JASA BOOK REVIEW

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Understanding Acoustics: An Experimentalist's View of Sound and Vibration, Second Edition

Steven L. Garrett

ASA Press and Springer, New York and Switzerland, 2020. 783 pp. Price: free electronic download or $59.99 (hardcover). ISBN: 978-3-030-44786-1

In 2017, I (author B.E.A.) started regularly teaching a course on vibrations and fluids. The first half of this course covers vibrations of a mass-spring system, strings, bars, membranes, and plates. The second half of the course covers fluid acoustics of plane and spherical waves, sound radiation, reflection and transmission, and waves in ducts. For many years *Fundamentals of Acoustics* by Kinsler *et al.*[1] was used for this course. In the spring of 2017, the Acoustical Society of America asked me to review the first edition of *Understanding Acoustics* by Garrett. I agreed, thinking that this book covered the right topics for this course and that this would give me the opportunity to decide if Garrett's book was a good fit or not. After reviewing the book, I adopted it (more information on that book selection process is written in Ref. 2).

Garrett's[3] second edition of *Understanding Acoustics* has a lot of textural explanations and a large quantity of topics covered, comprising 783 pages. Its strength is that it covers a wide variety of topics and has many conceptual discussions surrounding the development of equations. The book's chapters are mainly divided into two categories: vibrations and waves in fluids. The breadth of the topic coverage is very similar to that of *Fundamentals of Acoustics* by Kinsler *et al.*[1] but Garrett provides additional examples and textural explanations beyond that of Kinsler *et al.* Some major advantages of *Understanding Acoustics* are that it was published more recently and the second edition is available for free, with downloadable access available worldwide, thanks to the Veneklasen Foundation. The book is written for physics or engineering, advanced undergraduate or graduate student audiences. Students should have familiarity with partial differential equations and complex numbers. Many errors in the first edition are now corrected in the second edition.

The first chapter provides a background mathematical treatment of Taylor series, Fourier synthesis, complex numbers (or "convenience numbers" as Garrett refers to them), units, and error analysis. Chapters 2–6 comprise the vibrations material. An in-depth discussion of the "simple" harmonic oscillator is given, including the damped oscillator, the driven oscillator, resonance, quality factor, and coupled oscillators. Garrett often adds in unique analyses of the oscillator such as determining a characteristic speed of waves in the oscillator, the virial theorem, Rayleigh's method, adiabatic invariance of a pendulum, frictional damping, phase locking, and an extension to moving-coil loudspeakers. The limiting case of coupled oscillators provides a nice transition into his String Theory chapter. He provides an in-depth discussion of waves in strings and image sources created by boundaries. He includes extensions to musical consonance and scales. As in the previous chapter he includes deeper topics on strings such as point mass perturbations and nonuniform tension, followed by both the force driven string and the displacement driven string. Before transitioning to waves in bars and plates he provides an in-depth introduction to elasticity and derives various elastic moduli. He even discusses buckling, torsional and coil springs, viscoelasticity, complex moduli, and rubber springs. The chapter on bars goes over the usual longitudinal, torsional, and flexural waves and boundary conditions. But it also includes unique topics like the quartz crystal microbalance, sonic pile driving, and resonant ultrasound spectroscopy to extract material properties from measured resonance frequencies of a bar. Finally, the vibrations chapters are concluded with an analysis of membranes and plates. Modes in rectangular and circular membranes are discussed but additional topics on modal density, modal degeneracy, the relationship of adiabatic invariance to mode similarities, annular membranes, and an extension to microphone diaphragms is given. His treatment of plates is limited to a clamped circular plate, but students are introduced to the complexities of plates.

Chapters 7–15 comprise the waves in fluids material (though Garrett classifies the nonlinear acoustics in chapter 15 as an extensions chapter). *Understanding Acoustics* has a few detailed chapters before introducing the wave equation. It starts with ideal gas laws and hydrodynamics, considering microscopic models, thermodynamic processes, specific heat, Navier-Stokes, and entropy. Garrett then introduces lumped fluid elements as a precursor to describing one-dimensional waves. Apparently, the thinking was to develop the equations for waves in fluids using an approach that is similar to one usually used to develop the equations for waves in strings. Start with a series of coupled masses and springs, and in the limit that you have an infinite number of these connected masses and springs, the system of discrete masses becomes a continuous string system. Garrett spends a whole chapter discussing acoustical masses and springs and introduces the reader to the DELTAEC modeling software used for thermodynamic modeling of 1-D systems. Dissipative hydrodynamics are then discussed, where thermal and viscous boundary layer losses are introduced. After three background chapters on motion in fluids, chapter 10 deals with waves in one-dimensional fluids, including standing waves, driven systems, and junctions. This is followed by a chapter on reflection and transmission in layered fluid media and for oblique incidence, and on refraction with constant sound speed gradients. Chapter 12 dives into radiation and scattering, considering monopoles, in-phase monopoles, dipoles, the translational sphere dipole, line arrays, and the baffled piston. Extensions to topics on multipole expansion, microphones, sonobuoys, and swim bladders are also included. His 3-D enclosures chapter introduces key concepts in room acoustics and statistical energy analysis. It is a good, albeit brief introduction to the ideas of modal density, diffuse fields, the critical distance, and the Schroeder frequency. Cylindrical and spherical enclosures are also analyzed, which are not typically covered in room acoustics textbooks. Finally, waveguides finish off this chapter discussing phase and group speed, evanescent waves, driven waveguides, and losses in them. Chapter 14 returns to losses in sound propagation, though now in free space. Classical sound attenuation is introduced along with molecular relaxation losses in gases, gas mixtures, fresh water, and salt water. Transmission loss in waveguides is treated along with some extensions to ideas in quantum mechanics. The final chapter in the book is on nonlinear acoustics. The first half of the chapter covers the usual topics of wave steepening, shock wave formation, and harmonic generation. He also introduces various topics in nonlinear acoustics such as the parametric array, resonant mode conversion, and levitation from radiation pressure.

One unique aspect to the book is the inclusion of Garrett's humor, anecdotes, historical insights, and personality, which is not typical in most dry textbook styles. From his half-drum "Solomongo" problem that he claims King Solomon invented and Richard Feynman enjoyed playing (complete with an altered photo of Feynman), to his introduction of "Garrett's First Law of Geometry" that angles that look alike are alike, to his inclusion of a dog-body shaped loudspeaker as an example of a compact source, to Feynman's story about re-teaching MIT students the idea of a tangent using a French curve, Garrett's humor shows up in various places. His personality shows in his inclusion of experimental extensions, humorous anecdotes, and references to popular culture. To help illustrate principles, he refers to a variety of things like the Santa Ana winds, the Fender Stratocaster, the Internal Revenue Service, the eye of a fly, the head of a whale, and the Grateful Dead.

Each chapter includes problems at the end and a solution key for instructors can be obtained. The problems generally deal with real-life systems and applications such as the cantilever used in an atomic force microscope rather than a simple drawing of a box-shaped cantilever. Many problems deal with traditional acoustics applications such as microphones and accelerometers, but there are many problems that consider unique applications such as the Lennard-Jones potential, the Trinity Site atomic bomb, Galileo's cantilever, ionic bonding, African M'bira thumb piano, galvanometer ribbons, the moon's atmosphere, climate change, the Schlagwetter-pfeife or methane whistle, a party balloon, a hot tub, a nuclear reaction pool, and the Space Shuttle. One criticism is that there is not a large quantity of problems, nor are there many simplistic problems that precede the challenging application-based problems. Several problems would benefit from the addition of a figure to show the system being analyzed.

The book does a good job of explaining the relevant physics behind key equations and offering physical insight into derived results. Although I am very familiar with the book, I do not use it as a quick reference book like I do with Kinsler *et al.*[1] Having said that, I learned many new insights from Garrett[3] that I would not have learned directly from studying Kinsler *et al*. Garrett's derivations can be hard to follow; it is not always clear where the first equation used in a derivation comes from, or how each step in a derivation is made. An instructor using this book in their class can use class time to expound on the derivations. In my class that utilizes this book, I aim for breadth of topic coverage (i.e., we cover both vibrations topics and waves in fluids topics) rather than in-depth coverage of fewer topics. Thus, I typically only cover the first half of most chapters in the book. Even though only half of the chapters' material is covered, students can then study the later halves of chapters on their own as appropriate since they are now used to Garrett's style. The book was developed from teaching two different courses, one on the vibrations material and a second class on the waves in fluids material, and this two-class approach could certainly be adopted by an instructor.

I will qualify my book review by identifying the principal interaction I've had with Garrett. I might say I first learned how to teach from Steve Garrett. As a Penn State Ph.D. student in 2006, I had the opportunity to teach Acoustics 402 along with Amanda Hanford (now an Assistant Research Professor at the Applied Research Laboratory at Penn State) and Andrew Barnard (at Michigan Technological University and will soon start as the Director of the Graduate Program in Acoustics at Penn State). We were given the opportunity to each teach one third of the course during the Spring semester of 2006 and Steve Garrett was the faculty member overseeing our teaching of the course. I learned a lot from Amanda and Andrew but we each learned interesting insights in developing course notes, structuring a course, and in teaching students to understand and enjoy acoustics from Steve.

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[1]L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders, *Fundamentals of Acoustics*, 4th ed. (Wiley, New York, 2000).

[2]B. E. Anderson and S. D. Sommerfeldt, "Selecting a new textbook for a graduate level course on vibration and fluid acoustics," Proc. Meet. Acoust. **39**(1), 025004 (2021).

[3]S. L. Garrett, *Understanding Acoustics: An Experimentalist's View of Sound and Vibration*, 2nd ed. (Springer International, New York, 2020).