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ARCHITECTURAL ACOUSTICS

Marshall Long
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The field of architectural acoustics is well represented by a wide variety of books written at varying technical levels. What I feel has been lacking is an architectural acoustics book written at a level appropriate for an engineering undergraduate and a thorough reference for practicing architectural acoustical consultants. *Architectural Acoustics* by Marshall Long is a text that begins to fill that void. The book covers acoustic fundamentals at a level more advanced than typical architectural acoustics textbooks and also provides a great deal of practical and applied concepts often missing in more theoretical texts. Long's text touches on nearly every area of concern to an architectural acoustics consultant. I can whole-heartedly recommend it as a reference for architectural acoustical consultants, but the book could be improved upon for use as a textbook for students. I have used this text in three of my acoustic classes: an introduction to architectural acoustics, a class on noise and vibration control in buildings and also in a class on the analysis and design of acoustic performance spaces. In this review I will relate my experiences from using this book as the main text for those classes as well as some of the impressions of the students who used it.

The textbook has a beautiful photo of the Grosser Musikverinessal on its cover, is well bound, and is well printed on acid free paper. This is a very well made book. The text is 872 pages long with 611 figures. The following list of the 22 chapters provides a good overview of the book's coverage:

1. Historical Introduction
2. Fundamentals of Acoustics
3. Human Perception and Reaction to Sound
4. Acoustic Measurements and Noise Metrics
5. Environmental Noise
6. Wave Acoustics
7. Sound and Solid Surfaces
8. Sound in Enclosed Spaces
9. Sound Transmission Loss
10. Sound Transmission in Buildings
11. Vibration and Vibration Isolation
12. Noise Transmission in Floor Systems
13. Noise in Mechanical Systems
14. Sound Attenuation in Ducts
15. Design and Construction of Multifamily Dwellings
16. Design and Construction of Office Buildings

17. Design of Rooms for Speech
18. Sound Reinforcement Systems
19. Design of Rooms for Music
20. Design of Multipurpose Auditoria and Sanctuaries
21. Design of Studios and Listening Rooms
22. Acoustic Modeling, Ray Tracing, and Auralization

The book concludes with a good list of references and a thorough index.

The first chapter is a short history of architectural acoustic focusing on the development of acoustic spaces for theater and especially music. The students in my classes were very pleasantly surprised to find such a good, thorough, and concise history in one of their engineering texts.

The second chapter provides an introduction to the fundamentals of acoustic waves, covering the standard fare of plane waves, point, line, plane sources, and sound levels. The author's interpretation of sound from a planar source gives rise to a very useful expression between sound power and intensity from a planar source that I have not seen elsewhere. The figure/table of typical sound pressure levels actually gives distances from the object at which the sound level would be measured and the text includes a figure with typical sound power levels of objects, both of which are missing from most texts. In this chapter, Long introduces some advanced concepts such as acoustic impedance, energy density and phasors that are missing from architectural acoustics texts written for architects. However, since complex pressure and velocity are not used again until Chapter 6, the introduction is a little out of place in Chapter 2. The introduction to spectrum and band analysis is a bit terse and probably needs to be augmented with more explanation and examples by an instructor using the text.

The third chapter covers human perception of sound. This section is probably the most complete one that I have found in any text focusing on architectural or engineering acoustics. The chapter begins with a good description of the auditory system which leads to the section on loudness which includes both loudness and loudness levels but leaves noisiness until later in the chapter. After a quick review of frequency weighting networks, Long introduces NC and RC methods of rating background noise but leaves discussion of PNC and NCB to a later chapter. In his discussion of speech intelligibility measures, Long covers articulation index (AI) but does not mentioned the updated version called speech intelligibility index (SII), leaving a discussion speech transmission index (STI) to a later chapter. In discussing ALCONS, Long makes reference to reverberation time, a concept that is not defined or further discussed until Chapter 8. Long introduces the concept of speech privacy and the work of Chanaud, but does not discuss any of the recent research on the subject, nor does he reference any of the ASTM standards related to speech privacy (although he does mention E1110-86 when he revisits the topic in Chapter 16). In the section on occupational noise, the OSHA standards for noise dose and time-weighted-equivalent level are presented but Long does not discuss, or even reference, the updated exposure levels that were recommended by NIOSH over a decade ago. Similarly, the final section of the chapter on precedence effect and direction perception covers the historical research well, but does not present or reference the more recent work on the subject.

The fourth chapter covers acoustic measurements and noise metrics. The chapter begins with a fairly brief, but good, discussion of microphones and a very comprehensive description of broadband noise metrics such as day-night level but good, discussion of microphones and a very comprehensive description of broadband noise metrics such as day-night level L_{dn} (which was introduced in Chapter 3) and source variability corrections to L_{eq} and L_{dn}. The chapter describes some lesser used metrics such as Noise Pollution Level and the Traffic Noise Index. In the section on band limited metrics, the author presents the little used PNC curves in addition to NCB curves. The RC Mark II, now the metric suggested for use by ASHRAE, is not even mentioned. A discussion of specialized measurement techniques introduces time delay spectroscopy (TDS), energy time curves (ETC) and sound intensity before finishing with an introduction to the speech transmission index (STI).

Chapter 5 introduces environmental noise measurement and prediction and is far more complete than the coverage found in most other architectural acoustics or engineering acoustics texts. A good coverage of outdoor noise propagation is hampered by an unnecessarily long and detailed discussion of air absorption and refractive caustics which distracts the reader with its complexity. The section on automobile, railroad, and aircraft noise is quite good, although some of the information is dated.

Chapter 6 makes use of the phasors introduced in Chapter 2 in a more detailed description of simple harmonic motion and a brief introduction to the wave equation and its basic solutions. The text then introduces monopoles, dipoles and phased arrays – skipping a discussion of quadropoles. After a discussion on radiation from pistons, the rest of the chapter discusses radiation from loudspeakers and loudspeaker arrays.

Chapter 7 on sound and solid surfaces introduces the concept of the image source which leads into reflection of plane waves. Here the author derives oblique reflec- tion from a surface using a figure that has the x and y axes interchanged from the conventional locations, something which confused many students in my courses. In the discussion of reflection from finite pan- els, Long presents the analytical results of Rindel, but does not show how to make practical use of the complicated formulae he has presented. The chapter continues with a discussion of absorption and introduces a very confusing notation of α_a for absorption coefficient and α_r for the reflection coefficient. Students complained strongly about that notation. The chapter is interrupted with a long and poorly formatted table of absorption coefficients for common materials. Students complained about the interruption of the text and would have preferred an easier to read table placed at the end of the chapter or in an appendix in the back of the text. The table also lacks references to where the data were obtained. In the well detailed section on porous absorption mechanisms, the author describes a difficult to implement method of measuring flow resistance but neglects to reference the ASTM standard method. The chapter ends with a very good discussion of panel and Helmholtz absorbers.

Chapter 8 describes sound in enclosed spaces, first presenting the concepts of resonance in open and closed tubes and normal modes in rooms. While simple equations for the resonance frequencies in these enclosures are presented, more realistic formulae which include end effects or finite wall impedances are

not presented. More troublesome though is that Long implies (as do most authors) that sound can only exist in a tube or room at the modal frequencies. A more complete theory of modal analysis is not derived or presented, nor are references to more advanced treatments given. Within the discussion of room modes, Long presents the standard figure for "preferred" room dimensions that are designed to provide the most even spread of modal frequencies but does not explain when a designer would consider an even modal spread important or even why these dimensions are considered preferred. Long then moves into a discussion of diffuse field acoustics with a good derivation of the Sabine and Eyring equations. While the Millington-Sette equation is also presented, Long does not present or reference any of the other reverberation equations developed by Fitzroy, Arau-Puchades, or Kuttruff. Long then presents the Hopkins-Stryker equation for sound pressure level in a diffuse room along with a good discussion of its limitations and even presents some corrections, but never presents the Schultz equation. Long then presents some very recent (and complicated) formulae for sound pressure in long and narrow enclosures.

Chapter 9 and 10 cover sound transmission through walls and into enclosed spaces. In Chapter 9 Long develops the standard equations for sound transmission through single and double panel and presents the practical equations of Sharpe. In Chapter 10 Long applies transmission loss theory to sound transmission in buildings. Throughout this chapter Long presents the transmission loss information about many common building constructions, intermixed with the rest of the text. This presentation makes it difficult to read the text and also results in poorly formatted tables of sound transmission information. Like with the absorption data, students did not like the presentation and would prefer a much better formatted table placed at the end of the chapter or in an appendix in the text.

Chapters 11 and 12 present an introduction to vibration, vibration isolation and the practical application in noise control in floors. The treatment is far more detailed than most architectural acoustics text. The text could benefit from a more complete set of impact isolation class data for floor/ceiling constructions.

Chapters 13 and 14 of the text deal with mechanical system noise. Long includes many equations for sound generation from fans and in ducts as well as transmission through duct systems. Much of this information appears to have come from older versions of the handbooks of the American Society of Heating and Refrigeration and Air-conditioning Engineers (ASHRAE). While the basic trends that are predicted by the equations are useful for the mechanical designer or the acoustic consultant, it should be noted that many of the equations have been removed from recent versions of the ASHRAE handbook because of their inaccuracy or inapplicability to modern mechanical equipment.

Chapters 15 and 16 discuss the design of multifamily buildings and office buildings. The practical advice and design guidelines given here are more thorough than many other architectural acoustics texts. The section on speech privacy primarily follows the work of Chanaud and is an excellent presentation, but barely mentions the current ASTM standards on speech privacy, and does not mention of any of the recent work by Bradley and colleagues at the National Research Council (NRC) in Canada.

Chapter 17 covers the design of rooms for speech, beginning with basic design of auditorium spaces and following with a good discussion of several metrics for speech intelligibility. Long then describes the Lombard effect where the background sound level in a room increases as people try to talk over the background noise of others in the room but incorrectly calls this the "cocktail party" effect. Chapter 18 discusses sound reinforcement system design at a level in far more detail than most architectural acoustics or engineering acoustics texts. Chapter 19 discusses the design of rooms for music, condensing much of the information found in the texts by Barron and Beranek and examples from his own consulting. Chapter 20 discusses the design of multipurpose facilities and sanctuaries in a mostly qualitative way, but good practical guidelines are presented and many examples from his consulting work discussed. Chapter 21 presents studios and listening rooms basically through a review of the literature and again from examples taken from his own consulting business.

The final chapter of the text reviews auralization and acoustic modeling in architectural acoustics. The section on modeling briefly discusses the use scale models and some of their inherent problems, but primarily focuses on ray tracing. There is no discussion of radiosity, finite element, boundary element or other wave propagation numerical methods. Ray tracing theory is discussed in a fairly detailed manner, but since students and consultants will not be writing their own numerical implementations of the method, the inclusion of such detailed information seems superfluous.

As you can see from my brief descriptions, the book does a great job presenting of the breadth of architectural acoustics and also presents with more detail than is found in nearly any other text. The author has combined a good number of figures from a wide array of well referenced sources. But, such an attempt to provide depth over such a wide range of subjects in an 872 page book leads to some of the problems with the book, one of which is evident upon inspection of the printing of the table of contents (TOC). In the TOC, some chapter titles are listed in a large bold font while others are listed in a smaller bold font. This sort of inconsistency in the print formatting is found throughout the text. Another problem with the text is the inconsistent use of notation. In several sections for example, Long denotes the speed of sound by both c as well as c_0, and the ambient density by both ρ and ρ_0.

Long makes generous use of figures for illustrating basic physics, for explaining relationships between quantities, and for helping the reader to better understand the equations. Some of the figures have been developed by Long while others are clearly reproductions (properly referenced and with permission) from other texts or research papers. To provide consistency, Long has thoughtfully rewritten the text of those figures in a consistent font. Unfortunately, the font he selected is a fairly popular, but nonetheless difficult to read font that looks to mimic hand printing. The use of a serif font, or at least an easier to read sans-serif font would be a great improvement. Another problem with the simple updating of others figures is that the notation used in the figure is often inconsistent with that used in the text.

The book is very well referenced compared to most architectural acoustics and engineering texts, but unlike most texts, all the references are compiled in a

single list in author-year format at the end of the book. This list might be useful if there were also a list of references in the chapter at the end of each chapter, but there are no chapter lists. My students and I found the need to continually flip all the way to the back of the book and find a reference from the large list annoying and sometimes difficult, especially when there were multiple references for a given author-year combination.

The biggest problem I had when using this book as a text in my classes though is the omission of both examples and problems. The author does not include any example calculations at all. Undergraduate students, graduate students, and even practicing consultants will want to see how to apply the equations presented in the book. Both instructors and students want textbooks that include problems at the end of each chapter to aid in assigning homework as well as to give students more problems for practice.

Long's Architectural Acoustics is easily one of the most complete and comprehensive textbooks on architectural acoustics. The technical and math level is such that much of the information is accessible to architects and architecture students but advanced enough that in some sections, engineering undergraduates and even some graduate students will be challenged. The practical knowledge that is presented is excellent information for students and consultants alike. In summary, Long's book is an excellent reference text for architectural acoustical consultants and is also a good text for an engineering class on one of several areas architectural acoustics. If the problems of inconsistent notation were corrected, if the formatting of the absorption and sound transmission data tables and references were improved, and if some examples were added to help the reader understand the application of equations, the text would also be an excellent text for teaching architectural acoustics. As it is, the book may still be the best text available for teaching architectural acoustics to engineering students and I will continue to use it in my classes.

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