Preface

The present revision of *The Finite Element Method* was undertaken shortly before the passing in January 2009 of our close friend and co-author Olgierd C. (Olek) Zienkiewicz. His inspiration and guidance has been greatly missed in the intervening years. However, we hope that the essence of his writings is retained in the new work so that current and future scholars can continue to benefit from his insights and many contributions to the field of computational mechanics. The story of his life and works is summarized in *International Journal for Numerical Methods in Engineering*, **80**, 2009, pp. 1–45.

It is our intention that the present text could be used by investigators familiar with the finite element method in general terms and introduce them to the subject of fluid dynamics. It can thus in many ways stand alone. Although the finite element discretization is briefly covered here, many of the general finite element procedures may not be familiar to a reader introduced to the finite element method through different texts and therefore we advise that this volume be used in conjunction with the *The Finite Element Method: Its Basis and Fundamentals* by Zienkiewicz, Taylor, and Zhu to which we make frequent reference.

In fluid dynamics, several difficulties arise. The first is that of dealing with *incompressible or almost incompressible* situations. These as we already know present special difficulties in formulation even in solids. The second difficulty is introduced by convection, which requires rather specialized treatment and stabilization. Here, particularly in the field of compressible high-speed gas flow many alternative finite element approaches are possible and often different algorithms for different ranges of flow have been suggested. Although slow creeping flows may well be dealt with by procedures almost identical to those of solid mechanics, the high-speed range of the supersonic and hypersonic kind will require a very particular treatment. In this text we shall use the so-called *characteristic-based split (CBS)* introduced several years ago by the authors. It turns out that this algorithm is applicable to all ranges of flow and indeed gives results which are at least equal to those of specialized methods.

We organized the text into 15 individual chapters. The first chapter introduces the topic of fluid dynamics and summarizes all relevant partial differential equations together with appropriate constitutive relations. Chapter 1 also provides a brief summary of the finite element formulation. In Chapter 2 we discuss convection stabilization procedures for convection-diffusion-reaction equations. Here, we make reference to methods available for steady and transient state equations and also one- and multidimensional equations. We also discuss the similarity between various stabilization procedures. From Chapter 3 onwards the discussion is centered around the numerical solution of fluid dynamic equations. In Chapter 3, the CBS scheme is introduced and discussed in detail in its various forms. Its simplicity and universality makes it highly desirable for the study of incompressible and compressible flows and in the later chapters we shall indicate its widely applicable use. Though not all problems are necessarily solved using this method in this book, as work of several decades is reported here, the reader shall find the CBS method in general at least as accurate as other methods and that its performance is very good. For this reason we do not describe any other alternatives to make the reader's life simple. The topic of incompressible fluid dynamics is covered in Chapters 4–6. Chapter 4 discusses the general Newtonian incompressible flows without reference to any special problems. This chapter could be used as a validating part of any fluid dynamics code development for incompressible flows. Chapter 5 discusses the non-Newtonian flows in general and metal forming and viscoelastic flows in particular. In Chapter 6 we discuss the special topics of gravity-assisted incompressible flows, which include treatment of free surfaces and buoyancy-driven flows. Chapter 7 is devoted to compressible gas flows. Here, we discuss several special requirements for solving Navier-Stokes equations including phenomena such as shock capturing and adaptivity. In Chapter 8 we discuss various basic turbulence modeling options available for both compressible and incompressible flows and in Chapter 9 we provide a brief description of flow through porous media. Chapter 10 discusses the shallow water flow and here application of the CBS scheme to a different incompressible flow approximation is considered. Although the flow is incompressible, the approximations and variables involved produce a set of differential equations similar to those of compressible flows. Thus, the use of methods already derived for the solution of compressible flow is obvious for dealing with shallow water problems. Chapters 11 and 12 provide a detailed overview on the numerical treatment of long and short waves. Both these chapters on waves are contributed by Professor Peter Bettess, University of Durham.

Two new chapters are introduced in this edition. The first, Chapter 13, presents an introduction to the important subject of fluid–structure interaction. We first discuss one-dimensional flow in flexible pipes where a solution using characteristics can describe many important features. This is followed by consideration of multidimensional problems where fluid flow can induce changes in shape of a solid. We restrict attention to simple cases of deformation such that salient features can be clearly described. In Chapter 14 the topic of biofluid dynamics is discussed. This important new area of application of computational fluid dynamics requires knowledge about biological systems. We discuss many of the challenges that are emerging in modeling systemic arterial circulation and present some detail flow results.

The last chapter of this book is a brief outline on computer implementation of the CBS scheme. Further details, including source code, are available from the website: www.zetacomp.com. The photograph featured on the front cover is one of the several beaches of Gower near Swansea, UK. This picture was taken by Dr Rhodri Bevan.

We hope that the book will be useful in introducing the reader to the complex subject of computational fluid dynamics (CFD) and some of its many facets. Further, we hope it will also be of use to the experienced practitioner of CFD who may find the presentation of interest to practical application.

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