Conversation with a Colleague: Michael R. Haberman

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Micheal L. Dent

Meet Michael R. Haberman

Michael R. Haberman is the next acoustician in our "Sound Perspectives" series "Conversation with a Colleague." Mike is currently an associate professor in the Walker Department of Mechanical Engineering at The University of Texas (UT) at Austin, with a courtesy appointment at the Applied Research Laboratories, UT Austin. He received his bachelor's degree from the University of Idaho, Moscow, in 2000 and his master's and PhD from Georgia Institute of Technology, Atlanta, in 2001 and 2007, respectively. In addition, he holds a Diplôme de Doctorat in Engineering Mechanics from the Université de Lorraine in Metz, France, which was awarded in 2006. Between 2001 and 2003, Mike was a research and design engineer at GN ReSound, Chicago, Illinois, where he worked on a team that introduced additive manufacturing as a tool for mass customization of hearing aid shells, the mechanical casing that encases the electronics and has a shape that is custom for each person to fit within their ear canal. He is a Fellow of the Acoustical Society of America (ASA) and served as the chair of the Technical Committee on Engineering Acoustics between 2018 and 2024. He has also been an associate editor for *The Journal of the Acoustical Society of America* since 2014. We asked Mike to give us his elevator pitch and then elaborate on his inspirations, contributions, and hopes for the future.

Give your "elevator speech" about the thrust(s) of your scholarly work over your career.

Waves can be found everywhere in nature. They allow the communication of information in many forms, notably in our ability to hear and see. From the standpoint of engineering and scientific research, the ability to control wave motion enables technological advances and fuels scientific discovery across all areas of acoustics. I have always found it fascinating that the structure of matter dictates every aspect of wave motion: propagation speed and direction, energy dissipation, and even the motion of particles that make up the whole. This interest has driven my study of material structure via acoustic and elastic wave propagation since my time as a graduate student.

I like to think of my research as having both a "top-down" and a "bottom-up" perspectives. What do I mean by that? The top-down approach is one in which we seek to infer unknown or evolving material structure by measuring acoustic waves transmitted through or reflected from the material. This is a classical nondestructive testing paradigm, which was central to me becoming interested in acoustics and has numerous applications in industry and scientific research. The bottom-up approach is effectively materials design for acoustics. My research in this area began in the field of composite materials and spilled into the exciting field of acoustic metamaterials (AMM). AMM are materials that are designed with small-scale structures that enable the control of acoustic and elastic wave propagation in ways that we once thought impossible.

What inspired you to work in this area of scholarship?

I would have to say my interest in acoustics was first sparked by an introductory course on fracture mechanics that I took in 1999 as an undergraduate mechanical engineering student at the University of Idaho! As strange as that may seem, it was during this course that it first became clear to me that acoustics is a field of study

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with broad utility for both engineering and scientific research. Specific to the content of that course was the use of ultrasonic nondestructive testing as an essential tool for damage detection and characterization in elastic components. As a student, I was astonished that we could use ultrasonic waves to monitor crack growth and even damage that is much smaller than a wavelength using this specialized technique. The next semester, I took an undergraduate-level acoustics course from Michael Anderson where I began to appreciate that while the field of acoustics encompasses physics, engineering, musical performance, human health, biology, and many other areas, all subfields of study ultimately rely on similar physical phenomena. I was hooked and Anderson convinced me to apply for graduate school to learn more, which is exactly what I did.

While in graduate school in a dual-degree program at the Georgia Institute of Technology and the Université de Lorraine, I was lucky to have had a wonderful PhD advisor, Yves Berthelot, who taught me to spend time learning from other areas of science to gain inspiration and insight to help address current research challenges. He also taught me that doing good research is a matter of asking the right questions and to not be constrained by what we think is currently possible. He instilled the idea in me that knowledge gained from other areas of science and engineering drives creativity in research and accelerates progress. His insights and encouragement during those years is what provided me with the tools that helped me see the potential in the field of acoustic metamaterials and to link my initial interests in ultrasonic testing to the design and discovery of new materials to control acoustic fields.

Of all your contributions during your career, which are you most proud of and why?

Of all of my previous and ongoing work, I am proudest of my work in the area of acoustic metamaterials (AMM). This includes my scientific contributions to the field and my efforts to promote this relatively new area of research to the acoustics community. Below I only focus on a few specific contributions by my research group.

I did not begin my research career in the field of AMM. As a matter of fact, the word "metamaterial" had only very recently been introduced into the scientific lexicon (in 1999 by Roger Waxler) when I started my graduate degree. At the time, metamaterial research was concentrated in the fields of electromagnetics and optics. My graduate research, which started in 2000, was focused on wave propagation in composite materials and was inspired by efforts to model ultrasonic waves in these heterogeneous materials for the purposes of improving nondestructive testing (NDT). Although my interest in acoustics was sparked by this "classical" area of acoustics, I was quickly drawn to the idea of designing materials to control acoustic waves. Fortunately for me, these two fields of study are in many ways two sides of the same coin. Both ultrasonic testing and AMM operate within the same physical domain and the behavior is bounded by the fundamental physical laws of elastic wave motion. The difference is ultimately the objectives of each field. AMM research seeks to design and create structured materials to manipulate the waves for a desired performance, whereas the research in ultrasonic NDT aims to characterize a structure using the information encoded in elastic waves propagating through complex structures of a given mechanical component. I ultimately found that the design of novel materials to manipulate acoustic and elastic waves captured my interest and made me excited for its potential for long-term impact in the field of acoustics.

My earliest published research that was explicitly in the field of AMM was on the topic of acoustic cloaking. My first publication on cloaking was an article in *The Journal of the Acoustical Society of America* (*JASA*) in 2011 in collaboration with Andrea Alù. This topic was clearly very compelling. I felt as though we were trying to turn science fiction into science. Our unique approach, which we called scattering cancellation, consisted determining a layering scheme for materials surrounding an object that minimized the scattered field over a specific frequency range. Though our work in this area was fruitful and showed promise to make acoustic sensors that minimally perturb the field the measure, most of the outcomes were theoretical and it has been left for future work to turn those ideas into reality.

My interests then turned to more general concepts. This included Willis materials, pentamode materials, and materials that enable nonreciprocal acoustic wave propagation, which I highlight briefly below.

Willis materials are a class of acoustic and elastic materials that have unique behavior due to the fact that the small-scale structure of the material (structure that is much smaller than the wavelength of propagating acoustic waves) is asymmetric. As a result, the momentum and stress fields of the material are functions of both the strain and velocity fields. In a classical material, the stress would only be a function of strain and the momentum would only be a function of velocity. These materials are named in honor of John Willis, who was the first one to predict this unusual material response in 1981 but only through mathematical models.

We first experimentally observed this behavior in 2017 using a simple impedance tube measurement. We simultaneously developed dynamic multiscale theoretical and numerical models to describe the emergence of this behavior from small-scale asymmetries and how it may be exploited to control scattering from objects, create more efficient acoustic lenses, and design materials that have direction-dependent absorption coefficients. Research in this area is still very active, with regular new demonstrations of concepts that make use of this novel material response.

Pentamode materials (PM) are elastic lattice materials that behave as fluids with direction-dependent properties over very wide frequency ranges. These materials were hypothesized in 1995 by Graeme Milton and Andrej Cherkaev but were considered something of a theoretical novelty until it was shown that they could enable acoustic cloaking and other exotic devices. My group, in collaboration with Andrew Norris and Preston Wilson, was the first to model, design, fabricate, and acoustically test two-dimensional (2D) and three-dimensional (3D) pentamode materials created from additively manufactured metals in the underwater environment. We demonstrated underwater acoustic focusing using 2D PM lenses and 3D PM materials with anisotropic longitudinal sound speeds over a wide bandwidth using additively manufactured structures.

Finally, I want to highlight our work on what has come to be known as “nonreciprical materials.” The principle of reciprocity essentially states that if you can hear someone, they can hear you. The ability to purposefully break this restriction on wave propagation could lead to exciting new capabilities in acoustics, such as the ability to simultaneously transmit and receive acoustic signals from the same device at the same time. My research with Benjamin Goldsberry and Samuel Wallen has made several key contributions to this area, primarily in the use of waves propagating through mechanical lattices with deformations that change in time and space. We showed that slowly varying nonlinear deformations of lattice structures could be leveraged to generate nonreciprocal elastic wave propagation and generalized our computational tools to address this problem to consider nonreciprocal beam vibrations and elastic wave mode converters. The generality of the concepts we have demonstrated on this topic will enable exploration of realistic elastic media and structures for improved control of vibroacoustic motion.

What are some of the other areas in which you feel you made substantive contributions over your career?

In my mind, one of the best aspects of the field of acoustics is the wide range of engineering and science that it touches. Though I was initially inspired to study acoustics by concepts in ultrasonic nondestructive testing, the reality is that most of my research career has focused on more fundamental topics of acoustic and elastic wave propagation through the study of metamaterials. However, I have continued to do research in ultrasonic methods for material characterization and damage detection. Two specific examples are my work with Jinying Zhu on the use of acoustics to detect damage in concrete bridge decks and ongoing work with Ofodeke Ezekoye where we are using ultrasonic waves to detect damage in lithium-ion batteries (LIB).

Soon after my arrival at UT Austin in 2007, I began to interact with several colleagues whose research focused on nondestructive testing. One project, led by Jinying Zhu, who is currently at the University of Nebraska-Lincoln, involved the creation of air-coupled ultrasonic testing methods to search for damage in concrete bridge decks. We focused spark-generated N-waves using an ellipsoidal reflector system to excite resonances in concrete that indicate long horizontal cracks known as delaminations that can be found 10-20 centimeters deep within the structure. Interestingly, the ellipsoidal reflectors were inspired by previous work in nonlinear acoustics by David Blackstock and Wayne Wright at UT Austin. The resulting surface motion, amplified by the resonance associated with the depth of the delaminations, radiate acoustic waves that we detected using microphones placed at the focus of parabolic reflectors. The entire system was demonstrated on interstate highway bridges and the data was fused with ground penetrating radar to improve the efficiency and accuracy of bridge deck inspection. Versions of this system are being developed by industry for future use in infrastructure projects throughout the U.S.

More recently, I began working with Ofodeke Ezekoye to leverage ultrasonic waves to detect damage and to monitor the state of charge and state of health of LIB to ensure safe operation. This work is an essential component in recent efforts to develop testing methodologies that merge electrical, chemical, mechanical, and ultrasonic information to help ensure the safety of existing LIB systems. Furthermore, we are working with colleagues at the National Renewable Energy Laboratory in Boulder, Colorado, to integrate ultrasonic testing into testing protocols for the next generation of batteries, such as solid-state batteries, in order to assess battery safety when subjected to different charging protocols, environmental conditions, and other factors prior to the widespread integration into the market.

What do you think are the most pressing open questions that you would like to focus on over the next 5-10 years?

The field of acoustic metamaterials finds itself at an inflection point where further advances requires more direct engagement with researchers and practitioners in areas outside of acoustics, particularly in the areas of materials science and advanced manufacturing. I intend to do so in order to address open questions involving the creation of acoustic materials that can adapt their properties to a changing environment. This requires an understanding of wave propagation through materials whose structure changes with time and an ability to work across disciplines in science and engineering to make it possible. Interestingly, this knowledge is also applicable to open questions in application-driven research on the use of ultrasonics to detect changes and classify damage in energy storage systems like lithium-ion and next-generation batteries.

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Contact Information

Michael R. Haberman
haberman@utexas.edu

Walker Department of Mechanical Engineering
The University of Texas at Austin
Austin, Texas 78712-1591, USA