symmetric hyperbolic systems in the sense of Friedrichs including, for example, linearized Euler equations. The authors would like to acknowledge AIRBUS support under contract ADNUMO.

### Spurious modes in mixed finite element formulation for Galbrun equation

H. Weisbecker, R. Rodriguez, S. Marburg  
Technische Universität Dresden

Sound propagation in moving media can be described by Galbrun's equation for the oscillating component of the fluid displacement. A displacement based finite element formulation using standard Lagrangian elements produces spurious modes and is not feasible for numerical solution. Recent investigations in the literature have shown that the use of Mini elements and Taylor-Hood elements suppress the effect of spurious modes. Herein, the quadratic eigenvalue problem for the mixed formulation in 2d using Mini elements is set up and solved in a linearized form (state space formulation). The authors show that spurious modes are still appearing when using Mini elements for the mixed formulation with unknowns for displacement and pressure. In the non-damped case, however, these spurious modes can clearly be identified and separated from physical modes. Examples encompass the one-dimensional duct problem and an annular duct.

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### Computational Issues of Seismic Wave Modelling

G. Seriani

OGS, Sgonico, Trieste

The wave phenomena that are generated when wavefields propagate in complex heterogeneous media are almost impossible to investigate using only a theoretical approach. It is therefore necessary to use numerical simulations, which should be able to take into account all the physical parameters specific to the problem under investigation. Seismic wave modelling is a relatively young field of investigation, not yet widely used for solving practical problems as they require 3D simulations that, in the recent past, were almost unfeasible.

Nowadays, they can be done at a reasonable computational cost and they will be even more practicable in the near future because of continuous increase of computing power and the lowering of machine costs. The main applications are in seismology, in earthquake engineering, in engineering

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seismology and in exploration geophysics. The complexity of the Earth models that must be considered pose severe modelling constraints from the point of view of both algorithms and implementation. This overview aims to present the main issues that make the seismic wave modelling a difficult task and to discuss the various aspects and the conflicting constraints that must be taken into account to obtain correct solutions and to implement efficient computing codes.

### Simulation of seismic wave propagation in a complex 3D geological model based upon an unstructured MPI spectral-element method: a non-blocking communication strategy

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In the context of seismic exploration, it is of crucial importance to develop efficient numerical tools to model seismic wave propagation in complex structures with great accuracy at scales of at least tens of kilometers. For this purpose, the seismic wave equation can be solved numerically in heterogeneous media using different methods, for instance the finite-difference technique or the boundary integral technique. In the last decade, the spectral-element method, which is more accurate and flexible, has been used extensively in the context of regional or global seismology. It is a high-order variational method that retains the ability of finite elements to handle complicated geometries while keeping the exponential convergence rate of spectral methods. Complex topographies, dipping or curved interfaces, interface and surface waves, and distorted meshes can be easily taken into account.

The formulation of the SEM based on the displacement vector and on Gauss-Lobatto-Legendre numerical integration which is implemented in our software package called SPECSEM has the property to retain a diagonal mass matrix and is therefore easier to implement than classical low-order finite-element methods.

Applications of the SEM to elastodynamics have shown that high accuracy (i.e., small numerical dispersion) is obtained. The time discretization is an explicit conditionally-stable second-order centered finite-difference scheme.

Here, our goal is to be able to propagate seismic waves resulting from an earthquake in complex 3D geological models. For that purpose we create and mesh both homogeneous and fractured geological models using the CUBIT mesh generator developed at Sandia (USA). The unstructured meshes are partitioned using the SCOTCH software package in order to minimize edge cuts and therefore optimize load balancing in our parallel blocking or non-blocking MPI implementations. We show the results of several simulations and illustrate the fact that they exhibit good scaling.

A Discontinuous Galerkin method for 3D elastic wave propagation :  
analysis and applications

N. Glinsky-Olivier<sup>1</sup>, S. Delcourte<sup>2</sup>, L. Fezoui<sup>1</sup>

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We are interested in the simulation of P-SV wave propagation in an isotropic, linearly elastic medium by solving the 3D velocity-stress formulation of the elastodynamic equations. For the discretization of this system, we focus on Discontinuous Galerkin methods which are finite element methods allowing discontinuities at the interfaces introduced via numerical fluxes as for the finite volume methods. The extension to higher order in space is realized by polynomial functions, locally on tetrahedra, which do not necessitate the inversion of a global mass matrix since an explicit scheme in time is used.

Moreover the interpolation order may be different in two neighbouring elements making the DG method well adapted to h-p strategy. The method is suitable for complex meshes, highly locally refined meshes and even non conforming finite element ones. Finally, DG methods are easily parallelized. We propose here a method, based on centered fluxes through the interfaces and a leap-frog time-discretization, which leads to a non-dissipative combination. The extension to higher order in space is realized by Lagrange interpolants ; the domain is discretized in tetrahedra.

In order to study mathematical properties of this method, two changes of variables are introduced leading to a symmetrical pseudo-conservative formulation of the system.

Thanks to this formulation, we are able to realize an analysis of the 3D scheme by taking into account the boundary conditions of free surface and absorbing conditions: energy preservation, stability result (CFL condition) and convergence analysis. Some numerical illustrations of these theoretical results will be presented especially the propagation of an eigenmode in a 3D domain. More realistic test cases of waves generated by point sources in homogeneous and heterogeneous media will be also detailed.

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## Data filtering for array imaging in heavy clutter

C. Tsogka<sup>1</sup>, L. Borcea<sup>2</sup>, G. Papanicolaou<sup>3</sup>, F. Gonzalez del Cueto<sup>2</sup>

<sup>1</sup>IACM-FORTH, Heraklion, <sup>2</sup>Rice University, Houston, <sup>3</sup>Stanford University

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We consider an array imaging problem where, by sending probing signals from sources at the array and recording the scattered echoes, we want to estimate the compact support,  $S$ , of small, distributed or extended reflectors, embedded in heavy cluttered media. By clutter, we mean inhomogeneities in the speed of propagation of the waves which are not known in detail and we model as a random process. The clutter is characterized as heavy when it produces strong reflections that overwhelm the coherent scattered field from the reflector we wish to image. Such heavy cluttered media arise naturally in applications such as exploration geophysics, nondestructive evaluation of materials, foliage penetrating radar, etc.

To make coherent imaging possible in heavy clutter we propose to filter the unwanted echoes due to the cluttered medium prior to imaging. This is a challenging problem given that we have no prior information neither on  $S$  nor on the cluttered medium. To address this question, we present two filtering approaches:

(1) The first approach distinguishes the echoes due to the reflector we wish to image from reflections due to layered interfaces using as tool the dependence of travel times on the offset between sources and receivers in the array. This filter which can be applied only to layered media annihilates single (primary) reflections at isolated, strong (layered) interfaces in a medium, as well as, the incoherent backscattered field from random layering.

(2) The second filtering approach is more general and can be applied to arbitrary cluttered media. The main idea is to identify the time windows that contain the coherent echoes from  $S$ , by doing a spectral decomposition of the local cosine (LC) transform of the response matrix recorded at the array. The two approaches will be presented and numerical results will illustrate their efficiency and robustness.

Efficient Boundary Element Method for wave propagation problems

M. Schanz

TU Graz, Institute of Applied Mechanics

Wave propagation phenomena occur in reality often in semi-infinite regions. It is well known that such problems can be handled well with the Boundary Element Method (BEM). Focusing on wave propagation problems a formulation in time domain is preferable. But, it is also well known that the BEM with its dense matrices becomes prohibitive with respect to storage and computing time. Several approaches have been developed to overcome these drawbacks. Approaches, such as fast multipole gain their efficiency basically from an analytic kernel approximation. The main difficulty of these methods is that the so called degenerate kernel has to be known explicitly.

Hence, the present work focuses on a purely algebraic approach, the Adaptive Cross Approximation (ACA). This technique has been applied successfully to elliptic problems. That is why the time discretisation is done with the Convolution Quadrature Method. With a proper reformulation of this technique (initially published by [1]) uncoupled elliptic problems in Laplace domain have to be tackled and the time dependent solution is obtained straight forward.

The elliptic problems in Laplace domain allow the usage of the normal procedure to speed up the BEM with ACA. By means of a geometrical clustering and a reliable admissibility condition, first, a so called hierarchical matrix structure is set up. Then each admissible block can be represented by a low-rank approximation if care is taken to sort each degree of freedom in case of vectorial problems. This technique can be easily applied to different physical problems as, e.g., acoustics, elasto-, visco- or poroelasticity, because ACA requires no analytical kernel expansion.

[1] Banjai, L.; Sauter, S.: Rapid Solution of the Wave Equation in Unbounded Domains. *J. Numer. Anal., SIAM*, (to appear), 2009.

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## An efficient Wave Based Method for three-dimensional acoustic scattering and transmission problems

B. Bergen, D. Vandepitte, W. Desmet

K.U.Leuven, Department of Mechanical Engineering, Heverlee

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Element based methods, such as the finite element method and the boundary element method, are most commonly applied for the numerical analysis of (vibro-)acoustic problems. These methods use approximating polynomial shape functions to describe the dynamic response variables. Due to the associated pollution error, the element discretization must be refined with increasing frequency. In this way, the required computational resources limit the use of these element based methods to applications in the low-frequency range.

The wave based method (WBM), which is based on an indirect Trefftz approach, is an alternative deterministic prediction method. It applies wave functions which are exact solutions of the governing differential equation to describe the dynamic field variables. As a result, a dense element discretization is no longer required, yielding a smaller numerical system. The enhanced computational efficiency of the WBM as compared to the element based methods has been shown for the harmonic analysis of both two- and three-dimensional bounded and two-dimensional unbounded acoustic problems. This paper presents an extension of the WBM for the analysis of three-dimensional acoustic problems in unbounded (scattering) and semi-unbounded (scattering and transmission) environments. The problem domain is partitioned into a bounded and an unbounded part by the introduction of a truncation sphere. The bounded part of the problem, inside the sphere, is modelled using existing WBM wave sets. In this paper, a suitable wave function set is proposed for the modelling of the unbounded part exterior to the truncation sphere. These functions are chosen to satisfy both the governing Helmholtz equation and the Sommerfeld radiation condition. In the case of a semi-unbounded problem, the wave functions will additionally satisfy the zero normal velocity condition on the rigid baffle plane. The accuracy and efficiency of the method is evaluated in some numerical examples.

Producing expressive music by training and retargeting acoustic parameter

S. Lui

Hong Kong University of Science and Technology

The use of artificial intelligence methods as learning tools has become a hot topic in recent years, especially for areas requiring large amounts of empirical data such as musicology. Recent research has shown that it is possible to represent musical style by appropriate numerical parameters, and identify different music styles with inductive machines. It is also observed that the music style parameters of a performer are locally and globally related to each other. Performers tend to perform music sections and motives of similar shapes in similar ways, where music sections and motives can be identified by an automatic phrasing algorithm. Based on these results, an experiment is proposed for producing expressive music from raw quantized music files using machine learning methods like Support Vector Machines (SVMs). Experimental results show that it is possible to induce performance style by using the acoustic music parameters extracted from the audio recordings of their real performance.

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Infrasound monitoring for the study of the atmospheric dynamics I & II

E. Blanc<sup>1</sup>, A. Le Pichon<sup>1</sup>, L. Ceranna<sup>2</sup>, T. Farges<sup>1</sup>

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The recent development of the Infrasound International Monitoring System for the CTBT (Comprehensive nuclear Test Ban Treaty) verification, represents a powerful tool to measure permanently, at a global scale and over large periods of time, the characteristics of the waves and dynamics of the atmosphere in relation with the climate. The first way is to monitor quasi continuous infrasound sources such as ocean swells or volcanic eruptions to determine the fluctuations of the stratosphere and mesosphere in relation with the activity of planetary waves and large scale polar disturbances such as Vortex Intensification or Sudden Stratospheric Warming. The second way is to monitor gravity waves which are observed in the lower frequency range of the infrasound data. Large scale waves, mainly produced in tropical regions, influence the mean circulation of the middle atmosphere by transporting moment and energy from tropical to polar regions with a possible role on tropospheric climate. This paper demonstrates through different examples the potential of the network to observe these waves as well as changes in the atmospheric wave guide in relation with atmospheric parameters. As the network will provide long duration observations, it is suggested to use them to study the atmosphere in relation with the climate evolution.

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Room 3

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## The IMS Infrasound Network: detections of man-made and natural events around the world and contribution of the Network on geophysical hazard monitoring

P. Campus

CTBTO, IMS/ED/AM, Vienna

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One of the biggest challenges faced when the International Monitoring System (IMS) Network of the Comprehensive Nuclear-Test-Ban Treaty Organization (CTBTO) was designed consisted in the construction of an Infrasound Network comprising 60 stations: in fact, ten years ago, none of these 60 infrasound stations existed. Since then, a significant effort has been made to establish the Infrasound Network, which now counts more than 68% of its stations operational. The increased number of stations, located all around the world, has permitted to detect several types of events, both man-made and natural, in very different geographical areas, opening the way to a broader analysis of the performance of the Infrasound Network. Beside the main mandate of the CTBT IMS Infrasound Network, data from this network could play an important role in a wide variety of international geophysical hazard warning systems, ranging from the identification of potential damage from shallow earthquakes, landslides and avalanches in remote areas to the monitoring of global warming and global volcanic activity. A number of examples of events detected by the IMS Infrasound Network is presented.

### Passive acoustic remote sensing with infrasound

L. Evers

KNMI, De Bilt

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Infrasound can travel over large distances, both in altitude and laterally, because of its low frequency contents which hardly attenuates. The infrasonic recordings of a repetitive explosive source, with ground truth in space and time, have been used to obtain information on the wind and temperature structure in the stratosphere. Especially, fine scale structure, not covered by atmospheric models, seems to leave a signature in the passively obtained recordings.

Not only signals can be used to probe the upper atmosphere, also the continuous background noise from interacting oceanic waves contains information. These so-called microbaroms are observed all over the world, for example from the Atlantic and Pacific Ocean.

A change in the detectability of microbaroms can directly be coupled to changes in the upper atmospheric flow. An illustrative example are the infrasonic recordings during a Sudden Stratospheric Warming (SSW).

A SSW is a drastic feature in the stratosphere where the temperature increases with tens of degrees in just a few days. Furthermore, the wind, i.e.,

the polar vortex, suddenly slows down or even changes direction. The role of such phenomena, like a SSW, in weather and climate are currently being debated. Infrasound might serve as tool for passive remote sensing of upper atmospheric processes where currently only models and satellite observations are the main source of information.

### Effects of atmospheric turbulence on azimuths and grazing angles estimation at the long distances from explosions

S. Kulichkov

Oboukhov Institute of Atmospheric Physics RAS, Moscow

The effect of the atmospheric fine structure on the azimuth and grazing angle of infrasonic signals recorded at long distances from surface explosions is studied both theoretically and experimentally. The data on infrasonic signals recorded at a distance of about 300 km from surface explosions. There were explosions to destruction of soviet medium range missiles and 31 Finnish explosions to destruction of old weapon and armament. The experiments were carried out during different seasons. Variations in the azimuths and grazing angles of infrasonic signals are observed in all experiments. A theoretical interpretation of the experimental results is proposed on the basis of the theory of anisotropic turbulence in the atmosphere. The theoretical and experimental results are compared, and a satisfactory agreement between these results is noted.

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### Infrasonic radiation of May 13, 2008 eruption at Mt. Etna: source modelling and monitoring implication

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The period May 8-16, 2008 was characterised at Mt. Etna by intense and spectacular volcanic activity, which affected two of the four summit craters, the North East Crater, the South East Crater (hereafter NEC and SEC, respectively), and an eruptive fissure (EF) opened east of the summit area on May 13. The study of infrasonic signals allowed to follow the evolution of the eruptive processes and gave accurate information about eruption onset and location, and dynamics of the explosive processes. Three families of events with different features were detected: NEC, SEC and EF events. The first family is composed of transients lasting up to 10 seconds, characterised by frequency between 1 and 2 Hz, low values of peak-to-peak amplitude and source location constrained at NEC. The second one shows shorter duration (about 2 seconds), larger peak-to-peak amplitude and higher

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frequency. Finally, in the third one the events exhibit very short duration (about 1 second), frequencies mostly ranging between 2.5 and 4 Hz and higher peak-to-peak amplitude. The source mechanism of these events was investigated and showed different source mechanism for these events. NEC events were interpreted as due whether to resonance of fluids (magma or gas) in a conduit closed at both ends, or to Helmholtz resonator, while SEC and EF events to oscillations of Strombolian gas bubbles before they burst. Finally, the source parameters, such as bubble radius and conduit length, were constrained.

## Electrostatic Mechanism of Lightning Associated Infrasonic Pulses from Thunderclouds

V. Pasko

Penn State University

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Thunderstorms represent significant sources of infrasonic wave activity spanning a broad altitude range from the troposphere and up to the thermosphere [e.g., 1]. It has been pointed many decades ago by C. T. R. Wilson [2] that sudden reduction of the electric field inside a thundercloud immediately following a lightning discharge should produce an infrasound signature. Wilson [2] noted that the pressure within a charged cloud must be less than the pressure outside, similarly to that within a charged soap bubble. In contrast to the sudden expansion of the air along the track of a lightning flash, the sudden contraction of a large volume of air must furnish a measurable rarefaction pulse [2]. Many experimental and theoretical contributions followed these predictions (see [3] and extensive list of references therein). In the present work, a model based on linearized equations of acoustics with classical viscosity and atmospheric gravitational stratification effects is employed to study electrostatic production of 0.1–1 Hz infrasonic waves from thunderclouds, with particular emphasis on the still poorly understood initial compression phase of the observed infrasonic waveforms. It is demonstrated that a growth of charge density in thundercloud prior to lightning discharge on time scales on the order of 2 to 6 seconds, comparable to typical documented time scales of generation of charge in thunderclouds, leads to formation of a pressure reduction in thundercloud, which is always accompanied by emission of compression waves closely resembling those observed in experiments prior to arrival of a rarefaction pulse generated in accordance with the electrostatic mechanism originally proposed by Wilson [2] and further developed by Dessler [4] and Few [3].

[1] Blanc, E., *Ann. Geophys.*, 3, 673, 1985.

[2] Wilson, C. T. R., *Phil. Trans. R. Soc. London A*, 221, 73, 1920.

[3] Few, A. A., *J. Geophys. Res.*, 90, 6175, 1985.

[4] Dessler, A. J., *J. Geophys. Res.*, 78, 1889, 1973.

### Buried Object Detection/Localization using Noisy Laser Doppler Vibration Measurements

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The detection of buried objects by acoustic means is hampered by the fact that, at frequencies high enough to render a reasonable image of the object that is suitable for detection purposes, the energy is rapidly absorbed in the ground. One approach that has shown some success, is to excite the ground with a low-frequency high-energy signal, which then excites a resonance in the object, such as a mine. The ensuing vibration is capable of causing a detectable signal on the surface of the ground, which can be detected by the use of a Lased Doppler Vibrometer (LDV). Although this technique has been successfully demonstrated, there is still a need to improve the detection and localization performance. Originally, the detection technique used a sliding bandpass filter to scan the scattered LDV energy. This provides an energy map of the area scanned by the LDV, which indicates the location of the object. One drawback of the LDV approach is that it generates "speckle noise," a type of noise arising from the coherent nature of the laser beam. A more recent technique utilizes an autoregressive model of this noise, that is, the target-free data. This then leads to an inverse filter that "whitens" the noise. Upon the appearance of any target data in the signal, a whiteness test indicates a detection. This approach has demonstrated improvement over the bandpass filter approach. This paper demonstrates a further improvement over this approach by augmenting the prewhitener with a model of the mine itself. By incorporating both the whitening filter, which is in fact, a model of the noise, with a model of the mine as a resonator into a model-based processor (Kalman filter), still more improvement is obtained by both enhancing the mine signal and improving the detection performance.

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### Detection of Buried and Partially Buried Objects Using Wideband Sonar

C. Capus, Y. Pailhas, K. Brown

Heriot-Watt University, Riccarton, Edinburgh

The Ocean Systems Laboratory is developing wideband acoustic sensing methods for underwater target detection and tracking. The wideband sensors are based on bottlenose dolphin sonar, covering a frequency band from around 30kHz to 150kHz and having a frequency dependent beamwidth considerably larger than conventional imaging sonars. Using lower frequencies than typical high resolution imaging sonars provides the opportunity to interrogate partially and fully buried objects. This paper presents results from experiments to determine how the characteristic midwater wideband response of a target changes when the target comes into contact with a sediment surface and with increasing burial in the sediment. The experi-

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ments have been conducted in the OSL test tank using a range of cylinders and cable samples with two sediment types: very fine sand; coarse sand/grit mixture. At the frequencies used, we have demonstrated target detection at burial depths up to 10cm. In softer sediments, for the targets under consideration, certain features of the spectral response are well preserved and may be suitable for classification even when only the clear water responses are known in advance.

### Burial depth dependence of scattering of evanescent waves by cylinders

N. R. Cerruti, A. L. Espana, T. M. Marston, C. F. Osterhoudt, D. B. Thiessen, P. L. Marston  
Physics and Astronomy Dept., Washington State University

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For some situations evanescent acoustic waves are important in the detection of objects buried below the sea floor. Even in the absence of absorption, the local amplitude of the incident evanescent wave decays with increasing burial depth at a spatial rate that depends on the grazing angle of the source. It is possible experimentally to simulate some relevant properties with a system using immiscible liquids [IEEE J. Oceanic Eng. 33, 397-404 (2008)]. Our investigation of the scattering off of cylinders based on measurements, theoretical considerations, and computations [J. Acoust. Soc. Am. 125, 2732 (2009)] reveals that the dependence of the scattered wave on the effective burial depth of the cylinder can have an exponential spatial decay rate as much as twice that of the evanescent wave decay rate. From a generalization of reciprocity, suitable bistatic placement of the receiver should reduce the decay rate and this reduction has also been observed. [Supported by ONR.]

### Three Dimensional Finite Element Source Simulation in Elastodynamics

Y. Teng

Femarco, Inc., New York, NY

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The simulation of a concentrated non-directional point source for elastic wave propagation problems in finite element algorithm has been a very challenging subject. The simplest or the most natural way to excite the elastic medium is to apply a directional forcing function to the structure. By using an energy-sharing-nodal-points technique, we have successfully simulated the following five types concentrated line sources of:

- (1) a directional-force ;
- (2) an omni-directional ;
- (3) a single-couple-without-moment;
- (4) a single-couple-with-moment; and
- (5) a double-coupled

for the two-dimensional elastodynamic case. The use of omni-directional source has been successfully applied to study the problems of a fluid/solid coupled medium with displacements as basic variables in both fluid and solid, as well as the problems in oil exploration.

In this paper, we extend the same technique to the case of three-dimensional elastodynamic. In order to simulate an omni-directional point source at source location point  $S(0,0,0)$ ,  $S$  is splitted into eight source points  $S1(-0,-0,+0)$ ,  $S2(+0,-0,+0)$ ,  $S3(-,+0,+0)$ ,  $S4(+0,+0,+0)$ ,  $S5(-0,-0,-0)$ ,  $S6(+0,-0,-0)$ ,  $S7(-0,+0,-0)$  and  $S8(+0,+0,-0)$ , and let them reside at the same location as point  $S$ . The forcing functions, with same magnitude but different outward  $x$ -,  $y$ - and  $z$ -directions, are applied to each individual source point. The total net force at the source point  $S$  is zero. For demonstration, we use a three-dimensional whole space as a preliminary example, the spherical spreading radiation patterns of the displacement magnitude can be clearly observed in the snapshots at different time intervals when an omni-directional point source is used.

### Numerical experimentation on effectiveness of passive and reactive means on acoustic field shaping inside enclosed spaces

Ö. Demirkan, M. Çaliskan, H. Özgüven  
Middle East Technical University, Ankara

This paper demonstrates effectiveness of different methods to predict acoustic pressure inside a rectangular, rigid walled cavity in the presence of reactive and dissipative elements. Helmholtz resonators, tuned to acoustic cavity modes, are used as reactive devices. Foam layers are applied as passive means to shape the acoustic field. Several case studies are presented to demonstrate effectiveness of these alternatives. Configurations of combined passive and reactive means have been tested. Finite Element Method is used to analyze sound field inside the cavity.

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### Characterization of shear wave velocity in seafloor sediments with noise-generated seismoacoustic interface waves

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<sup>1</sup> University of Connecticut, Storrs, <sup>2</sup> Norwegian University of Science and Technology, Trondheim

Using the ambient seismic noise to extract shear wave velocity structure has been successfully conducted with the use of seismic interferometry and surface wave dispersion based on a layered earth for land seismic surveys. This study extends the approach employed in land surveys to quantitatively characterize the shear wave velocity profile in the uppermost seafloor sedimentary layers. We regard the seafloor sediments as a system, the ambient seismoacoustic noise as the stimulus, a multi-channel seismometer/geophono-

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ne array as the monitoring device, and the empirical mode decomposition (EMD) adjunct with simulated annealing algorithm as the data processing scheme. With the use of extracted dispersion relation of the interface waves generated by the ambient seismoacoustic noise in marine environment, tomographical imaging of the shear wave velocity structure of the seafloor sediments will be discussed at the presentation.

### Wavelet transform for potential field anomaly separation

Y. Xu, T. Hao, Z. Li, S. Huang.

Institute of Geology and Geophysics, CAS, Beijing

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Regional anomaly separation from superposition potential field is a primary work in potential field inversion. Numerical methods have been developed to solve this problem based on the potential field characters. Generally, regional anomalies have the great amplitude in low frequency band. The multi-scale wavelet transform can be viewed as a set of filter operators. Low or band pass wavelet filters can be used in regional anomaly separation. In this paper, five wavelet basis: Haar, Daubechies, Symlets, Coiflet and Halo wavelet are used in data analysis. The cuboid combination model is used for synthetic analysis. The wavelet filter characteristics and their decomposition results are compared to the theoretical model. The high level decomposition results with low frequency components achieve good separation results. The five wavelet basis are also used to study the regional gravity anomaly in Yellow Sea. We calculate the spectrum of all the analysis results and estimate the average depth of geologic bodies using radial spectrum. Finally, based on the depth estimation result, the Halo wavelet decomposition result is selected as regional anomaly corresponding to the gravity anomaly induced by the Moho undulation.

### Efficient impulse response prediction by finite difference method

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An impulse response measurement is often carried out by using a time stretched pulse or a maximum length sequence pulse as a source signal. In a finite-difference time-domain (FDTD) simulation, smooth time variation is desired for a source term. Thus, a time stretched pulse is adopted for FDTD. When a hard source which fixes the field value is applied to the simulation, a spurious scattering by the source node occurs in the simulation. In contrast, the source term which is represented by a volume velocity or a volume force stimulates the acoustic field through update equations. Then, the artificial scattering is absent and that type of source term is called transparent. In this paper this type of source term is adopted to carry out

simulations. The band-limited impulse response is obtained by the volume velocity source in the FDTD computation. Using an optimized compact finite difference scheme, it is shown that the impulse response with almost flat frequency spectrum is obtained by the simulation of wave propagation in free space.

### Modelling of sound waves in the Persian Gulf

M. Sadrinasab

Khorramshahr University of Marine Science and Technology, Khorramshahr

The three-dimensional variability of sound speed in the Persian Gulf is investigated. In this study, a three-dimensional hydrodynamic model (COHERENS) is employed in a fully prognostic mode to derive sound speed profiles in the Persian Gulf, an evaporation-driven inverse estuary that is governed by the import of surface water from the adjacent ocean and the export of saline bottom gulf water through the Strait of Hormuz. During spring and summer, a cyclonic overturning circulation establishes along the full length of the Gulf. During autumn and winter, this circulation breaks up into mesoscale eddies, laterally stirring most of the Gulfs surface waters. Results of the model show that sound speed in the Persian Gulf depends mainly on the temperature in the surface layer whereas the bottom layer as well as the southern part of the Gulf depends on temperature and salinity. Maximum sound speed occurs during the summer in the Persian Gulf which decreases gradually moving from the Strait of Hormuz to the north western part of the Gulf. A gradual decrease in sound speed profiles with depth was commonly observed in almost all parts of the Gulf. However, an exception occurred in the Strait of Hormuz during the winter. The results of the model are in very good agreement with previous observations.

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### Multiple diffractions by close edges applied to creeping waves in a ray-tracing simulation

M. Vermet, N. Noe

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Computation of successive edge diffractions in asymptotic methods such as ray-tracing becomes difficult when distance between edges are small compare to wavelength. Consequently it is mandatory to have asymptotic formulations for multiple diffractions robust enough to ensure continuity and convergence of acoustic pressure in case edges are fractions of wavelength apart. We studied existing formulations and selected the most suitable one for the double diffraction case. We then show that these formula are of great interest as they can be applied to the case of diffraction by curved surfaces, i.e., to model creeping waves. Our approach consists in meshing

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these curved surfaces into small planar sub-surfaces. The resulting multiple adjacent wedges problem is solved by a beam-tracing algorithm to compute the diffracted field by the original surface.

Results of the method have been validated by comparisons with an asymptotic reference solution of diffraction by curved surfaces for simple cases and exact numerical methods (boundary elements method) for more elaborated cases. Our method has been integrated into a general 3D solution handling reflection and diffraction by curved surfaces.

### Finite-difference simulation of waves' propagation within multiscale elastic media

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The efficient and accurate numerical solution of the elastic wave equations is of fundamental importance for understanding the main peculiarities of seismic wave propagation in complex media. Explicit finite difference schemes are widely used for simulation of waves propagation because of their simplicity and efficiency on structured meshes. However, in the presence of small geometric features (caverns/cracks/fractures/pores) their straightforward application leads to unrealistic claims for computer resources. Among the most urgent areas where one faces with these troubles the most important seems to be seismic waves' propagation in fractured/carbonate reservoirs. These reservoirs hold clusters of caverns conjuncted by network of fractures. Caverns and fractures are scaled within the range of 0.001 - 0.1 meters, while their clusters can be spread for hundreds meters and more. Capacity of reservoir and its hydrocarbons recovery is tightly connected with distribution of caverns and fractures because they control hydraulic flow as conductors (open fractures) or barriers (mineralized fractures). There are some solitary attempts to establish correlation of scattering energy with capacity of collector, but without of any reasonable physical justification.

The principal goal of the paper is implementation of the first step towards quantitative study of cavernous/cracked/fractured reservoirs by means of analysis of scattered seismic waves. These peculiarities are governed mainly by properties of subseismic heterogeneities. The regular way to simulate propagation of seismic waves through a multiscale medium is its upscaling/homogenization up to some effective medium.

But this approach annihilates scattered waves and does not provide desired knowledge about relation between these waves and subseismic structure of reservoirs. In order to be able to reveal this relation we apply finite-difference techniques based on grids with local refinement in space and time.

### Simulation based prediction of the sound radiation of railway wheelsets

C. Klotz<sup>1</sup>, V. Quarz<sup>1</sup>, S. Koch<sup>1</sup>, M. Beitzelschmidt<sup>1</sup>, T. Kohrs<sup>2</sup>

<sup>1</sup>TU Dresden, <sup>2</sup>Bombardier Transportation GmbH

The Project LZarG (Quiet train on real track), which is supported by the German Federal Ministry of Economics and Technology (BMWi) includes a subproject B2, which is devoted to the acoustical structural optimization of railway running gears.

Emphasis is placed on the development of a CAX- process chain in particular for the optimization of wheelsets. In addition to the modelling of the structural dynamics and the excitation mechanisms in the wheel rail system, the simulation based prediction of the radiated sound is an important element of the optimization process.

For the prognosis of the sound radiation of rail vehicles and track, the software TWINS (track wheel interaction noise software) has established itself as the reference tool for the rail industry as well as for researchers. The calculation of sound radiation for this software is based on analytic formulae for the calculation of radiation efficiencies considering simplifications of real wheelset structures, which are based on conventional wheelset shapes. Therefore TWINS is of limited use for the examination unconventional wheelset structures.

In this paper, an alternative approach is presented, which is based on structural calculations in ANSYS and subsequent application of the boundary element method for the prediction of the resulting sound radiation. For this purpose, the BEM software WAON is employed.

The different methods are explained and the effect on the predicted sound pressure or sound power is demonstrated for an example wheelset. The advantages and disadvantages of the two calculation procedures are illustrated.

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### An optimal passive control of beam vibration

V. Makarenko<sup>1</sup>, S. Marburg<sup>2</sup>, V. Tokarev<sup>1</sup>

<sup>1</sup>National Aviation University, Kiev, <sup>2</sup>Technical University Dresden

Modeling of linear vibration of isotropic beams excited with harmonic concentrated force is presented. The investigation is aimed on vibration response and noise radiation attenuation by attachment of concentrated masses to vibrating system. Beams are assumed as thin. The equation of beam transverse motion with arbitrary number of attached concentrated masses is formulated from principle of virtual work. The solution to the problem was found by application of Rayleigh-Ritz approach. The influence of point mass weight and location on eigenfrequencies of first 5 modes are described for simply supported and cantilever beam carrying concentrated masses. The investigation indicate eigenfrequencies reduction for the point

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mass location in the peaks of transverse motion of the beams. Also this takes place for the mass weight increase. An optimization was performed for reduction of beam vibration response at a single point  $x_0$  of beam and for the whole beam.

$\min LVP = 10 \lg \int_{w_{\min}}^{w_{\max}} w(x_0) w^*(x_0) dw$ , where  $w, w^*$  are displacement and its complex conjugate.

The results of optimization were attained with Genetic Algorithm. Optimization illustrates significant vibration reduction for the mass location close to the point of researcher's interest.

The vibration response and sound radiation reduction is achieved due to two effects. The first refers to the excitation influence decrease due to the nodal line shift in the position of exciting force. The second relates to the change of amplitude and dimension of the wave part, in which the point of researcher's interest is located. Both of these effects are caused by the mode shape changes.

Experimental investigations indicate satisfactory adequacy of theoretical approach. Similar investigations have been performed for vibration of composite beam possessing various fiber angles and carrying point masses. Also the mechanical behavior of the clamped plate including the effect of point mass inertia was investigated following the same procedure.

## Noise Reduction Design of Fluid-valve System in Linear Compressor using CAE

J. Lee

Noise Vibration Laboratory, Graduate School of Mechanical Engineering, Busan

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A refrigerant with high speed and pressure is blamed for noise in a refrigerator. Especially, when the refrigerant circulates in a compressor, flow-induced noise is generated due to interaction between the refrigerant and valves in the compressor. Although many experimental researches have been done to reduce this noise, no one can make a way to reduce the noise. For this reason, a computational analysis is brought to solve the problem. The system is defined as internal flow that streams in a duct, and quadrupole sound sources are defined to show an acoustic field. Applying a fluid-structure interaction analysis to problems, ADINA is used to know about dynamic behaviors of the structures. Next, the behaviors are applied as boundary condition in FLUENT to put out information of fluid. This information contains velocity on the entire node which is used to make the quadrupole sound sources in the domain. SYSNOISE, a noise analysis program, gives users the acoustic field through a BEM. In order to compose the quadrupole sound sources, spherical sound sources are arranged based on a theoretical quadrupole sound sources concept in SYSNOISE. After getting data, all computational analyses are experimentally validated.

**Nonlinear acoustic phenomena in viscous, thermally relaxing fluids: shock bifurcation and the emergence of diffusive solitons**

P. Jordan

U. S. Naval Research Laboratory, Stennis Space Center, MS

In this talk we will consider the propagation of finite-amplitude acoustic waves in fluids that exhibit both viscosity and thermal relaxation. Under the assumption that the thermal flux vector obeys the Maxwell-Cattaneo law, which is a well known generalization of Fourier's law that includes the effects of thermal inertia, we derive the weakly nonlinear equation of motion in terms of the acoustic potential. We then use singular surface theory to determine how an input signal in the form of a shock wave evolves over time, and for different values of the Mach number. Then, numerical methods are used to illustrate our analytical findings. In particular, it is shown that the shock amplitude exhibits a transcritical bifurcation; that a stable, nonzero equilibrium solution is possible; and that a Taylor shock (i.e., a diffusive soliton), in the form of a tanh profile, can emerge from the input shock wave. Finally, an application related to the kinematic-wave theory of traffic flow is noted. [Work supported by ONR/NRL funding (PE 061153N)].

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**Well Posedness and Optimization in Nonlinear Acoustics,  
with Application to High Intensity Ultrasound Focusing**

B. Kaltenbacher

University of Stuttgart, Department of Mathematics

High intensity focused ultrasound plays a role in several medical and industrial applications such as lithotripsy, thermotherapy, ultrasound cleaning or welding, and sonochemistry. Depending on the underlying excitation device, the task of appropriately steering the desired pressure distribution leads to a boundary optimal control or an optimal shape design problem. In this task, we first of all present local and global in time well-posedness and exponential decay results for the underlying partial differential equations modelling the nonlinear propagation of ultrasound. These are the Westervelt equation or the Kuznetsov equation. Based on these well-posedness results, we study well-posedness of optimization problems modelling ultrasound focusing by means of tracking type functionals for the acoustic pressure. Moreover, we derive first order necessary optimality conditions and provide sensitivities based on an adjoint technique.

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[joint work with Christian Clason, University of Graz, Irena Lasiecka, University of Virginia, Slobodan Veljovic, University of Erlangen]

## An approach to model second sound in solids

S. Bargmann  
TU Dortmund

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Usually, heat conduction in solids is based on Fourier's law which describes a diffusive process. However, in some situations the predictions according to Fourier's law fail miserably. One of these situations occurs at temperatures near absolute zero, where the phenomenon of second sound was discovered in the 20th century. Second sound refers to a wave-like heat propagation which can be found in very pure crystalline solids at cryogenic temperatures.

In this presentation, the very promising approach introduced in 1991 by Green and Naghdi is followed because it is capable of accounting thermal pulse transmission in a very logical and consistent manner. The entire theory is subdivided into three types, labeled type I, II and III. A wide range of heat flow problems can be modeled and the classical theory (type I) is fully embedded. The novelty of their approach is the introduction of the so-called thermal displacement, a field whose time derivative is the empirical temperature. The linearized version of type I is equivalent to Fourier's diffusive, parabolic heat equation. The non-classical type II exhibits the outstanding property of being non-dissipative. The resulting heat equation is hyperbolic and corresponds to the well-known wave equation. Type III is a general extension and contains type I and II as limiting cases. Both, type II and III, cope with the disadvantages of classical heat conduction and are capable of modeling the second sound phenomenon. In this presentation, a computational modelling approach for Green--Naghdi thermoelasticity is given. We suggest a discretization based on Galerkin finite elements for the spatial as well as for the temporal discretization of the equations. The coupled system of equations is solved monolithically. A consequent algorithmic elaboration and numerical implementation is derived. Finally, numerical examples are compared to the experimental results in order to underline the performance of the discretization suggested.

## Dynamics of Generalized Hydrodynamics

C. Escudero  
Consejo Superior de Investigaciones Científicas, Madrid

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The equations of continuum hydrodynamics, the Euler and Navier-Stokes equations, can be derived from the Boltzmann equation, which describes rarefied gas dynamics at the kinetic level, by means of the Chapman-Enskog expansion. This expansion assumes a small Knudsen number, which is the ratio among the mean free path of the gas molecules and the macroscopic characteristic length. As a consequence, the Navier-Stokes equations are able to successfully describe sound propagation when the frequency of a

sound wave is much higher than the collision frequency of the particles. When both frequencies become comparable, these equations give a poor account of the experimental measurements. Continuing the Chapman-Enskog expansion to higher (Burnett and supra-Burnett) orders does not improve considerably the Navier-Stokes results. A series of generalized hydrodynamic equations has been introduced in the literature along the years in order to improve the continuous description of small scale properties of fluid flow, as ultrasound propagation. We will describe some of the proposed approaches, and we will analyze the resulting equations of fluid motion. In some cases the dynamics becomes more complex than in the original fluid mechanical equations, creating unexpected effects and giving rise to new mathematical structures in the equations.

Another phenomenon that has been studied in the context of generalized hydrodynamics is heat propagation. According to Fourier's law heat transfer occurs diffusively, while some generalized hydrodynamics models propose a different sort of propagation. In order to avoid infinite speed of disturbances, heat transfer is considered as a wave phenomenon similar to sound propagation in air, which leads to denominate it as 'second sound'. Some generalized hydrodynamical models attempt to describe second sound as a purely classical effect.

#### An analogue to shock formation of internal bore slope increases.

A. Warn-Varnas<sup>1</sup>, S. Chin-Bing<sup>1</sup>, S. Piacsek<sup>1</sup>, K. Lamb<sup>2</sup>

<sup>1</sup>Naval Research Laboratory, Stennis Space Center, <sup>2</sup>University of Waterloo, Waterloo, Ontario

Barotropic tidal motion over topography in presence of stratification transforms barotropic tidal energy into baroclinic tidal energy. An internal baroclinic tidal bore is generated. The internal bore separated lower density water from higher density water. As the internal bore propagates, its leading edge steepens through nonlinear effects and the slope increases in time. Prediction of internal bores in the Yellow Sea are conducted with the Lamb nonhydrostatic model. This model was previously tuned to SAR and hydrography data, Warn-Varnas et al. (2005)[Warn-Varnas, A., S. A. Chin-Bing, D. B. King, J. A. Hawkins, K. G. Lamb, and M. Teixeira, Yellow Sea ocean-acoustic solitary wave modeling studies, *J. Geophys. Res.*, 110,C08001, doi: 10.1029/2004JC002801, 2005.]. The slope increase of the predicted internal bore is tracked up to its disintegration into solitary waves. The behavior of the slope is compared with analytical results derived from shallow water equation. The shallow water analytical solution considers the formation of a shock between water masses of two different densities. Shock formation time, angle of slope to range and jump amplitude is compared to full nonhydrostatic model predictions. Changes in refraction caused by internal bore slope increases are undertaken.

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## High Frequency Acoustic Propagation in a Stratified Turbulent Flow

R. Field, P. Gallacher, D. Hebert, E. Jarosz

Naval Research Laboratory, Bay St. Louis

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From June 29 through July 11 2008, an acoustic/oceanographic experiment was conducted in the Gulf of Mexico. The experimental objectives were to determine the effects of turbulent flow on acoustic signals in the acoustic communications band of 10.5 - 20 kHz. The area chosen in the Gulf was the Alabama Alps, part of a group of reef-like structures collectively known as the Pinnacles. In particular, the Alabama Alps rises to about 15-17m above a relatively flat sea floor of 90m depth. Depending on the direction of flow, turbulent wakes periodically form in the vicinity of these structures. In addition to the experimental effort, the NRL-MIT nonhydrostatic ocean model was used to simulate turbulent flow around the Alabama Alps from which sound speed structure can be obtained. Oceanographic simulations were performed with barotropic forcing speeds of 5, 10 and 50 cm/s. The flow is hydraulically controlled in the 10 cm/s case and in the 50 cm/s simulation the flow is supercritical with respect to the Froude number. Also, the 50cm/s case demonstrates the formation of nonlinear waves behind the Alps that are dispersed downstream. The resulting sound speed structures from these three simulations are used in the FEPE acoustic model to investigate the effects of turbulent flow on transmission loss within the 10.5 - 20 kHz band as a function of range, depth and time.

This work is supported by the Office of Naval Research, Program Element PE 62435N.

## The numerical solution of a modified wave equation that incorporates a causal propagation operator to describe acoustic propagation through dispersive moving media.

G. Norton

NRL Code 7181, Stennis Space Center

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The numerical solution of acoustic pulse propagation through dispersive moving media requires the inclusion of attenuation and its causal companion, phase velocity. For acoustic propagation in a linear quiescent medium, Szabo [J. Acoust. Soc. Am., 96, 491-500 (1994)] introduced the concept of a convolutional propagation operator that plays the role of a causal propagation factor in the time domain. This operator was originally proposed to replace the loss term responsible for attenuation due to thermal conduction and viscosity of a quiescent media in the Westervelt equation. The operator has been successfully incorporated in the Westervelt equation replacing this traditional loss term. Additionally the operator has been incorporated in the linear wave equation for quiescent media. It has been used to study propagation and scattering from such widely diverse media as

bubble plumes in the ocean and ultrasound propagation in human tissue. In this work, this method is extended to address acoustic propagation in dispersive moving media. The development of the modified wave equation for sound propagation in dispersive media with inhomogeneous flow will be described, along with examples presented. The resulting modified wave equation is solved via the method of finite differences.

### Bangs and reverberations - sound propagation in an urban environment

D. Hewett<sup>1</sup>, J. Ockendon<sup>1</sup>, D. Allwright<sup>2</sup>

<sup>1</sup> Oxford Centre for Industrial and Applied Mathematics, Oxford, <sup>2</sup> The Smith Institute for Industrial Mathematics, c/o Mathematical Institute, Oxford

The main analytical and numerical difficulties in the study of sound propagation in an urban environment are due to the complexity of the environment. The presence of buildings, vehicles and other obstacles gives rise to complicated reflection, diffraction and absorption effects, and introduces multiple propagation paths between source and receiver. This makes it difficult for a listener to locate the source of the sound, particularly when the source is not in a direct line of sight. This in turn has implications for situational awareness and event localisation in the context of military operations, for example.

In free space the localization problem for an impulsive source is readily solved by Time Difference Of Arrival (TDOA) localization. In urban environments a naïve application of the standard TDOA method requires a high receiver density, because the method assumes a direct line of sight between source and receiver. In this work we investigate how the TDOA method can be adapted to domains containing obstacles. We also mention the non-impulsive case when a harmonic source is switched on instantaneously. After a suitable time this returns to a frequency domain problem which has interesting properties in the particular case of a network of narrow streets.

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### Acoustic source location in an urban environment

D. Albert<sup>1</sup>, L. Liu<sup>2</sup>

<sup>1</sup> USACE-CRREL, Hanover, NH, <sup>2</sup> University of Connecticut, Storrs, CT

Low frequency sounds transmitted outdoors in urban areas with many buildings are complicated compared to sound propagating in open areas because of the multiple reflections and diffractions produced by the buildings. In such areas, classical methods like beam-forming or direction-of-arrival estimates to determine the source location can fail completely. A relatively new signal processing method known as time reversal processing can potentially be used to decode the complex signals and determine accurate source

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locations, even using only non-line-of-sight sensors. Counter-intuitively, the scattered waves from building walls and corners play a positive, not adverse, role in time reversal source detection by effectively increasing the effective aperture of the sensor array. The method requires time series recordings of the sound and a map of the building locations as input. This method is demonstrated using a finite difference time domain propagation model and is shown to be robust with respect to building location errors. This research was funded by US Army Corps of Engineers.

### Acoustic inspection of road vehicle cargo

D. Hutchins<sup>1</sup>, L. Davis<sup>1</sup>, G. Diamond<sup>1</sup>, P. Zimmerman<sup>2</sup>, J. Peter<sup>3</sup>

<sup>1</sup>School of Engineering, Coventry, <sup>2</sup>Department of War Studies, Kings College, London, <sup>3</sup>British Geological Survey, Kingsley Dunham Centre, Nottingham

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This paper reports progress on an acoustic system, designed to obtain information on the contents of cargo transported by road. Specifically, the intention is to provide a screening method for trucks fitted with trailers that have flexible curtains along both sides of the container. The aim is to provide information of the contents, as the truck drives past an inspection point.

The method is to use a swept frequency chirp signal, which passes through the sides of the trailer and out the other side to a receiver. The sound field then interacts with both the curtain walls and the contents, to set up a complicated set of resonances and multiple reflections. The chirp signal is used, together with a cross-correlation, to obtain frequency spectra along a certain propagation path. This spectrum, and other information from the cross-correlation output, can then be used to extract variations in a given property along that path. If multiple paths are chosen, there is scope for reconstructing images via some form of tomography.

This paper will describe progress to date in sending signals through objects, and how physically such a system could be constructed. Results will be presented which show that the cross-correlation approach has the ability to find resonances even in the presence of background noise. The relationship between frequency selection and object identification will be discussed, as will the practical aspects of designing such a system for real-time, outdoor use.

## Time Reversal Techniques for Broadband MIMO Sonar Systems

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Multiple Input Multiple Output (MIMO) systems have been recently developed for mobile communication and as well by the radar community. The radar community has pointed out multiple advantages of MIMO systems such as diversity gain for target detection, angle of arrival and Doppler estimation. Coherent processing also allows super-resolution for target localisation. We propose a new formulation for broadband MIMO sonar systems independent of the target model. We present experiments done in our tank (Width x Length x Depth: 3 x 4 x 2 m) with a broadband MIMO system (2 transmitters, and 4 receivers). The transmitters cover the frequency band from 30 kHz to 150 kHz. We demonstrate experimentally the advantage of Time Reversal for MIMO systems by focusing the energy on the target independently of the medium. We propose a pseudo Time Reversal technique which focuses the energy directly back to the receivers increasing the SNR by a factor of  $N$  where  $N$  is the number of transmitters.

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## Statistical characterization of an underwater acoustic signal with applications in ocean acoustic tomography and geoacoustic inversions

Michael Taroudakis

University of Crete and Foundation for Research and Technology-Hellas Institute of Applied and Computational Mathematics, Heraklion, Crete, Greece

The presentation is a review of a new method for acoustic signal characterization based on a multilevel analysis of the signal by means of 1-D wavelet transform. It has been shown that the coefficients of the wavelet transform treated as random variables obey a certain statistical law described by a family of symmetric  $\alpha$ -stable distributions. Thus, the acoustic signal is characterized by a set of parameters, which correspond to the parameters of the probability distributions for each level of the signal transform. It has also been shown that by using the Kullback–Leibler divergence as a measure of the difference between two probability distributions, and the statistical characterization of the acoustic signal, two different signals corresponding to two different set of environmental parameters can be recognized as such, thus enabling the formulation of the inverse problem of the estimation of the environmental parameters on the basis of the measurements of an acoustic signal, as an optimization process.

Two different approaches for the treatment of the inverse problem are presented and discussed. The first approach is based on neural networks and

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the second one on genetic algorithms. The two approaches are conceptually different having in common the use of the statistical characterization of the acoustic signal. Numerical inversion results based on simulated experiments for typical shallow water environments are also presented illustrating the benefits and possible limitations of the proposed signal characterization method for solving problems of ocean acoustic tomography or bottom recognition.

**ACKNOWLEDGEMENTS :** The work has been partially supported by the ESONET NoE. Contributions from P. Tsakalides (University of Crete and FORTH), George Tzagkarakis (University of Crete) and Kostas Smaragdakis are also acknowledged.

### Using low frequencies for geoacoustic inversion

A. Tolstoy

ATolstoy Scientific, Inc., McLean

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Broadband sources are necessary for accurate geoacoustic inversion. However, the higher frequencies (above 100 Hz) are best suited for the estimation of geometric parameters (such as source location and water depth) and of surficial bottom properties (such as top sediment gradient and sound-speed at the bottom/ocean surface). The lower frequencies (25–100 Hz, i.e., LF) are better for estimating sediment thickness  $h_{sed}$  (for sediments thicker than 15 m) and the half-space sound-speed  $chsp$  (assuming at least one sediment over the half-space).

This paper proposes an inversion method which uses the LF spectrum only to estimate  $h_{sed}$  and  $chsp$  – even in the presence of errors in source location (depth and range), water depth, and ocean sound-speed profile. The method considers a full search of the parameter space at 30 Hz and continues by considering only sequential high value parameter combinations (using MFP) as frequency slowly increases (5 Hz increments). Once  $h_{sed}$  and  $chsp$  have been determined, improved accuracy in other bottom parameters and in geometric parameters as well as in ocean sound-speed profiles can next be achieved by gradually increasing the frequencies used in the inversions while also increasing the corresponding search space. It is important to note that a complete search of the parameter space seems to be necessary at each frequency in order to find a unique solution rather than just a „data fit“. The lower frequencies allow for complete searches of rather crudely sampled, limited, parameter spaces. Use of the higher frequencies to start is not recommended since this would require too fine and too large a search space. Examples considered are simulations of SW06 scenarios.

**A Novel Reconstruction Algorithm for Thermo Acoustic Tomography Imaging  
by Kirchhoff Migration**

Z. Liu, L. Liu

School of Engineering, University of Connecticut, Storrs

Kirchhoff migration is a widely used image reconstruction algorithm in exploration seismology. To reconstruct the structure of human brain in biomedical imaging, we have developed a novel imaging reconstruction algorithm for thermo-acoustic tomography (TAT). The Kirchhoff migration has been constructed in two steps.

First, the wave-equation datuming technique with Kirchhoff integration was used for virtually ,moving' the transducers from outside the skull into the inner boundary of the skull to compensate the severe insertion loss caused by the skull. Second, all of the brain medium heterogeneities throughout the entire domain of the brain were taken as the acoustic sources, and relocated through wave back propagation through Kirchhoff migration. We have applied this approach to both synthetic and experimental ultrasound data collected for TAT. The reconstructed brain images based on synthetic and experimental data have shown that major brain structures can be clearly identified. For the synthetic data, the location of structures is coincided with the original model. For the experimental data the reconstructed image mimics the major features shown by the anatomic cross-section. Our results show that this reconstruction method has significant potential in future biomedical imaging for a more practical application of TAT for through-skull brain imaging.

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**Full Frequency Transmission Loss modelling using FE, SEA and FE/SEA Coupled**

D. Blanchet

ESI GmbH, München

Transmission loss modeling plays a vital role in the design of acoustically efficient products. Whether in the aircraft, automotive or train industry, transmission loss measurements and simulation are used to improve the vibro-acoustic performance of components. Since fewer prototypes are built and therefore fewer tests can be made, the accurate prediction of transmission loss over the full frequency range of interest has become increasingly important. Modeling transmission loss of a complex structure involves the use of deterministic methods such as FEM and BEM at lower frequencies and statistical methods such as SEA at higher frequencies. Recently, a theoretical breakthrough in vibro-acoustics provided the ability to rigorously couple FEM and SEA in a single model. This paper introduces the theoretical foundation of the FE/SEA coupled approach and compares transmission loss predictions with traditional methods (FEM, BEM, SEA)

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and with test. It also compares computation time and memory usage since FE/SEA Coupled reduces the DOFs of the linear system to be solved.

### Analysis of panel contributions to sound pressure field inside an enclosure

S. Wu<sup>1</sup>, A. Pierce<sup>2</sup>

<sup>1</sup>Wayne State University, College of Engineering, Detroit, <sup>2</sup>Boston University, Aerospace and Mechanical Engineering Department

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This paper concerns the development of an accurate and cost-effective method to analyze contributions of individual panels to the sound pressure field inside a vibrating structure. This method can have a significant impact on reduction of noise transmission into vehicle passenger compartments or aircraft cabins. Currently, panel contribution analysis is done through measurements of transfer functions between a possible cause (force excitation or panel vibrations) and a receiver (driver ear position). Another approach is to measure the Green's function between a point volume source at a field point (driver ear position) and vibro-acoustic responses on the panel surface by using the principle of reciprocity. Both these methods can be time consuming because of an excessive number of measurements necessary. The present paper shows that the sound pressure at a field point can be related to the acoustic energy flow or acoustic intensity from any individual panel of a vibrating structure. In particular, the normal component of the acoustic intensity on the surface of a vibrating structure is reconstructed by Helmholtz equation least squares (HELs) method based on measurements of the acoustic pressure close to the surface. The normal acoustic intensity distribution on each panel is correlated to the acoustic pressure at a field point and its contribution ranked. This method can be very cost effective in analyzing relative contributions of individual panels of a structure to the resultant sound pressure field. Examples of using this method to analyze sound transmission into a vehicle passenger compartment are demonstrated.

Locating multiple incoherent sound sources in a non-ideal environment

N. Zhu, S. Wu

Wayne State University, College of Engineering, Detroit

This paper presents the modeling and testing results of using a novel technology to locate and monitor multiple incoherent sound sources in 3D space in real time. The most salient feature of this technology is its capability of handling all types of signals such as broadband, narrowband, continuous, impulsive and tonal sounds over the entire audible frequency range (20 to 20,000 Hz) in a non-ideal environment. Source locations are displayed in (x, y, z) coordinates in real time and viewed through an automatic tracking and focusing camera that can cover 3500 solid angle. In particular, this technology requires only four microphones and a four-channel data acquisition board. So the device can be made very light, portable, easy to use and inexpensive. The underlying principle of this technology is a hybrid approach involving modeling of acoustic radiation from point sources, triangulation, and signal processing techniques. The impacts of signal noise ratio, microphone spacing, ranges of target sources, and frequencies on the resultant spatial resolution and accuracy in locating target sources are examined through numerical simulations and experimental validations based on a wide variety of practical signals such as helicopter noise, human conversations, truck pass-by noise, gun shots, clapping, coughing, etc. Formulations for estimating errors in locating sources are developed. Satisfactory results are obtained in most cases, even when the surrounding environment is non-ideal with relatively high background noise and reverberation.

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Recovery of material properties via minimization for the seismic wave equation in 1, 2 and 3 dimensions

J. de Villiers, M. Braun

University of South Africa, Pretoria

The interest in inversion for the seismic wave equation is based on its application in geo-physical exploration to assist in locating natural resources. In this contribution seismic wave inversion is performed via minimization of a sum of squares objective function of the form

$$F(a) = \sum_{i=1}^M \sum_{j=1}^N [u(r_i, t_j, a) - w(r_i, t_j, a_0)]^2,$$

where  $u$  is the calculated amplitude and  $w$  is the measured/simulated amplitude at  $M$  points  $r_i$  and for a grid of  $N$  time-values  $t_j$ , with respect to the model parameters  $a$  describing the material properties and where  $a_0$  is the set of model parameters used when obtaining  $w$  via simulation. The algorithms for this purpose are provided by the MERLIN package. The Levenberg-Marquardt method for the minimization of a sum of squares was

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used. In order to validate the approach before using experimental input data the amplitude  $w$  was obtained via solving the applicable wave equation with a suitable initial wave form and for a certain functional form of the material parameters parametrized by  $a_i$ . Starting out with an initial guess for the material parameters the Levenberg-Marquardt method was employed to find the parameters that minimize  $F(a)$ .

Two numerical approximation methods were employed. Firstly, the finite-difference method was used to propagate the wave equation numerically. Secondly, the finite element method employing interpolation polynomials of 4th order was applied to model the material properties in terms of  $a$ . We present results of model calculations for one, two and three dimensions.

### Uncertain parameter identification from experimental modal analysis using polynomial chaos expansion

K. Sepahvand<sup>1,2</sup>, S. Marburg<sup>2</sup>, H.-J. Hardtke<sup>2</sup>

<sup>1</sup>Persian Gulf University, Bushehr, Iran, <sup>2</sup>Technische Universität Dresden, Germany

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A mixed stochastic numerical experimental approach based on the novel polynomial chaos expansion method is developed for the identification of uncertain parameters from experimental modal analysis data. A new formulation for stochastic vibration of modal problem based on the polynomial chaos expansion is presented. The polynomial chaos expansion is used for representation of uncertain parameter and modal data. The relation between the uncertain parameters, modal parameters, and the coefficients of polynomial chaos expansions is obtained by using the stochastic inverse problem. The issue is investigated for linear and non-linear cases. It is shown that in the non-linear case, the determination of the polynomial chaos expansions shifts the ill-posed inverse stochastic problem to a well-posed deterministic problem, from where the coefficients can be determined. The experimental modal analysis data, measured for sample wood plates, are used for validation of the numerical results.

**A finite element method to model attenuation and dispersion effects in highly heterogeneous fluid-saturated porous media**

J. Santos<sup>1</sup>, C. Ravazzoli<sup>2</sup>, S. Picotti<sup>3</sup>, J. Carcione<sup>3</sup>

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P-wave attenuation due to slow-wave diffusion is a significant loss mechanism at seismic frequencies. This effect is known as mesoscopic loss and is caused by the presence of heterogeneities larger than the pore size but smaller than the predominant wavelengths. Performing numerical simulation of wave propagation in these type of highly heterogeneous media using Biot's equations of motion would be computationally very expensive or not feasible due to the extremely fine meshes required to represent these heterogeneities and their attenuation effects on the fast P-waves. This work presents an efficient procedure to overcome these difficulties.

First, equivalent complex P-wave and shear moduli are determined numerically at a finite number of temporal frequencies solving Biot's equations of motion with boundary conditions representing oscillatory compressibility and shear tests on a representative volume of bulk material.

Second, by fitting a suitable viscoelastic model to the computed moduli we obtain an equivalent frequency dependent constitutive relation, which is used to perform numerical simulations of wave propagation phenomena at the macroscale.

The numerical solution of the oscillatory compressibility and shear tests and the equivalent viscoelastic model is obtained using finite element procedures. Numerical experiments show the implementation of the methodology to simulate and analyze the attenuation and dispersion effects suffered by the fast P-waves when travelling in patchy gas-water saturated porous media.

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### **An efficient Trefftz based method for acoustic porous material modelling**

E. Deckers, D. Vandepitte, W. Desmet

K.U.Leuven, Department of Mechanical Engineering, Heverlee

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Currently, the finite element method (FEM) is most commonly used to predict the harmonic behaviour of poro-elastic materials. The applied calculation models are often based on the poro-elastic Biot equations which contain frequency dependent parameters. As a result, the FEM system matrices have to be recalculated for each frequency which harms the effectiveness of the method. Additionally, due to the discretization into a large number of small finite elements, the huge computational efforts involved practically restrict the use of the FEM to low-frequency applications. In this paper a Trefftz based wave based prediction technique for more efficient solution of poro-elastic problems is described. Wave functions that exactly satisfy the governing decoupled Biot equations are used as an expansion set to approximate the field variables. In this way, the three propagating wave types existing in porous elastic media are explicitly incorporated. This yields smaller numerical model sizes which makes the prediction technique applicable for solution at higher frequencies. This paper introduces the basic concepts and formulations of the technique and illustrates its potential through some validation examples and a comparison with the FEM.

### **Finite element modeling of acoustics in thermoviscous fluid**

N. Joly

Laboratoire d'Acoustique de l'Université du Maine, Le Mans

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The thermoviscous character of the fluid has to be considered in the modeling of acoustics when a great accuracy is required (in metrology applications) or when a refined description of the field inside the boundary layers is needed (in MEMS or small devices, or to study nonlinear processes such as acoustic streaming or thermoacoustic effects). Accounting for these thermoviscous effects consists in multi-physics and multiscale modeling, combining acoustic propagation at the wavelength scale and momentum and heat diffusive transfers at the scale of boundary layer thicknesses. The modeling method presented is based on a linear formulation using the particle velocity and the temperature variation variables, which is easily implemented in the finite element method. Because acoustic wavelength and boundary layer thicknesses have very different length scales, anisotropic and adaptive meshing is used to optimize the node distribution on the mesh. The method is applied to axisymmetrical and bidimensional models, illustrating the ability of this method to compute accurately, for complete devices, both propagation and diffusion processes, at reasonable computational cost.

Acoustic modeling of perforated plates

R. Christensen

SENSE (SDU) and Oticon A/S, Odense M

Microperforated plates are characterised by having a number of holes with radii in the submillimeter range. For each hole the thickness of the viscothermal boundary layer becomes comparable to the radius and hence a representative acoustic model of the plate should include acoustic resistance as well as acoustic mass. Acoustic measurements have been carried out for a number of perforate samples and results have been compared to analytical as well as Finite Element models where dissipation is included. The use of the microperforated plates as damping elements in hearing aids is examined.

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BEM in anisotropic layered media

W. Kreuzer, G. Rieckh, H. Waubke

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When using the boundary element method in combination with a layered anisotropic medium, one of the major problems is the lack of an usable closed form of the Green's function for such a medium. In our approach the system is transformed into the Fourier domain with respect to space and time ( $[x,y,z,t] \rightarrow \omega [k_x, k_y, k_z, \omega]$ ), where it is possible to calculate a numerical approximation of this function on a given grid.

Furthermore, at any given arbitrary depth  $z$  it is possible to formulate this approximation as a linear combination of basis-functions depending only on  $k_x, k_y$  (for the  $x$  and  $y$  directions) and the material parameters of the layer, but not on the depth  $z$ . With this formulation it is possible to set up the boundary integral equation, which will be solved in the semi-Fourier domain  $(k_x, k_y, z, \omega)$  to avoid numerical problems.

We will present our approach using the example of a tunnel in layered soil with orthotropic material parameters and discuss some aspects concerning numerical stability and efficiency.

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## Boundary condition at low frequencies in time-domain acoustic BEM for the interior problems

H. Jang, J. Ih

KAIST (Korea Advanced Institute of Science and Technology), Dae-Jeon

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Time-domain acoustic boundary element method (TBEM), which is based on the time marching scheme and Kirchhoff integral equation, can be a powerful tool for transient and time varying acoustic problems. The problem is that, for analyzing the sound propagation in time, boundary condition should be also defined in time-domain. Often, frequency-dependent boundary condition has been implemented for time domain calculation. In the low frequency calculations, boundary condition is difficult to measure precisely, but its effect on the propagation has been usually regarded as negligible.

We investigated the role of boundary condition at the low frequency range for the TBEM analysis of interior problems. As a test, sound propagation in a rigid one-dimensional duct with an excitation at an end was adopted. For each frequency band excitation, time history of sound field in the box was calculated. In early times, results showed good agreement with measurement, but they were monotonically increased with time. However, this cannot happen in reality because of the energy loss. From the analytic solution, it was shown that this phenomenon is a characteristic of time-domain methods at low-frequencies in interior problems. To resolve the problem, it is essential to consider boundary condition at low frequencies for TBEM calculation. From the assumption that the sound distribution in the box is nearly uniform at very low frequencies less than the first resonance, the boundary absorption coefficient from the measured reverberation time was employed in the TBEM simulation.

As a result, the phenomenon of monotonically increasing pressure disappeared and results agreed well with measurement.

Comparison of computational performance of the fast multipole BEM based on different translation theories

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<sup>1</sup>The University of Tokyo, Chiba, <sup>2</sup>Niigata University

The fast multipole BEM (FMBEM), which is a drastically efficient BEM with the use of the fast multipole method (FMM), has been well known and applied a lot in the field of acoustics. In the FMBEM, efficient translation of expansion coefficients between multipole/local expansion points is so important. In three-dimensional Helmholtz fields, the diagonal form proposed by Rokhlin has been widely adopted for efficient translation of expansion coefficients. However, it is well known that this diagonal form causes numerical instability at low frequencies, which greatly decreases the accuracy of the FMBEM, when the analysis frequency is much smaller than that corresponding to the size of elements.

This paper deals with the fast multipole BEM for low-frequency calculation. Some techniques, which are based not on Rokhlin's diagonal form but the original multipole expansion theory, have been proposed for translation of expansion coefficients for low-frequency problems. Among these techniques we adopt those proposed by Gumerov and Duraiswami and investigate them through numerical studies with respect to accuracy and efficiency. Based on this investigation, we apply these translation techniques to the FMBEM. The procedure is validated and tested against a conventional FMBEM based on Rokhlin's diagonal form with respect to the accuracy, efficiency and stability.

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Adaptive Box Parallel Implementation of the Multipole Method for Acoustic Scattering

J. López<sup>1</sup>, M. López-Portugués<sup>1</sup>, J. Taboada<sup>2</sup>, H. Rice<sup>3</sup>, F. Obelleiro<sup>4</sup>

<sup>1</sup>Universidad de Oviedo, Gijón, <sup>2</sup>Universidad de Extremadura, Cáceres, <sup>3</sup>Trinity College Dublin,

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The use of low frequency methods, such as the Boundary Elements Method (BEM), to analyze scattering problems permits to obtain very accurate solutions. The BEM eventually requires the solution of a linear system of equations with N unknowns. A direct solution of the system requires huge computational resources (memory and time) that may be dramatically reduced by means of iterative solvers, such as the Generalized Minimum Residual (GMRES) method, in combination with speed-up techniques, such as the Fast Multipole Method (FMM). In addition to the usage of low computational complexity algorithms it is interesting to consider the growing relevance of parallel computing. Efficient algorithms that are prone to parallelization may be considered to dramatically enhance the scope of application of the BEM and allow to take complete advantage of present and new-future computational resources.

The performance of a parallel implementation of the FMM to speed-up the

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GMRES matrix-vector products is considered in this study. The developed implementation employs the Message Passing Interface (MPI) allowing its usage on both shared and distributed memory environments. A hybrid domain partition technique is considered in this work that yields a very low memory footprint implementation. Moreover, the use of octree structures has been crucial to develop some efficient workload distribution techniques that are also presented. As a consequence, a highly scalable implementation of the FMM is presented in here. Some acoustic scattering problems are analyzed by means of the implemented tool. A special focus is given to scattering from airplanes which shows the interest of the implemented tool on acoustic scattering analysis and prediction. Results on computational resources usage and parallel performance are also shown.

### High-Fidelity Real-time Broadband Reverberation Model for Range and Cross-Range Dependent Environments

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In order to model reverberation at sonar and torpedo frequencies, it has previously been necessary to make certain compromises, resulting in undesirable inaccuracies. These inaccuracies arise due to the fact that reverberation modeling was based on spectral factorization, which does not allow correct broadband non-zero Doppler simulation in real time for a multi-channel receiver. This paper presents a new approach, closely related to the point-scatterer method, which avoids the limitations of the spectral factorization method. Previously, this approach has shown excellent results for the two-dimensional, range-dependent case. Here we generalize the method so as to also allow cross-range dependence. Instead of transmitting the pulse itself, the method transmits a superposition of many copies of the pulse, each copy with a random amplitude and phase. This „noiselet“ allows the simulation to mimic the point scatterer method without requiring a prohibitively large number of scattering points. We refer to it as the Early Randomization Method, or ERM. The propagation model used, the GRAB ray model, contains the bathymetry information, enabling the ERM to produce a statistically realistic reverberation field without requiring an unrealistically large number of rays. The propagation model assigns a noiselet, Doppler-shifted as required, for each two-way ray pair. It then corrects for beam patterns, absorption and time delay effects and sums the results for each receiver element. Transforming the result into the time domain provides the desired time series for each receiver array element. The computational load increases linearly with the number of receiver elements,

instead of with its cube, since there is no power spectral density matrix to factor. Since the randomness is introduced directly into the noiselet, the ERM is not limited to a particular statistical model, allowing non-Gaussian cases to be treated. Comparisons to results of the CASS/GRAB model will be given.

### Imaging using scattering of flexural waves

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In the context of defect detection, flexural waves can be employed in order to find inhomogeneities in plates. Using this type of waves, an acoustical image is obtained without scanning the plate locally. Conventional imaging techniques, such as backpropagation or synthetic aperture focusing, have the disadvantage of providing only limited resolution. Partial improvement can be achieved by increasing the frequency range or the number of transducers, for instance. If however the full scattering problem is taken into account, it is possible to obtain images of higher resolution as well as better quantitative information about the defects present in the material under investigation. The associated inverse problem has to be regularized in order to be stable in the presence of noise. Results obtained with the presented method are shown for the detection of thickness variations in metal plates.

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### Scattering waves as reliable tool for collector capacity estimation

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As a rule all oil field in East Siberia are confined not to classical structures, but to local heterogeneous areas produced by local lithologic substitution. These areas usually possess higher level of fissuring and, so, together with reflected waves should generate rather intensive scattered waves. Therefore, one can conclude that total wave field within such media can be represented as a superposition of reflected and scattered/diffracted waves. Of course, one needs in both of these waves in order to study reservoir structure. So, one needs in adaptable seismic imaging procedure. This procedure should be able to be tuned to image either regular interface or, vice versa, to destroy their image in order to be focused on imaging of scattering object. We believe that presented below Focusing Transformation is the perfect tool to do that.

The most prominent area where this transformation may be applied is computation of new seismic attribute - intensity of scattered energy. It happens, that for some oil field there is reliable correlation of this attribute

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and collector capacity. The method for imaging scattered waves for 3D heterogeneous media is applied for mapping 3D cracked areas, decompression areas and so on within consolidated granitoid subsurface block. This block is chosen as one of the possible sites for subsurface nuclear waste deposit. The approach bases on the use of asymmetric samples from multi offset data in order to avoid regular reflections and to concentrate on scattered/diffracted waves. This is possible because of the almost circular dispersion index for scattering via small intrusions. In the paper results of real data processing are presented.

On the base of Focusing Transformations a new seismic attribute is introduced and justified - intensity of scattered waves. It was computed for some real oil field (Nepsko-Boroubinskoe) in East Siberia region. Regression analysis proved its reliability as predicting factor for estimation of collector capacity.

### Ultrasound Harmonic Scattered by Fluid Spheres

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Ultrasound imaging is based on the detection of the harmonic scattered from objects. Harmonic imaging has been shown to increase the image quality. Many different Imaging techniques as B-mode scan and computerized tomography have been applied. Tomography is based on diffraction theory for continuous wave. It requires knowledge of the acoustic field scattered by an object immersed in a fluid. This paper analyzes the ultrasound harmonic scattering by a sphere surrounded by a compressible fluid medium. The KZK equation is considered for describing the propagation of fields before and after scattering. A numerical code based on the spectral method has been developed. The scatters are homogenous spheres of some liquids medium such as Glycerol and Ethanol. The sphere is located at the focal point  $z_0 = a^2/\lambda$  and it is illuminated by the field radiated from a circular piezoelectric disc with radius  $a = 5$  mm functioning at the fundamental frequency of 2.2MHz. The ultrasound field on the sphere surface is determined using the reflection coefficients within the phase correction according to the curvature of the surface illuminated. The harmonic are propagated back to the source using the KZK model. We, hence, study the effect of the scatter's radius and the fluid nature contained into the scatter on the fundamental and second harmonic beam patterns. Diffracted harmonics are narrower than the fundamental and the beam widths are growing as the diameter of the sphere decreases showing the diffraction effect. We described a numerical code able to simulate the scattered ultrasound harmonic from an object immersed. The proposed approach may have promising applications in ultrasonic characterization and tomography harmonic imaging.

Efficient Simulation of Acoustic Fluid-Structure Interaction Models  
by Means of Model Reduction

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Finite element modeling enjoys widespread use in the simulation of acoustic problems. In case of coupled fluid-structure interaction problems it usually forms the method of choice and computer models reflecting reality with a high accuracy can be set up quickly. However, due to the requirement that the element size should be significantly smaller than the wavelength a high dimensionality of the state vector in the finite element model results. Furthermore, the application of the popular pressure formulation leads to asymmetric system matrices making the solution of the resulting system of linear equations even more complicated.

Especially in fully developed 3D problems with several millions of elements, these two facts limit the straightforward application of the standard finite element method to acoustic problems.

In the work presented here a model reduction approach to overcome these limitations is investigated in the case of continuous wave problems. Using this approach we can gain computational efficiency without any compromise from the physics side. Besides presenting the necessary background of our approach, we will demonstrate the applicability of the method by means of several application examples including exterior (loudspeaker sound field) and interior acoustics (passenger compartment of a car). Due to the reduced system size, significant speed-up can be obtained in comparison with the standard method.

Furthermore, we will show how this new approach can be used in the design flow and device optimization.

Finally, investigations on the scalability of the method in case of models with several million degrees of freedom are presented.

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Room 2

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The solution of parametrized linear systems with multiple right-hand sides

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The solution of linear systems with a parameter is an important problem in engineering applications, especially in structural dynamics, acoustics, and electronic circuit simulations and related modelreduction methods such as Pade via Lanczos. In this paper, we present a method for solving parameterized linear systems with multiple right-hand sides, based on Krylov methods. We show that for this class of applications, a simple deflation method can be used.

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## Application of a subspace method using the ARNOLDI-Algorithm to problems in hearing research.

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Finite element description of problems from hearing research, such as the modelling of the middle ear or the inner ear often result in large dimensional models. This is due to the multi-scale and multi-field properties of the structures under investigation. Finite element models easily reach degrees of freedom larger than a million and calculation in frequency or time domain becomes time consuming. The question of how to reduce large systems of linear ODEs resulting from finite element description comes up. Here we present a Krylov subspace formulation making use of the moment matching theorem to reduce the order of the problem in the frequency domain. The method allows for structure-preserving order reduction of systems of linear ODEs. The algorithm to generate the orthogonal basis for Krylov subspace projection including higher order moments is based on the SOAR-method presented by Bai and Su in J. Sci. Comput. 26 (2005). A modified Arnoldi algorithm is used to span a orthonormal basis of a second order Krylov subspace. A cantilever beam in a channel filled with fluid is used as a computational test case to examine different influences such as the boundary conditions, damping, excitation or meshing on the reduction method. The results for the reduced model are compared with those from the direct solution in ANSYS. Finally the method is applied to a finite element model of the middle ear containing the stapes, incus and malleus the so called auditory ossicles, the tympanic membrane and the ear canal. It is shown that the implemented method leads to a significantly reduced model which preserves the second order structure of the original model and possesses a sufficient accuracy.

A Review of Krylov-Arnoldi Projection Framework Techniques  
For Interior Structural Acoustic Analysis and Optimization.

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In this work, a review of reduced order models (ROMs) developed for undamped and damped, fully-coupled structural-acoustic models, resulting from the well known unsymmetric, Eulerian displacement-pressure (u/p) FE/FE formulation [1, 2, 3], using Krylov Subspace based direct projection techniques are presented. The ROMs are obtained by applying Galerkin and Petrov-Galerkin type projection [4] of the coupled system matrices, from a higher dimensional subspace to a lower dimensional subspace, whilst matching the minimum and maximum number of moments from the coupled higher dimensional system. The vectors for second order and state space projection are computed efficiently using one of the several Arnoldi variants - depending on the nature of the coupled problem under investigation.

The computational efficiency and accuracy of the proposed techniques are demonstrated via five numerical test cases: (a) A structurally damped, strongly-coupled, plate backed water filled rectangular cavity system [5] (b) A strongly-coupled, water filled ABAQUS benchmark model [6, 7] incorporating undamped and damped behavior (c) A weakly-coupled, cubic air filled cavity backed by a simply supported square steel plate (d) A weakly-coupled, demonstrator vehicle model structure (classical automotive NVH problem), incorporating an adhesively bonded roof panel for constant and linearly damped material dependent matrix models [8] and (e) A coupled vibro-acoustic NVH optimization problem, where, the goal is to optimize the interior acoustic behavior by tailoring the lamination angles of the enclosing composite structure. The optimization is carried out using a Latin Hypercube/Mesh Adaptive Direct Search technique implemented in MATLAB [9]. The computational efficiency, solution state(s) accuracy and a qualitative analysis of results obtained by the Krylov-Arnoldi framework are presented and discussed.

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## Meteorological influence on the simulation of sound propagation in urban areas

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**Room 3**

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Noise exposure in urban areas is an important factor which influences the well-being and quality of life of urban residents. Street noise, that will be able to cause long-term effects on the state of health, is the main source of noise in urban areas. Particularly in residential areas near main roads this problem is essential, because prescribed noise levels are often exceeded here. When analysing this problem, the influence of the atmosphere on sound propagation under specific urban environmental conditions also has to be investigated, especially for longer sound paths. Thereby, the spatial and temporal variability of meteorological quantities like temperature, wind vector and air moisture leads, e.g., to refraction and thereupon to an increased or decreased noise exposure. To operationally answer questions of noise protection, the sound propagation model of the atmosphere using ray-tracing (SMART) has been further developed. With this model it is possible to combine the effects of meteorology and ground surface in outdoor sound propagation. In the present study, this model, which considers the influence of the vertical atmospheric structure on sound refraction and absorption, was enhanced to allow simulations of sound propagation in urban areas. Thereby, investigations of the dependency of the sound propagation on temporally variable weather conditions under the special urban influence were performed. Furthermore, as a consequence of noise exposure near residential areas, noise barriers are often installed along busy roads. To quantify the effect of this active noise protection, a barrier was implemented in SMART. The results of first studies illustrate that special weather conditions might reduce the effect of such noise barriers.

PSpice Modelling Ultrasonic Transducer-s Effect on Modulated and Coded Excitation

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The electro-acoustical behaviour of an ultrasonic transducer can be simulated using the PSpice simulation tool. The simulation can be made using the Leach model that represents the transducer in the form of an electrical circuit which parameters are deduced from the acoustical characteristics of the transducer.

In previous works we had exploited the PSpice model to study the variations of the transducer-s sensitivity versus the frequency and the magnitude of the supplied excitation. The influence of the backing medium and the propagating medium on the response of the transducer has been studied also.

It was shown that coded excitation signals as FM and binary complementary Golay codes can be utilized to improve ultrasound image resolution and the signal to noise ratio (SNR). We used the PSpice model to simulate the ultrasonic transducer-s effect on these signals. We studied different modulated and coded excitations as square pulse, Gaussian modulated pulse, AM and the FM modulated pulses and the inversed phase pulse. The transducer responses are simulated at 2.2MHz for different backing media and some propagating media namely water, glycerol and a tissue like lossy medium. Simulation results showed that the supplied signal is filtered by the transducer according to his broadband. This broadband enlarges as the acoustical impedance of the propagating medium increases. However the growth of the impedance of the backing medium makes it thinner. FM signal has a large broadband however the magnitude is less important because of the energy distribution in this band. We noticed also that the fundamental frequency disappears in the case of two cycles of a pulse inversion signal unless we supply the transducer with a frequency of twice the central frequency of the transducer. The third harmonic appears as well.

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### Transversal vibrations of specially tapered rod

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As it was shown earlier the parabolically tapered end of rod do not reflect the flexural waves with frequency high enough. This result was obtained by WKB-approximation analysis of the tapered rod flexural vibration equation. More thorough investigation displays however, that just for parabolic tapering there exist the exact analytical solutions of corresponding rod equation. Input impedance matrix of parabolically tapered rod will be calculated and modified WKB-approximation for rod with arbitrary smoothly varying cross-section will be suggested.

### The seismic wave equation expressed in terms of longitudinal and transverse components for non-constant Lamé parameters

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It is well known, that the solution of the isotropic seismic wave equation can be separated into longitudinal and transverse components, provided the density is constant and only the Lamé parameter  $\lambda$  is varying while  $\mu$  is kept fixed. However, when  $\mu$  is also a function of  $x$ , this separation breaks down.

As shown in this contribution, it is still possible to use the Helmholtz

ansatz  $u = \nabla \psi + \nabla \times A$  to derive the transformed set of equations

$$(d/dt)^2 \psi - c_l^2 \nabla^2 \psi = F(\psi, A, \nabla \mu)$$

$$(d/dt)^2 A - c_t^2 \nabla^2 A = G(\psi, A, \nabla \mu)$$

where  $c_l = ((\lambda + 2\mu) / \rho)^{0.5}$  and  $c_t = (\mu / \rho)^{0.5}$ , while F and G are functions of  $\psi$ , A and  $\nabla \mu$ .

While coupled, this presentation is still more convenient computationally than the original formulation, since the scalar wave equation has a much simpler structure than the vector wave equation. The numerical solution of the transformed set of equations is discussed in some detail.

Analytical and Numerical Investigation of Intermodulation Phenomena in Nonlinear Longitudinal Propagation of Elastic Waves

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The presence of various types of damages in materials cancels the integrity of structures resulting in serious problems in apparatus operation. Hence, the detection and assessment of damages is crucial in everyday engineering and is usually implemented by means of nondestructive testing techniques. Moreover, early detection of structural defects is very important because it can reduce significantly the cost of manufacturing. It has been verified that when elastic waves propagate in solids, the waves interact with localized or distributed damages generating nonlinear effects. Usual evidences of nonlinear propagation are the distortion of waves, the generation of wave harmonics, as well as the generation of intermodulation terms (sums and differences of excitation frequencies). In the present study, two basic mechanisms of nonlinearity are considered. The first is based on the stress-strain constitutive relation. In particular, we consider that the stress is a quadratic function of the strain; in other words, a second order Taylor expansion is employed. The second mechanism, is associated with nonlinear losses. In both cases, the perturbation method is applied to investigate the generation and the relative magnitudes of intermodulation terms when a finite beam is excited by two longitudinal waves with different frequencies. Furthermore, explicit finite difference schemes are developed to examine numerically the propagation of the waves. Both analytical and numerical studies are considered valuable to improve our understanding of the physical mechanisms that are responsible for the nonlinear propagation phenomena.

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Electroseismics of gas hydrate-bearing sediments: numerical modeling

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This work presents a numerical model to simulate the physical phenomena in which there is conversion between electromagnetic and kinetic energy beneath the surface of the Earth. The electroseismic equations linking the diffusive electromagnetic and seismic wavefields are solved using the finite element method. The subsurface is modeled as a 2D fluid-saturated layered porous media, and effective solids and fluids are built to take into account both the ice fragments cementing the solid matrix and floating in the fluid. Electromagnetic sources generating both transverse electric (TE) and transverse-magnetic (TM) modes are considered. The numerical examples illustrate the capabilities of the procedure to detect gas hydrate bearing sediments beneath permafrost areas.

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## Calculations of acoustical fields on base of the hydrodynamic equations system

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**15:30–16:00**

General (independent of the medium type) and non-perturbational (the inhomogeneity has not to be small) approach to the calculation of the acoustical field in the isotropic media with arbitrary signs and values of the effective density and compressibility is proposed.

Usually the acoustical wave processes in the inhomogeneous media are treated by use of the wave equation or Helmholtz equation. The medium in such case is characterized by the only parameter which is either refraction index or sound phase velocity. However these equations resulted from linearized system of the hydrodynamics equations, where two parameters (density and compressibility) are used. Equivalence to the hydrodynamic description is restored when inhomogeneity of the density is taken into account. Helmholtz equation is proved to be rather difficult in this case. For example, if analyzed system contains boundaries where medium parameters change, generalized functions must be included that makes equation solving difficult. The solving is rather difficult in case of arbitrary boundaries.

In order to overcome these difficulties exact scattering theory methods (not based, for example, on Born approximation) were used to calculate acoustical field in the complex structures. Lippmann-Shwinger equation for hydrodynamics equation system and its Green function were derived analytically in matrix form.

The problems of discretization, matrix inverse procedure, regularization, incorrectness and so on are discussed.

The proposed method was applied for the calculation of the acoustical fields in so-called double negative media or media with negative refractive index (media with both negative effective density and compressibility) that became of great science interest after their realization. The results of the computer simulations of the wave processes in such media are presented.

Active noise control in a stochastic domain based on a finite element model

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We consider the finite-element model based optimization of active noise control. Pre-defined number of actuators are located on the boundary of a three-dimensional enclosure such as car cabin, for example. Harmonic noise is minimized at specific locations by using actuator-emitted signals. The noise control system can be made more robust by considering random parameters such as small variations in the acoustic space. In vehicle acoustics, these variations could be changes in the posture of vehicle driver. We study the treatment of this aspect by using a stochastic computational domain in the finite element model. This leads to a quadratic optimization problem. Our robust active noise control leads to significant noise reductions in numerical experiments with a realistic car interior.

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Room 4

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New Absorbing Boundary Conditions for the acoustic wave equation approximated by an IPDG formulation

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The solution of a scattering problem generally involves the coupling of the physical model with absorbing boundary conditions (ABC). The efficiency of such conditions has a big impact on the accuracy of the numerical solution and their construction is thus one of the main step to implement the numerical method.

Another issue concerns the way of discretizing the wave equation in particular when it is set in heterogeneous media. Despite the fact they imply high computational burdens, finite element methods are commonly preferred to finite difference ones since their high flexibility and among them Discontinuous Galerkin approximations seem to be very efficient. This work deals with the construction of ABCs which are easy to include into the discretization scheme without modifying its CFL condition. This question was raised in a previous work where it was observed that the 2nd-order condition proposed by Hagstrom et al. requires to considerably reduce the CFL condition when the wave equation is written as an Interior Penalty Discontinuous Galerkin (IPDG) formulation. Herein new ABCs are developed for regular arbitrarily-shaped boundaries. They depend on two parameters and are constructed from the factorization of the wave equation written as a 1st order system by extending the theory of Taylor to evanescent waves. The idea of including evanescent waves was suggested by Hagstrom et al. to extend Higdon's ABCs. The approach we adopt here al-

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lows to complete the classical 1st-order ABC involving the mean curvature of the boundary and naturally leads to a 2nd-order condition which is easy to include into an IPDG formulation. Numerical experiments have been performed by including the new ABC into the IPDG formulation. It is observed that they do not modify the CFL condition, for any value of the parameters we have tested. Hence the new ABCs seem to be more adapted to the IPDG formulation than the conditions of Hagstrom et al. and more accurate than other 2nd-order ABCs.

### Fast High-Order Method for Solving the Acoustic Wave Equation in Heterogeneous Media

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The solution of the full wave equation implies very high computational burdens to get accurate results. Indeed, to improve the accuracy of the numerical solution, one must considerably reduce the space step. Obviously, this results in increasing the number of unknowns of the discrete problem. Besides, the time step, whose value fixes the number of required iterations for solving the evolution problem, is linked to the space step through the CFL condition. Recently, Joly and Gilbert have optimized the Modified Equation Technique (MET), proposed by Shubin and Bell for solving the wave equation, with larger space and time steps while preserving the accuracy of the solution. Most of the works devoted to the solution of the wave equation consider first the space discretization of the system before the time discretization. Herein we apply first the time discretization thanks to the MET. After this, a bilaplacian operator appears and we have to consider  $C1$  finite elements (e.g. the Hermite ones) or Discontinuous Galerkin Finite Elements (DGFE) whose  $C1$  continuity is enforced through an appropriate penalty term. In a strongly heterogeneous media, the solution is no longer  $C1$  because of the discontinuities of the physical parameters and Hermite elements are no more adapted to this problem. DGFE can however be used by imposing the continuity of a suitable physical quantity instead of the  $C1$  continuity.

Hence, we have chosen to discretize the 2nd-order operator by the Interior Penalty Discontinuous Galerkin Method (IPDGM). We will describe how the IPDGM can be extended to the discretization of the bilaplacian operator. We will also illustrate how the new technique can be applied to even order approximation. Numerical results in 1D and 2D will illustrate that the CFL conditions of the 4th and 6th order schemes are the same as the one of the classical Leap-Frog scheme. Thus this approach seems to improve the order of the approximation without increasing the computational burden.

### A general ray-tracing solution to reflection on curved edges and diffraction by their bounding edges

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In the area of acoustic propagation simulation, few ray-tracing implementations take into account reflection on curved surfaces and diffraction by their surrounding edges. Most ray-tracing softwares usually rely on a meshing of the model into planar surfaces and straight edges, hence limiting drastically the variety of simulated model types. Furthermore, this discrete solution, using classical physical formulations, does not converge towards the solution of the curved problem when refining the mesh. At last, other methods based upon the search of reflection or diffraction points using optimization techniques cannot be efficiently used to combine properly multiple interactions.

In this article, we propose a general 3D method taking into account reflections and diffractions on any kind of surface and edge, in complement of classical ray-tracing features. The method is based on a beam-tracing algorithm. We show that this technique, which propagates wave fronts, is perfectly suited to handle curved geometry, whether it is defined analytically or by a fine mesh. Moreover, the geometrical processing of diffraction by straight or curved edges becomes natural in an adaptive beam-tracing technique.

Results of simulations implementing the proposed approach compare well with exact numerical methods (2.5D and 3D boundary element methods) on test cases combining multiple reflection and diffraction phenomena.

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### Finite-difference simulation of sonic log for anisotropic media with attenuation

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Full wave acoustic logs are very important borehole measurements providing knowledge about physical properties of surrounding rocks. Historically these methods have been based on the use of axially symmetric, or monopole, wave phenomena in a fluid-filled borehole. Recently, logging tools based on excitation and reception of non-axially symmetric wave phenomena have been developed and used in order to explore near borehole media. Moreover, real media themselves are 3D heterogeneous, so real sonic waves never possess any axial symmetry. Earth media attenuate and disperse propagating waves. Both these effects are often quantified by the Quality Factor  $Q$  and introduced via Generalized Standard Linear Solid. In order

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to be able to recover physical properties of surrounding rocks by sonic data one should fully appreciate key peculiarities of elastic waves propagation within 3D heterogeneous viscoelastic formations.

We believe that the most effective way is to do that by means of 3D numerical simulation. This follows necessity to develop software providing a possibility to perform a range of numerical experiments for a variety of models and a range of different source positions. Most of the previous 3D FD studies are done for Cartesian coordinates. But, the use of these coordinates leads to saw-like representation of the sharpest interface of the problem - interface between fluid-filled borehole and enclosing rocks. In its own turn this provokes generation of rather strong artifact known as „numerical scattering“. Our main reason to introduce cylindrical coordinates is to avoid this artifact. Our approach possesses two key items providing its advantage with respect to a few another attempts to use cylindrical coordinate system for 3D numerical simulation of acoustic logs:

- 1) periodical azimuthal refinement of spatial grid cells in order to avoid their inflation with radius increase;
- 2) implementation of Perfectly Matched Layer (PML) without of azimuth splitting.

### Trigonometrically fitted symplectic integration method

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Thursday, 10.09.2009

Room 4

14:30–15:00

We report on the application of symplectic integration methods to the FDTD computation of low frequency noise propagation. For the spatial discretization, compact FD (Finite difference) schemes with improved resolution efficiency are used. For the time integration, three groups of symplectic integration method (SIM)s are tested and the results are compared. First group is a new set of coefficients that we have found for the third-order Yoshida-Ruth type SIM. A good news about this new set of coefficients is that it has larger stability limit than the Ruth's coefficients. Second group is the trigonometric fitting (TF) technique applied to the SIM. TF schemes have an advantage of being very accurate when the frequency of the system is known. We derived simple formulations for the second and third-order schemes. The fourth-order schemes have more complicated expressions. These TF-SIMs with second to fourth-order are compared with the existing TF method of second and third-order by Simos (Phys. Lett. A, 06). Third group is the weighted average of TF-SIMs intended to improve the overall performance of the integration when a spectrum of frequencies are included.

Quantifying the Effects of Interface Roughness on Reverberation using Finite Elements

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A finite element model for acoustic propagation and reverberation in a shallow water waveguide with rough interfaces is presented. This solution serves as a benchmark for approximate methods. Pressure fields for the entire domain are computed for a range of frequencies and a time dependent solution at a specific receiver location is obtained through Fourier synthesis. Preliminary analysis of a comparison of solutions from the finite element model, parabolic equations and the ray approximation method revealed short time differences in reverberation likely due to fathometer scattering. The effects of rough interface scattering on reverberation at low frequencies will be explored through a sensitivity study of the reverberation on the roughness parameters. Also, a sensitivity study on the effects of rough interface discretization on reverberation will be presented. Results can be used to guide environmental characterization for acoustic propagation modeling. [Work Sponsored by ONR, Ocean Acoustics]

**Thursday, 10.09.2009**

**Room 4**

**15:00-15:30**

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