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Selecting a new textbook for a graduate level course on vibration and fluid acoustics

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At Brigham Young University we offer a graduate level course on the fundamentals of acoustics. This course has traditionally covered vibrations in masses and springs, strings, bars, membranes and plates in the first half of the course. The second half covers the derivation of the wave equation, wave propagation, reflection/transmission phenomena, and source radiation problems. For decades, we used Kinsler and Frey's "Fundamentals of Acoustics" book but the rising costs, lack of updates, and dissatisfaction with the rigor of the book motivated us to find a new text. For a few years, we used Kinsler and Frey for the vibrations portion of the course and also Blackstock's "Fundamentals of Physical Acoustics" for the fluids portion. Two books meant even higher costs, although the Kinsler and Frey text was also used in another class at that time. When we switched instructors for the course, Anderson was asked to review Garrett's "Understanding Acoustics" text and he ended up adopting it for this course. This talk will review our experiences in switching textbooks and discuss our reasons for selecting our current text and how we are using it in class in conjunction with pre-class reading quizzes, which has helped increase classroom discussions.

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1. HISTORY OF FUNDAMENTALS OF ACOUSTICS AT BYU

Brigham Young University (BYU) has a course called Physics 561: Fundamentals of Acoustics. Students who take this course are primarily either physics or engineering majors. Some of the students are senior level undergraduate students and some are graduate students in their first year. Students are required to have a solid background in calculus, partial differential equations, and boundary value problems. Physics 561 is split into two units, the first on vibrations of simple harmonic oscillators, transverse waves in strings, elastic longitudinal waves in bars (i.e. rods),[1] elastic transverse waves in bars (i.e. beams),[2] transverse waves in membranes, and vibrations in plates. The second half of the course focuses on topics in fluid acoustics, including an in depth development of the wave equation, plane and spherical wave propagation, various acoustical quantities, one-dimensional standing waves, reflection and transmission, radiation from line sources and the baffled circular piston,[3] and more recently includes an introduction to waveguides, room acoustics, and nonlinear acoustics.

The course has been around for decades at BYU. For the vast majority of this time, Physics 561 was the first course that students would take that was focused on acoustics. Prior to the year 2011, the course heavily utilized the textbook *Fundamentals of Acoustics* by Kinsler *et al.*[4] The first unit of the course covered chapters 1-4 of the book, including essentially every section of those chapters. The second unit of the course covered chapters 5-7 and 9-11, utilizing at least 75% of the material in these chapters. The book by Kinsler *et al.* was ideal as an introductory textbook in terms of the level of the math and the topic coverage. Students from physics and engineering backgrounds came in to the class well prepared.

In Fall 2008, a new introductory acoustics course was developed at the senior undergraduate level to provide students with a bit more of an application driven approach to prepare students for less-rigorous level jobs in acoustics with a Bachelor of Science degree.[5] This meant that the level of the material in the Physics 561 course could be developed at a deeper level, particularly the second half of the course. The book by Kinsler *et al.* was maintained as the book used for the first unit of the course (still covering chapters 1-4). But between the years of 2011 and 2016, the *Fundamentals of Physical Acoustics* textbook by Blackstock[6] was used for the second unit of the course instead. Specifically chapters 1-5, and 13 from Blackstock's book were covered. During these years of the course being offered, more time was spent on reflection and transmission problems in ducts than was previously done. The students were exposed to the transient approach to problems rather than only using the time harmonic system approach that Kinsler *et al.* heavily utilizes. Further, the Lagrangian approach to fluid acoustics was used in addition to the Eulerian approach.

For a couple decades, the primary instructor for Physics 561 was author SDS. There were only a few years that the course was taught by author BEA and by Kent Gee. In the year 2017, BEA took over the teaching of this course. The decision was made to switch to the *Understanding Acoustics* textbook by Garrett.[7] The course was still divided into the traditional two units and a similar topic coverage. For the first unit of the course on vibrations, chapters 1-6 of Garrett were used. For the second unit of the course on fluid acoustics, chapters 8, 10-13, and 15 were used. The first half of the chapters of Garrett's book have a similar coverage to the books used in the past for this course. The second half of each chapter typically delved into deeper topics or specific applications. Thus, the first half of each of these chapters was focused on for the course. Essentially, the depth provided by the Blackstock book on fluid acoustics topics was sacrificed for consolidating to a single book, though Garrett's book is still at a deeper level of coverage than the book by Kinsler *et al.*

2. FEEDBACK ON TEXTBOOKS FOR AN INTRODUCTORY GRADUATE LEVEL ACOUSTICS COURSE

The *Fundamentals of Acoustics* textbook by Kinsler *et al.*[4] is perhaps a must have book for a serious acoustician. It is a go-to book to find equations and results quickly (if you have used it for a course). Key equations are clearly visible and solutions for several different boundary condition cases are given. However, the book is weak on textual explanations. There is not a lot of discussion of the physics that leads

to fundamental equations and the quantity of important physical insights about key equations is somewhat lacking. Further, there are not likely to be new editions of the book in the future. The latest 4th edition was published in the year 2000 and the primary authors of the textbook have long since passed away. The book has steadily increased in price and a new version of the textbook costs over $200 USD. One strength of the book is the quantity of good and straightforward problem sets. The problems are fairly generic, but there are many of them and because of the wide use of the textbook in acoustics courses, errors in the solution key and in the textbook in general, have been extensively tracked.

The *Fundamentals of Physical Acoustics* textbook by Blackstock[6] is a high quality book with great physical insights. Theoretical developments in the book are often provided in both the time and frequency domains, which provides students with different ways of applying the equations developed to understanding acoustical phenomena. This text is different from many texts in that it provides considerable development in the time domain. Author SDS has found that most students experience more difficulty conceptualizing acoustic phenomena in the time domain, so the text is very useful in helping them better understand time-domain problems. The development of acoustic concepts in Blackstock's text is noticeably deeper than the same concepts in Kinsler *et al*. As one example, three chapters are devoted to reflection/transmission phenomena, with one chapter focusing on the time domain and the other two chapters focuses primarily in the frequency domain. This is significantly deeper than the corresponding treatment in Kinsler, *et al*. Blackstock also considers both linear and nonlinear developments in the text, although for purposes of this senior level course, the nonlinear developments were generally omitted. The problem sets in the book are generally good and encourage students to think more deeply about the concepts. One downside for the Physics 561 course at BYU is that the book focuses on fluid acoustics and does not cover strings, bars, membranes, and plates in any particular depth. Thus, this text needs to be supplemented for a course that covers both structural vibration and fluid acoustics. The textbook is a first edition and was published in the year 2000 without an updated edition since then. Thus is it also just as old as the book by Kinsler *et al.*

The *Understanding Acoustics* textbook by Garrett[7] offers a lot of textural explanations and a high quantity of advanced material. The book covers both vibrations topics and fluid acoustics topics with a similar scope of topic coverage to the book by Kinsler *et al.* The book is aimed at explaining the relevant physics behind key equations and it also offers physical insight into the results that are derived. The textbook can be hard to follow through some of the derivations. Sometimes it is not clear to the students how the textural explanations lead to the first equation used in a given derivation, or from one step in a derivation to the next. However, the instructor for the course can assist students with this. The quantity of problem sets in the book is limited but the problems are always connected to real world examples and each of them is quite challenging. Several of the problems could be improved by adding a figure that helps to show the system being analyzed. Even though only the first half of most chapters was used from the *Understanding Acoustics* textbook, the advantage of this is that because students are now very familiar with Garrett's writing style and notation, they could study the more advanced topics presented in the second half of the chapters later on, as appropriate. Unfortunately, many errors were found by the author BEA and by his students. Most of these errors were simple typographical errors in the equations or incorrect references to equations or figure numbers. Finding errors in the textbook is perhaps common with first edition books. This led to students being somewhat uncertain of equations and for some students this caused them to read more carefully to try to find errors, meaning they probably read at a more in-depth level than they otherwise would have. BEA relayed these errors back to Garrett, who subsequently incorporated them into a second edition. The second edition of the textbook was published in the year 2020 and has not been able to be used for this course yet.

As a comparison of coverage from each of these three textbooks, consider their coverage of Euler's equation. In the textbook by Kinsler *et al.* the relevant section is 5.4, which starts on p. 117 and spans about a page and a half. Ten equations are given in this section, with the end result equation given with a box around it to call attention to it. Many small-signal assumptions are made from the outset – an inviscid fluid is assumed, and nonlinear and gravitational contributions are briefly given without discussion. The important mathematical details are provided in the derivation but there is very little textural explanation about the development of Euler's equation. In the textbook by Blackstock, the relevant section is A.2 of Chapter 2, which starts on p. 69. The relevant pages are approximately p. 69-77 and then also from p. 91-

93 and spans about 11.5 pages. Technically only 31 equations are numbered on these pages but there are many more unnumbered equations and figures provided to assist in the mathematical development. This material starts by deriving the Navier-Stokes equation, neglecting gravitational forces, but including viscosity and not making the linear, small-signal assumptions from the beginning. Blackstock does impose the small-signal assumptions later on. His coverage has a wealth of historical insights and discussions of the complex physical phenomena involved. In the textbook by Garrett, the relevant section is 8.4, which starts on p. 437 and spans nearly 6 pages. Sixteen equations are provided in this derivation. Garrett neglects viscosity and gravitational forces. He draws attention to the Venturi tube to provide a conceptual explanation of a time-independent fluid acceleration, which physics majors are likely familiar with from freshman level physics courses. Small-signal approximations are made and after developing Euler's equation in one dimension and in three dimensions he relates it to the concept of inertance and an acoustical mass. It should be noted that both Kinsler *et al.* and Garrett have chapters later on in the books that delve more into the nonlinear aspects of Euler's equation.

3. REASONS FOR CHOOSING *UNDERSTANDING ACOUSTICS* FOR PHYSICS 561

The author BEA selected the *Understanding Acoustics* textbook by Garrett[7] for several reasons. The first reason is that it is easiest to stick with one textbook for a course rather than using two. It is generally cheaper for the students to buy one book rather than two. Each book has its own notation and symbols that it uses and it is hard for students to adjust to learning two different styles of notation. Since the Acoustical Society of America (ASA) Press decided to cosponsor the publication of Garrett's book they wanted feedback on the quality of the book prior to publication. BEA was asked to review Garrett's book. This gave BEA the opportunity to become familiar with the book at a time when he was deciding whether to change the textbook for the Physics 561 course. BEA was scheduled to teach this course for several years, so it made sense for him to select a book to stick with for some time. BYU, like many universities, has a library contract with Springer and this allows students and faculty to have free electronic access to several books, including *Understanding Acoustics*. Additionally, there is a paperback hardcopy of the book available in black and white print for ASA members, currently for $25 USD. Thus, Garrett's textbook provided the chance to use a single textbook to cover all of the desired topics for this course, though the cost was a reduction in rigor offered by the textbook by Blackstock[6] for the second half of the course.

4. USING READING QUIZZES TO MOTIVATE STUDENTS TO READ THE TEXTBOOK

The author BEA believes that students greatly benefit from reading a textbook in addition to participating in class lectures. In many courses, students are often encouraged to read but in practice they often do not unless there is additional motivation. BEA had a teaching assistant help develop reading quizzes for the students to take before coming to class through an online course management platform. The quizzes are due 10 minutes before class starts, giving BEA a little bit of time to see which questions the students missed before starting class. The quizzes were setup to have a 10 minute time limit imposed and include approximately 3-5 questions so that students could not easily read the material while working on the quiz. The reading quizzes were not given a very large weighting in the overall grading for the course (less than 10%). This type of process falls in line with the ideas behind the Just in Time Teaching (JiTT) pedagogical strategy.[8]

The reading quizzes for this course were designed to be easy if a student had read the assigned reading but it would be difficult if they had not. If the students had read, they may not know the answer to a particular quiz question right away, but they should know exactly where in the reading to find the answer to the question. The questions and answers were often intentionally controversial, with students disagreeing with minor wording differences in the answers. Even though the reading quizzes are not worth many points for the students' overall grade, the students came to class invested in wanting to know the right answer and wanted to discuss the wording of the quiz questions. This led to increased participation from the students

at the beginning of class. Partial credit for incorrect quiz questions is given based on whether there was some ambiguity in a particular question or an answer. The discussion of the reading quiz questions at the beginning of class often resulted in BEA adjusting the coverage of his lecture to go more quickly over parts the students seemed to already understand and spend more time on the parts they had more questions about.

Sometimes the reading quiz questions were simply true or false questions, such as this one:

Question 1:
During vibrations at a modal frequency, the kinetic energy in a string is maximum when the string's displacement is simultaneously equal to zero at every point on the string.

A. True
B. False

Sometimes the questions were written such that several of the answers sounded like they could be correct, to a student who had not read, but a student who had read would either remember the correct answer description or they would find the answer through a quick search of the reading material, such as with this example:

Question 2:
What is the method of images used for?

A. Taking the sum of complex numbers that are complex conjugates to increase a signal by 6 dB without increasing the reactive power present.
B. Psychological experiments in the 1930s wherein test subjects were placed in a room of wall to wall mirrors for 48 hours in order to study how perception of visual image impacts emotional well-being.
C. Tracing ray lines through an acoustic lens to find the location of either a real or virtual image.
D. Mathematically defining boundary conditions by reflecting a signal conveniently across a boundary and superimposing the two signals.

As a final example, sometimes the questions were multiple answer questions where the student needed to recall several assumptions made throughout a derivation or several implications of a particular development, such as in this question:

Question 3:
Which of the following are natural consequences of dispersion (discussed in the assigned reading)? Choose 3 answers.

A. Wave speed through a medium is dependent on frequency
B. A single frequency entering a thin film of specific width is constructively cancelled when it bounces back
C. Separation of white light into colors when it is sent through a glass prism
D. Surface waves on water spread out with smaller wavelengths faster than longer wavelengths
E. Sound waves spread out more in all directions with more dispersion
F. Traffic jams on the I-15 freeway after a BYU-Utah game

5. SUMMARY OF CONSIDERATIONS FOR SELECTING A TEXTBOOK

There likely isn't a perfect textbook for a particular course unless you take the time to write one yourself. It is a difficult process to select a textbook and to switch from a traditional textbook that has been used for a course for many years. When you switch textbooks you must get used to a different notation and it may be best to adopt that notation in your lectures so that students get used to one consistent set of

notation. The problem sets in a new textbook are also typically going to be unfamiliar to the instructor and this requires some work for the instructor and the teaching assistant to get up to speed on the new problems so that they can assist students and also grade their homework submissions in a fair manner. Every author has their own perspective, with strengths and weaknesses to their perspective, and generally this perspective doesn't exactly match your own. Each textbook is written with a different level of rigor. The instructor needs to select a textbook that matches the level of rigor desired for their target course. Reducing the cost of textbooks for students is also an issue to keep in mind, with one book typically being cheaper than two books and books that are out of print being more likely to be more expensive than newer books.

REFERENCES

[1] B. E. Anderson and W. D. Peterson, "The song of the singing rod," J. Acoust. Soc. Am. **131**(3), 2435-2443 (2012).
[2] B. E. Anderson, "A laboratory experiment to test the limits of Bernoulli-Euler theory for flexural waves in bars," Proc. Meet. Acoust. **29**, 025004 (2018).
[3] B. E. Anderson, "Understanding radiation impedance through animations," Proc. Meet. Acoust. 33(1), 025003 (2020).
[4] L. E. Kinsler, A. R. Frey, A. B. Coppens, and J. V. Sanders, *Fundamentals of Acoustics*, *4th Edition* (John Wiley and Sons, Inc., New York, 2000).
[5] K. L. Gee, S. D. Sommerfeldt, T. W. Leishman, B. E. Anderson, and J. D. Blotter, "Improving undergraduate noise control education at Brigham Young University," Proc. Internoise, 10521 (2009).
[6] D. T. Blackstock, *Fundamentals of Physical Acoustics* (John Wiley & Sons, Inc., New York, 2000).
[7] S. L. Garrett, *Understanding Acoustics* (Springer and ASA Press, Switzerland and New York, 2017).
[8] G. N. Novak, E. T. Patterson, A. Gavrin, and W. Christian, *Just-in-Time Teaching: Blending active Learning and Web Technology* (Prentice Hall, Saddle River, New Jersey, 1999).