Xàtiva

2018

Symposium on Acoustic Metamaterials

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Organizing entities

The European Cooperation in Science and Technology (COST) provides funding for the creation of research networks, called COST Actions. These networks offer an open space for collaboration among scientists across Europe (and beyond) and thereby give impetus to research advancements and innovation.
COST is bottom up, this means that researchers can create a network - based on their own research interests and ideas - by submitting a proposal to the COST Open Call. The proposal can be in any science field. COST Actions are highly interdisciplinary and open. It is possible to join ongoing Actions, which therefore keep expanding over the funding period of four years. They are multi-stakeholder, often involving the private sector, policymakers as well as civil society.

DENORMS (Designs for Noise Reducing Materials and Structures) - CA 15125, is funded by the European Cooperation in Science and Technology (COST). DENORMS activities were launched on 9th March 2016 for 4 years. DENORMS aims at designing multifunctional, light and compact noise reducing treatments. In order to achieve this, DENORMS brings together skills and knowledge of the complementary, but still disconnected, communities of scientists working on acoustic metamaterials, sonic crystals and conventional acoustic materials across Europe and overseas. Our Action provides a framework for an efficient information exchange, helps to avoid duplication of research efforts and channel the work of groups involved in different projects towards our common goal. New approaches to the theory of sound interaction with materials and structures and standard methods of their performance characterisation are being developed. The participation of European companies in the network will facilitate the knowledge transfer from the academia to industry.
Action page: https://denorms.eu

Created under the impetus of the DENORMS Action CA15125, YRAM is a newly founded network dedicated to PhD candidates and ECI (Early Career Investigator) working on acoustic and elastic metamaterials and aims at enhancing collaborations and co-working between young researchers in this field. This network is still in the building step, we are really interested in ideas, suggestions, desires? If you want to join the building team, please feel free to contact us: yram.contact[at]gmail.com!
A specific online area will be shortly dedicated to share job/post-doc announcement on the YRAM website: https://yramnetwork.wordpress.com.
You can also follow YRAM on LinkedIn, Facebook and Twitter to stay informed.

Xàtiva is a municipality and a city in the Valencian Community (Spain) located in the south of the province of Valencia, in the north of the Central Comarcas and capital of the La Costera region. It has the largest number of enclaves in Spain, with a total of twenty-six, and in 2015 it had 29,095 inhabitants (INE). The city is together with a dozen municipalities very close to it an integrated urban area (AUI)) that had 51,246 inhabitants in 2007.

The Universitat Politècnica de València is a public, dynamic and innovative institution, dedicated to research and teaching which, while maintaining strong links with the social environment in which it carries out its activities, opts for a strong presence abroad. It is a young university, which celebrates its 50th anniversary during the academic year 2018-2019.

LAUM is a Joint Research Unit of the University of Le Mans and the CNRS (UMR 6613). The laboratory's workforce is about 140 people (teacher-researchers, researchers, IATOS, ITA, doctoral students, post-docs and guests).
The Laboratory's activities are mainly focused on acoustics "of the audible" but the laboratory has integrated in recent years new research topics in the field of vibrations and ultrasound.

The National Center for Scientific Research, or CNRS, is a public organization under the responsibility of the French Ministry of Education and Research. Founded in 1939 by governmental decree, the CNRS aims to: Evaluate and carry out all research capable of advancing knowledge and bringing social, cultural, and economic benefits for society; contribute to the promotion and application of research results; develop scientific information; support research training; participate in the analysis of the national and international scientific climate and its potential for evolution in order to develop a national policy.

Organizing committee

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Arnaud Duval (Working Group 3 Leader)

Forewords

It is our great pleasure to welcome you all here to Xàtiva for the first Symposium on Acoustic Metamaterials.

We want to thank our the COST-DENORMS Action CA15125 and the organizing entities: Universitat Politècnica de València (UPV), the Young Researchers in Acoustic Metamaterials (YRAM) and Ajuntament de Xàtiva. This symposium, devoted to Early career investigators (i.e. researcher whose career spun less than 8 years since the date of the PhD) and PhD candidates coming from a huge number of countries in Europe as France, Spain, Italy, Germany and indeed from many other countries around the world, reflects the international character of the research activity developed in the field of acoustic metamaterials.

The first Symposium on Acoustic Metamaterials (SAM) is the fifth DENORMS workshop and it will be held from 7th to 9th November 2018 in Xàtiva (Spain). SAM aims at sharing new advances and breakthroughs as well as fostering the community of young researchers in the field of acoustic metamaterials. SAM will be organized around different sessions comprising 20 min talks and 3 plenary lectures.

Among other topics, discussions will be related to:

- Acoustic/elastic metamaterials and phononic crystals,
- Acoustic/elastic metasurfaces,
- Non-reciprocal manipulation of acoustic/elastic waves,
- Acoustic/elastic meta-devices based on transformation acoustics, parity-time symmetric acoustics, topological acoustics,
- Novel physical concepts for harnessing acoustic/elastic waves,
- New applications of metamaterial-based functional devices for acoustic sensing, cloaking, imaging, absorption, energy harvesting,

It is an exciting time to be working in Acoustic metamaterials. During the symposium we will enjoy and hear a lot about the emerging applications and its impact upon sound transport, waves absorption, noise control and much more.

We hope you will enjoy the meeting.

Welcome!

Best wishes from the organizers.

Symposium Schedule

Wednesday, 7th of November

9H00-9H20	Registration	
9H20-9H30	Welcoming words	
9H30-10H30	**Plenary talk: Topological Sound**	**Johan Christensen**
10H30-11H30	Session: Noise Control	Théo Cavalieri
	10H30-10H50: Straw-inspired anisotropic metamaterial for sound absorption	Weichun Huang
	10H50-11H10: Sound transmission loss enhancement of double panel partitions at their mass-spring-mass resonance using resonant metamaterials	Rocha De Melo Filho Noé Geraldo
	11H10-11H30: Enhancing sound attenuation in a duct by using a poroelastic lamella network	Li Ke
11H30-12H00	Coffee Break	
12H00-13H30	Session: Noise Control 2	Vicent Romero-García
	12H00-12H20: Characterization of 3D printed thin membranes for low-frequency noise attenuation in small-scale applications	Cecilia Casarini
	12H20-12H40: Limits of mass density for acoustic metamaterials composed of clamped elastic plates in air	Matthieu Malléjac
	12H40-13H00: Acoustic characterization of Silica aerogel clamped plates for perfect absorption purpose	Alan Geslain
	13H00-13H20: Perfect and broadband acoustic absorption by metasurfaces made of aerogel clamped plates	Antonio Alejandro Fernández-Marín
13H30-16H00	Lunch	Pebrenegre
16H00-17H40	Session: Phononic/Sonic Crystals	Luis Miguel Garcia-Raffi
	16H00-16H20: Use of Sonic Crystals for noise mitigation in the launch pad	Iván Herrero-Durá
	16H20-16H40: Acoustic performance of phononic crystals for underwater applications	Gyani Shankar Sharma
	16H40-17H00: Experimental realization of A underwater double-zero-index phononic crystal with Dirac- like point	Wonjae Choi
	17H00-17H20: Sound emission from airflow through sonic crystal	Viktor Hruska
	17H20-17H40: An ultrasonic acoustic beam shifter	Paul Daly

17H40-18H00	Coffee break	
18H00-19H00	Session: Homogenisation	Jean-Philippe Groby
	18H00-18H20: Acoustic wave propagation in graded effective anisotropic fluid layers under oblique incidence	Théo Cavalieri
	18H20-18H40: Dynamic behavior of ribbed plates with inner resonance, homogenized models versus experimental measurements	Pascal Fossat
20H00	Dinner/Lab presentations	Rincón de Granà

Thursday, 8th of November

9H30-11H10	**Session: Noise control**	Matthieu Malléjac
	9H30-9H50: Numerical methods with acoustic losses and shape optimization: design and under- standing of advanced acoustic setups	Peter Risby Andersen
	9H50-10H10: Low-frequency sound absorption of rigidly-backed waveguides laterally loaded by acoustic resonators	Eloise Kalavsky
	10H10-10H30: Modelling of Acoustic Black Hole based Mufflers	Neha Sharma
	10H10-10H30: Enhancing Broadband Absorption through Functionally-Graded Perforated Materials,	Teresa Bravo
	10H30-10H50: One dimensional modelling of self-cloaking inside ducts using liners	Maaz Farooqui
	10H50-11H10: Plant usage potential in noise control	OzgurYerli
11H30-13H30	Visit of the Castle	
13H30-15H30	Lunch and free time	
15H30-16H00	Shuttle back to Casa de la Cultura	
16H00-17H00	**Plenary talk:** **Soda cans: acoustic Helmholtz resonators for controlling the propagation**	**Fabrice Lemoult**

17H00-18H00	**Session: Noise control**	Alan Geslain
	17H00-17H20: Development of lightweight, integrated and multifunctional acoustic metamaterials/metasurfaces to reduce noise from next generation aero-engines: modelling and data	Imran Bashir
	17H20-17H40: Potential application of acoustic metamaterials on double- and single-glazing windows for sound reduction	Fanyu Meng
	17H40-18H00: Tunable Transmission Properties of Acoustic Waves Propagating in a Waveguide Grafted with Acoustic Resonators by Filling Liquids	Tingting Wang
18H00-18H20	Coffee break	
18H20-19H00	**Session: Opto-acoustics**	Víctor Sánchez-Morcillo
	18H20-18H40: Playing the metamaterial guitar with light and ultrasound	Jun-Yu Ou
	18H40-19H00: Observation of Brillouin scattering self-cancellation in silica nanowires	Omar Florez Peñaloza
20H00	Concert	Casa de la Cultura (2nd floor)

Friday, 9th of November

9H30-10H30	**Plenary talk:** **Local Hilbert transform for management of fields in optics and acoustics**	**Kestutis Staliunas**
10H30-11H30	Session: New perspectives	Weichun Huang
	10H30-10H50: Dissipative Envelope Solitons In 1D Acoustic Metamaterials	Jiangyi Zhang
	10H50-11H10: Theory for Willis coupling prediction of acoustic metaatoms	Anton Melnikov
	11H10-11H30: Non-Hermitian systems & metamaterials: More prospective	Ananya Ghatak
11H30-12H00	Coffee Break	

12H00-13H30	Session: Vibrations and flexural waves 1	Rubén Picó
	12H00-12H20: Absorption of flexural waves by 1D resonators in the case of reflection and transmission problems	Julien Leng
	12H20-12H40: Observation of topologically protected helical edge waves in elastic plates	Marco Miniaci
	12H40-13H00: Design of Locally Resonant Metamaterial for Structural Acoustic Applications	Jaesoon Jung
	13H00-13H20: Uncertainties in wave characteristic of one-dimensional periodic structures using fuzzy approach	Ravi Singh
13H30-16H00	Lunch	Bar El Carmen
16H00-17H00	Session: Vibrations and flexural waves 2	Julien Leng
	16H00-16H20: Influence of the boundary conditions and control of edge modes in finite locally resonant metamaterials	Luca Sangiuliano
	16H20-16H40: Waves Dispersion in Functionally Graded Plates on elastic medium	Mokhtar Nebab
	16H40-17H00: Negative group velocity state in the vicinity of elastic instability in soft composites	Viacheslav Slesarenko
17H00-17H20	Coffee break	
18H00-18H40	Session: Noise control	Cecilia Casarini
	18H00-18H20: Acoustic Diffusers and Metadiffusers in Orchestra Pits: the Good, the Bad, and the Loony	Eric Ballestero
	18H20-18H40: Acoustic performance of horizontally aligned carbon nanotubes in a soft elastic medium	Yifeng Fu
18H40-19H00	Closing ceremony	
20H00	Tapas experience	Puerto de Granà

Invited Speakers

Johan Christensen is a research fellow at the Universidad Carlos III de Madrid. Broadly speaking, he is interested in wave physics and the theoretical description and numerical modeling of acoustic and mechanical metamaterials. The science of plasmonics in structured media also belongs to his line of research. In 2010 he was awarded his PhD at the Autonomous University of Madrid followed by a postdoctoral stay at the Spanish National Research Council until 2012 in Madrid as well. He was hired as an assistant research professor at the Technical University of Denmark in Copenhagen until mid 2016. He has obtained numerous awards and grants such as a Marie-Curie Doctorate fellowship, Carlsberg fellowship, Young Elite researcher prize from the Danish Research Council, Ramon y Cajal fellowship and a Starting Grant from the European Research Council.

Fabrice Lemoult is a French researcher. He graduated from ESPCI Paris in 2007, then obtained a Master at University Paris 7 in 2008, and did his PhD at Insitut Langevin, supervised by Mathias Fink (2008-2011). After his PhD, he did a postdoctoral research at Pr. John Page?s group, University of Manitoba at Winnipeg (Canada), working on the Anderson localization in granular media. He then joined the group of Bernard Bonello at the Institut des NanoSciences de Paris studying phononic crystals with Lamb waves. He joined the Institut Langevin in Spetember 2013 as Associate Professor. His area of expertise includes transient propagation of fields in complex, reverberating and locally resonant media, subwavelength imaging and focusing, electromagnetic and acoustic metamaterials, photonic and phononic crystals.

Kestutis Staliunas Graduated Theoretical Physics, Vilnius University, Lithuania, 1985. PhD in Physics, Vilnius University, 1989. Habilitation in Physics, Vilnius University, 2001. A.v. Humboldt fellow in Physikalisch-Technische Bundesantstalt (PTB) Braunschweig, Germany, 1991-1992. Between 1993-2003 senior research fellow in Braunschweig PTB and University of Hanover researching on nonlinear pattern formation in lasers (optical vortices, spatial solitons) and Bose condensates. Since 2004 ICREA research professor in Universitat Politècnica de Catalunya (UPC), Barcelona, head of research group on lasers, photonics and meta-photonics, nonlinear laser dynamics. Professional experience: around 250 articles in scientific journals with appr. 5000 citations (h-factor 40); appr. 500 presentations in conferences (appr. 100 invited ones); 2 patents, 1 monograph. Up to now directed (or currently directing) 15 PhD projects.

Invited talks

Topological Sound

Johan Christensen *† [1]

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Recently, we witnessed a tremendous effort to conquer the realm of acoustics as a possible playground to test with sound waves topological protected wave propagation. Acoustics differ substantially from photonic and electronic systems since longitudinal sound waves lack intrinsic spin polarization and breaking the time-reversal symmetry requires additional complexities that both are essential in mimicking the quantum effects leading to topological robust sound propagation. In this talk I will give a detailed overview on topological states of acoustic matter and present a few examples on: valley-Hall acoustics, non-Hermitian sonic crysals, and Majorana-like zero modes for sound waves.

*Speaker

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Soda cans: acoustic Helmholtz resonators for controlling the propagation

Fabrice Lemoult *† [1]

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Metamaterials are composite media structured at a scale much smaller than the wavelength and offer incredible possibilities to engineer the propagation of waves. I will discuss the use of an everyday object for building such a metamaterial in acoustics: a soda can. After establishing the effective propagation properties, I will show different strategies to mold the flow of waves by playing on the unit cell of the soda cans' metamaterial.

*Speaker

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Local Hilbert transform for management of fields in optics and acoustics

Kestutis Staliunas *† [1]

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Hilbert transform is associated with the breaking of symmetry of space or time. For instance in optics the breaking of symmetry of time (the causality principle) imposes the Hilbert transform on spectra. This is known under Kramers-Kronigs relation in optics. What we propose is the Hilbert transform in 2D or 3D space which can break the symmetry of the space locally. We derive such a local Hilbert transform for arbitrary directionality field. We show that the application of such a local Hilbert transform can result in focalisation of light into desired patterns, for instance can create sinks, or vortices of the optical waves. We discuss how to implement the analogous local Hilbert transform in Acoustics, to achieve smart management of sound fields.

Keywords: Hilbert transform, Kramers, Kronigs relations

*Speaker

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Contributed talks

Straw-inspired anisotropic metamaterial for sound absorption

Weichun Huang *† [1], Logan Schwan [1], Vicente Romero-Garcia [1], Jean-Michel Génevaux [1], Jean-Philippe Groby [1]

[1] Laboratoire d'Acoustique de l'Université du Mans – Le Mans Université, CNRS UMR6613 – Avenue Olivier Messiaen 72085 LE MANS CEDEX 9, France

Straws or straw-like natural materials, such as wheat, reed or rattan, have been used as thermal insulation material for thousands of years throughout the world. But its functionality on sound absorption is only studied through rudimentary models and methods. Here, we propose an anisotropic acoustic metamaterial design, inspired by straw stack for prefect sound absorption. The physics of the porous media in idealized straw-stacks is enriched by tailoring inner resonances. The approach to this straw-inspired metamaterial relies on the homogenization of a periodic arrangement of straw-like quarter-wavelength resonators. Several optimal designs are found out by critical coupling technique. The main features of such porous medium are the possibility for the effective compressibility to become negative around the resonance and the drastic reduction of the effective sound speed (slow sound) at very low frequency. Impedance tube measurements on a 3-D printed metamaterial layer evidence multiple absorption peaks stemming from sub-wavelength Fabry-Pérot interferences in the backed layer. And impedance tube measurements are performed on 3-D printed samples with controlled parameters to validate the theoretical results. The experimental data is in good agreement with the theoretical model. Applications may concern sound absorption upon reflection, sound insulation for transmissions, and orientation-selective absorption due to the anisotropy.

Keywords: Bioinspired material, Straw, Anisotropy, Homogenisation, Critical coupling, Perfect absorption

*Speaker

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Sound transmission loss enhancement of double panel partitions at their mass-spring-mass resonance using resonant metamaterials

Rocha De Melo Filho Noé Geraldo * [1,2], Lucas Van Belle [1,2], Claus Claeys [1,2], Elke Deckers [1,2], Wim Desmet [1,2]

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[2] DMMS lab, Flanders Make – Belgium

Double panel partitions suffer from a poor sound transmission loss at their mass-spring-mass resonance, at which the two panels resonate on the stiffness of the core material. This study evaluates the potential of resonant metamaterials to improve the sound transmission loss at the mass-spring mass resonance. Two double panel partitions are investigated: the first one has a separating air gap and the second one is a sandwich panel with a foam core. For both double panel partitions, resonators are applied to one of the two panels to create a bending wave stop band. . To evaluate the metamaterial solution during the design phase, two methods are proposed. For the double panel with a separating air gap, the Multiple Reflection Theory is extended by incorporating the equivalent dynamic mass of the metamaterial to predict the sound transmission loss of the metamaterial double panel. In the case of the metamaterial sandwich panel, the sound transmission loss is predicted by extending Heckl's model with the equivalent dynamic mass. The equivalent dynamic mass is calculated using the predicted stop band limits obtained from finite element unit cell modelling. This allows to incorporate complex and realisable resonator geometries in the analytical sound transmission loss formulations. The metamaterial solutions are realised and evaluated experimentally. Both metamaterial solutions outperform their original configurations in the targeted frequency region of their original mass-spring-mass resonances, demonstrating the metamaterial potential to improve the sound transmission loss for this vibro-acoustic problem. Furthermore, the proposed design methods allow for fast and accurate sound transmission loss predictions for these metamaterial double panels, validated by the good agreement between the predicted and measured acoustic insulation performance.

Keywords: metamaterials, stop band, mass, spring, mass resonance, dynamic mass, sound transmission loss

*Speaker

Enhancing sound attenuation in a duct by using a poroelastic lamella network

Li Ke *† [1], Benoit Nennig [2], Nicolas Dauchez [3]

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A structured poroelastic material constituted of lamellas is investigated in order to improve sound attenuation in a duct at low frequency. Compared with homogeneous porous materials, this kind of structure take advantage of its small weight and of strong skeleton resonances.
Transmission and reflection measurements are realized for two orientations of the lamella network in a rectangular duct with a 10 cm x 20 cm cross-section. A numerical computations are also performed to identify the physical mechanisms of sound dissipation consisting in structural, viscous, and thermal losses. It is observed that the structural and viscous dissipation are strengthened near the frequency associated with the first bending resonance of the lamellas occurring around 375 Hz for a lamella of 2.5 cm thickness.
Finally, an optimization of the structural dimensions and the acoustic properties of lamellas is proposed to get a more effective sound attenuation.

Keywords: Lamellas Networks, Low frequency, TransmissionLoss

*Speaker
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Characterization of 3D printed thin membranes for low-frequency noise attenuation in small-scale applications

Cecilia Casarini * [1]

[1] Department of Electronic and Electrical Engineering [University of Strathclyde] – United Kingdom

In this work we present and characterize thin viscoelastic membranes fabricated with a novel 3D printing technique, that allows us to better control parameters such as Young's Modulus, density, thickness and resonance frequency of the materials. These parameters are retrieved with different methods, namely impedance tube measurements, transfer matrix method, nanoindentation and laser interferometry. The results are promising, as resonance frequencies as low as 300 Hz could be achieved in membranes 70 μm thick and having a diameter of 15 mm. The outcomes of this work can be used to build acoustic metamaterials for low-frequency sound absorption in small-scale electroacoustic devices. Part of this research has been conducted through a Short-Term Scientific Mission funded by DENORMS.

Keywords: Acoustic Metamaterials, Thin Membranes, 3D Printing, Characterization

*Speaker

Limits of mass density for acoustic metamaterials composed of clamped elastic plates in air

Matthieu Malléjac * [1], Aurélien Merkel [2], José Sénchez-Dehesa [3], Johan Christensen [2], Vincent Tournat [1], Vicent Romero-García [1], Jean-Philippe Groby [1].

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Metamaterials composed of a periodic arrangement of plates or membranes in air are of growing practical interest because of their peculiar properties such as the overcoming of the so-called mass-law, or the possibility to obtain zero dynamic mass density. Due to the strong dispersion around the forbidden band gap associated to the plate resonances in bulk periodic systems, different regimes characterized by different values of the effective dynamic mass density can be exhibited, either negative or positive, going through zero-mass dynamic effective density. The aim of this work is to experimentally, numerically and theoretically report and characterize the anomalous propagation of sound waves in a one-dimensional periodic system of thin elastic clamped plates emphasizing the near zero density regime. A zero-dynamic mass density system possesses an infinite phase velocity (in the lossless case). Therefore, a plane wave impinging the structure is not phase-delayed during its propagation in the structure and as a consequence, there is no change of phase for the transmitted waves. This specific feature leads to interesting phenomena such as cloaking or super- squeezing effects. In this work, we first present an inverse method to recover the mechanical properties of elastic clamped plates from the reflection and transmission coefficients measured in a 4 microphones impedance tube. We then analyse the effective behavior of a finite-depth periodic system composed of such plates depending on the properties of the unit cell.As an example, sound wave propagation through the designed metamaterials without and with an embedded scatterer (a sphere or diaphragm) is finally presented to prove the efficiency of our metamaterials to allow propagation without phase accumulation as a cloaking zero-mass density system.

Keywords: Plate, metamaterial, Zero, density, Super, squeezing

*Speaker

Acoustic characterization of Silica aerogel clamped plates for perfect absorption purpose

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Silica aerogel has been widely studied as bulk material for its extremely low density and thermal conductivity. Plates or membranes made of this extremely soft materials exhibits interesting properties for sound absorption. A novel signal processing method for the characterization of an acoustic metamaterial made of silica aerogel clamped plates is presented. The acoustic impedance of a silica aerogel clamped plate is derived from the elastic theory for the flexural waves, while the transfer matrix method is used to model reflection and transmission coefficients of a single plate. Experimental results are obtained by using an acoustic impedance tube. The difference between the measured and modeled reflexion and transmission coefficients is minimized under constraints to recover the acoustic parameters of the silica aerogel plate. Once the properties of the silica aerogel plate are obtained, the perfect absorption condition is derived by studying the reflection coefficient of a aerogel plate rigidly backed with a cavity in the complex frequency domain. Reflection measurements with a varying cavity length from 1 mm to 65 mm are performed to valid the perfect absorption condition. It is found that the use of silica aerogel plate exhibit perfect absorption condition for several configurations.

Keywords: Acoustic metamaterials, Aerogel, Perfect absorption

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Perfect and broadband acoustic absorption by metasurfaces made of aerogel clamped plates

A. A. Fernández Marín *† [1,3], Vicent Romero-García [1], Jean-Philippe Groby [1], Noé Jiménez [2], Francisco Cervera [3], José Sánchez-Dehesa [3]

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Silica aerogels are nanoporous lightweight materials the frame of which consists of an assembly of connected small cross-sections beam-like elements resulting from fused nanoparticles. This particular assembly additionally provides silica aerogel a very low elastic stiffness when compared to rigid silica structure of identical porosity. Therefore, when aerogel plates are clamped, they are excellent candidates to design acoustic metamaterials, because they exhibit subwavelength resonances and present efficient absorption capabilities. In this work we will study an acoustic metasurface made of metaatoms combining silica aerogel clamped plates (considered as a punctual resonators) and impedance cavities to obtain perfect absorption in a broadband frequency range. The results obtained show a good agreement between the analytical results and those obtained with the numerical simulations. The absorptive properties of the designed metaatoms are encouraging and can be applied to design more complex metasurfaces for the broadband absorption of sound.

Keywords: Acoustic metamaterials, Aerogel, Perfect absorption

*Speaker

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Use of Sonic Crystals for noise mitigation in the launch pad

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An unusual context for the acoustics is the environment of a launchpad during the launching of space aircrafts. This acoustic environment has traditionally received much less attention than other variables as temperature or gases flow. Adopting solutions for the control of noise that now result unsatisfactory is necessary since payloads are becoming more and more sensitive and may be affected by the strong acoustic loads during the lift-off. In this context, the use of acoustic metamaterials based on Sonic Crystals emerges as a practical possibility to build up a metadiffuser that prevent acoustic loads over the spacecraft. A proof of concept based on the use of Sonic Crystals (SCs) as a noise mitigation method in the first stages of the lift-off of space rockets has been proposed as a first step of the study, analyzing both theoretically and experimentally the diffusion coefficient and the Insertion Loss (IL) in reflection of four different SCs with different lattices and filling fractions, using a flat reflector as a reference for the quantification of the noise reduction. The experimental study of a system in the linear regime consisting of a sound source radiating a SC in water partially covering an open cavity is performed. Due to the spreading of the reflected waves, a broadband noise reduction in the area of the source is observed.

Keywords: sonic crystal, launch pad, noise mitigation, diffusion coefficient, insertion loss

*Speaker

Acoustic performance of phononic crystals for underwater applications

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Acoustic coatings applied externally to marine vessels can significantly reduce underwater noise pollution as well as absorb external sound waves for stealth purposes. In this work, analytical and numerical models are developed to study the performance of phononic crystals comprising voided or hard inclusions embedded in a soft rubber with a steel backing plate for maritime applications. The analytical model is based on homogenisation theory whereby the phononic crystal is modelled as layered composite materials with effective geometric and material properties. The numerical model is based on the finite element method. Voided inclusions in the rubber coating are shown to exhibit monopole resonance which is governed by the ratio of bulk to shear moduli of the host rubber medium, leading to frequency dependent effective elastic modulus. Peaks of high sound absorption for the periodically voided rubber medium with a steel backing plate are attributed to the mass-spring resonance of the system as well as interference between waves scattered by the voids and reflected from the steel plate. Hard scatterers embedded in rubber are shown to exhibit dipole resonance, which is governed by the ratio of the density of the scatterers to the density of the host medium and results in frequency dependent effective dynamic density. Peaks of high sound absorption for the rubber medium with hard inclusions are attributed to the dipole resonance of the scatterers as well as interference between waves scattered by the inclusions and reflected from the steel plate. Phononic crystal designs comprising both voided and hard inclusions in a host rubber medium with a steel backing plate are also examined. An acoustic coating comprising a layer of hard inclusions followed by a layer of voided inclusions in the direction of sound propagation is found to exhibit very high sound absorption in a broad frequency range, not achieved using the corresponding designs comprising only voided or hard inclusions.

Keywords: acoustic coating, phononic crystals, homogenisation, finite element method

*Speaker

Experimental realization of A underwater double-zero-index phononic crystal with Dirac-like point

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Phononic crystals are artificially-designed periodic structures that exhibit unprecedented material properties. Double-Zero-Index Phononic Crystals (DZIPnCs) have both zero density and zero bulk modulus and are known to possess better transmissibility than Single-Zero-index phononic crystals for which only one of the two properties is zero. It has been found that DZIPnC can be used to be realized at the Dirac-like point, where three modes meet at a frequency in the band structure. In addition, it has been shown that DZIPnC may support Dirac-like point only at the Gamma point and the three modes are two dipoles and one monopole. Thus, waves propagating in such material have much lower sound speed than the matrix's one. However, in acoustic systems, slow wave structures are difficult to realize experimentally, and then their applications are very limited. We found a method to make DZIPnC with hard inclusions exhibiting a Dirac-like point, which can widely expand its applicability. We experimentally realize an underwater collimator with the DZIPnC. This talk will explain the methodology and simulation/experimental results.

Keywords: Zero, index material, phononic crystal, Dirac, like point

*Speaker

Sound emission from airflow through sonic crystal

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Aeroacoustics of airflow through a sonic crystal is studied by means of numerical experiments based on the flow simulations and subsequent treatment by aeroacoustics analogies. The main concern is the power and the directivity of the sound sources. The results show that the crystal is capable of emitting the low-frequency sound and the Strouhal law application is discussed in order to establish a rule of thumb for similar scenarios. The noise sensation is briefly mentioned.

Keywords: sonic crystals, vortex sound, cfd

*Speaker

An ultrasonic acoustic beam shifter

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The acoustic beam shifter is a metamaterial which exists within a class of engineered structures that execute fundamental wave deformations. The beam shifter alters the propagating direction of an impinging wave such that it is transmitted laterally shifted and distortion free. Since its derivation by transformation acoustics the theoretical properties of the beam shifter has been established, it has been designed and numerically simulated as a phononic crystal, then as an experimentally demonstrable perforated metamaterial. While previous work has focused on signals within the audible bandwidth, ultrasonic signals and their applications have received little attention. This paper explores the issues in analysing, designing, simulating and experimentally demonstrating a small scale, two dimensional acoustic beam shifter metamaterial fabricated by additive manufacturing technology for air borne, ultrasonic waves. Essentially, the shifter is a system of two dimensional waveguides and was fabricated with a stereolithographic printer. It is comprised of air filled channels made by positioning parallel, tilted plates of cured photopolymer at sub-wavelength spacing. In both the COMSOL Multiphysics simulation and in the experimental demonstration, ultrasonic beams, in the 35 kHz to 40 kHz bandwidth, were directed to the origin of the shifter for a range of incidence angles and a high resolution, sub-wavelength pressure map was collected adjacent to the exit interface. The results were compared with two control configurations: first, in the absence of any structure then second, with an acoustically inert block, equally sized to the shifter, in place. Beam shift distances were on the order of one wavelength. Analytical, simulated and experimental results were in accordance with each other. Finally, potential applications of the metamaterial within the current ultrasonic engineering paradigm and in conjunction with transmitters and receivers are suggested.

Keywords: Acoustic metamaterial, ultrasonic, beam shifter, 3D printer

*Speaker

Acoustic wave propagation in graded effective anisotropic fluid layers under oblique incidence

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This paper deals with the use of graded anisotropic layers for admittance matching purposes between highly-contrasted media. The capabilities of such material as acoustic treatments are numerically investigated throughout this paper. The microstructure anisotropic unit cell is designed from simple geometric volumes, being an ellipsoid extruded from a cuboid, creating symmetric elliptic pores one each face. It is then saturated by air while the skeleton of the structure is considered to be perfectly rigid. The material effective properties of the anisotropic fluid are derived from the solutions to the homogenized unit cell problems for viscous and thermal dynamics of the internal saturating fluid. Albeit, the macroscopic layer is heterogeneous assuming large wavelengths and the scale separation (*Homogenization of Coupled Phenomena in Heterogenous Media, Auriault, Boutin, Geindreau, 2009, ISTE*). The plane wave propagation problem sets the material as a layer of finite depth (but infinite in the other directions) against a rigid backing. Acoustic propagation is considered as a plane wave front impinges the anisotropic heterogeneous layer with oblique (elevation and azimuthal) incidence. The direct propagation problem is solved using three different common methods (Transfer Matrix Method, Wave-Splitting Transfer Green Functions and Peano-Baker Series) which all show good agreement. We show the ability to reach perfect absorption with such design and the overall tunability of its effective parameters both in terms of angle of incidence and frequency range, and finally discuss about its application for aircraft engines fan noise reduction.

Keywords: anisotropic, equivalent fluid, metamaterial, graded materials, porous materials

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Dynamic behavior of ribbed plates with inner resonance, homogenized models versus experimental measurements

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The dynamic behavior of periodic unidirectionally ribbed plates is investigated. The behavior of the unit cell is analyzed through multi-scale asymptotic method in order to derive the governing equations of the effective mechanical behavior. This approach allows obtaining a relevant representation of the main physical mechanisms at different scales. Design rules providing parameters suitable for inner resonances depending on the geometrical and/or mechanical contrasts of the structure components are also established. Homogenized models are derived from linear elasticity constitutive laws applied to the plate and the beam coupled together. Solving the problem in frequency domain leads to explicit dispersion relations that highlight atypical dispersion features impacting flexural and torsional waves coupled with guided waves. This global model is then extended to an orthogonally stiffened plate, and the case of a rectangular beam grid is firstly homogenized. The dynamic contribution of locally resonant internal plates is given under analytical form for several boundary conditions, then introduced into the grid model. The relevancy of the models is verified using finite element computations. Finally, experimental validation consists in post-processing the measured responses using inhomogeneous wave correlation technique. This enables to recover dispersion curves that can be compared to the analytical predictions. The good qualitative and quantitative agreement obtained show the relevance of homogenized models to describe the dynamics of locally resonant periodic plates. This approach can be used to describe the motion of stiffened panels of industrial interest, design structures having specific features in a given frequency range, such as unconventional radiation efficiency and sound transmission loss.

Keywords: Asymptotic homogenization, Periodic structures, Inner resonance media, Locally resonant plate, Inhomogeneous Wave Correlation

*Speaker

Numerical methods with acoustic losses and shape optimization: design and understanding of advanced acoustic setups

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The Boundary Element Method with viscous and thermal losses has successfully been applied to the study of the effect of viscous and thermal losses in single- and double negative metamaterials. The results have shown that losses can play a decisive role in their performance. The design of new metamaterials should certainly include acoustic losses, rather as a contribution than an obstacle to the desired objective. In this context, numerical methods with losses have been used as a basis for the recent development of shape optimization methods that may allow new understanding and design of physically realistic acoustic setups that are designed to fulfill specific functions. Acoustic metamaterials can be included in this class. Numerical implementations and shape optimization techniques will be outlined in the presentation, together with some practical examples.

Keywords: BEM, viscothermal losses, optimization, metamaterials

*Speaker

Low-frequency sound absorption of rigidly-backed waveguides laterally loaded by acoustic resonators

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In this work, a homogenisation-based theory that predicts the acoustical properties of metamaterials comprising a rigidly-backed waveguide laterally loaded by acoustic resonators is developed and validated with finite element simulations. The theory shows that low-frequency sound absorption peaks can be achieved not only by exploiting the sub-wavelength resonant behaviour of the loading resonators but also due to their interaction with the waveguide. Remarkably, the peak associated with the interaction between the local constituents is located at a frequency much smaller than the sub-wavelength resonance frequency of the acoustic resonators. We provide several examples on how the low-frequency sound absorption of rigidly-backed waveguides laterally loaded by acoustic resonators can be tuned and improved by introducing specific structural modifications to the material constituents and/or local material heterogeneities featuring multiple scales.

Keywords: low frequency sound absorption, metamaterials, homogenisation, waveguide, resonators

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Modelling of Acoustic Black Hole based Mufflers

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The present work investigates the influence of internal linings with graded properties, on the performance of open termination ducts and mufflers working within low frequency range. The functioning of such linings has been associated to the Acoustic Black Hole (ABH) effect. These structures work on the principle of impedance matching, and in theory, realized to achieve total absorption of sound in closed terminating channels. Theoretically, closed termination retarding structures have been derived to achieve total absorption of sound (M. A. Mironov and V. V. Pislyakov, 2002), thus representing an ideal ABH.Based on similar principles, theoretical basis has been established to develop semi-analytical models for an open expansion chamber, embodied by the muffling section (N. Sharma, et. al., 2017). Plane wave radiation incident through inlet end of the muffler, is made to undergo impedance matching while traversing through the lined flare of varying wall admittance. The governing equation for defining such pressure variations within a muffling section, has been obtained as the generalized Webster's Equation, which is a linear differential equation with spatially varying coefficients. Use of Webster's Equation aids in scaling down the dimensional consideration of the system. Solution of these equations has been carried out with much simplification with the use of the WKB Approximation (developed by Wentzel Kramers Brillouin and Jeffrey, which is similar to LG Method formulated by Lieuville and Green (Bender and Orszag, 2013)). In the present paper, the general semi-analytical solution has been derived further to obtain profile parameters such as the characteristic impedance and wave number. An analytical insight developed with the understanding of these parameters will be useful in finding the various resonance frequencies of the system. Altogether, dealing with the configurations theoretically, will richly contribute towards not just realizing, but also optimizing the physical significance of the constituting features of these ABH based open termination mufflers.

Keywords: Acoustic Black Hole (ABH), total absorption of sound, lined flare mufflers, generalized Webster's Equation, WKB Approximation

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Enhancing Broadband Absorption through Functionally-Graded Perforated Materials

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Acoustic metamaterials can be engineered on the subwavelength scale to control sound transmission or reflection on selective spectral bands. In this paper, we analyze the sound absorption and transmission properties of a functionally-graded sonic crystal made of alternating layers of air and perforated plates whose filling fraction, that depends on the layer thicknesses and the perforation ratio, can be varied along the propagation direction. A theoretical model based on modal matching formulation and Fourier-Floquet expansion of the diffracted orders predicts the pressure and velocity fields through the multilayer structure. It accounts for an arbitrary number of rigid perforated plates with a two-dimensional array of subwavelength holes, eventually submillimetric, separated by thin air gaps. The absorption and transmission performance well compare against those obtained from impedance translation methods using effective perforate impedances, provided that the holes pitch is greater than a quarter wavelength in air. Parametric studies have been carried out under normal incidence to assess the dependency of the acoustic band gaps on the thicknesses of the fluid/solid layers, on the perforation ratio and on their variation within the structure. Optimization studies have been performed to find the graded structure constitutive parameters that maximize the acoustic dissipation of the system, i.e. both the absorption and the transmission loss, over a broad frequency range. The resulting input impedances are compared against optimal impedance relationships deduced from coherent perfect absorption criterion. Of interest is to consider a graded structure with a membrane-coated end plate that already provides low transmittance.

Keywords: functionally, graded phononic crystals, perforated plates, sound absorption and transmission, impedance matching, optimization study

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One dimensional modelling of self-cloaking inside ducts using liners

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Novel phenomenon of broadband self-cloaking inside ducts using liners is proposed. In the audible range the plane waves inside duct is guided around an object using liner impedance. A one dimensional modelling of this phenomenon is presented using Mild-slope formulation. This explanation is inspired from the domain of water waves. This analytical method is comparatively simpler in application and the results agree well with solution of Helmholtz equation.

Keywords: acoustic cloak, back scattering reduction, liner surface modes, self, cloaking, mild slope equation

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Plant usage potential in noise control

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Besides the technological developments and changes in the community, urban environments are affected negatively due to transporation and traffic problems. On one hand, highways built to shorten the travel period and the bypasses to speed transportation time and capacity brings comfort in service functions, on the other hand, creates numerous negative effects like functional, visual and auditory damages in urban environments. People always complain the traffic noise. We know that some plants can reduce noise levels. Our group will try to explain how can we use plant materials in noise control and which plants can reduce the noise levels. With this topic, the role of plant material in reducing the effects of noise were discussed and the plantation design for an effective noise control and plant species that could be used to eleminate or reduce noise for cities were proposed. Vertical gardens are an often used type of practice in urban areas in recent years. Especially the amount of noise in the underpasses on the highways is increasing due to the reflected sounds. The use of vertical gardens on the side walls of the underpasses is expected to reduce noise. Vertical gardens located in some underpasses on the Anatolian Motorway in Istanbul were chosen as the study area. Due to the use of a wide variety of plant species and the availability of existing vertical gardens, these areas had been chosen as study sites. The study examined the differences in noise reduction rates according to leaf varieties of plant species used in vertical gardens. It is concluded that some differences in the amount of noise according to different texture and size characteristics of the leaves. As a result, noisy absorptive plant species detected and suggestions for the applications to be used in the shrubs had been brought up.

Keywords: vertical garden, noise, plant

*Speaker

Development of light-weight, integrated and multifunctional acoustic metamaterials/metasurfaces to reduce noise from next generation aero-engines: modelling and data

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Increased air transport has resulted in greater annoyance from aviation noise. The WHO identifies noise as the second biggest environmental public health risk in the EU. Conventional barriers cannot mitigate civil aviation noise. The aim of this work is to attenuate noise at source, designing innovative configurations which are able to absorb, dissipate, and redirect acoustic waves. To achieve this, new light-weight multi-functional acoustic metamaterials and metasurfaces are being investigated to be used inside, at the inlet and at the exhaust of nacelles without adding weight to the aircraft. Periodicity-enhanced metamaterials and metasurfaces are artificial structures with acoustic properties not found in natural materials. They have already been proven in room acoustics and in traffic noise but they have not been explored for aeronautical applications [1]. This study focusses on designing new metamaterials and metasurfaces, and also on tackling the new challenges of modelling sound propagation and diffraction involving moving sources in moving media [1]. This provides a significant challenge in predicting sound propagation through aero-engines as conventional methods are not applicable. The work presented here considers the development and re-formulation of existing techniques to incorporate the aeroacoustic environment and to validate results with experimental data. The novelty of the work lies in: modelling and testing the properties of existing metamaterials and metasurfaces in an aeroacoustic environment; enhancing them using resonance and internal structure; studying new designs; investigating thin layer porous materials at the microstructural level; surface wave manipulation; upward diffraction, and the combination of these effects. Metamaterials and metasurfaces can exhibit nearly arbitrary values of effective density and modulus, which may be manipulated to modify acoustic effects for noise control. Evidence has been found that metasurfaces support surface wave propagation and can act like a locally reacting rigid-framed hard-backed poroelastic material at cell spacing smaller than a wavelength [2]. Concentrating acoustic energy in surface waves, and redirecting the energy away from the receiver may reduce the impact of noise generated by aircraft. Upward diffraction of sound from nacelles is achieved by transmission through a suitable array of periodically spaced multilayer cylinders with different radii called GRaded INdex Sonic Crystal (GRIN-SC) [3]. Recently, it has been shown that a 'Tube-in-sphere resonating meta-surface' can achieve sound absorption at wavelengths much larger than the resonator size over a narrow frequency band [4]. This work is being extended to enhance the controllability and tunability of propagation over wide frequency bands in aeroacoustic environments.

Keywords: aviation noise, aeroacoustics environment, metamaterials, metasurfaces, absorption, propagation

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Potential application of acoustic metamaterials on double- and single-glazing windows for sound reduction

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Double-glazing windows are able to assure a moderate degree of sound insulation whilst enabling natural ventilation. This work explores the possibilities of applying acoustics metamaterials in the double- and single-glazing windows for sound insulation. The discontinuous Galerkin (DG) method is used to predict sound transmission through the window. The sound insulation level is measured by the Sound Reduction Index (SRI), which is calculated by the level difference of the incident and the transmitted sound through the window. The window lies between a source and receiver room with rigid walls which provide diffuse fields. The sound insulation is further studied with various staggered window openings, window depths, window heights.

Keywords: Double, /Single, glazing windows, acoustic metamaterials, sound reduction

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Tunable Transmission Properties of Acoustic Waves Propagating in a Waveguide Grafted with Acoustic Resonators by Filling Liquids

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The propagation of acoustic/elastic waves is completely forbidden in the bandgaps. It has since then been observed that band gaps can arise because of two different mechanisms, Bragg interference and local resonances of substructures in the unit cell. In this work, we designed a tubular waveguide grafted with periodic acoustic resonators. Local resonance band gaps appear close to the resonance frequencies. Tunability is realized by filling the waveguide or the resonators with water. We compared the transmission properties of the waveguide or resonators filled with different amount of liquids. A theoretical model is used to explain why the transmission typically shows a zero around a resonance frequency of a single resonator and to evaluate the coupling between evanescent waves originating from a grafting point and propagating waves. Of particular interest is the effect of the added amount of water. In order to investigate numerically the dispersion relations and the transmission properties of the samples, we used a three-dimensional time-harmonic finite element model of pressure wave propagation. Experiments were performed in the audible range with a simple acoustic system composed of a finite periodic sequence of air resonators. Measurements were conducted using a sound card connected to a personal computer to generate Gaussian pulses with adjustable central frequency and bandwidth. The pulses were played with a loudspeaker placed at one end of the waveguide. The same sound card was used to sample the signals recorded with a microphone at the other end of the waveguide. It is verified that locally resonant band gaps of the periodic PCs are generated around the resonance frequency of single resonator. Filling water into the waveguide increases the cut-off frequencies of guided modes and thus enables one to open band gaps at higher frequencies. By increasing the amount of water in the waveguide, the coupling between evanescent waves originating from the resonators and propagating waves in the tubular waveguide can further be tuned continuously. We find that the lower frequency edge of the band gap remains almost fixed, while the upper edge of the band gap increases notably as the level of water increases. As a result, band gaps become gradually wider. Furthermore, the attenuation in the band gap increases. In general, numerical results are found to be in quite good agreement with experimental results, as well as with theoretical predictions. The present work is relevant to the practical design of tunable acoustic devices.

Keywords: Tunability, acoustic resonator, locally resonant band gaps

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Playing the metamaterial guitar with light and ultrasound

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The ultimate goal of metamaterials research may be described as arbitrary control over material properties at any point in time and space. Fundamentally, this requires the ability to modify a metamaterial structure with sub-wavelength spatial resolution. Here we demonstrate dynamic control over metamaterial properties beyond the diffraction limit based on acoustic resonances and electromagnetic resonances of nanomechanical metamaterials. Our nanomechanical metamaterials consist of coupled electromagnetic resonators supported by mechanical resonators, such that relative motion of the electromagnetic resonators changes the optical properties of the metamaterial array. The metamaterials have a thickness of 100 nm, with electromagnetic resonators consisting of gold nanorods arranged in a 700 nm x 700 nm unit cell, and supporting mechanical resonators consisting of silicon nitride strings of 200-300 nm width and 19-28 μm length. Thus, the structures exhibit near-infrared optical resonances (controlled by the gold nanorods) and mechanical resonances (controlled by the silicon nitride strings) at ultrasound frequencies of 100s of kHz to few MHz, where the resonance frequency is inversely proportional to the string length. The optical properties of the metamaterial arrays are modulated by nanostring displacement driven by (i) ultrasound, (ii) optical heating and (iii) optical forces. As efficient actuation of the nanostrings occurs only at their mechanical resonance frequencies, strings of different length can be addressed individually using ultrasound or light modulated at a string's resonant frequency. Our experimental demonstrations include modulation of light by ultrasound as well as selective actuation of individual metamaterial strings spaced by 700 nm by modulated light of 1550 nm wavelength. Importantly, mechanical resonances allow us to control metamaterials with light and sound with the same spatial resolution as the string spacing, i.e. the resolution of our approach is set by nanofabrication, not diffraction. In analogy with a guitar, use of optical and acoustic control signals to selectively excite vibration of individual strings at their different resonant frequencies may be thought of as playing a "metamaterial guitar" with light and ultrasound. In contrast to a conventional guitar, our vibrating metamaterial strings generate moving pictures by modulating light in time and space. In summary, dynamic control of the addressable nanomechanical metamaterials enables simultaneous spatial and temporal modulation of metamaterial properties, taking metamaterials to the next level of functionality. Further development of this concept could lead to superresolution spatial light modulators, transformation optics/acoustics devices, reconfigurable optical/acoustic components, parallel optomechanical sensor arrays, superresolution imaging devices and miniaturized spectrometers.

Keywords: nanomechanical metamaterial, optical force

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Observation of Brillouin scattering self-cancellation in silica nanowires

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The photo-elastic and moving-boundary effects can interact oppositely leading to the suppression of backward Brillouin scattering for specific Rayleigh acoustic modes. Here we present a theoretical analysis and discuss recent experimental results obtained in silica nanowires.

Keywords: Brillouin Scattering, Nanowires

*Speaker

Dissipative Envelope Solitons In 1D Acoustic Metamaterials

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In this work, we study analytically and numerically envelope solitons in one-dimensional (1D) weakly lossy nonlinear acoustic metamaterials with effective negative material characteristics (effective negative mass density or bulk modulus). Two systems with different dispersion properties are analyzed. The first one consists of a waveguide periodically loaded by clamped elastic plates showing a zero frequency band gap. The second one, a waveguide periodically loaded by side holes. Based on the transmission line approach, we develop a lossy nonlinear dispersive lattice model and applying the multiple scales perturbation method, we derive effective lossy nonlinear Schrödinger equation. Using the latter we obtain approximate analytical expressions for bright and gap solitons in the clamped elastic plates system and dark (black and gray) solitons in the acoustic metamaterials with side holes. We perform direct simulations to study the dissipation-induced dynamics of the envelop (bright, gap, black and gray) solitons. The limits of the three relevant parameters, i.e., nonlinear, dispersion and dissipation lengths, playing a role in the generation of the dissipative solitons are discussed in this work. Numerical and analytical results, relying on the analytical approximations and perturbation theory for solitons, are found to be in good agreement.

Keywords: Dissipative envelope solitons, acoustic metamaterials

*Speaker

Theory for Willis coupling prediction of acoustic metaatoms

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Acoustic metaatoms are the unit cells of acoustic metamaterials and metagratings. The properties of a metamaterial consisting of such metaatoms can be derived from a single metaatom polarizability. We present a method for extraction of the single metaatom polarizability inclusive Willis coupling terms applicable on numerical and experimental scattered pressure fields. Moreover, we developed a theory for fully analytical determination of the polarizablity of special shape resonant metaatoms. The extraction method and the theory have been numerically and experimentally validated and gives a helpful tool for acoustic metaatom design.

Keywords: Willis coupling, polarizability, metaatom, bianisotropy

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Non-Hermitian systems & metamaterials: More prospective

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Recently developed parity (P) and time-reversal (T) symmetric non-Hermitian systems [1] govern a rich variety of new and characteristically distinct physical properties, which may or may not have a direct analog in their Hermitian counterparts. Recent experimental realizations of such Hamiltonians and their theoretically predicted phenomenon becomes possible in optical systems, condensed matter systems, mechanical systems due to some special kinds of metamaterials (PT-synthetic metamaterial) which have provided a huge boost to this field. The highly unusual optical properties of non-Hermitian and PT-symmetric metamaterials (such as non-reciprocity, invisibility, anti-lasing etc.) could be used to devise an entirely new class of devices. Where a small but nonzero non-Hermiticity can increase the transmission to unity in an isotropic negative refractive indexed metamaterial [2], the concept of acoustic parity-time (PT) symmetry and its extraordinary scattering characteristics can contribute an invisible acoustic sensor with loss compensation and extraordinary wave manipulation [3]. Topological insulator metamaterials are also being extended to its non-Hermitian counterparts to see more new phenomenon and characteristics. Interestingly, in recent years it is observed that superconductivity is significantly enhanced in metamaterials. Motivated by this, for the first time, we study a non-Hermitian, PT-symmetric superconducting system [4] that possesses real quasiparticle spectrum in the PT -unbroken region of the Brillouin zone. Within a single-band mean-field theory, we find that real quasiparticle energies are possible when the superconducting order parameter itself is either Hermitian or anti-Hermitian. Within the corresponding Bardeen-Cooper-Schrieffer (BCS) theory, we find that several properties are characteristically distinct and novel in the non-Hermitian pairing case than its Hermitian counterpart. It is now an open task to engineer such a metamaterial which shows a PT-symmetry induced superconductivity to explore more on its extraordinary behaviors.

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Keywords: PT symmetric metamaterials, Non Hermitian Hamiltonian, Superconducting pairing, BCS theory, Topological insulator metamaterials.

*Speaker

Absorption of flexural waves by 1D resonators in the case of reflection and transmission problems

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The design of lightweight materials for vibration damping poses a scientific and technological challenge owing to increasing needs in several branches of industry. Classical passive solutions are usually based on the use of viscoelastic coating which increases the mass of the structure resulting in heavy treatments. This work proposes an analytical model based on the transfer matrix method and 1D thin beam theory. Numerical calculations are also developed in order to validate the hypothesis in the analytical model. Preliminary analytical results are presented throughout this work. In the case of a reflection problem of flexural waves, a simple system consisting of a semi-infinite beam terminated by another beam with a different thickness is studied. A transmission problem consisting in an infinite beam in which a beam with a different length is inserted is also treated. The composite material constituting the termination is modeled with the RKU method which makes it possible to consider the beam and the coating layer as a single composite. Preliminary experimental results are also shown to validate the analytical results.

Keywords: Flexural Waves, Perfect Absorption

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Observation of topologically protected helical edge waves in elastic plates

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Topologically protected waves in classical media provide unique opportunities for one-way wave transport and immunity to defects. Contrary to acoustics and electromagnetics, their observation in elastic solids has so far been elusive due to the presence of multiple modes and their tendency to hybridize at interfaces. We report on the experimental investigation of topologically protected helical edge modes in elastic Kagome plates. Through-thickness holes are induced to produce an accidental degeneracy of two Dirac cones. Such degeneracy is subsequently lifted by careful breaking of symmetry along the thickness direction, which emulates the spin orbital coupling in the quantum spin Hall effect. A non-trivial interface supporting helical edge waves is produced by joining two plates that are mirror-symmetric copies of each other about the plate mid-thickness. The experimental demonstration of topological protected wave motion in elastic continuous plates opens avenues for the practical realization of structural components with topologically non-trivial waveguiding properties and their application to elastic wave guiding and confinement.

Keywords: Scattering, free propagation, Topological protection, Control of waves

*Speaker

Design of Locally Resonant Metamaterial for Structural Acoustic Applications

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This paper presents the design and possible applications of locally resonant metamaterial (LRM) for structural acoustics that deals with the interaction between vibrating structures and sound radiations. LRM is a class of metamaterial, and it has unusual properties induced by local resonators inserted in a host structure. The most attractive property of LRM is subwavelength band gap which perfectly prohibits propagations of waves. To take the benefit of band gap, many designs have been proposed for decades with various applications such as vibration isolation, sound insulation, and energy harvesting. The paper presents structural acoustic applications that can be benefited from the band gap by controlling the propagation of flexural waves. The LRM design that induces flexural wave band gaps in a thin plate structure is presented. Unusual flexural wave propagations that can be realized by the LRM design are investigated. Finally, promising applications are presented by analysing the interaction between the propagation of flexural waves and the sound radiation.

Keywords: Locally resonant metamaterial, Band gap, Structural acoustics, Sound radiation, Sound transmission

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Uncertainties in wave characteristic of one-dimensional periodic structures using fuzzy approach

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Periodic structures have properties of controlling mechanical wave. These are used in aircraft, trains, submarines, space structures and demand high level of robustness, which can be ensured with consideration of the presence of uncertainty in the numerical models. The uncertainties, in terms of material properties and geometrical parameters, are mostly introduced in both the manufacturing and assembly process. In order to predict the wave characteristics of the periodic structures under the uncertainty, the wave finite element method in conjunction with fuzzy set theory has been applied to periodic structures; wave finite element method (WFEM) added with an additional dimension to model the uncertain parameter using the fuzzy set approach. Numerical experiments are performed to test the method with one-dimensional periodic rod and periodic beam with parametric uncertainty. The performance of the developed method is compared in terms of computational cost which offers computational advantages over the Monte Carlo Simulation.

Keywords: Periodic structures, uncertainty quantification, Wave finte element method, fuzzy set theory

*Speaker

Influence of the boundary conditions and control of edge modes in finite locally resonant metamaterials

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Locally resonant metamaterials are compact assemblies of conventional materials that can combine lightweight design and performant NVH properties in tunable frequency ranges, called stop bands. In these frequency regions, metamaterials outperform common vibro-acoustic solutions, beating the mass law. Stop band behavior in metamaterials is achieved from the dynamic interaction among host structure and its subwavelength resonant additions. Using the unit cell modelling approach, stop band behavior can be predicted in the metamaterial design stage for an infinite periodic structure. However, in practical applications, structure are of finite size and their dynamic behavior is influenced by their dimensions and by their boundary conditions. Since the effect of the dimensions and the boundary conditions of the finite structure is not included in the unit cell modelling, the stop band predicted for the infinite periodic structure might not be preserved in its finite counterpart. In fact, edge modes caused by the interaction of the finite metamaterial systems with their boundary conditions can reduce the width of the predicted stop band and the vibration attenuation achieved. This work provides a numerical and experimental investigation on the dynamic performance of a finite 1D metamaterial system with different boundary conditions. Numerical results demonstrate that edge modes reduce the width of the predicted stop band. Two methods are proposed to limit the effect of the edge modes and to preserve the metamaterial performance designed using the unit cell modelling. Experimental results from a test campaign on a manufactured 1D metamaterial system are in good agreement and confirm the numerical findings.

Keywords: finite resonant metamaterials, edge modes, boundary conditions, stop bands

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Waves Dispersion in Functionally Graded Plates on elastic medium

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Propagation of waves in a functionally graded plate on an elastic medium is studied using higher order theory and concept of neutral physicals surface. The foundation is assumed one parameter of Winkler or two parameters of Pasternak. The properties of the functional gradient materials (FGM) for the plate are assumed to vary continuously through the thickness of the plate and be distributed according to the volume. The equations governing wave propagation in the functionally graduated plate are derived using the Hamilton principle. An analytical solution is obtained for wave propagation in a functional gradient plate for simply supported boundary conditions using dispersion relationships. A comparison between two cases of distribution of the properties of materials through the thickness of the plate is carried out, in main mode of wave propagation and in phase of speed. The results of this corresponding work are done to verify the effectiveness of this theory.

Keywords: Wave propagation, elastic foundation, functionally graded plate

*Speaker

Negative group velocity state in the vicinity of elastic instability in soft composites

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In this manuscript, we spotlight important intrinsic connection between elastic waves and elastic instabilities in soft materials. It is well known, that elastic instabilities in soft composite materials can be harnessed to control wave propagation [1,2]. Indeed, since loss of the stability is accompanied by the drastic changes in the geometry and periodicity of the material, shear and pressure waves alter their behavior in post-buckling state, resulting, for instance, in opening of the bandgaps. At the same time, besides the geometrical changes, an induced stress state is another major factor affecting elastic waves in soft materials [3]. Considering importance of the stress state, is it possible to observe unusual behavior of the elastic waves without alteration of the geometry? Here through detailed study of S-wave propagation, we reveal the existence of special state with omni-directional negative group velocities, which foreshadows loss of the stability [4]. Exploiting layered composites, we demonstrate that only in the composites, which undergo buckling by the microscopic mechanism [5,6], the negative group velocity state is observed. We emphasize that this phenomenon is observed in still stable configuration with straight layers. Since the transition between states with positive and negative group velocities is fully reversible, the observed phenomena can be exploited for the creation of metamaterials with switchable properties.

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Keywords: negative group velocity, microscopic instability, soft composites

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Acoustic Diffusers and Metadiffusers in Orchestra Pits: the Good, the Bad, and the Loony

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Musical loudness in performing environments has recently become a subject of great interest in the entertainment sector. Indeed, recent evolution of health and safety concerns has created a plethora of new challenges for a broad range of activities. One of such is opera, and more specifically, the high sound levels originating from orchestra pits, generating musical discomfort and threatening the musicians' hearing. Whereas it is difficult and impractical to genuinely reduce orchestral sound levels by a significant margin, conventional counter-measures usually make use of acoustic absorption and diffusion to reduce the sound levels of certain frequencies as well as enhancing the performing parameters of musicians. However, orchestra pits are very limited on the amount of space available to apply any kind of traditional acoustic treatments and therefore require a more subversive approach in order to fine-tune the existing acoustic conditions into a more suitable performing environment for orchestra pit musicians. With the recent boom on metamaterial knowledge, it is possible – now more than ever – to create acoustic structures based on such science which allow for the mimicry of tailored acoustic effects (perfect absorption, phase-changing reflection, etc.) within a very restrained space. This will be leading to a discussion about (i) the effects of acoustic absorption and diffusion in orchestra pits, and (ii) the hypothetical suitability of deep sub-wavelength sound diffusers (metadiffusers) to reproduce either or both acoustic phenomena within the constraint framework of opera productions, which in such case would help tackle the difficult acoustic conditions encountered in orchestra pits.

Keywords: Deep, Subwavelength Sound Diffusers, Metadiffusers, Orchestra Pit, Musical Loudness

*Speaker

Acoustic performance of horizontally aligned carbon nanotubes in a soft elastic medium

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In this study, polydimethylsiloxane (PDMS) composites with the loading of 1 wt. % horizontally aligned multiwalled carbon nanotubes (MWCNTs with outsider diameter 10-20 nm, insider diameter 5-10 nm, and length 10-30 μm) are made, acting as metamaterials. The dispersion of MWCNTs is evaluated using scanning electron microscopy (SEM). The storage modulus (*E'*) and loss modulus (*E"*) are tested by Dynamic Mechanical Analysis (DMA). A water tank and a water-filled impedance tube are used to investigate the underwater sound absorption properties. Compared with the randomly dispersed MWCNTs, the agglomeration can be avoided, and the horizontally aligned MWCNTs show a significant improvement on the underwater sound absorption.

Keywords: metamaterials, sound absorption, aligned carbon nanotubes

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