[36] refer to the 35th reference: Wang, Twizell and Price? The reader should not have to be distracted by these considerations.

The Harvard system is the best way of referencing. In the text the reference is given as "Martin (1984)" or "(Martin, 1984)", depending on the context, and the references are given in alphabetical order at the end of the text. With this system the reader sees immediately the source and the date without having to be perpetually leafing forward to the end of the chapter or book.

Perhaps the World Scientific Publishers can be persuaded to instruct their authors to adopt the Harvard System.

W. L. WOOD

BOUNDARY ELEMENT ACOUSTICS: FUNDAMENTALS AND COMPUTER CODES, 2000, T. W. Wu, editor. Southampton: WIT Press. iv +238 pp + CD-ROM. Price £95.00, US$ 149.00. ISBN 1-85312-570-9.

## 1. BACKGROUND

There is a large body of research literature dealing with the calculation of acoustic fields by the boundary element method including many variations to the theory. Attempting to learn the principles of acoustic boundary elements from the research literature alone leads to an overload of information, much of it intensely mathematical. Although, at first sight, there are a number of books dealing with the application of boundary element methods to acoustics, many of these constitute further research literature, being the proceedings of conferences. This book aims to fill the role of a tutorial text. The early chapters are written by the editor and aim to fulfill the need for a straightforward tutorial on the boundary element method for acoustic problems. This tutorial is based on the direct formulation and the CHIEF method for overcoming the well-known non-uniqueness problem. Later chapters deal with more advanced topics, but still in a style that is biased towards teaching about the methods rather than reporting the research work. The book offers computer codes to back up the subject of most of the chapters of the book so that readers can examine it and try out example problems. The intended readership therefore comprises graduate students and researchers as well as engineers.

## 2. CONTENTS

The book starts with a short chapter, written by Seybert of the University of Kentucky, which introduces the wave equation for linear acoustics and sets out some of the basic terms of acoustics such as intensity, power, radiation efficiency and even, very briefly, the decibel, band analysis and A-weighting. This chapter is only eight pages long, but adequately introduces the terms of acoustics needed in the rest of the book.

Chapters 2–5, out of the total of nine, are written by the editor himself, and introduce the theory of the boundary element method. Chapter 2 derives the Kirchhoff–Helmholtz integral equation and its fundamental solution, or the Green function, and produces the direct formulation by collocation at the boundary. A number of issues that will be familiar to those who already know a little about the boundary element method are discussed such as the differences between the interior and exterior problems, the singular-value term at the collocation point, and the non-uniqueness difficulty that arises in the exterior formulation. The half-space Green function is also introduced. A brief explanation of the CHIEF method of overcoming the non-uniqueness problem is given but at this stage, no other methods are referred to. Despite the shortness of the chapter, the theory is explained well without being over-mathematical.

Chapter 3 introduces discretization for the two-dimensional problem. A computer program is included which implements the solution of two-dimensional problems using three-noded isoparametric elements. This uses the CHIEF method for treating the non-uniqueness problem. The subroutine calling structure of the program is presented and the purpose of each subroutine is briefly described but there is no further explanation of the working of the code. Two numerical examples are given. The first is an interior solution for a duct with a velocity prescribed at one end and a characteristic impedance at the other to imitate an open end. The second example comprises an exterior solution for a pulsating cylinder. The latter example includes a short discussion of the effect at the first non-unique, or "irregular", frequency of including a single CHIEF point.

In chapter 4, the presentation moves on to the three-dimensional problem. It concentrates on the integration of both triangular and quadrilateral elements with linear shape functions and deals with the transformations necessary to enable the numerical integration over elements that include singularities in the Green functions. The structure of a computer program to solve three-dimensional problems is described in the same fashion as that used for two-dimensional problems in chapter 3. Again, two numerical examples are shown. The first is for the internal field in a box with one vibrating wall and the opposite wall having the characteristic impedance of air to simulate an open side. A comparison of the solution is made with the analytical solution for plane waves. The second example is of a pulsating sphere and, again, answers are compared with the analytical solution at the first irregular frequency with and without the use of a single CHIEF point.

Chapter 5 introduces the idea of the double-layer potential, or the jump in pressure at the boundary, as the state variable. It derives the normal derivative integral equation and thereby explains the basic idea of the Burton–Miller method. The problem of the standard formulation breaking down for a thin body is demonstrated by recourse to a simple example. This leads to the derivation of the thin-body integral formulation and thence to a direct mixed-body boundary integral formulation. In the latter, the term "mixed body" refers to a surface that may be split into parts that are "thin", "regular" (i.e., not thin), or a perforated surface having an equivalent transfer impedance defined across it. The ideas are developed quite briefly and rely on the example of the analysis of an automotive silencer (muffler). No discretization or computational aspects are discussed in the chapter and there is no accompanying software.

After having dealt solely with the direct formulation so far, chapter 6 turns to the indirect, variational formulation. With this, as for each of the remaining chapters of the book, comes a change in authorship (and notation). The indirect formulation is therefore described by Vlahopoulos of the University of Michigan. Having the new concepts of both the indirect statement of the problem and the variational method of deriving a computable formulation, the chapter is longer than the preceding chapters. The indirect formulation is derived in terms of the pressure and gradient of pressure and these are revealed as the double- and single-layer potentials. Three boundary conditions are considered: prescribed pressure (Dirichlet), prescribed velocity (Neumann) and impedance (Robin). The boundary integral form of these is brought into the formulation by relating them to the primary variables of the indirect formulation. This results in four integral equations relating to the parts of the surface with different boundary conditions. (The impedance surface generates two integral equations, as both the primary variables remain unknown.) The numerical formulation linking the three parts of the surface is derived by the application of the variational principle, which is not derived in the text but introduced as a given result. The treatment of the hypersingular integrals, the discretization and derivation of the system matrix by imposing a stationarity condition on the total functional are dealt with very briefly. A section deals with the treatment of the irregular frequencies in this approach. Another deals with the issues of thin structures, i.e., the imposition of constraints to deal with free edges, and the definition of extra nodes and constraint equations at multiple connections. The chapter ends with three example analyses. The first is radiation from a thin disc; the second, of some geometrical complexity, is a two-chamber silencer and the third is a simple square section duct. The third example is produced by using the software provided to accompany the chapter. However, there is no other reference to the software in the text; indeed, the chapter does not deal with computatioal aspects. In this chapter, the mathematical nature of the material necessarily intensifies compared to the earlier chapters but the explanation is clear and time is taken to introduce the ideas carefully.

Chapter 7, on the modal analysis of acoustic cavities, is written by de Mesquita Neto, de Franca Arruda and Pavanello, of the State University of Campinas, Brazil, along with Rodrigues Carvallo of the Universidade Federal do Mato Grosso do Sul. The chapter limits itself to two-dimensional cavities and presents three different methods of modal analysis based on the boundary integral equation approach. Although the introduction to the chapter states the importance of modal analysis in cavity acoustics, it fails to give an argument for the use of the boundary element method rather than the finite element method for this purpose. The chapter starts by presenting the direct formulation for the boundary element method in terms of the velocity potential. For the modal analysis of cavities, the non-uniqueness problem and varied boundary conditions do not arise. The nature of the eigenvalue problem is set out concisely after which the greater part of the chapter describes and compares three schemes for identifying the eigenvalues and eigenvectors of the boundary element system matrix. The methods are: a direct search to find the zeros of the determinant of the system matrix, the estimation of the modal parameters from a number of frequency response functions calculated for point sources within the cavity, and finally a method called the multiple reciprocity method. The latter implements a formulation by which the system matrices become an expansion of terms in $k^2$, where $k$ is the wave number. The system can then be solved approximately by using matrix eigenvalue methods. The methods are each compared with the analytical solution for a rectangular cavity and also with a simple vehicle interior-shaped cavity. In this case, the basis of comparison is the result of a finite element calculation. The software that accompanies the chapter implements the multiple reciprocity method. It is described in terms of its structure and the role of each subroutine. The input and output files for the vehicle cavity example are also printed in the text.

The subject of chapter 8 is time-domain three-dimensional analysis. In this case, the co-authors are de Araújo of the Universidade Federal de Ouro Preto, Brazil and Mansur and Carrer of the Universidade Federal do Rio de Janeiro, Brazil. The theory of the time-domain solution is naturally very different from the frequency-domain theory developed in the book so far. Here a generalized potential, which can be taken to represent either the acoustic pressure or the velocity potential, is used to develop the time-dependent integral equation and the fundamental solutions, for the potential and the flux. The authors take some care to examine the properties of the equations and the singular integrands along the way. To allow for a time-dependent source distribution within the domain, a domain integration term is included in the formulation. A section on the numerical implementation follows. This treats the time-stepping process in some detail with attention paid to the order of time-interpolation functions and the concept of a spatial region of existence for the time-integrated kernel functions. The spatial discretization and integration process is also described in detail. This includes both boundary elements and three-dimensional volume elements (serving as "integration cells" only) to cater for the domain integration. Methods for both the non-singular and singular integrals are discussed leading to a section describing the accompanying computer code. In this chapter, the description of the code is quite detailed. It describes the general program structure and the structure of individual modules giving some flow diagrams and defining major program data structures/variables. Two simple applications are demonstrated, which can be compared with analytical solutions. The first is a "prismatic domain" (square-section duct) under a Heaviside step function loading at one end and zero-prescribed potential (pressure) at the other. The results for different time step lengths are examined for a number of positions along the duct. The second example is a sphere in a three-dimensional free field. A Heaviside step function of prescribed pressure at the surface of the sphere is applied. Results are examined at a point on the spherical surface and at three distances away from it.

The final chapter, by Wu of Wayne State University, Detroit, describes a formulation for predicting acoustic radiation from a moving source surface and which takes into account effects of the motion-induced turbulence. A formulation is derived which takes into account Lighthill's turbulence stress tensor. It contains surface integrals representing the effects of the surface displacement and unsteady force on the fluid by the vibrating surface, and initially contains a volume integral term representing the effects of induced turbulence. With some simplification for low Mach numbers, the effects from the volume integral can be neglected leaving only surface integral terms. The time integration is removed by assuming steady solutions in the moving frame of the surface. The extended Kirchhoff integral formulation that is obtained reduces to the classical Kirchhoff–Helmholtz integral equation when the translational velocity is set to zero. A comparison is made with formulations without the effects of turbulence and source convection motion. The step of taking the formulation to the boundary and its effect of introducing singularities into the integral terms is described briefly. The existence of irregular frequencies, shifted from those of the classical formulation by the effects of motion, is shown. The theory is developed a little further by introducing the half-space Green function analogous to that introduced in chapter 2. This leads to the presentation of a set of results from a model of vehicle moving on a plane. No software accompanies this chapter.

## 3. THE SOFTWARE

The inclusion of computer code to implement the theory taught in the book will be an attractive feature to many. The routines are all written in FORTRAN 77 and are placed on a CD-ROM, which should be readable as text files under any operating system.

The most studied code of the book will undoubtedly be that from the early chapters setting out the simpler, frequency domain, direct formulation. The FORTRAN provided by Wu for chapters 3 and 4 is written in a reasonably clear style with separate routines, which are each kept short. Given that text of the relevant chapters contains a brief description of the purpose of each routine and a diagram of the calling structure of the program, the code can be investigated easily enough but has a minimum of internal annotation. Most of the variable names have a self-evident meaning and can be identified as referring to the symbols used in the text.

The program provided with chapter 6 is not described in the text. Although it is structured, it is not annotated with comment statements. The form of the data input is easy enough to decipher but it is not clear if the software may be used much beyond the example set of input data given. This corresponds to the analysis presented in the text. The program code provided to accompany chapter 7 implements the multiple reciprocity method for modal analysis and is well structured and commented. The time-dependent solution software for chapter 8 includes data files for the two example problems described in the text. The code is annotated with comment statements and with the help of the detailed description in the text, it should be possible for the student to unpack it and analyse it.

## 4. REMARKS

The strength and *raison d'être* of the book in comparison with other available texts on the boundary element method is its tutorial style. It is aimed at postgraduate students and researchers rather than undergraduates, of whom few study the boundary element method in depth because of the advanced mathematics involved and the complexity of the subject. However, the early parts of the book form useful tutorial material that could be made use of in taught courses. While many will go through the first four or five chapters, studying the detail and perhaps investigating the source code, most readers will choose out of the remaining chapters according to their own interests. The indirect method, modal analysis and time-domain analysis are complicated and demanding subjects and the student must work hard to understand all the issues involved.

Commercial software implements the indirect variational method and chapter 6 is a good text for the user to become familiar with the theoretical issues that must be understood before such software can be used proficiently.

For those with an interest in modal analysis using the boundary element method, and especially the multiple reciprocity method, chapter 7 will provide a good way into the subject.

Chapter 8 fulfils its stated aim of giving a general insight into the field of time-domain boundary element methods. With the detail of the theory given and of the accompanying code, a researcher interested in this field of boundary elements could make this chapter the focus of useful study. The work involved, due to the complexity of the theory, should not, however, be underestimated.

The subject of the last chapter, the solution for a field from a moving source, has important application areas but is also complex. The theory is not revealed in the level of detail that it is in some other chapters but it does discuss the assumptions embodied in various formulations produced by researchers in the field. Again, for those with an interest in the field of boundary element research, the chapter gives a useful introduction.

The combination of tutorial text on the direct, frequency-domain formulation, the selected advanced topics and the inclusion of the FORTRAN code make the book a useful "springboard" for researchers in boundary element acoustics.

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