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Book Review

Sound and Structural Vibration: Radiation, Transmission and Response, 2nd ed. Frank Fahy, Paolo Gardonio. Academic Press, Amsterdam (2007). xxx + 633pp., ISBN: 13:978-0-12-373633-8; 10:0-12-373633-1

Why is fluid–structure interaction such an interesting subject for research workers? My own answer would lie in the apparent incompatibility between the type of wave motion permissible in a fluid, for example an acoustic wave governed by a dispersion relation $\omega^2 = c^2k^2$, and the type of wave motion permissible in a structure, for example a plate bending wave governed by a dispersion relation $\omega^2 = (D/m)k^4$. Here ω is the frequency of the wave, k the wavenumber, c the acoustic wave speed, D the bending stiffness of the plate, and m the mass per unit area of the plate. The incompatibility implies that the contact between fluid and structure involves something of a clash, and that fluid–structure interaction may be regarded as a battle in which the structure, deploying such weapons as plate stiffness and inertia, competes for dominance with the fluid, which naturally calls into play its own stiffness and inertia. Whether the contact pressure between the fluid and structure is a significant influence on the structure, for example, is a matter which can only battle can decide.

Of course, a struggle can be unequal. For example, in high-frequency bending-wave motion of a metal plate in water, the dominant influences are plate stiffness and plate inertia only, so that the fluid becomes a 'slave' to the motion of the plate. This is the regime of light loading. A more equal struggle occurs in the corresponding motion at low frequency, when the dominant influences are plate stiffness, fluid inertia, and contact pressure, giving the regime of heavy loading. At intermediate frequencies, a quantity just as important as these three low-frequency influences is the plate inertia (this fact is not particularly obvious), so that there exists a separately identifiable regime in which four influences are important simultaneously. In any but the most unequal struggle between the fluid and structure, a new phenomenon emerges: a surface wave propagating in the plate and neighbouring fluid. Such a coupled wave, which cannot exist in a fluid with a completely rigid or a completely soft plane boundary, has its own nature and laws, different from those of the fluid or structure in isolation, and can contain a large amount of energy, eager and available to be scattered into sound at corners, junctions, and imperfections in the structure.

The book under review deals with such matters, always with practical engineering needs in mind, but drawing on physical and mathematical ideas as appropriate. The book is even-handed about adopting a wave theory or a mode theory approach as appropriate to the problem in hand, and this second edition includes chapters on wholly numerical methods and on active control, two research areas in which the authors' home department, the Institute of Sound and Vibration Research at Southampton University, is pre-eminent. The authors explain the required mathematical theory, for example Fourier integral transforms and delta functions, when needed in the text, giving clear and detailed verbal descriptions in preference to overly dense arrays of equations.

The particular topics dealt with in the book are as follows. The first chapter covers the basic ingredients: sound waves in a fluid, longitudinal and transverse waves in a solid, and bending waves in bars, plates, and cylindrical shells. To my mind, a fascinating aspect of bending waves is that, from the viewpoint of elasticity theory, a bending wave in a plate is a sum of a longitudinal wave and a transverse wave so positioned and oriented that they have almost completely cancelled each other out; the bending wave, being the residual left over, can and does have properties (for example frequency proportional to wavenumber squared) quite unlike any combination of longitudinal and transverse waves without such cancellation. This justifies the short shrift given to elasticity theory in most texts on bending waves; it is better to start from scratch, as in this book, with concepts specific to bending waves.

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The second chapter defines the fundamental ratios between such quantities as force, velocity, angular velocity, and moment. These ratios are various forms of impedance and mobility functions, both as scalars and as matrices; they are calculated for some basic structural elements, e.g. infinite and finite beams, plates, and cylindrical shells, and are related to energy flow. Chapter 3, the longest in the book, gives an account of sound radiation by vibrating structures, including some of the complexities which arise for such structures as beam-stiffened, corrugated or sandwich plates, cylindrical shells, and irregularly shaped bodies. Fluid loading is covered in Chapter 4, which includes such calculations as the way in which the fluid loading affects the natural frequencies of vibrating plates and cylinders. Chapter 5 analyses sound transmission through partitions, with particular attention to the design of effective partitions between rooms, a most important area of applied acoustics. The chapter includes also a detailed account of sound transmission through the walls of a cylindrical shell, important for the design of domestic and industrial pipework. Chapter 6 is reciprocal to Chapter 3, in that it determines the structural vibrations produced by an incident sound field, and includes a full account of the relevant reciprocity principles, especially those associated with Rayleigh and Liamshev. Chapter 7 covers similar physical problems to those in Chapters 3 and 4, but with the fluid in an enclosed volume, so that sound radiation to infinity is no longer possible. Thus modal expansions now come to the fore, and the chapter includes an introduction to statistical energy analysis (SEA).

Chapter 8, new to this edition, gives an introduction to numerical methods suitable for fluid–structure interaction. Such methods, though they can leave the underlying scaling laws rather obscure, are essential when 'realistic geometry' is the paramount consideration. A reader who opens any recent issue of JSV will see that a knowledge of the material in this chapter, on finite element analysis and boundary element analysis, is essential for understanding a high proportion of contemporary research papers on sound and vibration. Chapter 9, also new to this edition, provides a substantial seventy-five page introduction to active sound and vibration control. The fundamentals of feed-forward and feedback control are presented, followed by an account of the physical principles of transducers, actuators, strain sensors, and accelerometers. The complementary aspects of active structural acoustic control (ASAC) and active vibration control (AVC) are discussed, and the chapter finishes with a detailed account of the design and operation of smart panels. These last two chapters do an excellent job of bringing the first edition up to date.

This book is an excellent text which will be found interesting and useful by both students and research workers. The authors succeed in conveying their enthusiasm for the subject, and their exposition is lucid. The problems at the ends of the chapters will be useful for students and teachers. I feel sure that not a few of the younger readers of this book will one day be writing papers for JSV.

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