TECHNICAL
COMMITTEE
REPORT

Structural Acoustics and Vibration

Robert M. Koch

Postal:
Naval Undersea Warfare Center
Code 00T1, Building. 1346/4
Newport, Rhode Island 02841-1708
USA

Email:
robert.m.koch@navy.mil

Christina J. Naify

Postal:
Jet Propulsion Laboratory
4600 Oak Grove Drive
Pasadena, California 91109
USA

Email:
Christina.J.Naify@jpl.nasa.gov

The structural acoustics and vibration field partners a technically diverse research community with a surprisingly broad spectrum of technical applications.

Members of the Structural Acoustics and Vibration Technical Committee (TCSA) share a common interest in the scientific examination of both (1) linear and nonlinear mechanical vibrations, shock, or structure-borne wave propagation within solid media and (2) the interaction of these structural dynamic systems with adjacent acoustic environments. Some of the principal TCSA technical focus areas include the study of the response, damping, isolation, and active/passive control of mechanical systems subjected to dynamic excitations; the modal or resonant, transient dynamic, or shock response of these systems; and the coupled structural acoustic behavior of vibratory mechanical systems that either excite or are excited by acoustic radiation in a surrounding acoustic fluid. Structural acoustics (also termed vibroacoustics) can thus be fundamentally defined as a multidisciplinary coupled field of physics referring usually to the characterization of either (1) the sound power emitted by a vibrating structure subjected to external dynamic excitation or (2) the vibrational response of structures excited by incident sound fields or other fluid excitation. TCSA members include a wide range of researchers and practitioners from across academia, industry, and government as well as a group of active student members just beginning their study and professional contributions to the exciting structural acoustics and vibration technical area.

Perhaps the majority of those working in the field have academic training in some discipline of structural mechanics to start. That is, it seems that most of these scientists and engineers first established their technical training in the solid mechanics arena and added an additional or later concentration in acoustics. This is likely due to the broader and more extensive nature of generalized structural mechanics versus acoustics disciplines both in the workforce and in university programs worldwide. Other structural acousticians, fewer in number but growing as a percentage of the structural acoustics and vibration investigator population, obtained degrees focused directly on structural acoustics or more broadly on acoustics, physics, electrical engineering, or materials science as a path to entering the field.

The technical disciplines of structural acoustics and vibration are applied and researched every day across an extremely broad spectrum of applications in the academic, governmental, and industrial workforces. Virtually any simple mechanical component or complex system subject to structural or acoustic excitation will respond with appreciable mechanical vibration, significant radiation of sound, or both. For example, structural acoustics and vibration applications span all manner of manned and unmanned vehicles including aircraft and other aerial launch vehicles, underwater vehicles, and naval surface craft as well as cars, trucks, and trains. Because these vehicles are utilized in the commercial, military, or public sectors, with widely varying structural acoustic requirements and design methods

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for each, understanding the concepts of vibration and acoustic response has wide-reaching importance.

Many of these systems may also act as excitation sources for the technical area of building vibration and noise as well. For example, ground-borne wave propagation and radiated sound power resulting from large public transit systems such as trains often propagates into nearby buildings, resulting in unwanted mechanical vibration and noise within those structures. Building design is thus studied from the standpoint of structural acoustic and vibration in these structures due to excitation by external sources (trains), general mechanical systems (HVAC systems), and even human-generated sources. Ground-borne vibration is not always undesirable, however. As an example, structural acoustics and vibration researchers are responsible for the many recent advances in utilizing the purposeful generation of in situ shear waves into the ground as a means for characterizing soil composition at building construction sites and for other seismic/geotechnical purposes (Foti et al., 2015).

Specific commercial industries involving structural acoustics and vibration include a wide and varied range of consumer products from copy machines to wind turbines to pumps and piping systems to musical instruments. Even a variety of biomedical devices and instruments such as hearing aids and ultrasonic diagnostic equipment are increasingly reliant on structural acoustic and vibration scientists and engineers to provide a comprehensive understanding of wave-structure interaction. Finally, this technical area also encompasses many more general topics that span many of the aforementioned applications such as active vibration and noise control, structural health monitoring, metamaterials and phononic crystals, acoustic transducers and sensors, and fluid flow-induced vibration and noise.

Regardless of the specific application area above, the typical structural acoustics and vibration practitioner will likely utilize one or more of the following modern scientific methods of investigation in his/her workday activities: (1) theoretical/analytical calculations, (2) experimental examination, or (3) computational physics-based modeling and simulation. Using the theoretical method involves the assembly and coupling of the governing equations of motion for a given vibroacoustic system and solving them in a largely closed-form manner, incorporating mathematical methods as required for the solution. Alternatively, empirical investigation of the structural acoustics and vibration behavior of a given system typically requires the fabrication and testing of the system, with significant attention given to proper instrumentation selection and the calibration required for the collection of accurate measurement data. Scientists and engineers involved primarily in experimental investigation typically spend a substantial part of their workday in work and machine shops, laboratories, and possibly specialized test facilities such as anechoic or reverberant acoustic chambers, transmission loss chambers, or shock machines. Last, a large variety of physics-based computational mechanics and acoustics algorithms, solvers, and software tools have been developed that allow for the virtual solution and examination of complex structural acoustics and vibration problems. Details on the more commonly used numerical approaches in everyday use and also continually being researched and improved for use in simulating structural acoustics and vibration problems is described below.

Although structural acoustics and vibration researchers are generally interested in understanding the physics and predicting the fundamental mechanisms and signature levels of structural acoustics and vibration in complex systems, perhaps the majority of the time they are investigating the structural acoustics and vibration response to attempt to limit and/or control it in some manner (see article by Schnitta in this issue of *Acoustics Today*). That is, the primary focus of structural acoustics and vibration can likely be divided into two basic approaches, control and reduction of structural acoustics and vibration. The idea of control can be either to limit the response (reduction) or to tailor the response to a desired reaction by enhancing or frequency shifting of select desired natural vibratory resonances or modes. The methods used to control vibration and acoustical responses vary from simple and inexpensive so-called passive treatments to complex active and adaptive control. Passive treatments can vary from those incorporated a priori during the design of structures themselves to produce a desired acoustic response (e.g., including in the original design a set of resilient passive isolation mounts between a motor and its adjacent mounting structure) to retrofitted or add-on treatments that alter the existing structural response (e.g., sound insulation or damping coatings that may be sprayed on retroactively once an undesirable acoustic environment arises). The simplest examples of ubiquitous passive treatments are those utilizing softer isolation- and/or damping-based properties such as foams and rubbers, which are used to mitigate the acoustic or vibration response in a wide variety of applications from industrial machinery to transportation systems.

With the advent of more sophisticated electronics and electronic control mechanisms, the approach of active-mode cancellation or control has become increasingly attractive and thus increasingly studied. The basic concept behind active control involves first measuring or predicting the acoustic or vibration response and then utilizing active elements such as piezoelectric transducers to generate wave fields to either enhance or, more commonly, reduce the response. A primary complication to this approach stems from the vibrational complexity of most structures, with most structures having complex, superpositioned, or superimposed vibratory modes. The responses of these structures are notoriously difficult both to predict and then to selectively control. Additionally, active control techniques require extensive electronics and complex control systems, which can be expensive and require precise tuning.

One of the newest fields of study in structural acoustics and vibration is the field of engineered acoustic or structural materials termed metamaterials (see the article by Haberman and Norris in this issue of *Acoustics Today*). Metamaterials, which came to the field of acoustics in 2000, is a field of advanced materials that are designed to provide a desired response by introducing subwavelength features into the studied domain. Extending the idea of composite structures, which provide effective properties that are a mixture of the constituent components, metamaterials enable acoustic and vibrational response beyond the properties of any of materials from which the structures are made (Haberman and Guild, 2016). By controlling the effective bulk modulus and sound speed of a region, propagation of acoustic and elastic waves can be tailored to behave in ways previously unachievable. Indeed, by exploiting resonance of local, subwavelength inclusions, it is possible to achieve negative effective bulk modulus and density either alone or in combination. As both modulus and density become negative as a function of frequency, a double-negative material is achieved, leading to subdiffraction limit hyperlensing. These effective properties are available only under excitation and should not be confused with the static properties of the constituent materials. Because of the range of achievable properties, the applications of acoustic and mechanical metamaterials are limited only by imagination. Although the most high-profile application of metamaterials is acoustic cloaking or the reduction in scattering profile by application of a coating over a structure (Norris, 2015), significant advances have been made using this general approach in the fields of sound insulation, lensing, and antennas.

With comprehensive understanding of the optimal expected acoustic and vibrational response of a structure, it is then possible to detect changes or damage to the region via changes in the acoustic response. This type of structural healthy monitoring can involve the identification of changes to vibrational resonance modes via measured modal analysis or detection of acoustic emission events during damage processes (Barre and Benzeggagh, 1994). Structural health monitoring via structural acoustics and vibration analysis provides a significant advantage over other types of damage detection in that is generally noninvasive so that the structure is not damaged during evaluation. Changes to the structure can thus be detected early, before catastrophic failure occurs. Although simple in concept, practical implementation is challenging due to the inherent complexity of most inspected structures. Resonance and modal responses from fasteners, structural reinforcement, and holes all cause multiple wave scattering and mode conversion responses that must be accounted for in detection of structurally destructive geometries such as cracks (Duroux et al., 2010).

To address control and design challenges, a range of physics-based numerical modeling and simulation techniques has been employed to the great benefit over time within the structural acoustics and vibration community. These techniques have ranged wildly in both complexity and accuracy. These techniques, available as both commercially distributed and custom software packages, include finite-element analysis (FEA), boundary-element analysis, energy-based FEA, and statistical-energy analysis. As a general approach, these techniques involve the following overall steps: defining the geometry, imposing physical conditions such as boundary conditions and deformation or frequency-domain loading excitations, and then utilizing the solver algorithms in computing the results such as eigenvalues, eigenvectors (mode shapes), transient structural response, and/or acoustic radiation response. Each of the techniques presents its own advantages and pitfalls, which must be accounted for via thorough understanding of the underlying physics of the system and also the computational cost penalty associated with the varying degrees of model fidelity and accuracy available and required. Without that background knowledge of the fundamental physics, it is possible, and indeed fairly common, to produce nonphysical results that do not represent the reality of the system. Regardless, these techniques present a powerful tool, with applications in diverse industries such as automotive, aerospace, and general commercial goods.

The wide range of structural acoustics and vibration applications and objectives discussed above provide for a rich field of active research over a broad spectrum of industry, academia, and government. This range of applications, along with the diversity of backgrounds for investigators of structural acoustics and vibration, is a testament to the broad and truly multidisciplinary nature of the field.

Biosketches

Robert M. Koch is the US Navy's Chief Research Scientist for research in acoustic/nonacoustic stealth, signature control, and silencing of tactical-scale undersea vehicles and systems. He is also an Adjunct Professor of Engineering at Roger Williams University in Bristol, RI, and a licensed Professional Mechanical Engineer. Dr. Koch is an Acoustical Society of America (ASA) Fellow and current chair of the ASA Structural Acoustics and Vibration Technical Committee. His current research interests include advanced computational methods for large-scale, physics-based structural acoustics analysis of coupled fluid/structure interaction systems, transient dynamic high-energy shock events, and autonomous unmanned and supercavitating high-speed undersea vehicles.

Christina Naify is a Materials Engineer at the US Naval Research Laboratory in Washington, DC. She has been actively involved in the Acoustical Society of America for eight years and has served as a member on the Structural Acoustic Technical Committee as well as on the Women in Acoustics and the Tutorial Lectures Committees within the Society. Dr. Naify received a BS in mechanical engineering from the University of California, Berkeley, and a MS and PhD in materials science from the University of Southern California. Current research interests focus on acoustic metamaterials for both air and water environments.

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