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BOOK REVIEW

Acoustics of Fluid–Structure Interactions. By M. S. Howe. Cambridge University Press, 1998. 560 pp. ISBN 0521 633206. £55.

This book is much more than the title suggests. It is the most comprehensive review of what is really understood about flow-induced sound and vibration that has ever been written. An enormous range of material, taken from nearly five hundred references, is arranged in a systematic way to define the foundations of a practical subject. Those engaged on the unsteady flow problems of aerospace and naval engineering should find the book extremely useful. These problems are notoriously difficult ones in which it is hard to separate assumption and conjecture from what is real and fundamental. This book concentrates on precise models of real effects, explaining by careful analysis what can definitely be learnt from the models, and avoids most of the approximation and empiricism that is common in the subject.

Most of the structures in the many fascinating physical problems that are modelled in the book come from the fluid domain, the boundaries of which are chosen to model simply some of the most acoustically significant elements to be found in engineering structures that are shaken by flow. This collection of most of the subject's known results will be useful for reference and also for providing the test cases needed for proving the effectiveness of computational methods, a subject still in its infancy.

The book is confined to models that are chosen for their analytical tractability, which are inevitably great simplifications of the real case. The models are very far from simple. Though the writing is clear and the explanations generally convincing, the concepts are frequently too difficult to be appreciated without other corroborating arguments or cross-checks with the initial references. I feel sorry for any reader who accepts the author's invitation to follow, even though they are correct, the explanation and workings set out in a single page of an example (example 3 in section 2.4.1) that reproduces the results of three very substantial research papers on ‘Sound waves in a bubbly medium’. There is a lot of material in this book and a great deal is expected of its reader.

The 100 page introductory chapter sets out as clearly as anyone could wish to see the principles and equations that govern the thermodynamics, mechanics and kinematics of continuous material in inhomogeneous motion. The style is reminiscent of Lighthill's, giving the impression that it is actually easier to do things properly than to adopt simplifying assumptions – but making few concessions to help the first-time reader. For example, on the very first page the Fourier transform of the Green's function is defined differently from the transform of other functions, a notational convention stated without comment. The central role of vorticity and total enthalpy is stressed early in the chapter, laying a good foundation for Howe's preferred way of analysing sound in inhomogeneous flow. The equations governing inhomogeneous motion of elastic solids are presented in a way that made me reflect on how little solids differ from fluids in this respect, and wish that both sets of equations had been set in terms of common variables. The equations for vibrating membranes, plates and shells are presented and the waves they support identified. The equations for sound in an irrotational flow are derived and methods given for solving them, using Fourier transform and Green's function techniques. Multipole sources in motion, boundary sources, multipole expansions, spherical and cylindrical harmonics, matched expansions, stationary phase and reverse flow reciprocity are all covered in the introduction, culminating in a description of vortex shedding and the unsteady forces exerted on fluid boundaries.

Chapter 2 describes in 50 pages most of the known results and techniques in the theory of aerodynamic sound. Starting with Lighthill's equation, its general solution is developed carefully to give a very good account of its scope and limitations. The reader who successfully works out the examples of this chapter will repeat many of the subject's most significant steps. Most applications deal with low Mach number flows, the sources being distinctly different when there are strong gradients in mass density. I find that Howe is particularly convincing when describing the sound created by entropy and vorticity fluctuations, though I am very surprised that he has missed Möhring's identification of sources in terms of vorticity alone. The absorption and attenuation of sound by flow inhomogeneity is handled through the same theory, as is the rich character imparted to the otherwise characterless sound of turbulence by particles in suspension and by bubbles in water. The definite analytical style and the precision of the treatment are somewhat relaxed in the concluding pages of this chapter. The empirical approach adopted for dealing with jet mixing noise, perfectly satisfactory for cataloguing data on the noise of current turbojets, is hardly likely to lead to any noise control. Howe himself produced a description of shock cell noise that is free of the empiricism in the papers he cites. He also appears to have forgotten that most of the structure in the empirical formula he gives for flight effects on mixing noise was theoretically predicted a long time ago.

The next 100 pages contain the theoretical basis for understanding and calculating the way sound is produced from flow over rigid boundaries. The flows are usually at low Mach number, with acoustic wavelength much larger than the boundary scale. The sources defined by unsteady vorticity and entropy are specified and their sound is calculated using Green's functions. Aolian tones, the sound of inhomogeneous material passing through nozzles and the transmission of internal sound through a nozzle and jet are all very clearly explained, as is the way sound is generated by unsteady flow in the vicinity of sharp trailing edges. The sound of flow sources near the apex of a wedge is set as an example; that should sort out the men from the boys.

Having set the scene Howe goes on to give clear prescriptions for handling flow noise problems involving the shedding of vortices. Because the treatment is so precise one can be confident in his proof that the sound of vortex shedding is frequently phased so as to interfere destructively with the primary sound. Vortex shedding generates anti-sound, though that is not his terminology. The unsteady flow and the sound created near sharp-edged bodies has received a great deal of attention because of the need to understand the loading of aerofoils in gusty flow and because of the practical importance of rotor blades operating in the wakes of other blades. Howe's coverage of this area is masterful – as are the examples he sets for the reader, though I consider his treatment of boundary layers and of boundary layer noise to be cases of exact analysis resting precariously on inadequate foundations. It is good to see a convincing treatment of the part played by unsteady shear stresses in the boundary layer, and, given the acoustical importance of the 'sharpness' of trailing edges, it is good also to see attempts to blunt the effect. Thick, rounded, perforated and serrated edges are all modelled and I would not have been at all surprised to see a definitive modelling of corrugated and ventilated edges also, or of the influence of streamwise vorticity. This chapter ends with an account of the sound-producing features of rotor blades and the compression waves created when a high-speed train enters or leaves a railway tunnel. The theoretical framework is versatile enough to give definite quantitative information in all these areas.

There follows a 60 page chapter on sound created in a fluid with flexible boundaries. The infinite, thin, flat, elastic plate is regarded as the simplest case: a surface carrying waves that are coupled to varying degrees with those in the fluid. The theoretical framework for calculating the sound of flow near this surface is given in detail, showing that the analysis is not very much more difficult than in the rigid surface case. Surface vibration is inextricably linked to the fluid it contacts: sound generally implies surface motion and vibration implies sound – but which causes which depends on other things. The section dealing with the scattering of bending waves by cracks, joints and ribs begins a coverage that is probably unfamiliar to most acousticians. The theory is much more intricate so the geometrical diversity in the model is necessarily restricted to keep problems tractable. These problems are clearly worked and illustrated. Few who will have reached this stage of the book could fail to see beauty in Howe's way of dealing with a line vortex that drives an evanescent flexural wave (which propagates ahead of the vortex), a surface wave that is scattered into sound by a supporting rib: the isolated fixed constraint upsets the balance that usually guarantees such flows are silent. Flow-generated surface waves are scattered into sound at trailing edges also and that sound is closely coupled to the sound of the sources that created the surface motion, a coupling Howe explains very carefully. It is inevitable that some of the cases are a little far fetched – the thin, edge-constrained, semi-infinite elastic plate for example. Such examples have probably more relevance for testing the consistency of approximate theories than they have to engineering practice.

The fifth chapter, at about 120 pages the longest in the book, deals with the effect of fixed surfaces on sound. Howe has been a pioneer in explaining how ordered flows, created by the interaction of sound with surfaces, are energized by the sound which is consequently attenuated. Damping of sound by smooth surfaces, because of viscous and thermal boundary effects, is relatively straightforward compared to the turbulent processes, which are also explained and made the subject of challenging examples. The attenuation of sound passing through a vortex sheet that is attached to a trailing edge is modelled and analysed and the results shown to be consistent with experiments. Sound incident on a splitter plate in flow and coupled to the unsteady displacement of the boundary layer, and sound that is modified as it perturbs the vortex sheet shed from the trailing edge of a plate, a flow that is sometimes attached to an adjacent compliant surface, are all modelled in detail, as are the characteristics of flow instabilities that make whistling noises. The way sound is absorbed by perforated screens and the effects of a bias flow on that process are the subject of clear examples. Convincing evidence is given of the close consistency of the model with practice. Then the effect of grazing flow past apertures is explained, situations in which sound can either be attenuated or created, when the aperture is coupled to a cavity for example. The model is more elaborate when the perforated screen supports bending waves. Howe's demonstration that flow-coupled surface waves can jump across gaps gives an intriguing insight into the ability of waves to ignore local irregularities – even severe irregularities. Flow-coupled surface waves can be damped in this way when their energy is spent on supplying the needs of a vortical wake. The chapter ends with the acoustics of flow through tube banks, linear and nonlinear, elastic or rigid with and without vortex wakes. The generation of mean flow by sound is also discussed.

The final chapter concerns resonant and unstable systems. The vortex sheet in a rectangular aperture is modelled carefully, a sheet that separates flow on either or both of it sides. The Rayleigh conductivity is evaluated as is the dynamics of the flow when one side of the sheet couples into a side branch or into a closed cavity. He gives a simple nonlinear theory of cavity resonance, simple that is in comparison with what has gone before. The theory of edge tones and the fluid dynamics of organ pipes naturally contains the Kármán vortex sheet as a simple example. Whether many readers will have the stamina to master the intricacies of 'vorticity generation at the labium' I rather doubt but they will be glad to know that the book has now lost most of its frantic pace. The section on combustion instabilities is very much easier to follow: those motions are relatively simple and their mathematics trivial in comparison with what we are now accustomed to. Combustion oscillations in modern gas turbines are severe enough to place definite limits on their operational scope, and much of the technology for coping with the problems has its foundation in the material of this book. Combustion engineers might well be some of the book's most interested readers. Thermoacoustic engines, heat pumps and refrigerators are the final topics, included I suspect for their novelty but explained for the first time in a way I could understand. I am as grateful for that as I am exhausted by the task of reading the rest of the book and making sure that I understand it well enough to comment. I would be interested to know how many others will read it as thoroughly: it is not easy but it is well worth the effort. For those professionally charged with improving the acoustics of powerful flows the book is essential reading.

J. E. Ffowcs Williams