Anglo-French Physical Acoustic Conference
22-24 January 2025
La Saulaie, Chédigny, France

AFPAC'25




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France

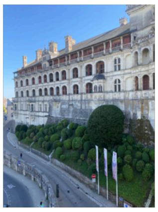
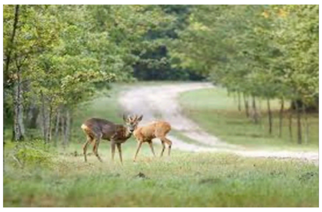
ABSTRACT BOOK

GREMAN | INSA Institut National des Sciences Appliquées Centre Val de Loire | Université de Tours | La Fondation Thérèse et René Planiol pour l'étude du cerveau | SFA Société Française d'Acoustique | IOP Institute of Physics

Preamble

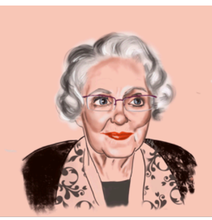
The Anglo-French Physical Acoustics Conference (AFPAC) is organised by Le Groupe d'Acoustique Physique and the Sous-marine et UltraSonore (GAPSUS) of the Société Française d'Acoustique (SFA) and the IOP Physical Acoustics Group. AFPAC provides a forum in which the current research activity in physical acoustics, underwater acoustics and ultrasonics is reviewed.

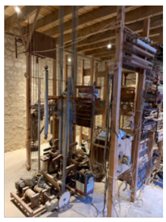
This year, the 23rd edition of AFPAC is organised by the GREMAN laboratory (INSA Centre Val de Loire, Université de Tours & CNRS) in the Loire Valley.

The scope for this conference is to encourage cross-fertilisation of ideas across different application areas in the field of physical acoustics. Topics include, but are not limited to: theoretical developments (all methods); experimental measurements; transduction; linear or nonlinear elastic or acoustic (bulk, surface, guided) wave radiation, propagation, scattering and reception; application to material characterisation, biomedical ultrasound, imaging (non-destructive testing, medical, underwater, seismology), SAW in electronic devices etc.

This conference will pay tribute to Thérèse Planiol, a pioneer of ultrasounds in Touraine, by organising a session on medical ultrasound, a gala dinner. These events are taking place at the Château de Saint Senoch, where she used to live.



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- Nader Saffari, University College London, UK (IOP - Physical Acoustic Group)
- Theodosia Stratoudaki, University of Strathclyde, UK (IOP - Physical Acoustic Group)

Wednesday 22 January 2025

	12:00	WELCOME at La Saulaire (		Welcome at La Saulaire (Registration / Badges)
	12:30	LUNCH		Lunch
				Title
SESSION I	13:50	Welcome	pages	Welcome at AFPAC 2025 and details
	14:00	Invited talk	1	Acoustic Imaging of the Structural and Compositional Properties of Underwater Objects / ***Alan HUNTER***
	14:25	S1 : Talk 1	*8-9*	Ultrasonic analysis of moisture content effect on the mechanical characterization of wood properties / ***Andres Arciniegas***
	14:37	S1 : Talk 2	*10*	Curved modal pencils for waveguides with continuously variable properties / ***Jordan Barras***
	14:49	S1 : Talk 3	*11-12*	Quantitative Measurement of Defects in Pipes using Guided Wave-based Full Waveform Inversion / ***Elias Rabbat***
	15:01	S1 : Talk 4	*13*	Ultrasonic characterization of porous materials using an inverse problem algorithm / ***Yassine Moradi***
	15:13	S1 : Talk 5	*14*	Statistical study of defect anisotropy effect on defect imaging accuracy / ***Omar Bouchakour***
	15:25	S1 : Talk 6	*15-16*	In-situ mapping of the annealing process using Spatially Resolved Acoustic Spectroscopy / ***Carolina Guerra***
	15:37	S1 : Talk 7	*17*	Identification of Lamb Modes on a Sensor Network for a Multimodal Tomographic Approach for Structural Health Monitoring / ***Garance Sauderais***
	15:49	S1 : Talk 8	*18-19*	Ultrasonic imaging of local acoustical nonlinearities in NDT: instrumentation limits and upgrades / ***Thomas Poisson***
	16:01	S1 : Talk 9	*20-21*	Estimating Green's functions to enhance leak localisation in buried water pipes / ***Joshua Hoope***
	16:13	COFFEE / TEA BREAK		
	16:35	S1 : Talk 10	*22-23*	Diffraction of Ultrasound From the Tips of Cracks: a Comparison of Analytical and Numerical Methods / ***Christopher Ashworth***
	16:47	S1 : Talk 11	*24-25*	Real-time Fouling Tomography in Pipes with Ultrasonic Guided Waves / ***Denys Iablonskyi***
	16:59	S1 : Talk 12	*26*	Topological Energy method for imaging delamination damage in rubber-metal assembly using 3D laser vibrometry / ***Nada Ben Jafela***
	17:11	S1 : Talk 13	*27*	High frequency diffuse acoustic field correlation for defect detection in Silicon wafers / ***Antonio Brozicevic***
	17:23	S1 : Talk 14	*28*	Non-destructive characterisation of 316L stainless steel porosity defects in metal laser powder bed fusion using ultrasonics and X-ray computed tomography / ***Antonio Brozicevic***
	17:35	S1 : Talk 15	*29*	Linking Elastic Constants to Microstructure: A Resonant Ultrasound Spectroscopy Analysis of a 316L Textured Polycrystal / ***Florian Le Bourdais***
	17:47	S1 : Talk 16	*30*	1D-CNN method for estimation of crack characteristics for ultrasonic non-destructive evaluation inspections / ***Thomas Beckingham***
	17:59	S1 : Talk 17	*31*	Finite Element Modelling for Machine Learning with Applications to Surface Breaking Crack Analysis / ***James Gaffney***
	18:11	S1 : Talk 18	*32-33*	Polymer viscosity monitoring with temperature using in situ ultrasonic method in a rheometer chamber / ***Nesrine Houhat***
	18:23	S1 : Talk 19	*34*	Attenuation and polarization of longitudinal critically refracted ultrasonic waves for residual stress assessment / ***Salah-Eddine Hebaz***
	19:00	DINNER		

Thursday 23 January 2025

			pages	Title
SESSION II	08:30	Invited talk	2	Coherent elastic waves in multiple scattering media: influence of resonances and positional correlations of scatterers / ***Tony Valier BRASIER***
	08:55	S2 : Talk 1	*35-38*	Investigation of Secondary Radiation Forces Near Boundaries: Interaction Dynamics with Primary Radiation Forces / ***Riaz Pervez***
	09:07	S2 : Talk 2	*39-41*	Subwavelength pulse focusing and perfect absorption in the Maxwell fish-eye / ***Gautier Lefebvre***
	09:19	S2 : Talk 3	*42-43*	Unexpected interaction between acoustic and weak shock waves / ***Ronan Delalande***
	09:31	S2 : Talk 4	*44-45*	Complex wavenumber band structure calculations with FEM for characterizing fluid-solid phononic crystals / ***Juliette Kessler***
	09:43	S2 : Talk 5	*46-47*	Experimental method for the retrieval of scattering coefficients of underwater metamaterial-based acoustic panels / ***Clément Larcade***
	09:55	S2 : Talk 6	*48-49*	Domain decomposition method for coupling semi-analytical form and finite element models of wave propagation / ***Romain Kubecki***
	10:07	COFFEE / TEA BREAK		
	10:30	S2 : Talk 7	*50-51*	Simple modelling of combined effects of stress and of rolling on anisotropy of guided wave radiation validated by finite element computations / ***Flavien Agon***
	10:42	S2 : Talk 8	*52*	Reconstruction of 3D slowly varying thickness waveguide using adiabatic Lamb modes and critical thicknesses / ***Alexandre Charau***
	10:54	S2 : Talk 9	*53-54*	Bubbles as a means of weak-source amplification, a 3d printed bubble-capture technique and its output dampening and frequency altering effects / ***Luke Prentice***
	11:06	S2 : Talk 10	*55*	Torsional pendulum driven by sound-matter orbital angular momentum transfer involving acoustic vortices / ***Elena Annenkova***
	11:18	S2 : Talk 11	*56-57*	Acoustic Pseudo-Vortices with Tunable Orbital Angular Momentum / ***Denys Iablonskyi***
	11:30	S2 : Talk 12	*58-59*	Acoustophoretic particle guidance in air using an ultrasonic phased array / ***Dmitrii Nikolaev***
	11:42	S2 : Talk 13	*60-61*	Generation of reconfigurable patterns on water-air interface using acoustic radiation pressure / ***Thibaut Devaux***
	11:54	S2 : Talk 14	*62-64*	Rotational Behavior of an Ultrasonically levitated Droplet Using Phased Array / ***Keita Okano***
	12:06	S2 : Talk 15	*65-66*	Volumetric ultrasonic imaging through complex geometry with a manually scanned 1D array / ***Richard Pyle***
	12:20	LUNCH at La Saulaie		
	13:30	Departure to Saint Senoch Castle (Bus transfer)		
			pages	Title
SESSION III: Tribute to Therèse Planiol	14:45	Invited talk	3	Detect, see and treat, different faces of ultrasound in medicine / ***Frederic PATAT***
	15:10	Invited talk	4	Bubbly microreactors, can we go from lab to industrial applications? / ***Madeleine BUSSEMAKER***
	15:35	S3 : Talk 1	*67-68*	Therapeutic Ultrasound on Biomimetic Models of Cancer / ***Daniel Silva***
	15:47	S3 : Talk 2	*69-70*	Quantitative X-ray elastography of coronary arteries using flexural pulse waves / ***Sibylle Gregoire***
	15:59	S3 : Talk 3	*71*	Development of an ultrasound scanner for intraoral imaging and exploration of periodontal tissues / ***Franck Levassort***
	16:11	S3 : Talk 4	*72*	Determining the Potential of Ultrasonic Treatment for Alzheimer's Disease by Enhancing Microglial Amyloid Beta Clearance / ***Parisa Abbasi Jamaati***
	16:23	COFFEE / TEA BREAK		
	16:45	Invited talk	5	Unveiling tissue secret using vibrations / ***Stefan CATHELINE***
	17:10	S3 : Talk 5	*73-74*	Simulation of transcranial ultrasound through coupling of volume integral equations and boundary element methods / ***Pierre Gélat***
	17:22	S3 : Talk 6	*75-76*	Identification of viscoelastic properties of soft materials based on the dynamic response of a spherical object placed at the sample interface / ***Hasan Koruk***
	17:34	S3 : Talk 7	*77-78*	In vitro investigation of the biophysical mechanisms underlying ultrasound neurostimulation / ***Tom Aubie***
	17:46	S3 : Talk 8	*79-80*	Deep learning for fast laser induced ultrasound tomography in tissue phantoms / ***Ahmed Al Fuwaires***
	17:58	S3 : Talk 9	*81-82*	Picosecond ultrasonics for cell imaging and characterisation: towards applications in cancer / ***Fernando Perez***
	18:10	Visit of Saint Senoch castle		
	18:45	DINNER GALA at the Castle		
	23:00	Return to La Saulaie (Bus transfer)		

Friday 24 January 2025

			pages	Title
SESSION IV	08:30	Invited talk	6	Second harmonic sound emission from a wineglass / ***Oliver Wright***
	08:55	S4 : Talk 1	*83-84*	Optimisation of acoustic energy harvester / ***Kehinde Omoteso***
	09:07	S4 : Talk 2	*85*	An efficient acoustic power transfer using a CMUT transducer / ***Paul Roche***
	09:19	S4 : Talk 3	*86*	Flexible piezoelectric sensors applied to reverberant acoustic field measurement for the Structural Health Monitoring (SHM) of a thermoplastic-composite gas tank / ***Samuel Rodriguez***
	09:31	S4 : Talk 4	*87*	Controlling flexural wave propagation using arrays of perpendicular gyroscopes / ***Katie Madine***
	09:43	S4 : Talk 5	*88*	Waves in piezoelectric plates: semi-analytical modeling and laser-ultrasound experiments / ***Clemens Gruensteidl***
	09:55	S4 : Talk 6	*89-90*	Towards On-Line Inspection of Additively Manufactured Powder Bed Fusion Parts Using Spatially Resolved Acoustic Spectroscopy / ***Martin Todd***
	10:07	S4 : Talk 7	*91-92*	Characterization and control of multi-MHz acoustic waves for acoustic crystalline undulators / ***Emmanouil Kaniolakis Kaloudis***
	10:19	COFFEE / TEA BREAK		
	10:40	S4 : Talk 8	*93-94*	4D time-domain Brillouin scattering of water ice phase transition under non-hydrostatic load / ***Nicolas Pajusco***
	10:52	S4 : Talk 9	*95*	Influence of the beam skewing in anisotropic plates on the dispersion curves / ***Sylvain Mezil***
	11:04	S4 : Talk 10	*96*	Deep Learning Techniques Applied to Time-Resolved Brillouin Scattering Signals / ***Andrea Faundez Quezada***
	11:16	S4 : Talk 11	*97-98*	Nanometric surface acoustic wave pulses generated and detected by laser / ***Samuel Raetz***
	11:28	S4 : Talk 12	*99*	Versatile optical design for high sensitivy laser detection of ultrasounds and vibrations, based on multi-chanel random-quadrature interferometry / ***Bruno Pouet***
	11:40	S4 : Talk 13	*100-101*	Poroelasticity in cells : insights from acoustic propagation / ***Lucie Vovard***
	11:52	S4 : Talk 14	*102-103*	New applications of laser generated sound sources / ***Konstantino Kaleris***
	12:10	LUNCH GRAB AND GO		
	13:00	DEPARTURE & BUS TRANSFERT TO SAINT PIERRE DES CORPS (TGV train station)		
	14:00	BUS ARRIVAL TO SAINT PIERRE DES CORPS (TGV train station)		

14:00 – Invited talk

Acoustic Imaging of the Structural and Compositional Properties of Underwater Objects

Prof. Alan Hunter

Conventional high-frequency sonar imaging systems operate in the hundreds of kilo-Hertz. They can produce stunning high-resolution images of the seafloor and underwater objects with near photo-like quality. The short wavelengths (on the order of centimetres or less) at these frequencies enable high resolution. However, the greater attenuation in solids limits their ability to penetrate surfaces and interrogate internal structure and composition. Current research is exploring complementary approaches using lower frequencies, where acoustic waves can penetrate below the seafloor and inside objects, as well as excite elastic waves. The propagation of elastic waves is influenced by a solid's material composition and structure, thus encoding this information into the acoustic response. This capability potentially enhances detection and classification, allowing for better discrimination between natural and human-made objects. This lecture will cover the motivation, progress, and challenges in this emerging field of seafloor imaging.

Thursday 23 January 2025

08:30 –Invited talk

Coherent elastic waves in multiple scattering media: influence of resonances and positional correlations of scatterers

The propagation of elastic waves in heterogeneous media is a fundamental research topic that concerns composite materials, porous materials, colloids and emulsions, with the aim of characterising these materials or optimising their performance. This topic has benefited from renewed interest with the development in the 2000s of metamaterials and in particular locally resonant metamaterials. These composite materials consist of a fluid or solid matrix containing an ordered or random distribution of scatterers, whose resonances alter wave propagation. In some cases, the macroscopic mechanical properties of these materials are modified in non-ordinary ways, opening the way to wave control or damping.

In this context, the aim of the presented work is to study the influence of positional correlations between scatterers and strong sub-wavelength resonances on the propagation of coherent elastic waves. To achieve this, the study is based on the systematic comparison of results from statistical models, numerical simulations and experiments. Experiments are performed in transmission through handmade samples in a water tank for longitudinal waves. An original setup using delay lines is developed to make reproducible contact measurements of shear waves. The numerical results are obtained using the MuScat code developed in the laboratory. This code is based on the solution of the multiple scattering equations as well as on the expansion of the incident and scattered fields on the spherical harmonics.

We investigate the case of distributions of dense beads embedded in a solid matrix. This particle-matrix pair exhibits two sub-wavelength dipolar resonances: a translational resonance that affects both longitudinal and transverse waves and a rotational resonance that affects only transverse waves [1]. Longitudinal coherent waves are then strongly influenced by the translational resonance and the study of statistical models shows that wave conversions are particularly important. Transverse coherent waves are influenced by translational and rotational dipole resonances, and increasing concentration leads to the simultaneous propagation of two coherent waves [2]. The influence of spatial correlations, especially short-range correlations, finally allows to optimise these non-ordinary effects [3].

[1] Duranteau *et al.*, Random acoustic metamaterial with a subwavelength dipolar resonance, The Journal of the Acoustical Society of America, 139(6), 3341-3352, 2016.

[2] Simon *et al.*, Propagation of coherent shear waves in scattering elastic media, Physical Review E **103**, L051001, 2021.

[3] Simon *et al.*, Propagation of elastic waves in correlated dispersions of resonant scatterers, The Journal of the Acoustical Society of America **155**, 3627-3638, 2024.

Thursday 23 January 2025 - Session 3 – 14:45 -- Invited Talk

Detect, see and treat, different faces of ultrasound in medicine

Prof. Frédéric PATAT
University of Tours Inserm U 1253 i Brain, 2 BvD Tonnellé, 37044 Tours Cedex

This presentation will review the history of ultrasound applications in medicine over the last 50 years. Acoustic waves, which are mechanical in nature, can be used to provide information about the anatomy and physiology of the organs being explored. We'll see how physics is favorable, or rather how researchers and engineers have been able to find ways of manipulating waves to provide maximum information in human bodies. Initially purely anatomical, ultrasonography was initially in the hands of a few experts, but has since become increasingly functional and available to a wide range of specialists. Like other imaging modalities, it is a formidable site of technological integration. The digital revolution that began in the 1980s and '90s enabled the implementation of demanding real-time calculations on commercial platforms, followed by the miniaturization of machines. At the same time, new materials and micro-technologies have provided the basis for highly complex, high-performance probes. Finally, ultrasound beams can carry enough momentum and energy to exert an active role on tissues, opening areas of biomechanical investigation and the development of ultrasound as a therapeutic modality. Ultrasound devices are now available as pocket devices for care professional as well as dedicated platforms for expert use or research investigations.

Acknowledgements
Many thanks to the AFPAC 2025 for its invitation.
My sincere thanks go to the following long list of colleagues who have contributed to this presentation through projects carried out together, scientific or medical discussions, and documents kindly provided: A Bouakaz, L Pourcelot, JM Escoffre, JP Remenieras, JM Grégoire, F Ossant, the CIC Tours team, B de Senneville, M Tanter, F Padilla, C Lafon, J Roumy, N Felix. Not forgetting all our colleagues and students, old and young alike, who have shared some of their research adventures.

Thursday 23 January 2025 - Session 3 – 15:10 -- Invited Talk

Madeleine Bussemaker

Bubbly microreactors, can we go from lab to industrial applications?

Sonochemistry relies on cavitation bubbles created through the application of an ultrasonic wave (20 kHz – 2 MHz) to a fluid medium. The micro-sized bubbles oscillate and collapse, creating unique high temperatures and pressures leading to plasma chemistry that have fascinating consequences not seen in other chemical environments. To enable sonochemical applications in industry the impacts of flow regimes (overhead stirring, flow-through) and reactor configuration (horn and plate transducers, applied frequency and power, wave reflection) on the sono-process of interest are researched.

Sonochemical effects are explored experimentally using dosimetry, sonoluminescence, sonochemiluminescence and pollutant degradation. We find that different chemical systems and measurement techniques have inconsistent responses to reactor configuration changes. This is attributed to disparities in energy requirements, reaction locations, and reaction mechanisms. Flow is suggested to impact sonochemical activity through: i) bubble transience (deviation from sphericity) and collapse shape, which in cases may enable nanodroplet injection or enhanced bubble fragmentation; ii) bubble clustering and subsequent coalescence; iii) wave propagation and hence standing and travelling wave components; and iv) aeration of solution and available nuclei. Variations in results and literature highlight the challenges of generalisation of parametric effects and/or identification of useful parametric spaces in the chaotic system.

Given the chaotic nature of sonochemistry, use of predictive models were explored using baseline sonochemical experiments. Cavitation parameters were identified based on the theoretical principles of bubble dynamics and reaction kinetics. Physical parameters included liquid height (H_R), frequency (f), ambient temperature (T_0), quantity of substance within the bubble (n_t), and liquid surface tension (σ). Two approaches were investigated using multi-parameter response modelling and machine learning. The response model was developed using dimensionless analysis and multiple linear regression and machine learning from CATBOOST. The modelling approaches were successful in our reactor and reflected trends in published data from other research groups. The potential use of predictive models was demonstrated as a viable method to explore industrial applications of these chaotic systems.

Bio

In my current position as a Senior Lecturer in Chemical Engineering at the University of Surrey I lead research in treatment of emerging contaminants, sustainable hair dyes, sonochemical engineering, waste/biomass processing, and ultrasonic effects in biological systems. I first became interested in ultrasonic cavitation through my PhD in ultrasonic processing of biomass at the University of Western Australia. Over the years I have broadened my research to include bacteria, black soldier flies, supply chain, ontologies and technoeconomic modelling. However, have always remained interested in the wonders of ultrasonic cavitation and what we can do with these tiny microreactors. I really enjoy working with both industry and academia for real-world applications of research, partnering with companies such as Arcadis, Element 6, Bio-Sep, Herb UK and Inspro Ltd. Recently I have co-founded a spin-out company Mantisonix that aims to stop the cycling of persistent organic pollutants, specifically PFAS in our environment through complete degradation.

Thursday 23 January 2025 - Session 3 – 16:45 -- Invited Talk

Unveiling tissue secret using vibrations

Stefan CATHELINE

The first part is devoted to human soft tissues. Elastography, sometimes referred as seismology of the human body, is an imaging modality now implemented on medical ultrasound systems, on MRI and recently in optical coherence tomography devices. It allows to measure shear wave speeds within soft tissues and gives a tomography reconstruction of the shear elasticity. The shear elasticity being the elasticity felt by fingers during palpation, elastography is thus a palpation tomography. In the first part of this presentation, a passive elastography method is described. Inspired by noise correlation seismology and time reversal, it allows to extract from natural shear waves produced in the human body by heart beatings, muscles activities, arterial pulsations, a shear wave speed estimation. Therefore, an elasticity palpation mapping with no shear wave source is conducted. Latest developments in micro-elastography of a single cell will be described.

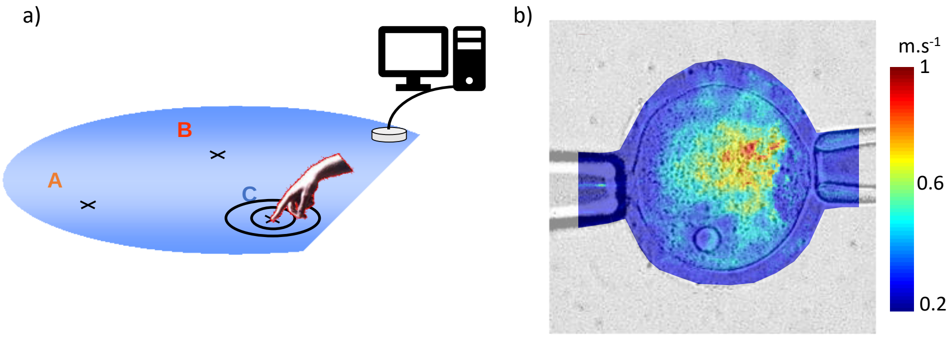

Figure : a) Experimental measurement of elasticity table, b) elasticity palpation of a single cell (oocyte).

Extraordinary behaviour of the acoustic transmission in metamaterial structures

Oliver B. Wright

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Abstract: Acoustic metamaterials, which are engineered structures composed of sub-wavelength resonators, are designed to control sound propagation in ways not found in natural materials. Here we discuss anomalous transmission through various acoustic metamaterial structures.

Electromagnetic metamaterials, consisting of sub-wavelength oscillators that show effective negative permeability or permittivity have led to many applications over the last 20 years. In parallel, acoustic metamaterials showing effective negative density or modulus were introduced [1,2]. Counterintuitive phenomena such as acoustic negative refraction, superlensing and cloaking were demonstrated.

Following progress in electromagnetism, in the domain of acoustics metamaterial-related giant extraordinary transmission of kHz airborne waves has also been reported [3], that is, greatly enhanced resonant acoustic transmission through membrane-covered holes. Similar observations were documented for surface or bulk acoustic waves in solids [4,5].

Here I first present recent kHz experiments on the extraordinary transmission of airborne sound through bare holes without the occurrence of any resonance [6]. Although resonances are essential in electromagnetism to overcome poor transmission through bare holes, this is not so in fluid acoustics. A plate perforated with bare holes can transmit nearly all the sound normally incident on it, which has practical applications in sound transparent screens. However, this phenomenon has not previously been systematically interpreted in terms of extraordinary transmission. Here we present such an analysis, and hope to make you appreciate, for example, how sound-transparent screens with holes at bank service counters work, and how to optimize them. Because of the enhanced acoustic energy density in the holes, we also propose applications in acoustic energy harvesting.

I then present two studies on stopping sound using metamaterial structures. In the first study [7] we propose an octagonal onion-like structure with interconnected labyrinthine shells that can reflect sub-kHz airborne sound when placed inside a cylindrical tube. The structure, fabricated by 3D printing, is found to stop 67% of the incident sound on resonance with a volume filling fraction of only 13%. In the second study [8-10] we propose metabeams that can stop all polarizations of sound, that is longitudinal, shear and torsional, travelling down them in the region of the kHz metamaterial band gap. Potential applications include sound and vibration control.

[1] Z. Liu, X. Zhang, Y. Mao, Y. Zhu, Z. Yang, C. T. Chan, and P. Sheng, Science 289, 1734 (2000).

[2] S. H. Lee and O. B. Wright, Phys. Rev. B 93, 024302 (2016).

[3] J. J. Park, K. J. B. Lee, O. B. Wright, M. K. Jung, and S. H. Lee, Phys. Rev. Lett. 110, 244302 (2013).

[4] S. Mezil, K. Chonan, P. H. Otsuka, M.Tomoda, O. Matsuda, S. H. Lee, and O. B. Wright, Sci. Rep. 6, 33380 (2016).

[5] T. Devaux, H. Tozawa, P. H. Otsuka, S. Mezil, M. Tomoda, O. Matsuda, E. Bok, S. H. Lee, and O. B. Wright, Sci. Adv. 6, 8507 (2020).

[6] E. Bok, J. J. Park, A. A. Maznev, S. H. Lee, and O. B. Wright, Phys. Rev. B 108, 144111 (2023).

[7] T. Zhang, E. Bok, M. Tomoda, O. Matsuda, J. Guo, X. Liu, and O. B. Wright, Appl. Phys. Lett. 120, 161701 (2022).

[8] H. Takeda, E. Murakami, M. Tomoda,1 O. Matsuda, K. Fujita, and O. B. Wright, Appl. Phys. Lett. 121, 131701 (2022).

[9] A. Ogasawara, K. Fujita, M. Tomoda, O. Matsuda, O. B. Wright, Appl. Phys. Lett. 116, 241904 (2020).

[10] K. Fujita, M. Tomoda, O. B. Wright and O. Matsuda, Appl. Phys. Lett. 115, 081905 (2019).

Wednesday 22 January 2025 - Session 1 - 14:25 -- Talk 1

Ultrasonic analysis of moisture content effect on the mechanical characterization of wood properties

Rebecca Dijoux[1], Andres Arciniegas[1], Nicolas Wilkie-Chancellier[1],Marguerite Jossic[2,3], Loïc Brancheriau[4]

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Construction, furnishings, musical instruments, daily life, energy - the raw material needs are diverse, as are the materials available to us. Unlike other raw materials, wood and wood-based products are a renewable resource, thanks to the ability of trees to capture carbon from the atmosphere and regenerate and to the determination of human beings to preserve and renew them. The use of wood-based products and construction systems enables buildings to reduce greenhouse gas emissions over their entire lifecycle, and to store carbon over the long term. Despite its use over the centuries, the great variability of this material places it at the heart of perpetual questioning. Indeed, being hygroscopic, anisotropic and heterogeneous, wood mechanical properties will vary according to numerous parameters such as the species considered, the orientation of the sample and climatic conditions. Characterizing the properties of wood and wood-based products is therefore an essential step in their development and use.

Among non-destructive testing methods, acoustic and/or ultrasonic techniques are widely used, due to their relative ease of use and low cost. To analyze the mechanical properties associated with wave propagation in an hygroscopic material, several vibration measurement techniques employ acoustic/ultrasonic actuators and sensors, including force hammers, vibrating pots, accelerometers, microphones, laser vibrometers and ultrasonic transducers. The advantage of these methods lies in their non-destructive nature and their ability to deliver results within a reasonable testing time (approximately one minute per sample).

Given the current state of knowledge, it seems necessary to take into account fluid/structure interactions to better understand mechanical wave propagation phenomena and to better characterize and monitor wood properties. The first challenge of this study is to set up a reproducible experimental protocol for monitoring the evolution of wood's mechanical properties at different moisture contents using ultrasonic transmission measurements. Signal analysis and processing are then carried out in order to extract the propagation parameters (propagation time, wave velocity, wave number,...) and damping (amplitude, wave attenuation) during sample drying. The second challenge involves comparing the results with pre-existing equations and models mentioned in the scientific literature.

In the course of this study, ultrasonic analyses were carried out on samples from different wood species to deepen our understanding of mechanical properties and wave propagation phenomena in wood at different moisture contents. Very little is known about these phenomena beyond the fiber saturation point since scientific consensus differ according to the frequency range of the acoustic technique. Consequently, the aim is to characterize the material's properties over a wide range of moisture contents, from saturated to dry. First results show that ultrasonic testing combined by viscoelastic modeling provides a better understanding of wood mechanical characterization at mesoscopic and macroscopic scales. In order to assist the analysis and interpretations, the results are compared to literature. This last supports the potential of ultrasonic methodologies for the mechanical testing and evaluation of wood, taking into account fluid/structure interactions.

Wednesday 22 January 2025 - Session 1 - 14:37 -- Talk 2

Curved modal pencils for waveguides with continuously variable properties.

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Elastic Guided Wave Testing (GWT) gathers a number of techniques for the inspection of metallic or composite plate-like structures. They enable fast scanning of large parts to detect all kinds of internal or surface defects. However, the complex behavior of GW represents a challenge. In particular, the interpretation of waveforms (obtained experimentally or by simulation) is difficult and can limit the applicability of GWTs.

A recently proposed model – the so-called modal GW pencil model [1, 2] – has been derived from well-known ray methods in optics and bulk elastic waves. It was first applied to field radiation into straight pristine plates of finite size (isotropic [1] or anisotropic [2]) allowing accurate modal interpretation of time-dependent signals. The aim of this presentation is to show how the pencil model can be extended to the case of thin plate-like structures with a possibly curved geometry or exhibiting slowly varying thickness (or material properties). This requires building a system of equations to obtain a ray (eikonal equation) and its differential properties (1st transport equation).

The presentation briefly describes the pencil model for inhomogeneous plates. A few examples of resolution methods are discussed, depending on the application case. In particular, results for an idealized corrosion defect are shown and compared with results simulated by a FE model solving the time-dependent elastodynamic equation.

[1] J. Barras, A. Lhémery and A. Imperiale, “Modal pencil method for the radiation of guided wave fields in finite isotropic plates validated by a transient spectral finite element method,” *Ultrasonics*, **103** (2020), 106078. 10.1016/j.ultras.2020.106078.
[2] J. Barras and A. Lhémery, “Modal pencil method for the radiation of guided wave fields in composite plates of finite size,” *NDT & E International*, **126** (2022), 102598. 10.1016/j.ndteint.2021.102598.

Wednesday 22 January 2025 - Session 1 - 14:49 -- Talk 3

Quantitative Measurement of Defects in Pipes using Guided Wave-based Full Waveform Inversion

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Pipelines have wide applications for use throughout industry, particularly for transporting oil and gas within the petrochemical sector. Various forms of in-service damage can occur, of which corrosion is a major issue. Managing this requires accurate measurement of any damage present to avoid unexpected failure or excessive conservatism. This work focuses on the application of Full Waveform Inversion (FWI) to the non-destructive evaluation (NDE) of inaccessible defects in industrial pipelines. Guided waves, which propagate efficiently over long distances while interacting with defects, offer significant advantages in assessing whether a structure presents some defect or not, but struggle to differentiate benign indications from dangerous flaws without physical access to the area of interest. An inspection approach using FWI applied to guided waves is presented and is shown to provide a high-resolution, quantitative approach to detect and characterise defects, such as cracks or corrosion, in complex pipeline structures.

The study involves the development of a method that iteratively updates an initial finite element (FE) model until it matches the real structure of the studied pipe. Guided waves are simulated within this model, and the resulting scattered wavefields are collected at strategically placed receivers. The core objective of the FWI process is to iteratively minimise the difference between these measured wavefields and the simulated responses, updating the model to accurately reflect the physical characteristics of the defects. The FWI method involves solving the wave equation in the FE model, which governs wave propagation in the presence of defects, and using the adjoint-state method to calculate the gradient of the misfit function. The nodal gradients are used to iteratively adjust the model's geometrical parameters, ensuring that each nodal update moves the defect reconstruction closer to reality. The method captures how small perturbations in the position of the model's surface nodes, affect the stiffness and mass matrices, and subsequently, the measured wavefield of the FWI model.

The results demonstrate that FWI, when applied to guided waves, can successfully reconstruct the geometry and material properties of surface defects with high precision. By accurately modelling the wave interaction with defects, the combined guided waves and FWI process can produce quantitative images that enable an accurate characterisation of physically inaccessible defects, enabling a more comprehensive understanding of the pipe's structural integrity through only a single set of measurements.

Keywords: Full Waveform Inversion, guided waves, non-destructive evaluation, finite element analysis, pipeline defect detection.

Wednesday 22 January 2025 - Session 1 - 15:01 -- Talk 4

Ultrasonic characterization of porous materials using an inverse problem algorithm

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This study investigates the characterization of porous slabs through the analysis of ultrasonic wave propagation. Porous materials are widely used in various engineering applications such as lithium-ion batteries. Understanding the acoustic behavior of these materials is essential for quality control of batteries, as well as for determining their state of charge (SoC) and state of health (SoH). The aim of this work is to show that acoustical measurements can answer these needs.

Here ultrasonic waves are used to assess the internal mechanical parameters of unknown porous slabs. A theoretical model of ultrasonic wave propagation through a multilayered system including porous layers has been developed [1]. This model is based on Biot's theory with adaptations from Allard's formalism [2] to calculate the theoretical transmission coefficient for an incident longitudinal wave.

This model is used to estimate the porosity, density, thickness, and longitudinal wave velocity of the porous layer using an inverse problem algorithm. After validation by comparing theoretical results with experimental data, we aim to apply this approach to battery characterization by measuring the mechanical properties of each layer within the battery to provide estimates of its actual state [3], including the state of charge (SoC) and state of health (SoH).

References:

[1] Y. Moradi, J. Bustillo, L. Haumesser, M. Lethiecq & K. Chikh. "*Towards Monitoring the State of Charge of Li-Ion Batteries using Ultrasonic Methods*". Anglo-French Physical Acoustics Conference 2024 (AFPAC'24), 17-19 January 2024, Lodge on Loch Lomond, Loch Lomond, Scotland.

[2] J.F. Allard & N. Atalla, (2009) "*Propagation of sound in porous media*". Chapters 6-11.

[3] Zhang. B, Y. Lyu, J. Gao, G. Song, Y. Zheng, Y. Lee & C. He (2023). "*Ultrasonic characterization of multi-layered porous lithium-ion battery structure for state of charge*". *Ultrasonics*, *134*, 107060.

Statistical study of defect anisotropy effect on defect imaging accuracy

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Back-propagation-based imaging algorithms require precise resynchronization of signals from the sensor network. Time shifts affecting these signals—usually resulting from sensor clock drifts—can be estimated and compensated in post-processing before applying the back-propagation algorithm [1], [2], using methods such as the Peak Correlation Technique (PCT). However, in some cases, particularly when the defect exhibits some anisotropy effect, additional time shifts can disrupt the backpropagated signals which compromise the accuracy of localization images. The study carried out in this work aims to statistically quantify the impact of these anisotropy-related shifts on the localization quality of defects. Derivations are made in a thin reverberating plate and covariance matrices are stored in a Full Matrix Capture mode for two scenarios: with and without defect. Numerical simulations based on A0 Lamb mode propagation are conducted to validate the theoretical findings.

Key words: back-propagation-based imaging, Peak Correlation Technique, anisotropy-related shifts.

References

[1] O. Bouchakour, E. Moulin, L. Chehami, and N. Smagin, 'Quantification and mitigation of the effect of resynchronization errors in ultrasound sensor network for passive imaging in elastic plates', *The Journal of the Acoustical Society of America*, vol. 155, no. 5, pp. 3283–3290, May 2024, doi: 10.1121/10.0025986.

[2] O. Bouchakour, L. Chehami, and E. Moulin, 'impact of resynchronization errors on the quality localization of defects in reverberant plates', *Anglo-French Physical Acoustics Conference 2024 (AFPAC)*, Jan. 2024.

In-situ mapping of the annealing process using Spatially Resolved Acoustic Spectroscopy

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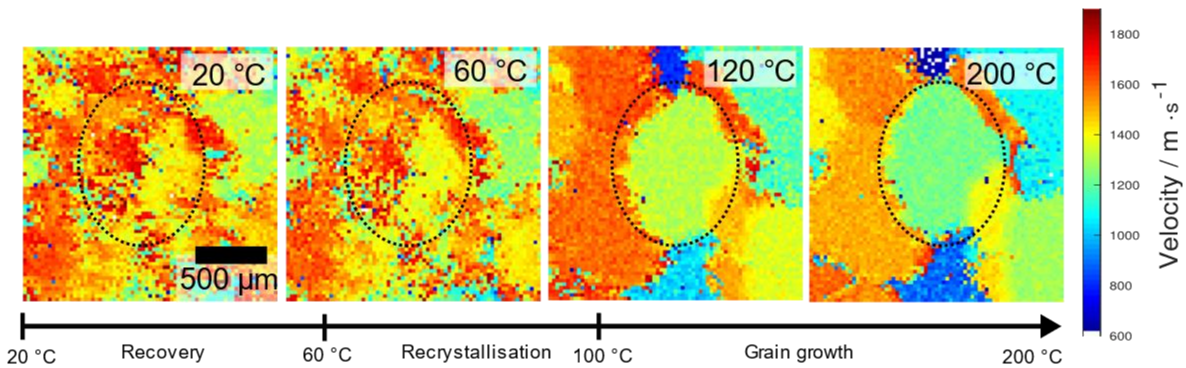

Figure 1. The annealing process observed at different temperatures by SRAS during the recovery, recrystallisation and grain growth.

Annealing is a heat treatment (HT) carried out in metal components to increase ductility and reduce plastic deformation through three stages, recovery, recrystallisation and grain growth [1]. The heat treatment is performed in many different components and alloys to achieve the desired materials' properties. However, deciding the temperature and time for cold working normally is carried out ex-situ, which means doing the HT and then observing the microstructure to know the best combination of these parameters. Spatially Resolved Acoustic Spectroscopy (SRAS) is a technique that provides the possibility to run in-situ observations of the phenomenon.

SRAS [2] is a powerful tool for material characterisation. It utilises laser ultrasonics to robustly and repeatably measure the surface acoustic wave velocity (SAW) [3]. These measurements can then be mapped to create images of material microstructure, identify the crystallographic orientation of each grain, and determine the stiffness tensor. SRAS is a non-destructive and versatile technique, allowing for the rapid measurement of large samples with different compositions and, under different stimuli, to observe in-situ microstructure changes.

In this talk, we will show the real-time monitoring of the recrystallization of new grains in regions exhibiting high plastic deformation. This phenomenon is evidenced by changes in the SAW velocity as shown in Figure 1, where it is observed that new grains are formed as temperature increases and some grow while others are consumed. This new instrument enables the real-time observation of phenomena occurring at different temperatures, opening up highly beneficial research opportunities.

References
[1] R. Smallman et al. Physical Metallurgy and Advanced Materials Engineering (2007), ISBN: 9780080976198
[2] P. Dryburgh et al. Acta Materialia (2022), doi: 10.1016/j.actamat.2021.117551
[3] R. Patel et al. Scripta Materialia (2017), doi: 10.1016/j.scriptamat.2017.07.003

Wednesday 22 January 2025 - Session 1 - 15:37 -- Talk 7

Identification of Lamb Modes on a Sensor Network for a Multimodal Tomographic Approach for Structural Health Monitoring

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The accurate identification and separation of propagating guided modes is a crucial step in the development of multimodal tomographic approaches for Structural Health Monitoring (SHM) of slender thin-walled structures. Classical methods based on multidimensional Fourier transforms are particularly fast and efficient for analyzing spatio-temporal wave signals. These are usually sampled in the direction of propagation at spatially equidistant points from the source. However, this direct method is not applicable when dealing with distributed sensors networks around an area to be monitored, as is the case with SHM tomographic techniques.

This paper investigates the performance of time-frequency transformations and the applicability of a Non-Uniform Fast Fourier Transform (NUFFT) for extracting the multimodal and dispersive properties of guided waves from a dataset obtained by non-linear spatial sampling. Assuming spherical wave propagation and an infinite medium, the signal acquired at a given position is projected along the principal direction of propagation. In this way, the spatio-temporal evolution of the wave packet can be tracked by several distributed sensors.

The study is carried out on signals simulated by analytical and numerical models of wave propagation in a homogeneous and isotropic plate. These are generated by a three-dimensional finite element model in the time domain. Experimental validation is carried out on an aluminum plate with wideband pulse excitation. Generation and detection are ensured by a pair of piezoelectric transducers in a pitch-catch mode to scan a set of points simulating two sensors networks : linear and circular. The first case is used as a reference for comparison.

The results showed that both techniques can be used to identify and separate multiple simultaneous modes in the plate using a non-linear distribution of sensors positions. Time-frequency analysis methods allow extracting the dispersion characteristics of guided waves from one or more receiving points and are therefore more suitable for non-uniform or arbitrary distribution of sensors. However, they present challenges in terms of inverse problem resolution and have significant computational costs. The NUDFT-based technique proved to be faster in dealing with the irregularity of the network, but it requires finer sampling and is therefore impractical for a reduced number of sensors.

Wednesday 22 January 2025 - Session 1 - 15:49 -- Talk 8

Ultrasonic imaging of local acoustical nonlinearities in NDT: instrumentation limits and upgrades

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Ultrasonic imaging methods, in an NDT context, show some limitations regarding specific defects type, such as closed cracks. Recently in the literature, methods based on the loss of amplitude due to nonlinear phenomenon occurring at the defect have been tested on steel samples, and present better sensitivity to closed cracks, allowing for an earlier detection regarding the fatigue of the material compared to standard imaging methods.

Some of these new methods are based on the fact that the superposition principle no longer holds true in case of a nonlinear dependency of the acoustic response on the amplitude of the transmitted ultrasonic wave. It is then necessary to reach a high enough amplitude to detect the nonlinear signatures of the defect, and to define a good indicator of nonlinearity in the response. The "nonlinear images" represent a mapping of this local indicator over the region of interest. The indicator is built by changing the amplitude of the transmitted waves. Such an amplitude variation can be obtained by modifying either the voltage across transducer elements [1] or the number of transmitting elements [2]–[5].

A limiting factor to the industrial application of these methods is the lack of transducers specifically dedicated to this type of imaging. Furthermore, artifacts induced by the instrumentation are problematic for a reliable application of the method.

This study has two objectives: the first one is to analyze some of the artefacts that might be involved in these imaging techniques in order to reduce their contribution to the images. The second one is to propose a design of phased array transducer that will maximize the nonlinear signature of defect, and minimize the artefacts reducing the image contrast.

[1] M. Ikeuchi, K. Jinno, Y. Ohara, et K. Yamanaka, « Improvement of Closed Crack Selectivity in Nonlinear Ultrasonic Imaging Using Fundamental Wave Amplitude Difference », *Jpn. J. Appl. Phys.*, vol. 52, n° 7S, p. 07HC08, juill. 2013, doi: 10.7567/JJAP.52.07HC08.

[2] S. Haupert, G. Renaud, et A. Schumm, « Ultrasonic imaging of nonlinear scatterers buried in a medium », *NDT & E International*, 2016, doi: 10.1016/j.ndteint.2016.12.010.

[3] J. Cheng, J. N. Potter, et B. W. Drinkwater, « The parallel-sequential field subtraction technique for coherent nonlinear ultrasonic imaging », *Smart Mater. Struct.*, vol. 27, n° 6, p. 065002, juin 2018, doi: 10.1088/1361-665X/aabcb2.

[4] J. Potter, J. N. Potter, A. J. Croxford, et A. J. Croxford, « Characterization of Nonlinear Ultrasonic Diffuse Energy Imaging », *IEEE Transactions on Ultrasonics Ferroelectrics and Frequency Control*, 2018, doi: 10.1109/tuffc.2018.2816243.

[5] Z. M. E. Saib, B. W. Drinkwater, et A. J. Croxford, « Characterisation of coherent nonlinear imaging », *NDT & E International*, p. 103107, avr. 2024, doi: 10.1016/j.ndteint.2024.103107.

Wednesday 22 January 2025 - Session 1 - 16:01 -- Talk 9

Estimating Green's functions to enhance leak localisation in buried water pipes

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Being able to accurately locate leaks in pipes is a vital task in the water industry, with millions of litres lost to leakage every day in the UK alone. In previous work [1], we have put forward a method of acoustic source localisation with an array of spatially spread sensors, specifically using the MUSIC algorithm to enable the resolution of multiple leaks with few constraints on the geometry of the array. However, this method, as with most source localisation methods, requires an accurate description of wave propagation between a candidate source location and each of the sensors. In practice, this is difficult, since a realistic pipe will have joints and junctions, introducing reflections and scattering to a measurable degree; forming an analytical model for each particular example would be impractical.

Exploiting the system's reciprocity and linearity, we present a method for a uniform sensor array that estimates the Green's function at each sensor position, from the measured responses to a known excitation at a known position. This approach uses the measured transfer function between each sensor and the one nearest to a candidate source, then backpropagates the remaining distance from the candidate source to the closest sensor. The backpropagation term is determined by averaging transfer functions of sensor pairs with equal spacing, providing an approximation of wave propagation in an idealised infinite, uninterrupted pipe.

To showcase this method, some results will be presented from experimental data of a buried 42 m long plastic pipe, which includes several risers, joints, and end caps; simulated data using an analytical model accompanies this. We will also present a brief sketch of the performance of this method under different parameters, such as signal-to-noise ratio, attenuation, and transmission/reflection coefficients.

References:

[1] Hooper, J. Z., Kalkowski, M., & Muggleton, J. M. (2024). Improving Acoustic Methods of Pipeline Leak Location with Distributed Sensing. *Journal of Physics: Conference Series*, *2647*(19), 192010. https://doi.org/10.1088/1742-6596/2647/19/192010

Wednesday 22 January 2025 - Session 1 - 16:35 -- Talk 10

Diffraction of Ultrasound From the Tips of Cracks: a Comparison of Analytical and Numerical Methods

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- Within Ultrasonic Non-Destructive Testing (NDT), an important technique used is Time of Flight Diffraction (ToFD) which relies on being able to detect diffracted waves. A key factor is that the amplitudes are very small and difficult to pick up above the noise level. Having a better understanding of how beam angles and roughness affect these signals is important for optimal set-ups for inspection design.
- This study is part of a long-term project on modelling the ultrasonic inspection of defects with rough and complex branched geometries. Such problems are very difficult to solve using analytical methods, so a natural alternative is to use numerical methods, such as the finite element method.
- Here we consider initial canonical problems, for which analytical or asymptotic solutions are tractable, to investigate the veracity of numerical methods before their implementation for more complicated geometries.
- In this work we consider a smooth semi-infinite crack, with incident plane waves of high frequency. Using the Wiener-Hopf technique we determine analytical solutions to the problem and compare with solutions obtained using Pogo [1], a time explicit finite element program.
- Initial results are showing good agreement between analytical and numerical results, improving as the finite element models are being refined with respect to representation of the semi-infinite crack and convergence of the solution. These initial canonical problem results give confidence that the behaviour of diffracted waves in Pogo is being modelled suitably to use the finite element model as a substitute for analytical solutions for complex geometries.

References

1. P. Huthwaite, “Accelerated finite element elastodynamic simulations using the GPU” Journal of Computational Physics 257, Part A, pp 687 – 707. 2014.

Wednesday 22 January 2025 - Session 1 - 16:47 -- Talk 11

Real-time Fouling Tomography in Pipes with Ultrasonic Guided Waves

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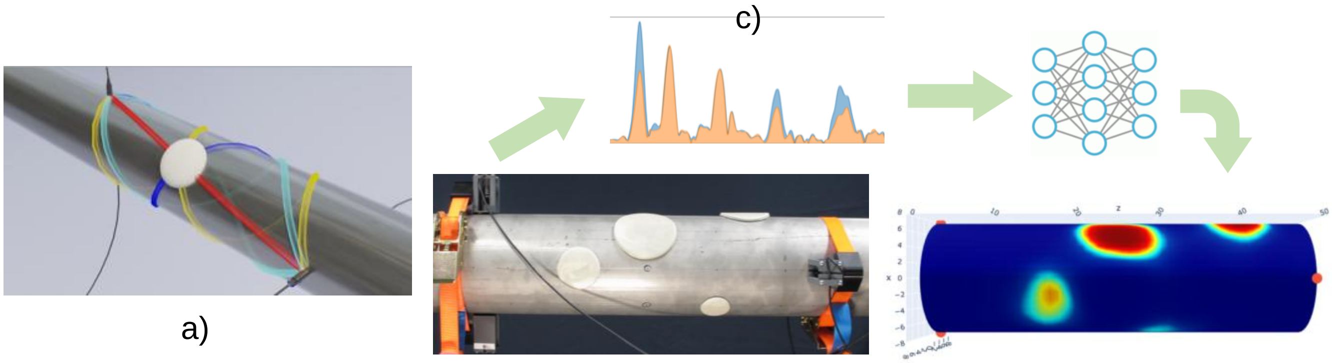
Industrial structures can become fouled for several reasons when unwanted substances accumulate on the inner surfaces. Detection and characterization of the fouled area are thus of critical importance for efficient industrial operations. Guided waves are sensitive to such deposits or defects and are typically generated and recorded using a network of ultrasonic transducers.



a) b) c) d)

Figure 1. (a) Schematic illustration of the experimental set-up with circumferential trajectories between two transducers. (b) Distribution of the fouling phantoms using Blu Tack material. (c) Experimental signal envelope with and without fouling. (d) Neural network output based on experimental attenuation data.

In this work, we present a method for accurate reconstruction of the fouling map using a pre-trained neural network. The training dataset can be quickly generated using an exponential attenuation model and doesn't require demanding finite element simulations. The fouling reconstruction algorithm required two measurements: one on the healthy pipe and another one with accumulated fouling. The attenuation information of the A_0 Lamb modes is then fed to the neural network that can output the fouling map within milliseconds. The proposed method is verified experimentally on the stainless-steel pipe (15 cm diameter, 2 mm thickness) using only four omnidirectional transducers (400 kHz central frequency) strategically placed on the pipe benefiting from the high-order circumferential trajectories (see Fig. 1). Such placement of the transducers (top, bottom, front, back with 50 cm separation) allows for identification of the clockwise and anticlockwise A_0 modes in the recorded signals, thus providing richer information about the pipe deposits with fewer sensors [1]. Moreover, the method can be easily extended to more complex structures e.g., storage tanks or pipeline connections, as it only requires the guided wave trajectories and wavepacket attenuation information.

[1] J. Korsimaa, M. Weber, P. Salminen, J. Mustonen, D. Iablonskyi, E. Hæggström, A. Klami, and A. Salmi, "Wireless and battery-operatable IoT platform for cost-effective detection of fouling in industrial equipment" Scientific Reports, 14084 (2024)

Topological Energy method for imaging delamination damage in rubber-metal assembly using 3D laser vibrometry

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The non-destructive evaluation of flexible rubber-metal composites is a critical problem for several applications, especially in the tire industry. Due to ageing, harsh operating conditions and impact, internal delamination and crack damage develop, causing large areas of separation between the layers. This leads to a deterioration in the performance of the structure and a risk of serious failure.

Over the past decade, various ultrasonic techniques have been developed to perform non-destructive inspection of these complex structures. However, it still suffers from a number of drawbacks, including the difficulty of accurately characterizing of defects and of interpreting the complex wave signals.

This work investigates the applicability of a promising ultrasound imaging technique, namely the topological energy, for the inspection of internal delamination damage. The study is carried out both experimentally and numerically using an accurate finite element model that resembles the original physical structure. The experimental setup uses a piezoelectric transducer for excitation, mounted on the surface of the sample. A 3D laser vibrometer (PSV 500 3D V) is used to monitor the reflected ultrasonic field. The obtained signals represent space-time data for the three components of the wave, which are then used for numerical reconstruction. The latter is carried out in two steps, using a forward and an adjoint model. The first consists of exciting the model at the same location as in the experimental setup and retrieving the complete deformation field. The second consists of the back-propagating time-reversed signals, measured at the same positions as in the experimental setup. The analysis of the two simulated wave fields highlights the echogenic zone, corresponding to an abrupt acoustic impedance variation. The results show that it is possible to locate the defect and estimate its extent.

High frequency diffuse acoustic field correlation for defect detection in Silicon wafers

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Abstract

Silicon wafers are generally subject to various types of defects, in particular those related to the manufacturing process, bonding, and micro-cracks. Several active methods are already proposed for defect detection such as thermography, impact testing, ultrasonic imaging [1,2], or more recently machine learning [3]. This work present an alternative global NDT method based on diffuse wave correlation. This latter is well known in geophysics applications and nowadays is well established for passive NDT/SHM techniques using guided waves (typically Lamb waves) for monitoring large scale structures using few number of sensors only [4]. The principal aim of the presented works is to enhance defect detection by integrating optical sensing techniques with surface acoustic wave (SAW) correlation methods for Layer On Substrate structures (LOS) in high frequency regime (typically [5-20] MHz). The introduction of diffuse field correlation for LOS imaging offers a global, multi-directional assessment of the material, overcoming the limitations of traditional approaches (only on one propagation path direction)[5].

To achieve this goal, signal processing based noise correlation and beamforming imaging [6] in anisotropic material (silicon (100)) is developed. Then, design and fabrication of wide band Interdigital Transducers (IDTs) is made for HF diffuse wave generation. The IDTs in this project are designed to enhance reverberation within the silicon wafer. These transducers are engineered to generate a high-frequency diffuse acoustic field within the silicon wafer, critical hypothesis for the proposed passive detection method. By incorporating Rayleigh waves and HF diffuse field correlation, this research introduces a transformative approach to material characterization, such as defect detection and imaging which offers a large panel of applications such as microelectronic industry.

Key words : Surface acoustic wave , Localization, NDT, IDTs transducers, Noise correlation

[1] B. Masserey, et al., "Defect detection in mono-crystalline silicon wafers using high frequency guided waves." AIP Conference Proceedings. Vol. 2102. No. 1. AIP Publishing, 2019.

[2] A. Mahmoud et al.,. "Review of micro-crack detection techniques for silicon solar cells." IEEE Journal of Photovoltaics (2013).

[3] A. Pan et al.,. "Enhancing wafer defect detection via ensemble learning." AIP Advances (2024).

[4] L. Chehami et al., "Experimental study of passive defect detection and localization in thin plates from noise correlation." Physics Procedia (2015).

[5] D. Fall et al., "Optimization of interdigital transducers for the generation of surface acoustic waves over a large bandwidth (20–125 MHz)." Sensors and Actuators A: Physical (2018).

[6] Y. Lingyu et al., "Guided wave phased array beamforming and imaging in composite plates." Ultrasonics (2016).

Wednesday 22 January 2025 - Session 1 - 17:23 -- Talk 14

Non-destructive characterisation of 316L stainless steel porosity defects in metal laser powder bed fusion using ultrasonics and X-ray computed tomography

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Laser powder bed fusion (LPBF) is a metal additive manufacturing (AM) process used to manufacture components that are not feasible with conventional manufacturing methods. Components manufactured by the LPBF process require nondestructive evaluation (NDE) to ensure that LPBF process defects do not hinder structural integrity or part serviceability. This is especially important for aerospace, medical, and other highly regulated industries. Characterisation of LPBF parts remains challenging due to heterogenous polycrystalline microstructure, solidification defects (e.g. porosity), and unstable AM process parameters. This work utilises ultrasonic immersion testing and X-ray computed tomography (XCT) to quantify porosity content in heterogenous polycrystalline 316L stainless steel LPBF parts. The pore and grain microstructure morphology are affected by LPBF process parameters. The laser-defocusing distance is one of the main process parameters that influence the build porosity and microstructure of the components manufactured in the LPBF process. For this study, a stripe scanning strategy with 67° degrees inter-layer rotation at different laser focus distances was carried out to manufacture porous 316L stainless steel samples. The laser power, scanning velocity, and hatch spacing were kept constant for this study. Ultrasound phase velocity, backscatter, and attenuation coefficient in SS 316L samples were experimentally measured using the conventional ultrasonic pulse-echo and through-transmission immersion techniques coupled with unfocused single-element transducers. The XCT inspection was carried out to obtain the sample density and pore morphology. The results of ultrasonic immersion testing show that phase velocity decreases with a rise in pore density and that the attenuation coefficient increases with frequency and porosity. The results from XCT imaging show that positive laser focus height produces a lack of fusion (LoF) pores, whereas negative laser focus height generates keyhole pore defects. The comparison of XCT and ultrasonic immersion testing results reveals that LoF pores generate higher attenuation due to larger volume and less sphericity than keyhole pores. This study demonstrates that ultrasound NDE can be used to evaluate LPBF pore defects. This work will be extended to produce realistic finite element modeling (FEM) simulations of ultrasound wave propagation inside heterogenous polycrystalline 316L stainless steel. Finally, the results from ultrasonic experiments will be compared against FEM simulations.

Linking Elastic Constants to Microstructure: A Resonant Ultrasound Spectroscopy Analysis of a 316L Textured Polycrystal

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In this work, we report our recent progress on the application of resonant ultrasound spectroscopy [1] (RUS) to a strongly textured stainless steel polycrystal made using the wire arc additive manufacturing (WAAM) process. The RUS technique, originally developed for single crystal elastic characterization, is also capable of solving the inverse problem of polycrystal effective elastic constants determination under the hypothesis that the medium is homogeneous. Additionally, an elastic symmetry family for the polycrystal must be chosen to perform the inversion. We discuss the problem of choosing the effective elastic constants symmetry, based on existing research from the field of texture characterization and polycrystal elastic wave propagation simulation. We show how the experimentally obtained elastic constants relate to the microstructural characteristics of the polycrystal measured by electron backscatter diffraction (EBSD). Finally, we use the elastic polycrystal wave-speed inverse model developed by Lan et al. [2] to derive pole figures from the elastic constants and compare them to those obtained using EBSD.

Figure 1. Stainless steel sample orientation map (top) and (111) and (100) pole figures measured using EBSD (bottom).

[1] A. Migliori *et al.*, « Resonant ultrasound spectroscopic techniques for measurement of the elastic moduli of solids », *Physica B: Condensed Matter*, vol. 183, n° 1‑ 2, p. 1‑ 24, janv. 1993, doi: 10.1016/0921-4526(93)90048-B.
[2] B. Lan, M. A. Carpenter, W. Gan, M. Hofmann, F. P. E. Dunne, et M. J. S. Lowe, « Rapid measurement of volumetric texture using resonant ultrasound spectroscopy », *Scripta Materialia*, vol. 157, p. 44‑ 48, déc. 2018, doi: 10.1016/j.scriptamat.2018.07.029.

Wednesday 22 January 2025 - Session 1 - 17:47 -- Talk 16

1D-CNN method for estimation of crack characteristics for ultrasonic non-destructive evaluation inspections

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Presented here is a Machine Learning (ML) methodology for the automated analysis of ultrasonic A-scan data. Specifically, 1-D Convolutional Neural Networks (CNNs) are used to estimate target quantities relating to the sizing and orientation of possible flaws or defects in components under inspection. The work focuses on two high-priority defect species in industrial plant safety: thermal fatigue and hydrogen cracking. Key innovations presented here include the approach to training dataset generation, which is achieved via realistic 2D physics-based modelling, and data pre-processing steps applied prior to the neural network training.

The use of ML, with a suitable volume of modelled data, demonstrates good performance when estimating defect quantities including height and tilt angle. Also shown is that without specific data pre-processing, performance deteriorates, particularly when estimating the height parameter. Additionally, it has been found that the performance when evaluating rough versus smooth defects is not significantly affected by the presence of roughness. The simulation framework incorporates experimentally measured transducer characteristics, and the data preprocessing mimics standard inspection procedures (bi-directional scanning). The use of modelled A-scan data addresses the common challenge of limited real-world training data in industrial NDT applications.

The intention of this work is to demonstrate the capabilities of ML when applied to A-scan data and show how a neural network could be used to automatically characterise a defect. It is envisaged that a neural network could be incorporated into an ultrasonic inspection system to complement current practice and to promote potential reliable automatic inspections.

This presentation is complemented by "Finite Element Modelling for Machine Learning with Applications to Surface Breaking Crack Analysis" by James Gaffney et al.

Finite Element Modelling for Machine Learning with Applications to Surface Breaking Crack Analysis

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Industries such as the power and aerospace sectors use non-destructive evaluation (NDE) to efficiently detect and characterise cracks to ensure the structural integrity of safety critical components. In the field, practitioners often use ultrasound testing (UT) methods (such as pulse echo, pitch catch, time of flight diffraction) to detect, size and characterise cracks. To help practitioners reliably analyse crack data from the pulse echo method, machine learning (ML) could be utilised. ML is increasingly very well suited to data learning and interpretation as computing power and parallelisation increase. For accurate ML predictions, a sufficient quantity of good quality data is required in order to generate a labelled dataset consisting of sufficient training, validation and testing data. Real defect data can be difficult to obtain, are costly to acquire and only directly relevant to the inspection parameters applied when data were collected. To overcome these limitations, high-fidelity finite element modelling can be utilised. This presentation will explain how finite element method modelling is generating good quality A-scans to be used within ML algorithms. This includes accurate transducer (temporal and spatial) characteristics and crack geometries (obtained from scanned cracks provided by industrial partners). The simulations also include improved procedural methods that mimic practitioner methodology (such as scanning from both sides and manipulating the transducer to get the maximum amplitude value in the scan). The simulations are used by an ML algorithm to predict the tilt angle and height of a 2D surface-breaking, rough crack using pulse-echo UT.

This presentation is complemented by 1D-CNN method for estimation of defect attributes by Thomas Beckingham et al.

Polymer Viscosity Monitoring with Temperature Using *in situ* Ultrasonic Method in a Rheometer Chamber

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Understanding material properties, especially viscosity, is essential across numerous industrial applications, including polymer rotomolding. Conventional rheological measurements are typically destructive and performed outside of the processing environment. Ultrasonic techniques offer a potential solution for real-time, *in situ* viscosity monitoring during industrial processes. In the present study, an ultrasonic instrumentation adapted to an oscillatory Anton-Paar rheometer is developed for simultaneous ultrasonic and rheological measurements. Experiments are performed on liquid polymer (silicone oils) with 4 calibrated viscosities (10^3, 10^4, 10^5 and 10^6 cSt). First, *in situ* time of flight (TOF) measurements are validated by a comparison with classical insertion-substitution measurements at 25°C. Subsequently, a correlation between ultrasonic longitudinal velocity and complex viscosity as a function of temperature is established within the 25–85°C range.

A high temperature 5MHz transducer is in contact under a 4mm thick quartz plate supporting the tested material (Fig.1.a). Synchronized measurements of acoustic signals, viscosity, and temperature are performed. A post processing procedure is implemented to estimate the time of flight (TOF) of the signal propagating through the low-thickness layer (1mm) of silicone oil and reflected by the upper rheometer metallic plate. This post processing procedure is based on the subtraction of the reference signal received without the silicone oil layer from the scaled and time shifted signal obtained with the silicone oil. The time shifting is achieved by intercorrelation, while the amplitude readjustment is done by calculating a weighting amplitude coefficient corresponding to each received wave packet.

Firstly, the developed setup and method are validated on four silicone oils with different calibrated viscosities. The results of the longitudinal velocity at 25°C obtained within the rheometer are compared to velocity measurements performed by a classical transmission method (insertion-substitution). A good agreement is obtained with those obtained in the rheometer: the discrepancies are less than 6.5%. It confirms the reliability of our in-situ measurement method.

In a second phase, simultaneous measurements of the ultrasonic velocity and the complex viscosity are achieved during a temperature rise from 25 to 85°C for the four silicone oils. It allows to track the evolution of the relative ultrasonic velocity as a function of the relative measured complex viscosity of the silicone oils (Fig.1.b). From Fig 1.b, it can be noted a linear increase of the ultrasonic velocity with the complex viscosity with a slope around 0.25 $ms^{-2}Pa^{-1}$. This result confirms the possibility to monitor the polymer viscosity by longitudinal velocity measurement during a variation of temperature.

This study opens new perspectives to polymer viscosity monitoring during industrial process.

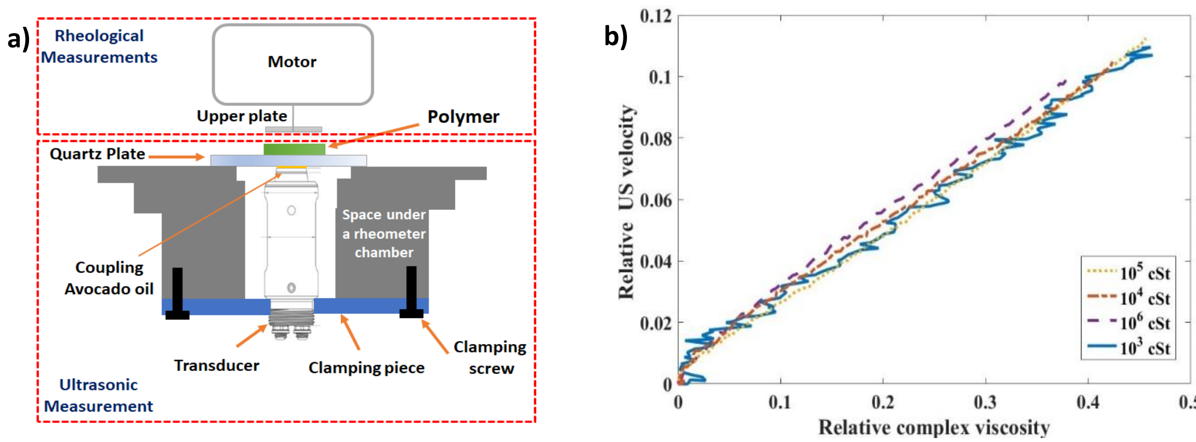

Figure 1. (a) Experimental setup (b) Relative ultrasonic velocity vs. relative complex viscosity for 10^3, 10^4, 10^5 and 10^6 cSt silicone oils during a temperature rise from 25°C to 85°.

Attenuation and polarization of longitudinal critically refracted ultrasonic waves for residual stress assessment

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Longitudinal critically refracted (Lcr) ultrasonic waves are widely used in non-destructive testing, particularly for its ability to provide relevant information on residual stresses present in industrial structures. However, current methods are mainly based on the acousto-elastic effect, which is manifested as a change in the averaged velocity of the Lcr wave in response to the deformation of the solid.

This paper investigates the propagation parameters of the Lcr wave and their sensitivity to residual stresses at the surface of metallic parts. The study focuses first on the characterization of the full wave field in pristine elastic solids, both numerically and experimentally. Emphasis is placed on two main characteristics of the subsurface wave, namely attenuation and polarization. The experimental validation is carried out on a metallic slab. The Lcr wave is classically excited using a compression angle beam piezoelectric transducer with a tilt angle close to the first critical angle. The measurement is performed at several points on the surface along the propagation direction, by a 3D laser vibrometer which detects the three components of the displacement field.

The second part of this work examines the application of the above aspects to the assessment of residual stresses. The experiment is carried out on a steel welded plate. The profiles obtained across the joint are compared with those resulting from relative velocity measurements. The results show that the monitored properties are equally sensitive to variations in residual stress levels. This provides a promising line of work for the development of an efficient baseline-free technique that will overcome the difficulties associated with the determination of the acousto-elastic coefficients as well as the small full-scale velocity variation.

Investigation of Secondary Radiation Forces Near Boundaries: Interaction Dynamics with Primary Radiation Forces

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Abstract:

Understanding the behaviour and characteristics of Secondary Radiation Force (SRF) near boundaries is crucial for advancing acoustic manipulation. Investigating the development and interaction of SRF near boundaries offers valuable insights into particle dynamics within confined environments. This article examines SRF generation through an induced boundary, which perturbs the Primary Radiation Force (PRF) in a mid-focused standing wave field. The experiments are first conducted on an expanded polystyrene sphere in the air, without a boundary. The simulated pressure field is perturbed at various frequencies using a stepped-sine method to identify the natural frequency of a trapped particle. Here we consider the particle to be the mass and the acoustic trap the spring. Next, a boundary is introduced to observe its influence on the natural frequency of the particle and hence the trap stiffness. The introduction of the boundary leads to a significant reduction in natural frequency, indicating the presence of the SRF is quantified by comparing the natural frequency measured with and without the boundary. Notably, as the particle nears the boundary, it encounters an attractive SRF force. To explore this, boundaries of different dimensions are tested, revealing that the attraction increases with the boundary size and the attraction distance slightly varies. These findings not only enhance theoretical models of acoustic manipulation but also enable more precise control in practical applications such as acoustic levitation, medical ultrasound, and microfluidics. The results provide a deeper understanding of SRF behaviour near boundaries, contributing to the advancement of both scientific knowledge and technological applications.

Key Words: Secondary radiation force(SRF), boundary, natural frequency, linear stiffness and perturbation of primary radiation force(PRF)

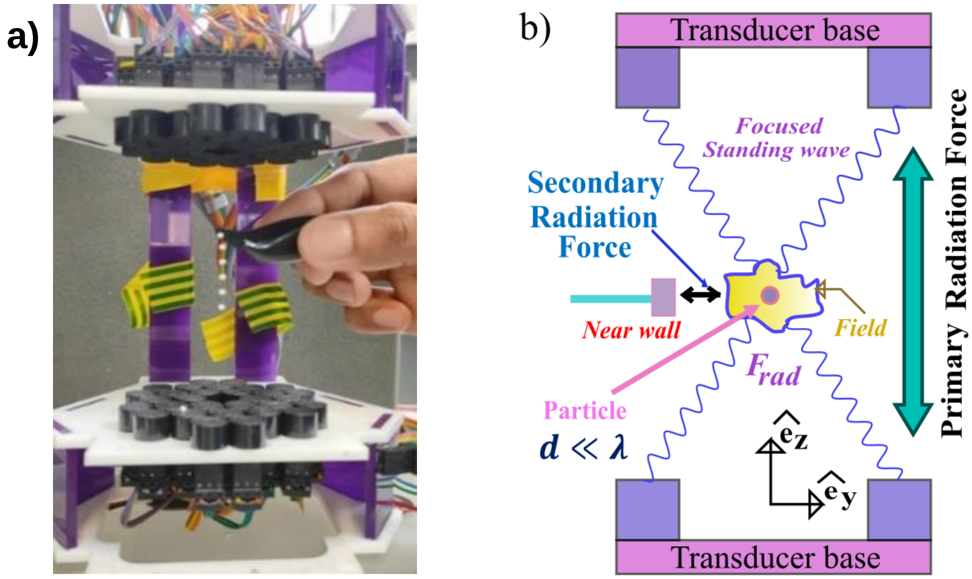

Fig. 1: a) The Ultrasonic Phased Array (UPA) b) The Schematic with experimental environments and parameters

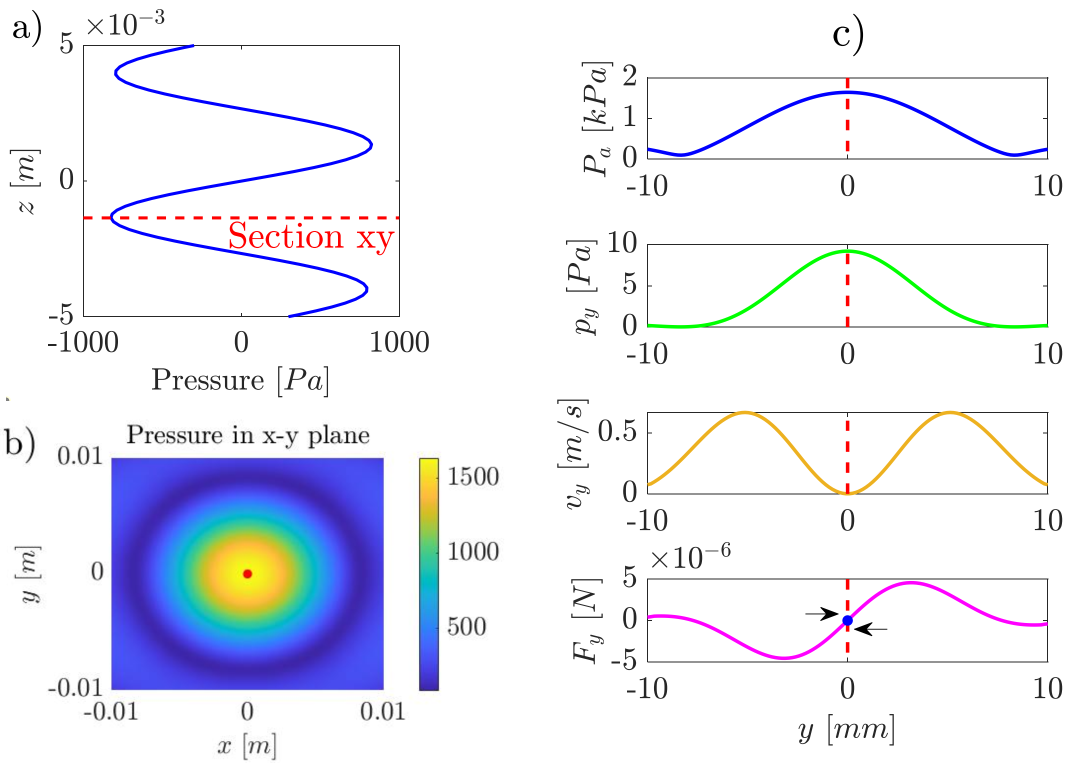

Fig. 2: a) Pressure distribution at central axis b) Pressure field xy plane and c) Ultrasonic radiation force in y direction.

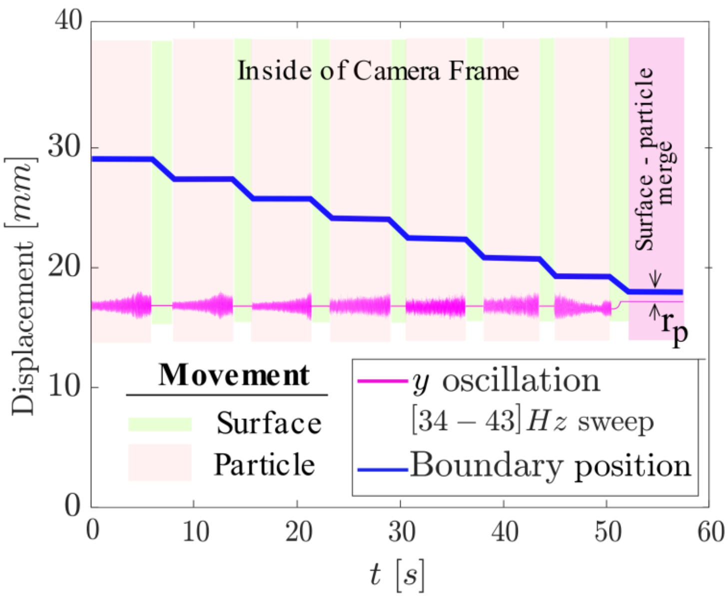

Fig. 3: A Quai-static experimental scenario near a boundary

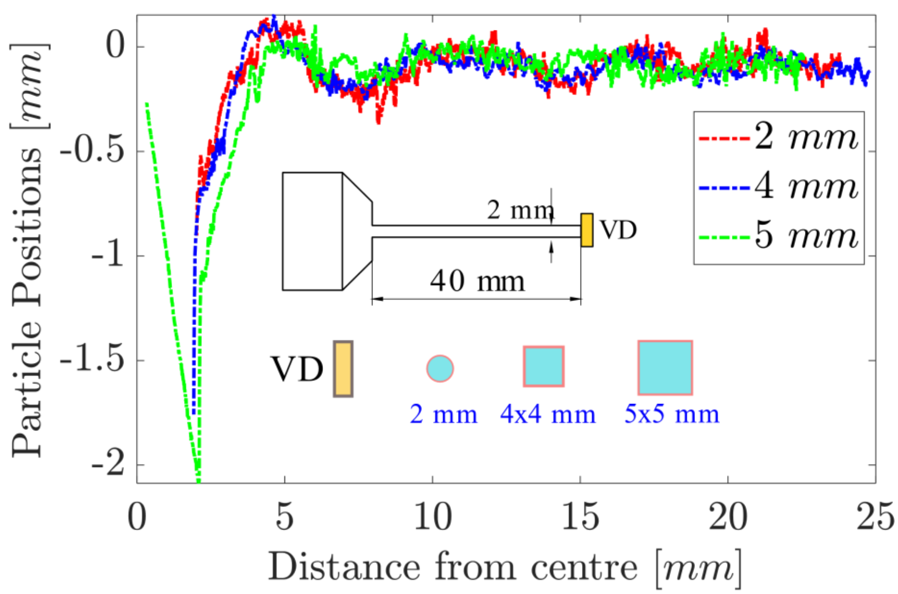

Fig. 4: Effects of particle position at varying boundary dimensions

References:

[1] L. P. Gor'kov. "On the Forces Acting on a Small Particle in an Acoustical Field in an Ideal Fluid". In: Soviet Physics Doklady 6 (1962), p. 773. ISSN: 0002-3264.

[2] T. Fushimi, T. L. Hill, A. Marzo, B. W. Drinkwater; Nonlinear trapping stiffness of mid-air single-axis acoustic levitators. Appl. Phys. Lett. 16 July 2018; 113 (3): 034102. https://doi.org/10.1063/1.5034116

[3] Blake E. Simon, Mark F. Hamilton; Measurement of acoustic radiation force on a sphere near a boundary. Proc. Mtgs. Acoust. 8 May 2023; 51 (1): 045002. https://doi.org/10.1121/2.0001769

[4] Oleg Sapozhnikov, Liubov M. Kotelnikova, Dmitry A. Nikolaev, Sergey A. Tsysar; Direct measurement of the radiation force of a focused acoustic beam on a spherical particle in water. Proc. Mtgs. Acoust. 4 July 2022; 48 (1): 045005. https://doi.org/10.1121/2.0001650

Subwavelength pulse focusing and perfect absorption in the Maxwell fish-eye

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All rays originating from any object point meet again at a single image point. This definition of an absolute optical instrument has been first embodied by the Maxwell fish-eye [1]. By means of a proper spatial variation of the refractive index, all rays emanating from a source at any position will refocus at another image point. This special class of instruments has attracted strong interest for the purpose of perfect imaging. Since the discovery of Maxwell, the family of absolute instruments has vastly expanded. The development of transformation optics, based on geometric transformation of space, has provided a new way to design such devices [2]. Among them are Luneburg or Eaton lenses, which have been revisited by this strategy.

The focusing properties of the Maxwell's fish-eye have been demonstrated experimentally for flexural waves propagating in a thin plate, where spatially dependent phase velocity is obtained by varying the plate thickness [3]. However, as the fish-eye cannot extend to infinity in practice, perfect imaging could not be achieved: a part of the wavefield is lost and cannot converge to the image point. This limitation can be circumvented by closing the fish-eye with mirror boundaries as proposed in Ref. [4],and a real absolute instrument can be achieved in the cavity.

A very different approach to obtain point-to-point focusing is to consider a time-reversal (TR) operation in a chaotic cavity. It has been demonstrated experimentally that ergodicity in a chaotic cavity provides refocusing of a time-reversed elastic pulse both in time and space, with a single detector in the cavity in place of a time reversal mirror on the boundary [5]. Because spatial refocusing with TR remains diffraction-limited, a time-reversed source was introduced at focus point as a sink to cancel the after-focusing outgoing wave, resulting in the sharp refocusing of the in-going wave [6].

Here we propose an absolute instrument in the sense of waves, which means not diffraction-limited. Our aim is to shape the optimal canceling signal that can eliminate any after-focusing echoes. We show that the sink of a TR experiment can play this role. Taking advantage of the closed fish-eye cavity, we demonstrate how the combination of a short time-reversal signal and a sink makes it possible to cancel dynamically the outward-going wave and achieve both perfect spatial and time focusing. When associated with the Maxwell fish-eye, the sink appears to act as a spectacular absorbing device, eliminating very quickly most of the field within the cavity, opening an original route toward perfect absorption.

[1] H. Harman, The Scientific Letters and Papers of James Clerk Maxwell (Cambridge University Press, 1990), Vol. 1(1846–1862), p. 024017.

[2] T. Tyc, L. Herzanova, M. Sarbort, and K. Bering, New J. Phys. 13, 115004 (2011).

[3] G. Lefebvre, M. Dubois, R. Beauvais, Y. Achaoui, R. K. Ing, S. Guenneau, and P. Sebbah, Appl. Phys. Lett. 106, 024101 (2015).

[4] U. Leonhardt, New J. Phys. 11, 093040 (2009).

[5] C. Draeger and M. Fink, Phys. Rev. Lett. 79, 407 (1997).

[6] J. de Rosny and M. Fink, Phys. Rev. Lett. 89, 124301 (2002).

Thursday 23 January 2025 - Session 2 - 09:19 -- Talk 3

Unexpected interaction between acoustic and weak shock waves

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During its propagation, a shock wave may come across different perturbations, including acoustical waves. Several studies have been dedicated to their interaction, investigating notably the stability of the shock waves. When limited to strong shock or neglecting effects such as entropy, this issue has been the subject of many studies for perfect gases. However, the particular acoustic-acoustic interaction between a weak shock wave and a sound wave has been scarcely investigated, especially in common elastic medium. Recently, an experimental investigation has put in evidence a non-negligible

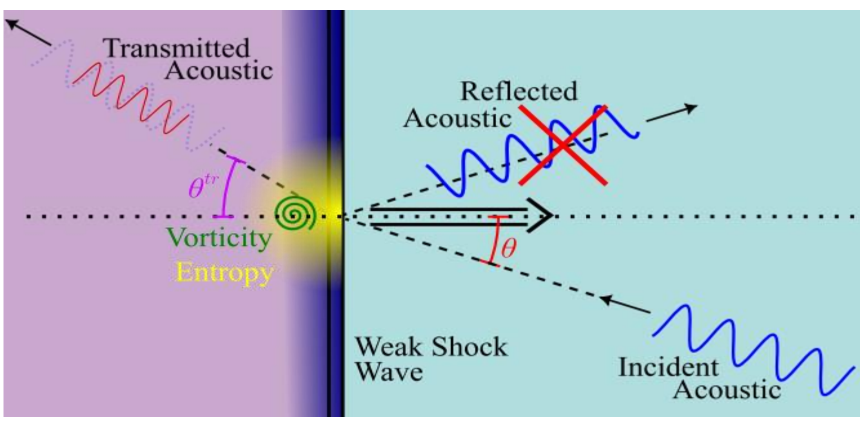

Figure 1: Drawing of contra-propagatives weak shock and incident acoustic waves encountering. The interaction leads to vorticity and entropy modes as well as a transmitted acoustic wave with different amplitude, propagation direction and frequency from the incident wave. Reflection is forbidden due to the supersonic velocity of the shock wave

interaction between those two waves, motivating a more extensive study. [1]

A 2D theory describing the encounter is developed, up to the third-order in shock magnitude. Several unique and unexpected regimes of acoustic transmission are identified according to the incident angle, the strength of the shock or the medium. As displayed in figure 1, generation of entropy as well as vorticity modes are determined. The perturbation of the shock wave by the acoustic wave is also quantified. The Doppler effect due to the encounter of the sound wave with the moving shock is identified. Finally, the amplitudes of the transmitted acoustic wave as well as the generated modes are calculated. In case of normal incidence, model is applicable to hyper-elastic solids and the present theory agrees with the experimental observations.

References :

[1] Ducousso, M. & al., Bulk probing of shock wave spatial distribution in opaque solids by ultrasonic interaction. Physical Review Applied (2021)

Thursday 23 January 2025 - Session 2 - 09:31 -- Talk 4

Complex wavenumber band structure calculations with FEM for characterizing fluid-solid phononic crystals

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The noise generated by offshore maritime activities is a significant concern due to its impact on marine species. Currently, various solutions are available to mitigate these noises. Traditional solutions effective in shallow water environments are no longer suitable at thousands of meters deep due to hydrostatic pressure. To mitigate these noise disturbances, acoustic metamaterials offer promising solutions, especially at great depths. These materials can modify the propagation of acoustic and elastic waves, thereby providing the ability to control and reduce radiated noise in water. Dispersion curves (relating wavevector and frequency for propagating acoustic modes) are essential tools for understanding propagation in metamaterials with a periodic structure. In the presence of losses and solid-fluid couplings, modes generally become complex, and the most relevant problem corresponds to the determination of the complex wavevectors k as a function of the real angular frequency ω. Different methods are currently used, such as the Layer Multiple Scattering [1] or the Extended Plane Wave Expansion [2] methods. They are suitable for spheres, cylinders, or homogeneous layers, but not adapted to complex geometries, which reduces the field of possible studies in terms of design. In this study, a numerical model, based on the Finite Element Method (FEM), has been developed to compute the dispersion curves of non-Hermitian periodic arrays consisting of solid inclusions with arbitrary geometry within a fluid medium. The variational principle considering Bloch-Floquet relations is developed, leading to an eigenvalue equation that gives the complex wave vector for a given real angular frequency ω. This approach allows to examine propagation modes within the structure under realistic conditions for sound sources by imposing a real frequency and searching for the associated modes.

The method is initially applied to a 1D solid-solid rubber-epoxy bilayer, and the corresponding results are compared to the results of an analytical model. Then dispersion curves are computed for a 2D solid/solid periodic array of rubber wires in a nylon matrix, and they are compared to the results obtained by the plane wave expansion method. Next, the analysis is extended to 3D solid-fluid periodic arrays of steel spheres in water, and the results are contrasted with those obtained by the Layer Multiple Scattering method. The

generalization of the method to structures with internal losses is emphasized. On the one hand, the developed method thus allows the characterization of coupled solid-fluid phononic crystals with more complex geometries, thanks to finite element modelling. On the other hand, it is possible to build isofrequency diagrams more efficiently with the complex wave number as an eigenvalue. This approach would notably enable the comparison of dispersion curves calculated at real frequencies with transmission loss curves of phononic crystals adapted to underwater noise reduction.

[1] Sainidou, Rebecca et al., (2005). The layer multiple-scattering method applied to phononic crystals. Zeitschrift fur Kristallographie. 220. 848. 10.1524/zkri.2005.220.9-10.848.

[2] Laude, Vincent et al., (2009). Evanescent Bloch waves and the complex band structure of phononic crystals. Phys. Rev. B. 80. 10.1103/PhysRevB.80.092301.

Experimental method for the retrieval of scattering coefficients of underwater metamaterial-based acoustic panels

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Material scattering coefficients remain the most widely used indicators for characterizing acoustic panels, either in air or water environments. Ideally, in order to connect these coefficients with both theoretical models and target applications, they should represent the scattering by a (virtual) transversely infinite panel. This constitutes a significant challenge, since measurements are usually carried out in open water tanks with panels of limited transverse size. In practice, measured pressure fields include contributions related not only to the panel material and structure, but also to its edges and support rig.

An experimental method used to extract the relevant coefficients in such a context is the 3-point method [1]. As its name suggests, it involves 3 pressure measurements at different hydrophone positions, on both reflection and transmission sides. This method then allows incident, reflected and edge-diffracted pressures to be found on one side, and transmitted, edge-diffracted and the so-called “infinite” pressures on the other. The “infinite” pressure corresponds to a backscattered wave on the transmission side and is used as a control parameter. A well-applied time window removes contributions from tank wall reflections, canceling this parameter.

When studying particular panels called periodic macro-inclusionary metamaterials, the complexity of these measurements is increased. Above a certain cut-off frequency, they behave as diffraction gratings and introduce off-normal diffracted waves, with a propagation angle function of the grating period and the frequency.

As it doesn't consider these additional waves, the 3-point method only works below the cut-off frequency for these panels. Above, the method has been revised to take these additional propagating waves into account, leading to the 5-point method [2].

This method is similar to the 3-point method but requires 5 pressure measurements at different points instead of 3. As the 3-point method, the 5-point method involves approximations which need to be studied to determine their impact on results.

To this end, measurements are carried out on a test panel made up of removable steel bars, allowing modularity of periodicity and configuration. Several results are studied, initially in the form of pressure field mapping, then in a smaller spatial window over a wider frequency range. The results are then compared with those obtained using finite element method (FEM) on an infinite panel. FEM is also used to test the method on different virtual panel configurations, using the same methodology as for the measurements.

[1] : Laetitia Roux, Monique Pouille, Christian Audoly, and Anne-Christine Hladky. Panel measurement method for the determination of scattering coefficients and edge diffraction in an open water tank. The Journal of the Acoustical Society of America, 147(2):1104–1112, February 2020

[2] : Laëtitia Roux. Acoustic metamaterials for underwater applications : homogenisation methods, design optimisation and experimental characterisation. Phd thesis, Université de Lille, September 2021.

Domain decomposition method for coupling semi-analytical form and finite element models of wave propagation.

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The purpose of the study is to simulate experiments in **N**on **D**estructive **T**esting, **S**tructural **H**ealth **M**onitoring or **I**maging an arbitrary large size layered structure. That structure supports local features of small size (e.g. stiffeners, sensors, other multi-physical entities) which disturb or create wave propagation (Figure). We aim to quantify the effects of these added features on the wave propagation within the main structure. The latter being large, standard 3D numerical methods, such as the **F**inite **E**lement (FE) method, are computationaly prohibitive.

On the other hand, the added features lend themselves well to FE modeling. Furthermore, the in-house **T**ransient **F**ield **C**omputation sofware (TraFiC[1]) based on the **F**ourier **F**ourier **L**aplace (FFL[2]) method enables efficient simulation of wave propagation in large flat or cylindrical layered waveguides in the absence of features. Our goal is thus to formulate and implement a hybrid method that integrates the different solvers used for each subsystem. In this context, the selected hybrid method relies on a **D**omain **D**ecomposition **M**ethod (DDM). DDMs are mainly developped to parallelize and accelerate computations; however, the distinct nature of the solvers calls for specific adaptations.

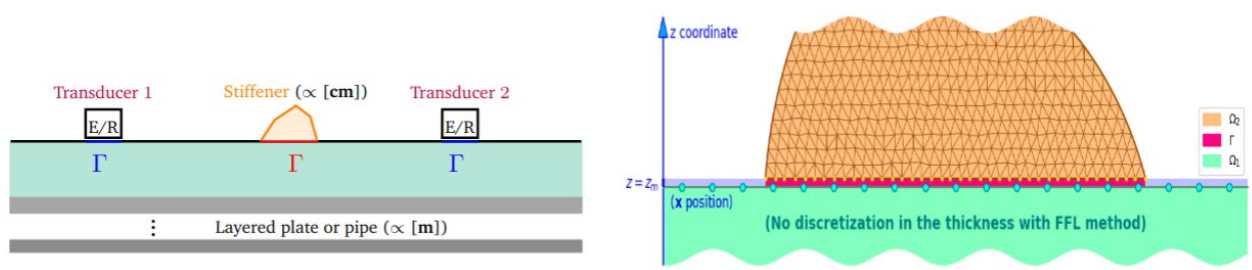

Figure – Geometry (Left) and Different meshes on the shared boundary (Right)

As commonly done in available literature addressing such situations, a non overlapping DDM is used to separate the structure from a feature added on its surface into two subdomains. This method is iterative, and consists at each iteration in solving a boundary-value problem in each subdomain. The boundary data on the shared boundary, for each problem, is defined using the solutions in both subdomains from the previous iteration. Following previous research[3] on Laplace and Helmholtz equations, a sequence of Robin conditions (impedance-like) is imposed on the shared boundary to ensure the convergence of the DDM. These Robin iterations are updated iteratively based on prior solutions, and the algorithm is proven to converge to subdomain solutions that satisfy the requisite kinematic and dynamic transmission conditions.

The DDM with the FFL method presents additional difficulties compared to standard DDM. To ensure the convergence of the DDM, we must address three major challenges. Firstly, the Robin condition ensure convergence of the DDM, but TraFiC provides the strucure response under normal stress boundary conditions. Secondly, the fields in TraFiC must satisfy the spatial Nyquist-Shannon criteria, particularly discontinuities must be smoothed. Lastly, a data exchange protocol between FE and TraFiC must be developped. Considering two-dimensional problems in a first stage, FE computation can also be performed in the large structure, allowing for a step-by-step validation of the DDM. Firstly a reference case is defined. Then, the validation of the DDM with FE in each subdomain is done to avoid the difficulties listed above. Futur work will focus on substituing FE with TraFiC within the main structure, for which we have potential solutions allowing to address the aforementioned challenges.

Research project financially supported by the DGA-AID and the CEA.

[1]https://github.com/eric-ducasse/TraFiC

[2]https://www.sciencedirect.com/science/article/abs/pii/S0041624X16300105

[3]https://hal.science/cel-01100932v4

Simple modelling of combined effects of stress and of rolling on anisotropy of guided wave radiation validated by finite element computations

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A model for the propagation of elastic guided waves in a plate subjected to multiaxial stress has been developed, assuming an isotropic initial state of the plate [1]. Here, we are interested in the case where the plate in its initial (unstressed) state is anisotropic due to the effects of rolling on its microstructure. Our aims are i) to derive a simple model predicting variations of modal wave velocities in rolled plates subjected to stress, ii) to account for both the diffraction effects of transducers and their bandwidth insofar as they affect time-of-flight measurements (usable in tomographic methods to characterize stress distributions [2]). General formulations in the literature of combined effects of elastic anisotropy and acousto-elasticity are very complex and imply a huge number of material constants to be known that prevent them from being used for inverting modal velocity variation for characterizing stress.

The model for predicting modes in stress-affected rolled plates is based on a modification of the semi-analytical finite element method (SAFE) to take account of anisotropy (as in [3]) and acousto-elasticity (as in [1]) and is combined with a semi-analytical model of modal radiation by finite sources [3]. In parallel, a time-dependent finite element model has been developed [4] to deal with various non-linear phenomena, including acousto-elasticity.

In this work, fields radiated by a finite source over a given bandwidth are computed in various cases of elastic anisotropy and applied stress by both the proposed simple modelling approach and the FE code for cross-validation. The two methods in hands share almost nothing in their core principles, except they were both developed to predict acoustoelastic propagation in waveguides. It is therefore unlikely that an error made in deriving or implementing one could lead to erroneous results similar to erroneous results predicted by the other. Correlatively, the fact that both methods predict the same results gives confidence in their ability to both converge towards accurate solutions when solving problems similar to those treated for validation purposes.

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[1] A. Abderahmane, A. Lhémery and L. Daniel, "The effect of multiaxial pre-stress on Lamb and shear horizontal guided waves," *J. Acoust. Soc. Am.* **149** (2021), pp. 1724-1736.

[2] A. Abderahmane, A. Lhémery and L. Daniel, "Stress imaging by guided wave tomography based on analytical acoustoelastic model," *J. Acoust. Soc. Am.* **151** (2022), pp. 2863-2876.

[3] J. Barras and A. Lhémery, “Modal pencil method for the radiation of guided wave fields in composite plates of finite size,” *NDT&E Int.* **126** (2022), 102598.

[4] A. Dalmora, A. Imperiale, S. Imperiale and P. Moireau, “A time-domain spectral finite element method for acoustoelasticity: Modeling the effect of mechanical loading on guided wave propagation,” *Wave Motion* **129** (2024), 103328.

Thursday 23 January 2025 - Session 2 - 10:42 -- Talk 8

Reconstruction of 3D Slowly Varying Thickness Waveguide Using Adiabatic Lamb Modes and Critical Thicknesses.

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In recent years, the utilisation of Additive Manufacturing (AM) processes for producing components with intricate geometries has expanded considerably. These complex 3D-printed structures frequently consist of thin shells, plates with varying thicknesses, or materials exhibiting functionally graded properties. The enhancement of Non-Destructive Testing (NDT) methods, especially with guided waves, presents a distinctive challenge, particularly when employing localised, contactless, or all-optical techniques such as laser-ultrasound. The utilisation of elastic waveguides permits the propagation of waves with complex dispersion characteristics, even in instances where the waveguides exhibit graded elasticity or non-uniform geometric features. Such properties give rise to atypical wave propagation phenomena. A substantial body of theoretical, numerical, and experimental studies has been devoted to the investigation of guided wave behaviour in free elastic plates with varying cross-sections and in graded elastic materials [1]. Nonetheless, the study of ultrasound propagation in these specific waveguides remains a relatively unexplored area of research.

The objective of this study is to deepen our understanding of the physical behaviour of adiabatic modes [2] in inhomogeneous elastic plates, with a particular focus on their adaptability to small perturbation. This study specifically examines higher-order adiabatic Lamb mode propagation in waveguides with linearly varying thickness. The analysis focuses on the impact of critical thicknesses, including cut-off (k=0) [3] and Zero-Group Velocity (V_g~0) [4] thicknesses, on mode propagation. By employing a pulsed laser with broadband excitation, the study enables the generation of Lamb modes, facilitating the observation of these pivotal points. Furthermore, thickness variations in all directions introduce substantial effects on mode behaviour, imparting an "anisotropic-like" character to the plate. Leveraging the observed cut-off phenomena, this experimental approach enables accurate reconstruction of the elastic waveguide profiles in AM-plate (aluminium) exhibiting such thickness variations.

[1] Pagneux and A. Maurel, Royal Soc. London Proc. Series A 462 (2006).

J. Postnova and R. V. Craster, Wave Motion 44 (2007).

[2] A. Pierce, J. Acoust. Soc. Am. 37, 19 (1965).

[3] Z. Hamitouche, M. E.-C. El-Kettani et al., Acta Acustica united with Acustica 95, 789–794 (2009).

[4] D. Clorennec, C. Prada et al., Appl. Phys. Lett. 89, 024101 (2006).

Thursday 23 January 2025 - Session 2 - 10:54 -- Talk 9

Bubbles as a means of weak-source amplification – 3d printed bubble-capture technique and its output dampening and frequency altering effects

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There is a growing need for underwater acoustic devices that are small in size compared to the wavelength that they produce. Current methods for high-power transmissions at lower frequencies rely on the use of large displacements or a large radiating area which is not feasible for a truly compact device. Work has already been done at the University of Strathclyde Department of Electronic and Electrical Engineering in the Centre for Ultrasonic Engineering studying the lesser water-boatman male insect (*Micronecta scholtzi*) which communicates through efficient generation of underwater sound despite being much smaller than the wavelength of its output. This is achieved by the animal using its air-supply as a secondary amplifier. As with other Corixinae the initial sound is performed by stridulation although in this case the striated organ and plectrum are located on the right paramere of the genital appendage, sending vibrations throughout the body of the insect. These vibrations in the body of the insect create a reactive acoustic near field in the surrounding water. It is thought that due to the tiny size of this insect compared to other of its species the stridulitrum is nearer to the carried bubbles which allows for greater pressure transfer into the bubble, stimulating the air supply bubble to oscillate at its Minnaert frequency. This frequency then represents the de facto "tone" of the insect's mating call at a much larger call volume than the insect would be able to produce through it's own physiology. The creation of a new system of bubble-based transmission based on this phenomenon is the focus of this work. These bubble-based transducers will be far more compact and far lighter than traditional underwater transmission technologies and so allow low-frequency transmission from much smaller and possibly unmanned surface and underwater vehicles.

Under natural conditions these bubbles would disseminate into the surrounding liquid or move away from the operational area.

At present one option of bubble tethering showing promise is 3d printed resin cages with a superhydrophobic coating and specially designed apertures. They are functioning as a means of non-desired frequency dampening with desired frequency amplification at only lower levels of signal which with further alterations will be able to be able to make a near-single frequency detection device for weak underwater signals.

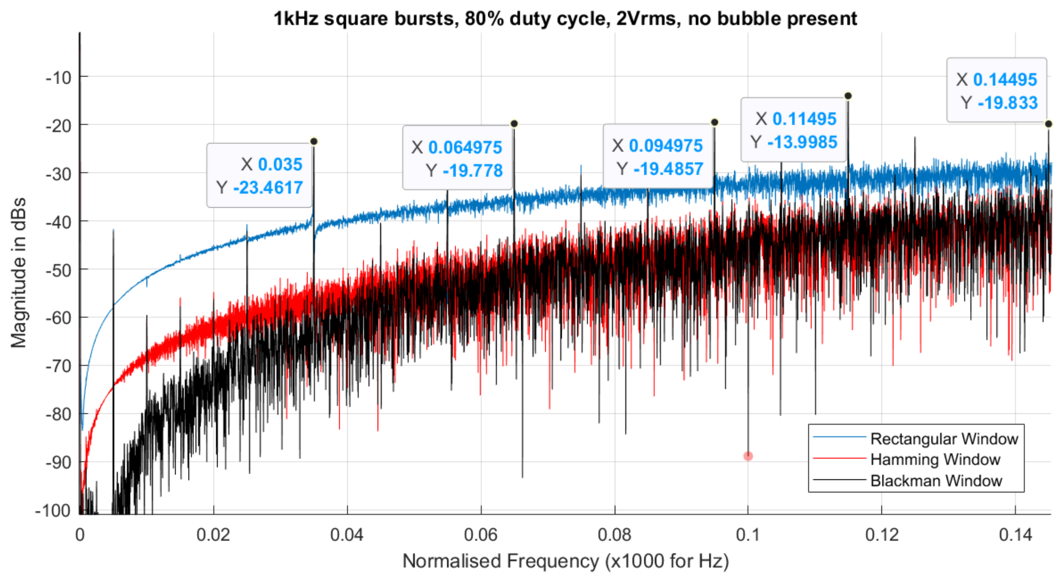

Figure 1: Magnitude and Frequency Values Without A Caged Bubble Present

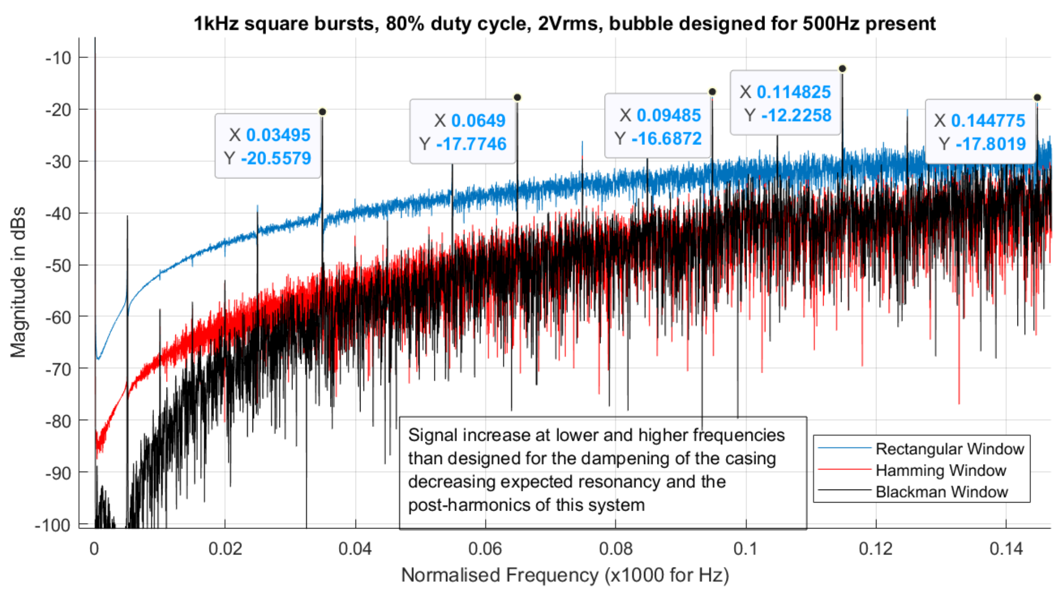

Figure 2: : Magnitude and Frequency Values With A Caged Bubble Designed for 500Hz Present

Thursday 23 January 2025 - Session 2 - 11:06 -- Talk 10

Torsional pendulum driven by sound-matter orbital angular momentum transfer involving acoustic vortices

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The transfer of the orbital angular momentum from sound to matter using acoustic vortex beams has been experimentally revealed only recently. The physics of such a process may involve two distinct mechanisms that can add one to another: a dissipative one driven by sound absorbing targets and a nondissipative one driven by angular momentum conversion as a result of a scattering process. In both cases, the mechanical consequence is the appearance of an acoustic radiation torque exerted on the irradiated body. Here, following recent developments of torsional pendulum driven by sound-matter orbital angular momentum transfer, we report on our recent advances, which are two-fold. First, we report on drastic improvement by more than two orders of magnitude of the quality factor of the mechanical resonance, reaching values >1000. Second, we extend the detection and measurement of acoustic radiation torque from a scalar framework to situations where the vectorial nature of the angular momentum matters. These results contribute to the development of sensitive wave-matter devices for rotational metrology applications encompassing material and wave aspects. This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No 101027737.

Thursday 23 January 2025 - Session 2 - 11:18 -- Talk 11

Acoustic Pseudo-Vortices with Tunable Orbital Angular Momentum

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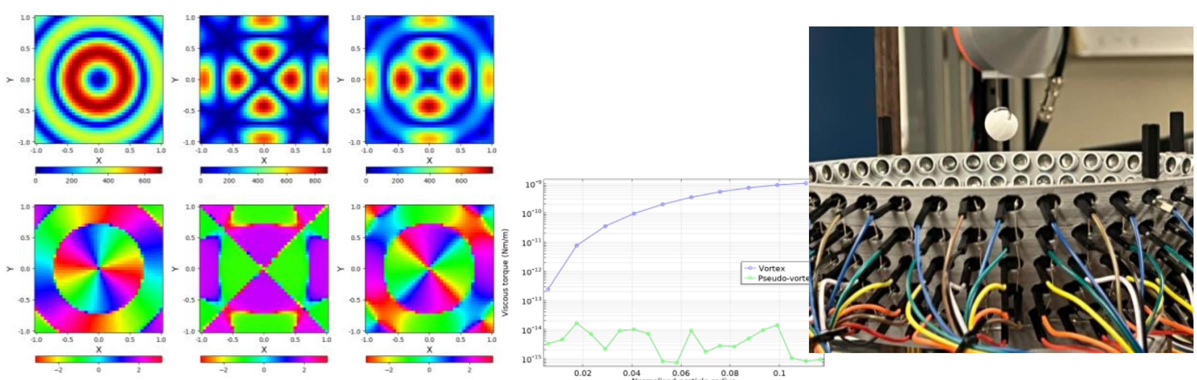
Acoustic vortex fields have been widely studied in the manipulation applications of materials in various media. However, due to orbital angular momentum caused by helicoidal wavefront, manipulation of the objects can be unstable. Several solutions were proposed to mitigate the high-speed rotation in vortices e.g. multiplexing of opposite chirality vortex fields using a phased array of transducers [1]. Another type of acoustic tweezers has been recently proposed in liquid media, the so-called petal field, that instead of continuous phase modulation requires only two opposite phases generated by the phased plate on top of the transducer [2].



a) b) c) d) e)

Figure 1. Absolute acoustic pressure and phase of vortex (a), petal field (b), and their sum (c). (d) Finite element method calculation of acoustic torque acting on a spherical particle as a function of its radius in vortex and petal fields. (e) Stable levitation of 1.5 cm styrofoam sphere in the petal field.

In this work we extend the applications of petal fields to airborne levitation using a phased array of transducers (see Fig. 1). The air-coupled ultrasound transducers operate at 40 kHz and are arranged into an open spherical sector with 20cm in diameter. The FPGA-based driving electronics allow for independent control of the phase and amplitude of each transducer with up to 30 Vpp. We have demonstrated both, experimentally and theoretically, that the petal field does not induce the orbital angular momentum while generating a similar acoustic radiation force as the vortex field and can stably levitate Mie particles. In addition, we propose two methods for controlling orbital angular momentum: petal field rotation in discrete steps by shifting transducers' activation in a polar direction; and mixing of petal and vortex fields with different ratios that enable control of the rotation speed of the spherical objects.

[1] A. Marzo, M. Caleap, and B. W. Drinkwater, Phys. Rev. Lett. 120, 044301 (2018)

[2] Y. R. Jia , D. J. Wu , J. Yao , Q. Wei , Z. Xu , and X. J. Liu , Appl. Phys. Lett. 116, e263504 (2020)

Acoustophoretic particle guidance in air using an ultrasonic phased array

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Over the past decade, advancements in acoustic levitation and tweezing have progressed significantly, primarily driven by developments in acoustic field shaping with phased arrays of transducers. This has enabled rotation and 3D translation of particles of various sizes and shapes [1]. These developments have opened new applications of air ultrasound including microassembly and containerless processing of materials. This study presents a novel particle manipulation technique in which particles are guided within a static ultrasound field by locally applying an acoustic radiation force, creating a directional push that determines particle descent trajectory under gravity.

The array of point air emitters surrounding the work area allowed for dynamic reconfiguration of the field to change the particle descent trajectory. For this application, the acoustic vortex field proved optimal, offering both strong mechanical action on the particles and axial symmetry, allowing for precise 3D particle trajectories. By adjusting the vortex angle as well as its pressure (Fig. 1a,b), the particle fall distance can be precisely controlled. (Fig. 1c).

A method for generation an inclined vortex by calculating the required phases and amplitudes for the array elements (Fig.1 d,e) has been developed. The motion of a small compared to the wavelength particle in gravitational and ultrasonic fields has been simulated by numerically solving Newton’s second law (Fig.1 a) with the acoustic radiation force calculated using the Gor’kov approximation.

A potential application of the proposed manipulation method is droplet-based printing, which typically uses a stationary droplet injector and a moving print bed [2]. The proposed method eliminates the need for moving parts, allows multiple nozzles to operate simultaneously, each of which can be electronically reconfigured through precise control of signals on the array elements.

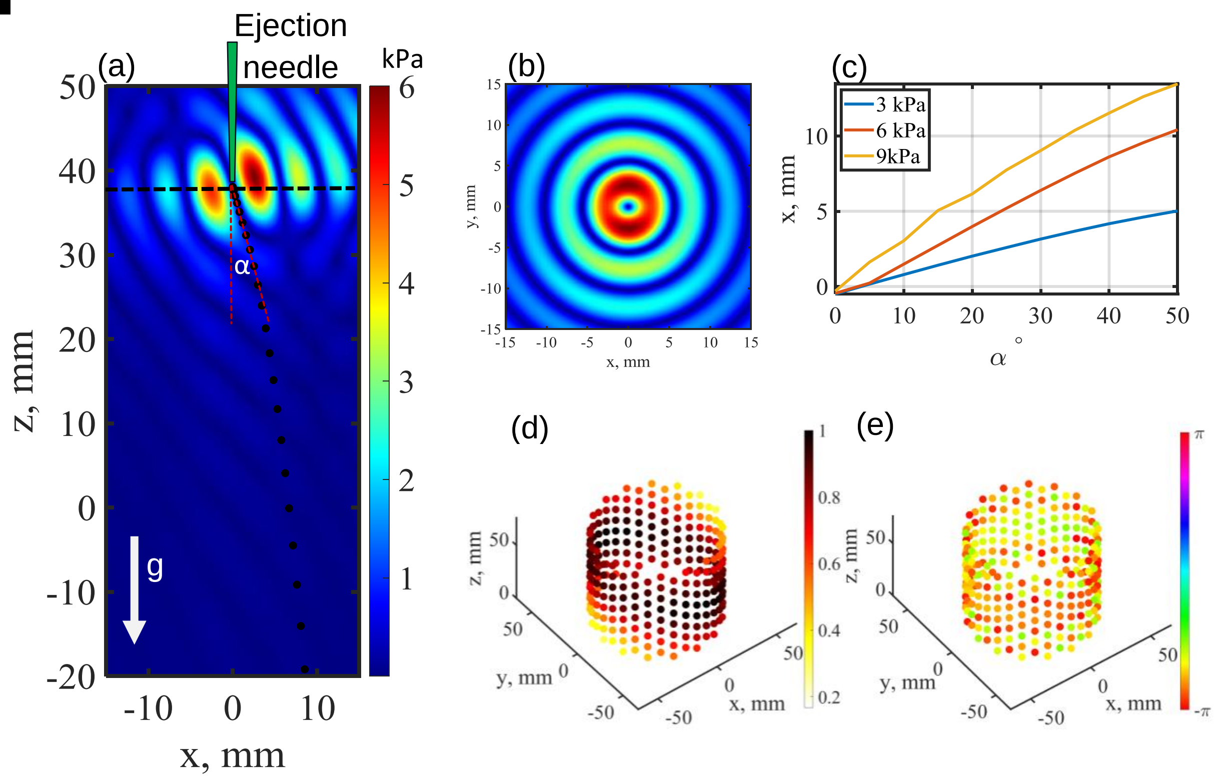

Figure 1. (a) Generated by the phased array tilted vortex field and the simulation of the movement of a small water droplet, (b) pressure distribution in the transverse plane. (c) Particle distance from the center in the $z = -20$ mm plane as a function of the vortex pressure and angle. (d) Amplitude and (e) phase of the applied signals to the phased array.

In the work, we presented a method for guiding particles using an acoustic vortex. A computational model was developed to generate a tilted vortex using a phased array and to simulate particle trajectories within the ultrasonic and gravity fields. Preliminary experiments with a 256-element phased array demonstrated repeatable trajectories for a sequence of water droplets, achieving a deviation of 2 mm over 8 cm distance and the ability to deposit droplets on a plate within 5x5 cm area.

References

1. Marzo, et al. Holographic acoustic elements for manipulation of levitated objects. Nat Commun 6, 8661 (2015).
2. Jiang J., et al. Review of droplet printing technologies for flexible electronic devices: materials, control, and applications. Micromachines 2024, 15, 333.

Generation of reconfigurable patterns on water-air interface using acoustic radiation pressure

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Acoustic radiation pressure (ARP) has been extensively studied for its ability to manipulate fluid interfaces without physical contact [1,2]. In our previous work, we have shown the possibility to control the spatiotemporal characteristics of interface deformation induced by ARP. By means of numerical simulations and an experimental approach, normal incident pressure wave configuration has been investigated.

In this work, we propose to investigate the influence of oblique incidence waves on water-air interface deformations generated by ARP. By controlling the angle of the incident acoustic field, both experimentally and numerically, we demonstrate the generation of complex, contactless deformation patterns, including ellipsoidal shapes. This approach is then extended to a system combining two ultrasonic transducers to further explore the effect of multiple wave fields on the deformation process as shown in Fig.1.

Figure 1: Image of a deformation of the water-air interface by combining two ultrasonic transducers.

Finally, the system was scaled up to utilize seven acoustic beams, enabling the creation of a dynamic digits display on the water surface. By adjusting the incident acoustic field in time and space, numerical values ranging from 0 to 9 were successfully displayed.

These results illustrate the potential of ARP for dynamic manipulation of fluid interfaces, opening avenues for applications such as enhanced communication across fluid boundaries.

References:

[1] F. Sisombat, T. Devaux, L. Haumesser & S. Callé, *Water-air interface deformation by transient acoustic radiation pressure*. Journal of Applied Physics 132, 174901 (2022).

[2] F. Sisombat, T. Devaux, L. Haumesser & S. Callé, *Contactless deformation of fluid interfaces by acoustic radiation pressure*. Scientific Reports 13, 14703 (2023).

Rotational Behavior of an Ultrasonically levitated Droplet Using Phased Array

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Fluid processes such as mixing and stirring different solutions are essential in fields such as analytical chemistry, material science, and drag discovery. However, these processes have problems such as non-uniformity of concentration caused by the container wall. One solution is the development of container-less processes. Hasegawa et al. (2020) succeeded to levitate two droplets with an ultrasonic phased array system and investigated the coalescence dynamics of these droplets. Honda et al. (2023) revealed that the internal flow generated during coalescence enhances mixing. Effective mixing techniques are especially sought after, as the laminar flow within micro-sized droplets limits natural mixing. Here, we use phased-arrays to induce rotation in the levitated droplet and understand how this can contribute to better mixing. This study clarifies the effects of droplet rotation on both droplet shape and internal flow.

The experiment was conducted with phased-array levitator with 72 small ultrasound transducers controlled through an Arduino Nano. As Figure 1 shows, the upper and lower bowls are divided into 4 sections, and an acoustic vortex is generated by giving a signal that is shifted by $4/\pi$ between each section. By switching the Standing Wave and Vortex signals at high speed, angular momentum is applied while keeping the droplet suspended. The frequency of each transducers is 40 kHz consuming around 10 W. The droplet shape and internal flow field were measured by visualization when the timing of rotation was used as parameters. Water and Glycerin were used as test fluids.

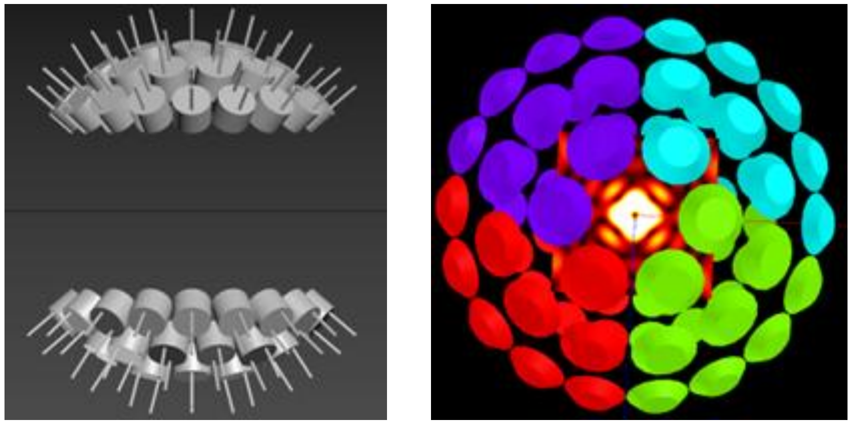
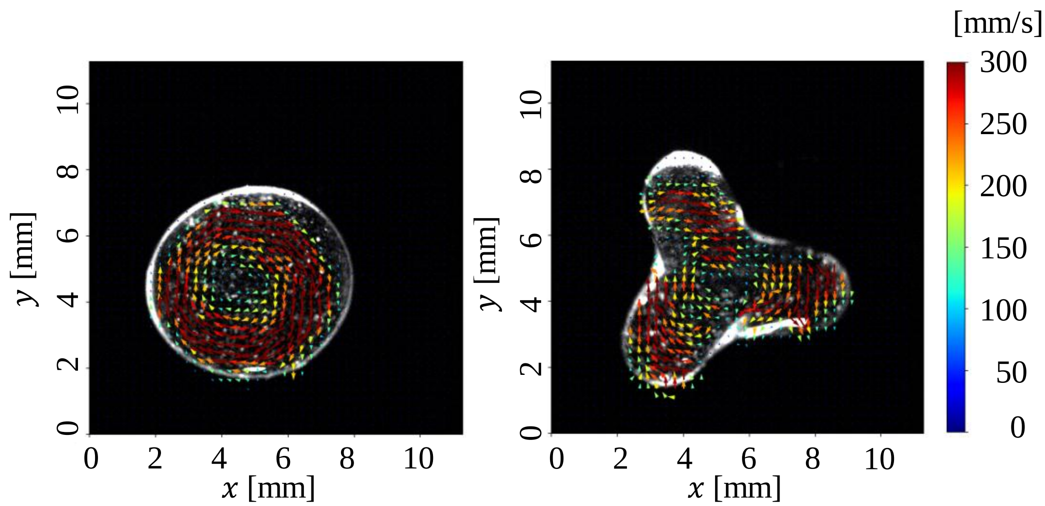


Fig. 1 Illustrtion of the phased-array Levitator



(a) Rotation (b) Deformation

Fig. 2 The flow field in a rotating levitated droplet and its deformation.

Figure 2 shows 5 mm water droplets exposed to alternating sound fields: a standing wave every 6 ms and a vortex beam every 1 ms. Tracer particles in the droplet reveal internal flow. In Figure 2(a), the equatorial velocity field shows rotation speeds over 300 mm/s at a 2 mm radius—ten times the velocity of a non-rotating droplet—indicating a rotation rate of about 1500 rpm. Figure 2(b) shows the velocity field after a delay, highlighting third-order mode deformation and a more complex internal flow. The connection between rotation and deformation will be discussed.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number 24K07317, and Japan Science and Technology Agency (JST) as part of Adopting Sustainable Partnerships for Innovative Research Ecosystem (ASPIRE), Grant Number JPMJAP2330.

References

Koji Hasegawa et al., "Coalescence Dynamics of Acoustically Levitated Droplets", Micromachines, Vol. 11(4), 343 (2020)

Kota Honda et al.," Coalescence and mixing dynamics of droplets in acoustic levitation by selective colour imaging and measurement", Scientific Reports, 13:19590 (2023)

Thursday 23 January 2025 - Session 2 - 12:06 -- Talk 15

Volumetric ultrasonic imaging through complex geometry with a manually scanned 1D array

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Complex geometrical features in engineering components often create stress raisers, making them a common target for non-destructive evaluation techniques such as ultrasonic imaging. However, trying to detect defects in complex geometry is challenging as Probability of Detection (PoD) varies significantly with sensor location, defect location and defect morphology. Satisfying PoD requirements in these situations can be made easier by intelligently combining information from multiple sensor positions, providing both inspection coverage and performance advantages. Achieving this in a resource efficient manner, practical for the intended application, is the focus of this paper.

In-service landing gear inspection is the application considered in this paper. While landing gear safety has traditionally been ensured by a 'safe-life' approach (requiring minimal in-service NDE), the wider context of this work involves in-service ultrasonic NDE of landing gear to facilitate a 'damage tolerant' safety case. The complex geometry present in landing gear incentivizes an inspection strategy involving multiple sensor positions to achieve both good coverage and field of view to areas of interest. While a 2D array can achieve volumetric imaging even without scanning, its low aperture size can place limitations on resolution and defect detectability. In addition, volumetric imaging with a high number of ultrasonic elements comes with significant computational expense. Because of this, scanning of a 1D array is the solution investigated here. In addition to the geometrical challenge, the restricted access and relatively uncontrolled environmental of 'on-wing' landing gear inspection necessitates manual (rather than robotic) delivery of the probe. This paper outlines an approach to ultrasonic imaging in this challenging scenario.

To produce a high-quality volumetric image from a set of ultrasonic phased array measurements (taken from multiple positions) there are three main data requirements: accurate knowledge of part geometry, material properties, and the orientation and position information associated with each ultrasonic measurement. In this work, probe orientation and position are provided by attaching the manually deployed probe to a FARO metrology 'arm'. This is used as a proof-of-concept tool with a view to replacement by a compact and lower cost (e.g., camera based) system in the future. A planned scanning path is then

conducted with full matrix capture data sets captured at intervals along it. Coupling between the phased array and the component's curved surfaces is achieved by a conformable water wedge. In post-processing, the positional information is used to create spatially encoded total focusing method images through the surfaces defined by the component's computer aided design file. Fusion of these images into a unified 3D space can most simply be achieved by addition of image amplitudes, but a variety of processing steps such as sensitivity scaling and detection probability fusion are also considered. As the resulting volumetric data draws from many sensor positions for each voxel, viewed from a wide range of angles, defect detection and characterisation performance potential is higher than for an individual ultrasonic image. Overall, the presented approach provides a low-cost route to forming volumetric ultrasonic images of complex geometry parts using a manually deployed probe.

"Therapeutic Ultrasound on Biomimetic Models of Cancer"

[1]Silva, D., [1]Rafik,T.S., [2]Haqshenas, R., [2]Saffari, N., [1]MacRobert, A., [1]Cheema, U. and [1]Gélat. P.

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Therapeutic ultrasound has displayed promising results in treating a range of cancer types, providing a contender that overcomes the patient quality of life issues observed in the invasive and systemic nature of conventional cancer therapy. Low-intensity ultrasound (LIUS) has been proposed to selectively eradicate breast cancer cells without harming non-malignant counterparts. Additionally, the combination of ultrasound with drug therapies has also been promising, enhancing delivery of therapeutic agents to treat various disorders, which is particularly important in cancer types usually resistant to drug therapies. This work aims to characterise the LIUS phenomenon and explore the use of LIUS in sensitising breast cancer to drug combinations.

A platform that aims to reduce the influence of conventional culturing vessels was used, opting to utilise mylar film windows placed underwater to achieve homogeneous cell sonication. Using this platform, 2D monocultures of MCF-7 and MDA-MB-231 breast cancer cells were seeded on mylar films coated in collagen and sonicated at varying temporal peak acoustic intensities (0.25–7 $W{\cdot}cm^{-2}$) for a total excitation time of 10 minutes. Following this, 3D cultures were used to begin recapitulating the relevant *in vivo* conditions, where cancer cells were seeded within collagen to form 3D hydrogels (tumouroids). To investigate the combination of LIUS with drug therapies, complex tumouroids of MDA-MB-231 were subjected to 5 minutes of ultrasound, at a temporal peak acoustic intensity of 7 $W{\cdot}cm^{-2}$ characterised at the last axial maximum of the field of a 1MHz 15 mm active diameter planar transducer (Precision Acoustics Ltd, TX_1_15), using a calibrated 0.2 mm needle hydrophone (Precision Acoustics Ltd). This was conducted prior to and after a 30-minute drug addition of doxorubicin or Caelyx. At 1 MHz frequency, 20% duty cycle, 100 Hz pulse repetition frequency, no changes in cancer cell viability were observed under the current parameters in both 2D and 3D cultures. However, MDA-MB-231 tumouroids displayed increased sensitivity to doxorubicin and Caelyx when combined with ultrasound sonication.

LIUS sonication of breast cancer cells under the current treatment platform did not induce any changes in viability. However, studies have shown that LIUS is able to induce cell death in cancer cell lines without inducing cell death in non-malignant comparisons. The underlying mechanism still remains unknown, but likely due to mechanotransduction pathways following the induction of shear stresses. Interestingly, the treatment of complex MDA-MB-231 breast cancer tumouroids with ultrasound enabled drug sensitivity, allowing a 50-60% reduction in live cancer cells compared to controls. This is particularly important as the MDA-MB-231 cell line is resistant to these drug combinations in cell culture. Moving forward, investigations will focus on utilising complex breast cancer tumouroids, a model that consist of a multicompartment composed of central artificial cancer mass surrounded by a healthy stromal compartment. This will enable exploring the potential pathways responsible for cellular responses to mechanical stimuli and increased drug sensitivity.

Thursday 23 January 2025 - Session 3 - 15:47 -- Talk 2

Quantitative X-ray elastography of coronary arteries using flexural pulse waves

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Dynamic elastography uses an imaging system to visualise the propagation of elastic waves, the speed of which is directly related to the elasticity felt by palpation. Very few studies have focused on X-ray elastography because of the technical challenges it poses: a planar image of an integration volume at a very slow sampling rate. We demonstrate that tracking a slow elastic wave guided along a one-dimensional structure is the solution. The recently discovered flexural pulse wave (Laloy-Borgna, et al. 2023), which is naturally generated by heartbeats and propagates along arteries, is the perfect candidate for X-ray elastography. As it reflects the cardiovascular health of patients, arterial elasticity is a biomarker of high clinical interest. We first validate the method by measuring the elasticity in arteries phantom using X-Ray. We then move on to data obtained in vivo on coronary arteries during a routine angiography examination. During coronary angiography, a catheter is used to inject an X-ray contrast dye into the patient's aorta X-rays are then taken as the dye spreads through the coronary arteries. It shows the movement of the coronary arteries for a few seconds and allows us to follow the natural flexural pulse waves. Figure 1 displays three frames taken from an angiography performed on the patient of case study (Vollenberg, Oord e Geuns 2022) as well as displacements field in the artery highlighted in red for two times. Using a spectro correlation method validated on the phantom experiment, we are able to estimate the phase velocity of waves in the artery of interest. From the dispersion curves we use a recently derived model of propagation for flexural waves in arteries to quantitatively estimate elasticity (Gregoire, et al. 2024). The obtained Young's moduli for rwo patients are E = 41 ± 29 kPa and E = 12 ± 9 kPa respectively. These preliminary results are expected to pave the way for X-Ray elastography.

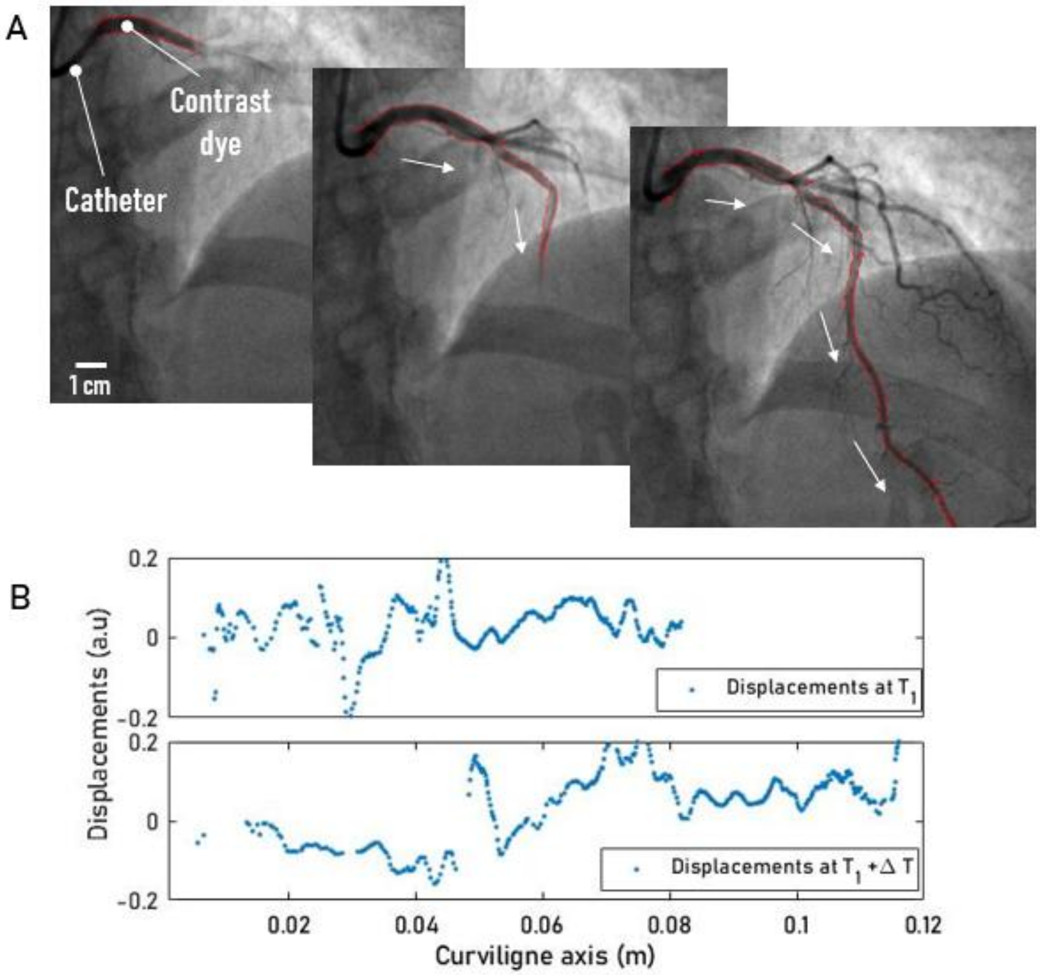

Figure 1: (A)Scans aquired at three instant. The artery of interest is highlited in red, whitearrows indicates the direction of the flow. (B) Displacements in the artery of interest computed on two frames delayed from ∆T = 0.07 s. Data are acquired from the pre-operation angiogram of patient of case study (Vollenberg, Oord e Geuns 2022)

Bibliography

Gregoire, S, G Laloy-Borgna, J Aichele, et S Catheline. «Flexural pulse wave velocity in blood vessels.» *The Journal of the Acoustical Society of America*, 2024.

Laloy-Borgna, G, L Puyo, H Nishino, M Atlan, et S Catheline. «Observation of natural flexural pulse waves in retinal and carotid arteries for wall elasticity estimation.» *Science Advances*, 2023.

Vollenberg, R, S Oord, et R Geuns. «Hangover after side branch stenting: The discomfort comes afterwards.» *Interventional Cardiology*, 2022.

Development of an ultrasound scanner for intraoral imaging and exploration of periodontal tissues

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Periodontal disease is an infectious syndrome presenting inflammatory aspects with a multifactorial etiology. This disease can be divided into two subcategories: inflammatory lesion of the periodontal system, without bone loss (gingivitis) or with bone lesions (periodontitis). While all of these diseases affect a significant proportion of the French population, to varying degrees, they are responsible for more than 45% of severe attachment loss (i.e., >5 mm) and 30 to 40% of total tooth extractions. Furthermore, they remain insufficiently detected and treated. Similar prevalence can be found in other European countries and more generally throughout the world. The current standard examination is intrusive, painful, and operator-dependent and ultrasound imaging can make it possible to visualize periodontal structures and detect periodontal diseases such as the measurement of periodontal pocket depth. High-resolution ultrasound (resolutions <100 µm) has already shown its potential for soft tissue visualization and could facilitate the early diagnosis and treatment of periodontal disease. New device should therefore allow for painless, quantifiable and precise measurement. The development of a miniaturized high-frequency focused single-element transducer (20-30 MHz) compatible with the requirements of an intra-oral device (performance, size, cost) is first essential. Simulation tools (equivalent electrical scheme and pseudo-spectral model) helped us with the design. The backing is a multiphase metallic material with a thickness of 2 mm and an acoustic attenuation coefficient of 1.2 dB/mm/MHz. The piezoelectric element is a P(VDF-TrFE) copolymer with a thickness of 18 µm and an electromechanical coupling coefficient (thickness mode) of 27%. The acoustic performances obtained are a center frequency of 26 MHz, a relative bandwidth of 66%, a depth of field of 1.8 mm, and axial and lateral resolutions of 43 µm and 120 µm, respectively. Imaging performance using a pulse-echo system on a tungsten wire (diameter = 25 µm) phantom was quantified. Finally, this transducer (4 mm height and 8 mm diameter) was integrated in an intraoral ultrasound probe and ex-vivo (on pig jaws) and in-vivo (on human) images (B-scan) were performed to validate the new device for the periodontal application.

Title: **Determining the Potential of Ultrasonic Treatment for Alzheimer's Disease by Enhancing Microglial Amyloid Beta Clearance**

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Dementia is one of the leading causes of mortality in the United Kingdom, with Alzheimer's Disease (AD) being its most prevalent form. As aging is the most significant risk factor for AD, the rising life expectancy and aging population are expected to increase the incidence of AD. Thus, identifying effective treatments for AD is crucial. According to the well-established amyloid beta (Aβ) hypothesis, the generation and deposition of Aβ peptides in the brain are neurotoxic and play a key role in AD development. Anti-Aβ antibody treatments have demonstrated adverse effects, including haemorrhaging, highlighting the need for new therapeutic approaches. One innovative approach involves using focused ultrasound combined with microbubble injection to transiently open the blood brain barrier, enhancing drug delivery. Despite the potential of this approach, its success depends on the efficacy of the administered medication. Ultrasound application is also associated with a reduction in brain Aβ level, however, inconsistencies in the parameters used, along with a limited understanding of the underlying physical and cellular mechanisms, hinder further progress in this area.

This study aims to explore the feasibility of employing ultrasound to reduce Aβ levels in the brain in mouse models of AD and define the cellular and molecular pathway through which ultrasound exerts its beneficial effects. To achieve this, we focus on microglia, the tissue resident immune cells that protect the brain from various threats, including Aβ. In AD, the accumulation of Aβ into rigid fibrillar structures can be sensed and phagocytosed by microglia, however, their ability to clear Aβ is perturbed as the disease progresses. Phagocytosis in microglia can be activated by calcium influx through the highly mechanosensitive PIEZO1 ion channel. Activating PIEZO1 channels through ultrasound may thus promote microglial phagocytosis of Aβ.

To test this hypothesis, living brain slices from mice with microglia transgenically labelled (CX3CR1-GFP), were used to image microglia and examine their responses to ultrasound. After exposing brain slices to focused ultrasound (Centre frequency= 2MHz, Pulse repetition frequency=40Hz, Pressure 1.2 and 0.9 MPa, Exposure time=30 minutes), morphological analysis revealed that ultrasound significantly altered microglial morphology, with a retraction of cellular processes, reduced ramification, and a more rounded appearance. This morphological shift highlights that ultrasound can induce a change in microglial functional properties and we are currently exploring whether this "activated" state is associated with increased phagocytosis of Aβ. Modelling and temperature measurements indicated that no thermal effects should be induced by ultrasound application, suggesting that observed changes in microglia were driven by ultrasound-induced mechanical cues.

Future work will focus on the exploring whether ultrasound affects microglia through the activation of PIEZO1 and whether ultrasound-activated microglia can effectively clear Aβ from the brain, which could potentially form the basis of a novel therapeutic strategy for AD.

Keywords: Ultrasound; Alzheimer's Disease; Microglia; Amyloid beta clearance; PIEZO1 ion channel

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Thursday 23 January 2025 - Session 3 - 17:10 -- Talk 5

Simulation of transcranial ultrasound through coupling of volume integral equations and boundary element methods

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Transcranial ultrasound stimulation is gaining traction as a clinical modality to alter neural circuits non-invasively inside the brain. Unlike traditionally used non-invasive brain stimulation methods such as electroconvulsive therapy, ultrasonic waves can be focused on both cortical and deep brain targets at a spatial resolution of a few cubic millimetres and without requiring a general anaesthesia. The wider clinical application and adoption of transcranial ultrasound relies on predicting the outcome of an intervention by guiding sufficient acoustic energy from the ultrasound transducer towards the targeted region while sparing tissue outside the focal zone. The cranium is a highly attenuating and aberrating medium, with spatially varying acoustic properties, which can vary strongly within an individual dataset. Patient-specific transcranial ultrasound simulations are therefore required to predict and optimise the outcome of treatment, thus ensuring the safety and efficacy of the procedure. Compensating for aberrated ultrasound waves caused by the skull can be a computationally challenging task due to large volumetric grids which are required to resolve the smallest wavelengths inside the computational domain. We have already achieved realistic simulations with the boundary element method (BEM) for the Helmholtz equation implemented in our open-source Python library, OptimUS (https://github.com/optimuslib/optimus). Our prior approaches were limited to harmonic wave propagation through piecewise homogeneous media. In practice, localised heterogeneities in materials such as bone may further aberrate the focus relative to the piecewise homogeneous cases. A volume integral equation (VIE) for heterogeneous materials that naturally couples with the BEM for unbounded domains was therefore formulated to generalise our approach, which allows us to take Hounsfield mapped speed of sound and density values from CT scans and import these into our model via an efficient Python pipeline. The computational gains of domain reduction compared with volumetric solvers were further increased using hierarchical matrix compression techniques. The VIE-BEM scheme was validated

with the analytical solution involving the scattering of plane waves by homogeneous spheres, with the finite element method (FEM) and with FEM-BEM coupling on a heterogeneous cube embedded in a homogeneous unbounded domain. Further validation on a piecewise homogeneous skull slab was carried out, as well as on a skull slab consisting of a nested cancellous bone volume inside a cortical bone domain. Our VIE-BEM formulation demonstrates high accuracy on a voxelised grid and fast convergence over a range of frequencies. Our computational techniques can be generalised to computational acoustics scenarios beyond our specific objective of transcranial ultrasound focusing.

Thursday 23 January 2025 - Session 3 - 17:22 -- Talk 6

Identification of viscoelastic properties of soft materials based on the dynamic response of a spherical object placed at the sample interface

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The mechanical properties of soft materials, especially viscosity, are difficult to characterize. A technique is presented to characterize the viscoelastic properties of soft materials using the dynamic response of a spherical object placed at the sample interface. The spherical object placed at the sample interface is pushed using a step force input and the dynamic response of the spherical object to this force is monitored. The sphere at the sample interface can be pushed using ultrasonic, magnetic, or mechanical excitation. Monitoring the displacement of the sphere using ultrasound is practical, yet displacement imaging can be performed using other methods, such as optical imaging or magnetic resonance imaging. The dynamic response of the spherical object placed at the sample interface is predicted using a comprehensive mathematical model. In this mathematical model, the effects of the shear modulus, viscosity, Poisson's ratio and density of the soft sample, the radius and density of the spherical object, and the damping due to radiation are considered. Overall, the shear modulus and viscosity of the soft sample are determined by matching the experimentally identified and theoretically predicted responses of the spherical object. The approach presented here can be used to improve material characterization in medical applications and will have a direct impact on our understanding of tissue properties.

References

[1] H. Koruk, J.J. Choi, J Acoust Soc Am, 145, EL410-EL416, 2019.
[2] J.H. Bezer, H. Koruk, C.J. Rowlands, J.J. Choi, Ultrasound Med Biol, 46, 3327-3338, 2020.
[3] H. Koruk, Eur J Phys, 43, 25002, 2022.
[4] H. Koruk, S.B. Yurdaer, H.O. Koc, A. Besli, Mater Today Proc, 57, 464-468, 2022.
[5] H. Koruk, H.O. Koc, S.B. Yurdaer, A. Besli, A.N. Pouliopoulos, Exp Mech, 64, 21-32, 2023.
[6] H. Koruk, A.N. Pouliopoulos, Processes, 11, 3402, 2023.

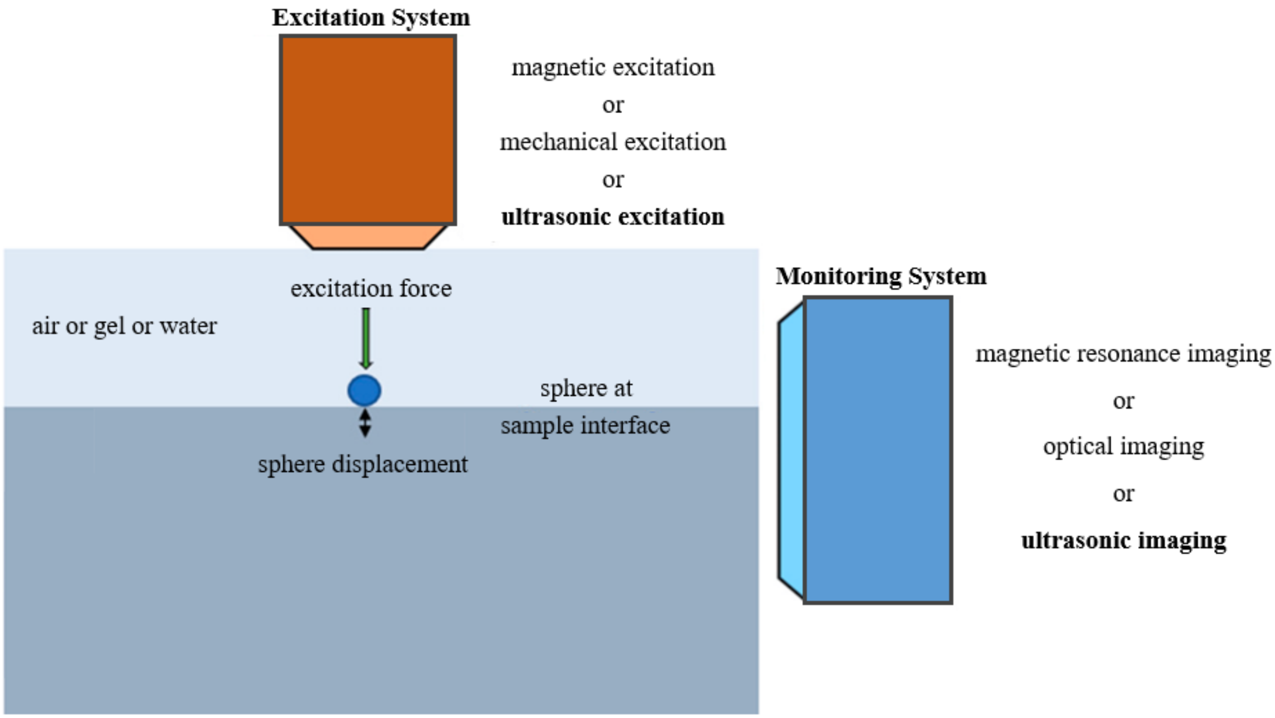

Figure 1: Illustration for determining the viscoelastic properties of soft materials based on measuring the dynamic response of a spherical object placed at the sample interface exposed to an external force.

In vitro investigation of the biophysical mechanisms underlying ultrasound neurostimulation

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Context

Focused UltraSound (FUS) has the potential of offering a minimally-invasive and targeted alternative to standard neurostimulation strategies. Although a number of studies have looked into demonstrating the efficacy of complex repetitive pulse ultrasound neurostimulation procedures on whole brain models, these do not facilitate the identification of the mechanisms underlying the effects ultrasound on neural structures. In contrast, the work presented here aims at shedding light on these biophysical mechanisms via the analysis of the spatiotemporal dynamics of neural responses evoked by single pulse ultrasound stimulations on an elementary *in vitro* neural model.

Method

The model used in this study consists in human progenitor cells differentiated into neurons and cultivated to form a simple 2D neural model. The network's activity was evaluated before, during and after FUS stimulations using calcium fluorescence imaging. We developed on a setup capable of inducing causal, targeted and repeatable ultrasound-induced calcium responses, allowing us to conduct two levels of investigations. First, we sought to identify – based on the study of the spatial distributions of FUS-evoked neural responses on a range of central frequencies – the physical mechanisms through which ultrasound can affect neural activity. At a later stage, we explored – via the introduction of a forced flow in the extracellular media and selective pharmacological blockade – the role of different biological actors and signaling pathways in the observed responses produced by FUS stimulations. The analysis of the spatiotemporal dynamic of the calcium activity was used throughout these studies to evaluate the implication of hypothesized mechanisms.

Results

Immediately after stimulations, strong and sustained elevations in intracellular calcium were repeatably observed for cells located within the ultrasound focus region (success rate of 80% over the last 45 trials). These causal responses were followed by the omnidirectional propagation of a slow calcium flux spreading throughout the network. Through a parametric study, we identified two frequency-dependent ultrasound neurostimulation regimes, characterized by predominant cavitation-driven effects at low frequencies (< 4MHz) and attenuation-driven effects on the higher end of the spectrum (5 and 8 MHz). Via analogies with random-walk diffusion models and experimental tests involving forced extracellular media flow, we also identified that those stimulations led to network-wide neural signaling occurring through both intra- and extra-cellular pathways. The involvement of several mechanisms such as calcium-induced calcium release and messengers such as glutamate were identified via pharmacological blockade. From these observations, we hypothesized that neurotransmitter release might have an important role when considering the potential mid- to long-term effects of ultrasound neurostimulation. Overall, the knowledge gathered in this works are a first step in bridging the gap that exists in the literature between descriptions of the short-term effects of ultrasound neurostimulation observed *in vitro* and mid- to long-term ones reported in behavioral studies conducted *in vivo*.

Thursday 23 January 2025 - Session 3 - 17:46 -- Talk 8

Deep learning for fast laser induced ultrasound tomography in tissue phantoms

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Ultrasound tomography holds high potential as a tool for medical diagnosis because it is non-ionising, faster and cheaper than magnetic resonance tomography and shows high specificity for cancer detection within highly heterogenic tissues [doi: 10.1016/j.radi.2022.01.006]. Medical application of ultrasound tomography, however, is currently limited by the excessive image reconstruction times required. In this feasibility study, we will address these limitations through the use of deep learning. Near-real-time tomographic imaging can be achieved by training the algorithm offline, ahead of deployment. In addition, we propose a laser-based system to facilitate flexible and non-contact generation and detection of ultrasound. These advantages allow for the imaging of regions of the body where contact with a transducer is not possible. Laser ultrasound also ensures repeatability as it is not operator dependent and offers the opportunity for automation, reducing image variability due to operator skill. This makes it a prime candidate for tomography in biomedically related applications.

The system presented in this study is used for all-optical generation and detection of ultrasound. Tissue phantoms with acoustic properties similar to those expected in biomedical settings are inspected using a laser ultrasound setup. The collected data is processed to extract time-of-flight (ToF) ultrasound measurements. A convolutional neural network (CNN) is trained offline with training data simulated using a model (the fast marching method [doi: 10.1007/s00521-021-06670-8]) to produce inputs (ToF data) and outputs (speed of sound (SOS) maps). Experimentally measured ToF data is then fed into the trained model that generates a predicted speed of sound map of the inspected region, resulting in near real-time image reconstruction.

In this proof-of-concept study, the phantom was held in water, in a cubic container of approximately 77 mm side length. One side of the cube (ultrasonic generation side) was made of glass coated with candle soot nanoparticles (CSNP). A pulsed laser of 1064 nm wavelength was incident on this glass CSNP interface and was highly absorbed by the CSNP, consequently generating a high amplitude ultrasonic pulse. The opposite side of the cube (ultrasonic detection side) was made of an aluminium coated glass for high reflectivity to the ultrasonic detection laser (laser vibrometer) of wavelength 633 nm. The water filled cube contained a cylindrical gel phantom of diameter 3 cm and with wave

speed 1455 m/s. Inclusions were placed in the phantom of varying SoS including 1480 m/s and 1540 m/s. Ultrasonic laser generation and detection in through transmission was used to scan along a 30 mm aperture centred with the cube, with a pitch of 2 mm, synthesising a 16-element ultrasound array. All signal combinations between ultrasonic generation and detection positions were captured. The phantom was rotated on a stage and transmission data acquired from 0º and 90º. The ToF for each of the pairs of generation and detection signals populated the ToF matrix which was then used as an input to the trained CNN to output the SoS map. These data successfully indicated the correct regions of varying speed of sound with and geometry and sizing of the imaged phantom.

Thursday 23 January 2025 - Session 3 - 17:58 -- Talk 9

Picosecond ultrasonics for cell imaging and characterisation: towards applications in cancer

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Cancer remains a leading cause of premature mortality worldwide. The elastic properties of cells and tissues have shown a significant correlation with their normal, dysplastic, and cancerous states [1]. The application of Phonon microscopy (picosecond ultrasonics) has enabled 3D elasticity imaging in cells *in-vitro* by using coherent phonon fields to determine the Brillouin frequency shift and signal attenuation speed, essentially through time-resolved Brillouin scattering [2]. In this presentation, we discuss novel methodologies surrounding picosecond ultrasonics towards their application in cancer research. Among our methods, we present developments in live-cell imaging, fibre-based imaging and measurement and artificial intelligence methods for the classification of the tissues.

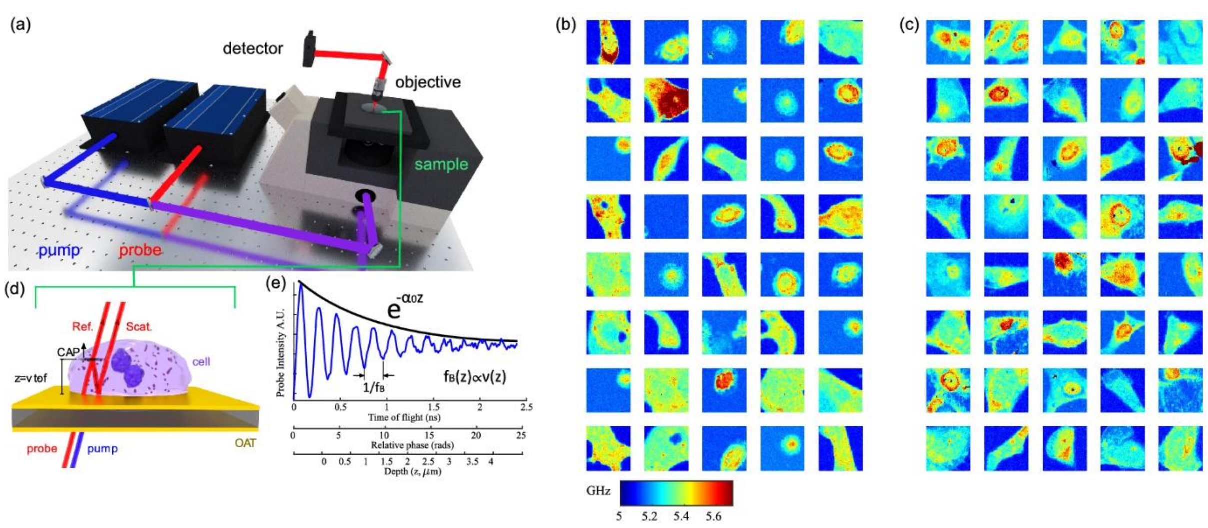

Figure 1: Phonon microscopy (a,d,e) and imaging of normal (b) and cancerous cells (c).

[1] Alibert C, Goud B, Manneville JB. Are cancer cells really softer than normal cells? Biol Cell. 2017 May;109(5):167-189. doi: 10.1111/boc.201600078. Epub 2017 Apr 6. PMID: 28244605.

[2] Pérez-Cota, F., Martínez-Arellano, G., La Cavera, S. et al. Classification of cancer cells at the sub-cellular level by phonon microscopy using deep learning. Sci Rep 13, 16228 (2023).

Friday 24 January 2025 - Session 4 – 08:55 -- Talk 1

Optimisation of acoustic energy harvester

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Abstract

This study suggested an effective low-frequency band acoustic energy harvester that primarily consists of a Helmholtz resonator (HR) with an attached piezoelectric (polyvinylidene oxide film, PVDF) device, which could simultaneously transform acoustic energy into electricity and reduce sound pollution. The fabricated acoustic resonator was designed to increase mechanical vibrations, boost sound pressure, and promote energy harvesting. The incorporation of a piezoelectric cantilever into the HR is to allow experimental tuning and matching of the mechanical and acoustic resonances, which maximises the efficiency of the harvester. Experimental studies on the fabricated acoustic energy harvester showed the design is highly efficient and economically feasible.. Therefore, resonator is the prototype of a sustainable and renewable energy system that can power micro-electric devices, smart gadgets, and many modern technologies.

Keywords: Acoustics, Helmholtz resonator, Piezoelectric, Energy Harvester.

References

[1] M. Safaei, H. A. Sodano, S. R. Anton, A review of energy harvesting using piezoelectric materials: state-of-the-art a decade later (2008–2018), Smart materials and structures 28 (2019) 113001.

[2] L. Xie, G. Wang, C. Jiang, F. Yu, X. Zhao, Properties and applications of flexible poly (vinylidene fluoride)-based piezoelectric materials, Crystals 11 (2021) 644.

[3] H. Li, C. Tian, Z. D. Deng, Energy harvesting from low frequency applications using piezoelectric materials, Applied physics reviews 1 (2014).

[4] Y. Wang, X. Zhu, T. Zhang, S. Bano, H. Pan, L. Qi, Z. Zhang, Y. Yuan, A renewable low-frequency acoustic energy harvesting noise barrier for high-speed railways using a Helmholtz resonator and a PVDF film, Applied Energy 230 (2018) 52–61.

[5] C. Gu, Y. Chen, W. Chen, P. Zhao, Acoustic energy harvester by electromagnetic mechanisms and Helmholtz resonator, in: IOP Conference Series: Earth and Environmental Science, volume 617, IOP Publishing, 2020, p. 012038.

[6] S. Noh, H. Lee, B. Choi, A study on the acoustic energy harvesting with Helmholtz resonator and piezoelectric cantilevers, International Journal of Precision Engineering and Manufacturing 14 (2013) 1629–1635.

An efficient acoustic power transfer using a CMUT transducer

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This paper reports on the analysis, design and experimental characterization of an electronic circuit that rises Capacitive Micromachined Ultrasonic Transducers (CMUT) to the level of piezoelectric transducers for acoustic energy transfer through the skin. CMUTs are competitive with commonly-used piezoelectric transducers. However, as their efficiency depends on their static biasing voltage (typically 40~120V), they are not commonly used in body implanted devices. To address this issue we propose a new, less expensive and reliable method that is based on a self-biasing process of the CMUT. With a low voltage (between 0.5V and 2V) as initial CMUT polarization, the CMUT device self-biases when a sufficient incoming ultrasonic pressure (20~150 kPa) impinges its surface. Then, when the bias voltage reaches the desired value, the battery is starting to recharge with the acoustic energy transferred.

The power transfer process is based on two successive steps: at first, the transducer is biased with a low voltage and excited by the incident ultrasonic pressure. The alternative energy produced is then converted by the first function into an amplified DC voltage using a multi-stage multiplier and a matching inductor. As this voltage is fed back to the CMUT device, after a few milliseconds, the CMUT bias voltage automatically rises to a desired saturation voltage. The process of electrical energy storage can then start by using a simple diode bridge.

This work presents the calculation of the key operating points of this solution, the experimental results and a comparison of the experimental transfer efficiency with the state of the art.

Using a calibrated ultrasonic source at a distance of 2 mm, an 8x6 mm² immerged CMUT device is used for the power transfer. With an incident ultrasound intensity of about 80 mW/cm², its bias voltage rises from the 2.2 V implanted battery voltage to a constant 55 V. Then an average electrical power per unit area of the transducer $\langle P \rangle$=15mW/cm² recharges the implanted battery. Based on passive impedance matching and a few multiplier stages, this electronic circuit consists of only 30 discrete components and can therefore be embedded in an implanted medical device. Finally, the comparison with the literature shows that this solution's efficiency is comparable with the state of the art's efficiencies. However, it is the first time that this amount of energy has been transferred to a battery through a CMUT device without the use of an external source of bias, a pre-charged CMUT or a dedicated integrated circuit.

Friday 24 January 2025 - Session 4 – 09:19 -- Talk 3

Flexible piezoelectric sensors applied to reverberant acoustic field measurement for the Structural Health Monitoring (SHM) of a thermoplastic-composite gas tank

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Acoustic emission techniques allow monitoring the health of the structure by listening and localizing the acoustic signatures of damages when occurring. In classical methods, several transducers are bounded to the structure and only the first travel of the wave from the source to the transducer is processed based on a model of wave propagation in an infinite medium. These methods require a relatively large number of transducers and a theoretical or numerical wave propagation model. The two methods used in this work are referred as time reversal and inverse filtering [1,2] and allow to free the user from these two constraints. They have been previously applied to composites plates with complex stiffeners [3]. We focus here on monitoring axisymmetric structures and more specifically a thermoplastic-composite gas tank. Both methods require first the collection of experimental transfer functions between future inspection points on the structure and each transducer. These transfer functions carry a very rich reverberated acoustic information and can be used with any medium as long as propagation is linear. Thus, the medium can be of any shape, heterogeneous and anisotropic. The acoustic emission process proposed is to listen and wait for a sufficiently energetic event to record the acoustic field for processing with time reversal or inverse filtering approach. The present work aims at using noninvasive printed flexible P(VDF-TrFE) piezoelectric sensors for both SHM techniques and at comparing two transfer function acquisition techniques: impact hammer and laser Doppler Velocimetry.

[1] M. Tanter *et al.*, *J. Acoust. Soc. Am.* 108, 223–234, 2000, 10.1121/1.429459.
[2] R. K. Ing *et al.*, *Appl. Phys. Lett.* 87, 204104, 2005, 10.1063/1.2130720.
[3] F. Ciampa *et al.*, *J. Acoust. Soc. Am.* 130, 168–175, 2011, 10.1121/1.3598458.

Friday 24 January 2025 - Session 4 – 09:31 -- Talk 4

Controlling flexural wave propagation using arrays of perpendicular gyroscopes

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In this presentation we demonstrate methods to control the propagation of elastic waves with periodic arrays of perpendicular gyroscopes on flexural plates. A perpendicular gyroscope is formed of two perpendicular beams—with the base of the vertical beam attached to the plate—and a gyroscope at the free end of the horizontal beam [1]. This design has similarities with the structure of a wind turbine, and for arrays, wind farms. The analytical model is studied alongside finite element simulations, in which boundary conditions are applied to simulate the presence of the spinners. The eigenmodes of individual gyroscopes are shown to produce dynamic chiral Chladni patterns in their attached plate. We investigate the control over the system afforded by altering parameters such as the rate of spin of the gyroscopes, the length of the beams and the orientation of the gyroscope axes. Particular attention is paid to the broken symmetries of the perpendicular gyroscope, leading to asymmetric dispersion surfaces which, in combination with the inherent active chirality of gyroscopes, can be exploited to control the propagation of waves on arrays of gyroscopes. This allows us to produce highly unusual unidirectional waves at chiral interfaces and a host of other wave guiding effects.

[1] Madine K. H. and Colquitt D. J. 2024. The perpendicular gyroscope: modal analysis of plate, beam and gyroscope multistructures. Phil. Trans. R. Soc. A.38220230358 http://doi.org/10.1098/rsta.2023.0358

Friday 24 January 2025 - Session 4 – 09:43 -- Talk 5

Waves in piezoelectric plates: semi-analytical modeling and laser-ultrasound experiments

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Piezoelectric layered materials are widely used in electronics for sensing and filtering applications. Waves propagating therein consists of a coupled electroelastic field. Conventional computational methods rely on root-searching of the characteristic equations, which is known to be slow and miss solutions. To resolve these issues, semi-analytical methods that discretize the resonant field have been developed extensively, in particular for purely elastic waveguides. In this contribution we present a semi-analytical approach based on spectral methods to compute electroelastic guided waves in plates. Electrically shorted (metallized surfaces) and open (non-metallized surfaces) plates can be considered. The effect of the electrical boundary conditions is analyzed and we find that the dispersion spectra are affected considerably. A monocrystalline 128° Y-cut Lithium Niobate (LiNbO3) wafer serves as a relatively simple test specimen. Our computations are in very good agreement with laser-ultrasonic measurements performed on electrically open-open, open-shorted and shorted-shorted wafers.

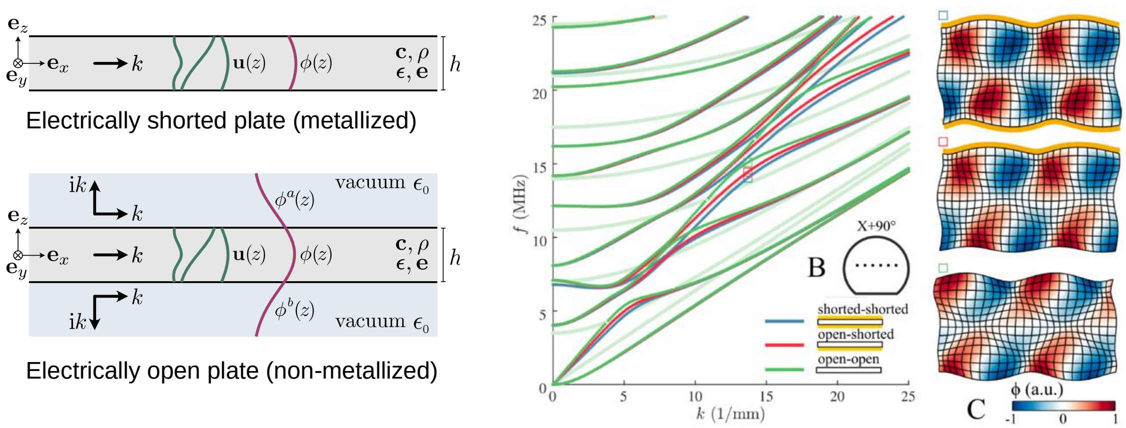

Fig. 1: Guided waves in a piezoelectric LiNbO3 wafer. (A) Sketch of the geometry and modal distributions. (B) Dispersion curves of waves propagating in X+90° direction with three different electrical boundary conditions. (C) Electric (color) and mechanic (mesh) field of the indicated modes.

Friday 24 January 2025 - Session 4 – 09:55 -- Talk 6

Towards On-Line Inspection of Additively Manufactured Powder Bed Fusion Parts Using Spatially Resolved Acoustic Spectroscopy

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Industrial actors are currently looking for methods of in-situ inspection techniques to improve the safety and confidence in Additive Manufacturing (AM), while reducing production costs. In-situ monitoring of powder bed fusion (PBF) AM requires non-contact techniques that do not disturb the high precision build geometries.

Spatially Resolved Acoustic Spectroscopy (SRAS) [1] is a non-contact laser ultrasound technique that provides data for the non-destructive material characterization of metals, including those with rough surfaces such as AM parts [2,3]. SRAS can provide quantitative data on microstructure, material homogeneity, and the geometric conformity of evaluated pieces.

We will show that the SRAS instrumentation can be designed to fit into an AM chamber (Aconity3D Midi+) to provide the industrially desired in-situ evaluation data that can help develop and progress the industry. This work will show proof of concept and progress on the development of the instrumentation. We will also outline the capabilities and limitations of the technology for studying AM pieces layer-by-layer, and address some of the challenges of constructing and operating equipment suitable for PBF environments.

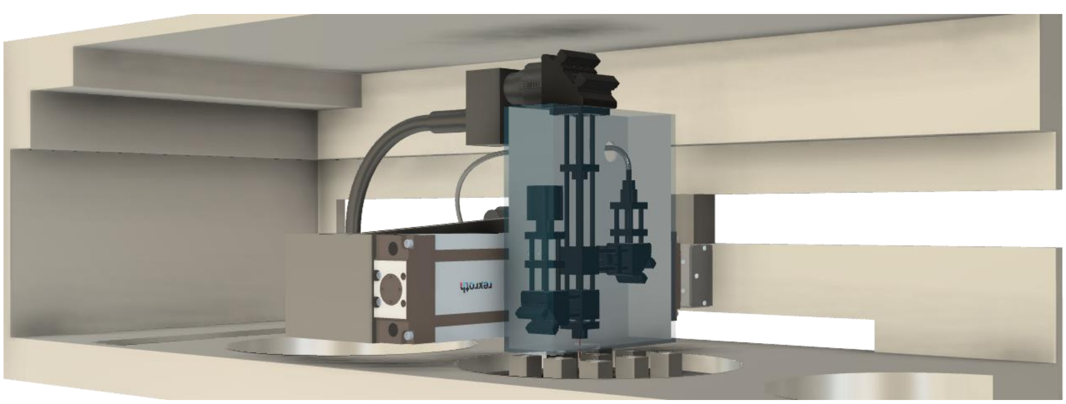

Figure 1 CAD model showing the working design of the in-situ SRAS instrumentation for a PBF chamber.

[1] R. J. Smith, et al, "Spatially resolved acoustic spectroscopy for rapid imaging of material microstructure and grain orientation," *ACCESS Measurement Science and Technology Meas. Sci. Technol*, vol. 25, p. 11, 2014, doi: 10.1088/0957-0233/25/5/055902.

[2] R. Patel *et al.*, "Imaging Material Texture of As-Deposited Selective Laser Melted Parts Using Spatially Resolved Acoustic Spectroscopy," *Applied Sciences 2018, Vol. 8, Page 1991*, vol. 8, no. 10, p. 1991, Oct. 2018, doi: 10.3390/APP8101991.

[3] W. Li, et al, "Imaging Microstructure on Optically Rough Surfaces Using Spatially Resolved Acoustic Spectroscopy," *Applied Sciences*, vol. 13, no. 6, p. 3424, Mar. 2023, doi: 10.3390/app13063424.

Characterization and control of multi-MHz acoustic waves for acoustic crystalline undulators

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Crystal-based Light Sources (CLS) is a promising new technology for the realization of narrowband and brilliant γ-ray sources, which have recently attracted interest due to their technically favourable characteristics and their wide range of applications in science and technology [1][5]. Crystalline Undulators (CUs) are CLS devices, in which gamma radiation is emitted when charged particles propagate through appropriately modulated crystal plains. Moreover, in CUs undulation is achieved by the static or dynamic periodic bending of the crystal lattice plains [6]. Dynamic periodic bending can be achieved by sinusoidal longitudinal acoustic waves propagating (AWs) inside the crystal, which can be generated by means of piezoelectric transducers or ultrashort laser pulses. The modulation of the crystal plains, and consequently the characteristics of the gamma radiation depends on the characteristics of the AW, and particularly its wavelength and amplitude. Homogeneous spatial distribution of the wave pressure is significant for narrowband light emission. The acoustic excitation of CUs allows for the emission of gamma-ray photons with energies that can reach several tens of MeV or more via tiny, inexpensive and highly practical devices. The tunable nature of AWs allows for control of the γ-radiation characteristics in terms of photon energy and brilliance by a single ACU device. Evidently, the CLS technology emerges as significantly favourable compared to contemporary methods such as Free Electron Lasers (FELS), which are limited to operate up to the X-ray regime [2].

Precise characterization and control of AWs induced inside crystalline materials is necessary for design and optimization of ACUs. This work presents techniques for fast optical imaging through ns interferometry and ns refractive imaging using ultrashort laser pulses. The very short interaction time of the optical pulses with the propagating acoustic waves allows for near-static and, consequently, highly precise imaging. The utilization of the aforementioned optical imaging techniques allows for the accurate detection and monitoring of the wavelength, amplitude and 2D spatial distribution of the propagating AWs. This work is carried out in the frame of TECHNO-CLS project of the EIC Pathfinder programme.

References

[1] A. V Korol, A. V Solov'yov, and W. Greiner, Springer Berlin Heidelberg, (2013)
[2] A. V Korol, A. V Solov'yov, Particle Acceleration and Detection, Springer Nature Switzerland (2022)
[3] A. V Korol, A. V Solov'yov, and W. Greiner, Eur. Phys. J. D 74, 201 (2020)
[4] A. V Korol, A. V Solov'yov, and W. Greiner, I, Int. J. Mod. Phys. E, Vol. 8, No. 1, 49–100, (1999)
[5] A. V Korol, A. V Solov'yov, and W. Greiner, International Journal of Modern Physics E, Vol. 9, No. 1, 77–105, (2000)
[6] R. Camattari, et al., Phy. Rev. Accelerators and Beams 22, 044701 (2019)

4D time-domain Brillouin scattering of water ice phase transition under non-hydrostatic load

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Time-domain Brillouin scattering (TDBS) [1-2] is an optoacoustic technique that uses femtosecond pulsed lasers to generate and detect coherent acoustic pulses (CAPs). The pump laser is absorbed by a thin layer which expansion lunches CAPs scattering the probe laser which leads to variation in the sample's reflectivity. The variation of reflectivity over the time-delay between the pump and probe lasers contains both Brillouin oscillations and echoes. The instantaneous frequency and amplitude of these oscillations are controlled by the local elastic, optical, and photoelastic properties. Extracting the acoustic velocity from the instantaneous frequency enables the conversion of time delay into depth, resulting in depth profiling with sub-optical resolution. By combining two-dimensional lateral scanning with depth profiling, TDBS enables 3D imaging and has been successfully applied to image coexisting phases of water ice VI and VII within a diamond anvil cell [3]. Repeated scans over time enable 4D imaging (3D spatial + 1D temporal), allowing the observation of transient processes such as phase transitions or crystallite formation and re-orientation.

Here, the 4D imaging capabilities of TDBS enabled following the dynamic transformation of the polycrystalline higher-pressure ice VII phase of H_2O to the lower-pressure ice VI phase. Pressures were generated using a membrane diamond anvil cell (DAC) where the H_2O–ice sample was squeezed between two diamond anvils, with the bottom anvil coated with a 20 nm layer of gold, acting as an optoacoustic transducer for the CAP generation by the pump laser. Starting with a polycrystalline sample of water ice VII at 7 GPa, the non-hydrostatic pressure was reduced to 2.15 GPa, initiating the reversible phase transition from ice VII to ice VI. Local pressure was monitored using the ruby fluorescence scale. TDBS scans ran continuously for over a month thus allowing to follow the phase transition in real time.

The sub-optical depth resolution of TDBS, potentially down to the width of the CAPs (tens to hundreds of nanometers), allows tracking the volume changes of individual grains over time. This capability enables the extraction of various physical parameters, such as the transformation rate constant in the Arrhenius equation. Our results show the advantages of the TDBS technique in high-pressure experiments, particularly over traditional Brillouin light scattering, which lacks the axial resolution necessary for such estimation.

[1] H. T. Grahn, H.J. Maris, J. Tauc, Picosecond ultrasonics, IEEE J. Quantum. Electron. 25 (1989), 2562-2569.

[2] V. E. Gusev and P. Ruello, Advances in applications of time-domain Brillouin scattering for nanoscale imaging, *Appl. Phys. Rev.* **5**, 031101 (2018).

[3] S. Sandeep, T. Thréard, E. De Lima Savi, N. Chigarev, A. Bulou, V. Tournat, A. Zerr, V. E. Gusev, S. Raetz, 3D characterization of individual grains of coexisting high-pressure H_2O ice phases by time-domain Brillouin scattering, *J. Appl. Phys.* **130**, 053104 (2021).

Influence of the beam skewing in anisotropic plates on the dispersion curves

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Measurement of the elastic guided waves allows one to evaluate a given sample's elastic parameters. A common technique is to acquire the distance-time matrix (B-Scan) and to assess its double-Fourier transform to reveal the dispersion curves. From the latter, the sample's elastic parameters can be evaluated by solving the inverse problem, i.e., by fitting the experimental results with the theoretical predictions. Thanks to GEWtool [1], which implements a semi-analytical model based on spectral elements, theoretical dispersion curves can be easily calculated. Experimental ones can be acquired with a laser ultrasonics setup by moving along a line one of the two lasers (the pump or the probe) relative to the other.

In the case of an anisotropic material, the experimental results can be strongly influenced by the source geometry, as shown in Fig. 1. The differences are due to the generated wave vectors: a line source generates only two, while a point source generates wave vectors in all directions. In anisotropic media, there is an angle between the power flux and the wavevector [2]. As we measure the modes associated with energy propagation along the scanned direction, extra modes appear when generating the acoustic field with a point source, in particular around the ZGV modes.

In this talk, we will explain the origin of these added branches, compare the results with the theory and discuss how the additional modes provide information on dispersion along other directions than the scanned one.

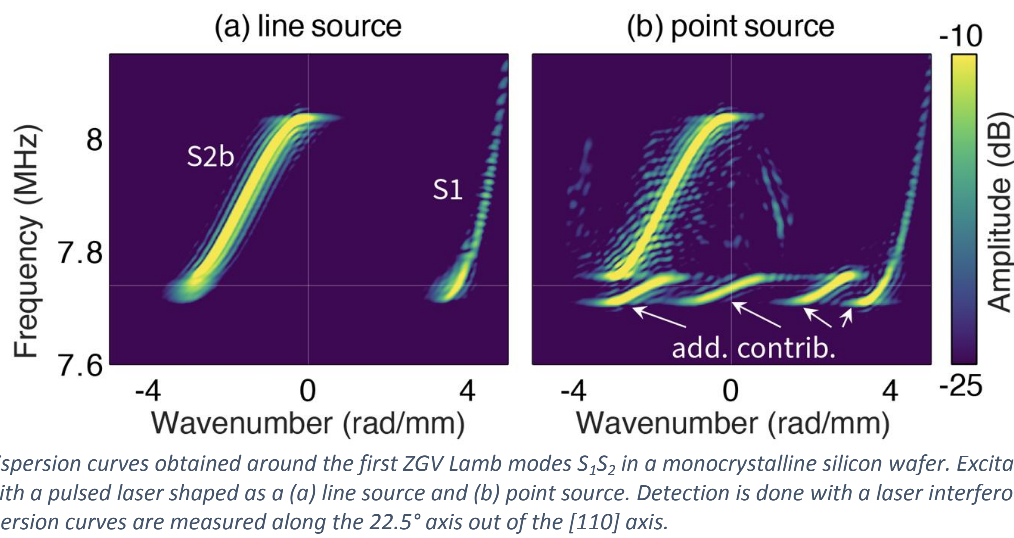

Figure 1: Dispersion curves obtained around the first ZGV Lamb modes S_1S_2 in a monocrystalline silicon wafer. Excitation is achieved with a pulsed laser shaped as a (a) line source and (b) point source. Detection is done with a laser interferometric probe. Dispersion curves are measured along the 22.5° axis out of the [110] axis.

[1]: D. A. Kiefer (2023). GEWtool [Computer software]. DOI: 10.5281/zenodo.10114243
[2]: D. A. Kiefer, S. Mezil, C. Prada, Sci. Adv. 9, eadk6846 (2023)

Friday 24 January 2025 - Session 4 – 11:04 -- Talk 10

Deep Learning Techniques Applied to Time-Resolved Brillouin Scattering Signals

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Recent developments in picosecond laser ultrasonic systems, utilising transducers and time-resolved Brillouin scattering (TRBS), have shown great potential for high resolution imaging for the characterisation of various materials, with particular emphasis on the elasticity of biological cells. This technique has been used to classify cancerous and non-cancerous cell types in specific datasets by analysing Brillouin frequency shifts that reflect changes in cellular mechanical properties. However, despite its promise, the quality of TRBS signals presents a limitation, primarily due to the signal-to-noise ratio (SNR).

While methods such as increasing transducer efficiency, signal averaging, or beam power can improve the SNR, they come with practical and biological constraints. For example, increasing laser power to enhance the SNR can lead to overheating or damaging biological cells, making these methods unsuitable for in vivo applications. Similarly, enhancing transducer efficiency alone does not fully address the depth-dependence of acoustic attenuation, which leads to a decreased SNR as the signal propagates.

This study explores the potential application of advanced signal processing techniques, specifically deep learning (DL), to address this challenge by improving the SNR of TRBS signals. By employing supervised learning models, we propose a data-driven approach to denoise TRBS signals, which may lead to more reliable and accurate measurements.

Additionally, to potentially enhance the interpretability of our cancer cell classification model, we introduce the use of class-activation maps (CAMs), a widely adopted tool in imaging field. CAMs could provide some level of transparency in the classification process, offering insights into how TRBS data informs cancer cell classification.

The integration of deep learning for signal enhancement and class-activation maps for model explainability presents a promising approach to TRBS analysis, offering potential improvements in signal quality and diagnostic accuracy. These advancements could open new possibilities for the application of TRBS in cancer detection and other biomedical imaging fields, contributing to more reliable and clinically applicable results.

Nanometric surface acoustic wave pulses generated and detected by laser

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This study presents a novel approach for generating and monitoring high-frequency surface acoustic waves (SAWs) on materials, enabling advanced nanoscale metrology and sensing applications. Traditional methods for generating SAWs above a few GHz frequencies face challenges, particularly in structuring laser-induced mechanical stresses at sub-THz wavelengths along the surface of materials. Femtosecond (fs) laser pulses, which contain THz-range frequencies, are commonly used, yet generating and monitoring broad-frequency SAW pulses at such scales has proven challenging. Previous studies have employed sharp laser focusing [1] or surface nanostructuring, such as metallic periodic gratings [2], cleaved superlattices [3-4], or individual nanowires [5], to achieve high-frequency SAW generation, but these later methods generally produce narrow-band wave packets due to resonances within the structures.

To overcome these limitations, we introduce a layered nanostructure approach that avoids resonance effects, thus enabling the generation and detection of wide-bandwidth GHz SAW pulses. This structure consists of opaque and transparent material layers with nm-scale thicknesses and closely matched acoustic impedances, ensuring minimal resonance and optimal conditions for broad-frequency SAW generation. Using a focused ion beam or precise polishing techniques, we cleave the layered structure to create a plane with nm-scale surface structuring, designed for efficient optical generation and detection of nanometric SAW pulses. Materials with perovskite crystal structures were selected due to their favorable acoustic impedance properties and availability in both opaque and transparent forms, providing versatility for the study.

In our proof-of-concept experiment, perovskite layers of nm thickness were grown by pulsed laser deposition on a transparent substrate. This substrate was subsequently cleaved to expose the layered structure's surface, enabling it to be uniformly illuminated by fs pump and probe laser beams. The generated coherent acoustic pulses (CAPs), including longitudinal and Rayleigh SAWs, were optically monitored as they propagated across the transparent layer, reflected, and returned to the opaque layer. Experimental observations were supported by theoretical models developed for CAP generation via thermoelastic effects and detection through photoelastic and reflectance modulation effects. Analytical and COMSOL simulations confirmed the experimental data, showing a three-phase Rayleigh SAW strain pulse, whose duration was mostly controlled by the opaque layer's SAW propagation time, thus broadening the frequency spectrum up to 40 GHz and generating nm-scale wavelengths.

The successful generation and detection of these broad-frequency SAW pulses over distances of ~200 nm with a sub-micrometer footprint mark a significant advancement in nanoscale acoustic metrology. This method holds promise for future applications in nanometrology and nanosensing, enabling precise manipulation and measurement of acoustic waves on the nanoscale.

Ackowledgements
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References
[1] N. Chigarev et al., J. Phys: Conf. Series 92, 012029 (2007).
[2] M. Shubert et al., Appl. Phys. Lett. 101, 013108 (2012).
[3] V. E. Gusev, In: D. Bićanić (eds) Photoacoustic and Photothermal Phenomena III. Springer Series in Optical Sciences 69, 323 (1992).
[4] C. Li et al., ACS Nano 18, 9331 (2024).
[5] R. Berte et al., Phys. Rev. Lett. 121, 253902 (2018).

Friday 24 January 2025 - Session 4 – 11:28 -- Talk 12

VERSATILE OPTICAL DESIGN FOR HIGH SENSITIVY LASER DETECTION OF ULTRASOUNDS AND VIBRATIONS, BASED ON MULTI-CHANEL RANDOM-QUADRATURE INTERFEROMETRY

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Laser-based ultrasonic (LBU) interferometer based on Multi-Channel Random-Quadrature (MCRQ) detection was initially proposed to address the specific needs for applying LBU inspection to industrial environments (optically rough samples, noisy and tough environment). The MCRQ detection is based on using array of detectors combined with parallel processing, in order to increase an interferometer collection efficiency and thus yielding better Signal-to-Noise ratio. This is achieved by taking advantage of the random phase distribution of speckles and since the detection principle does not rely on maintaining a specific interferometric state (No feedback needed to maintain quadrature detection), the system is inherently robust.

The electronic demodulation at the heart of the MCRQ detection is based on injecting a small interference signal, called calibration, and tracking it. The multi-channel signals are sorted based on the polarity of this imbedded calibration signal, which can flip its phase by 180^{o} depending on the speckle phase. The sorted multi-channel signals are then added coherently, building up to a strong signal.

We initially demonstrated a very efficient optical design based on a single multi-mode fiber that is used for (1) delivery of the probe beam, (2) collecting of the backscattered light, (3) generating the reference beam and (4) relaying the interference field on the MCRQ detector array. We recently expanded this fiberized design by combining it with a Cassegrain optical architecture, allowing it to further improve the receiver's performance and adding more flexibility in the design of laser receivers. We will demonstrate how this new architecture easily permits (a) simultaneous detection at multiple points and (b) simultaneous detection of the 3-components of the surface displacement (out-of-plane and in-planes). In addition we will also show how this MCRQ interferometer can be converted to a very sensitive Laser Doppler Vibrometer (LDV), with a large collecting aperture, when combined with heterodyne modulation/demodulation.

Poroelasticity in cells : insights from acoustic propagation

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Brillouin light scattering (BLS) has become a powerful tool for probing the viscoelastic properties of biological materials, especially living cells [1]. BLS spectroscopy measures the frequency shift and linewidth of inelastically scattered light, properties which can be linked to the propagation characteristics of acoustic waves at GHz frequencies. of the sample at the microscopic level. However, despite its increasing popularity in cellular mechanics research for the past ten years, the exact interpretation of BLS measurements in biological contexts remains contested. Specifically, there is an ongoing debate regarding what cellular components contribute most significantly to the observed BLS signal. In cells, some suggest that BLS predominantly probes intracellular water dynamics [2], while others argue for a dominant contribution from the cytoskeletal actin network [3]. On more complex biological systems, such as spheroids, a recent study has suggested that BLS is sensitive to a more complex network that cannot be described by linear mixing laws [4].

In the works discussed above, only the shift, linked to the acoustic velocity, is analysed, and the linewidth, linked to the attenuation, is discarded. To interpret the shifts, most studies have relied on basic mixing laws models [2], assuming that the cell is a two phase system composed of solid components bathed in a liquid. This approach, however, does not account for the interactions between cellular components, particularly when interpreting dynamic mechanical properties such as BLS linewidth, which reflects energy dissipation processes. Also, the absence of linewidth analysis limits our understanding of the material's full mechanical response, reducing the potential insights into cellular dynamics.

In this study, we present a novel framework for interpreting BLS data in living cells, integrating poroelasticity theory to model both BLS frequency shift and linewidth. Poroelasticity, traditionally used in the study of hydrated porous media, is particularly well-suited for complex, hydrated structures like hydrogels [5], where solid and fluid phases interact. This theory allows us to move beyond simple compositional analysis and to consider how fluid flow and solid matrix interactions within the cell influence the observed BLS properties. By applying a poroelastic model, we are able to capture both the elastic response of the cytoskeletal matrix and the viscous contribution of the fluid, offering a more complete understanding of BLS spectral features.

Our results demonstrate that the poroelastic model provides a more comprehensive description of BLS behavior in cells, addressing limitations of the mixing laws. This approach not only resolves some of the ambiguities in current BLS interpretation but also clarifies the importance of the solid network in cells, made up by DNA, proteins and other non-permeant structures, and thus opens up new outlooks for exploring the mechanical properties of living cells in various physiological and pathological states.

[1] Kabakova et al., Nature Reviews Methods Primers, 2024

[2] Wu et al., Nature Methods, 2018

[3] Scarcelli et al., Nature Methods, 2015

[4] Yan et al., Proceedings of the National Academy of Sciences, 2021

[5] Tanaka et al., The Journal of Chemical Physics, 1973

Friday 24 January 2025 - Session 4 – 11:52 -- Talk 14

New applications of laser generated sound sources

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Laser Plasma Sound Sources (LPSSs) constitute a new method for the generation of acoustic waves and sound transduction. In this work we present recent progress on the characterization, control and utilization of LPSSs in various applications. Laser-induced N-pulses are produced in atmospheric air or other gaseous or liquid media as a result of the thermoelastic response following ionization of the medium by high-intensity laser radiation (laser-induced breakdown). Similarly, in the case of solid targets, they are formed indirectly from the pressure produced in the surrounding air by material fragments detached from the target surface, or directly from the thermoelastic response of the material. For laser ionization of the atmospheric air, the interaction of high-intensity pulses with air molecules leads to the generation of high-temperature free electrons which interact with the initially cold heavy particles, namely ions, atoms, and molecules within causing them to rapidly heat [1,3]. This heating leads to a thermoelastic response of the air, resulting in the formation of an acoustic N-pulse. The duration of such pulses ranges from a few microseconds (or even hundreds of nanoseconds for femtosecond laser pulses) up to hundreds of microseconds, depending on the characteristics of the laser pulse. N-pulses exhibit a first-order high-pass spectral profile in the lower region of the acoustic frequency spectrum, specifically from 20 Hz to high frequencies (~20 kHz) or near ultrasound (<60 kHz), while for femtosecond laser excitation, it may extend to mid-ultrasound (up to ~500 kHz) or even MHz [3]. Their peak pressure can be very high (>130 dB) depending on the total optical energy deposited in the air.

Their mass-less nature and point-like (spherical) geometry, along with their repetitive impulse-like temporal profile and broad frequency spectrum, render LPSSs suitable for a multitude of applications. Here, results are presented from the utilization of LPSSs for a) the controlled generation of continuous sound signals within a frequency range of interest [4,5], b) for high precision acoustic measurements of phononic crystal structures [6] and c) for the generation of strong acoustic strains in crystalline materials [7]. The latter is part of the research carried out in the frame of the EIC pathfinder project TECHNO-CLS, towards periodic acoustic bending of the lattice of crystalline materials for the development of crystalline undulators, capable of generating narrowband γ-radiation via undulation of ultra-relativistic positron beams [8]. Experimental results are shown demonstrating the proof-of-principle functionality of the proposed applications, supported by numerical simulations.

[1] Oksanen, M. & Hietanen, J. *Ultrasonics* **32**, 327–331 (1994).
[2] Kaleris, K. et al. *J. Phys. D: Appl. Phys.* **53**, 435207 (2020).
[3] Couairon, A. & Mysyrowicz, A., *Physics Reports* **441**, 47 - 189, (2007).
[4] Kaleris, K., et al., JSV. **570**, 118000 (2023).
[5] Kaleris, K., et al., *Sci. Rep.* **11**, 476 (2021).
[6] Kaleris, K., et al., *Sci. Rep.* **14**, 12102 (2024).
[7] Kaleris, K., et al., *Nat. Commun. Mater.,* **5**, 93 (2024).
[8] Kaleris, K., et al., *Appl. Phys. A* **129**, 527 (2023).
[9] Kaleris, K., et al., *PRAB,* under review (2024).

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