Preface

Finite volume methods are nowadays routinely used in numerous applications and by a broad multidisciplinary scientific community. The main aim of this book is to make this important tool available to students, researchers and academics involved in the training of students in different science and technology fields in which numerical methods for partial differential equations are used. This book, a revised version of the Spanish edition [35], introduces concepts and numerical methods, as well as exercises, examples and applications that will contribute to reinforce the theoretical concepts learned. In addition, some of the exercises and examples involve the execution of MATLAB/Octave codes, also included in the book. The choice of contents is based on the author's own experience in teaching Ph.D. and Master's courses in different universities. In particular, the Spanish version of this book [35] has been used for many years as a textbook for courses on finite volume methods in the Master's course in Mathematical Engineering and in the Master's course in Industrial Mathematics (http://www.m2i.es). The latter is an official degree jointly delivered by the University of Santiago de Compostela (USC), University of A Coruña (UDC), University of Vigo (UVigo), Carlos III University of Madrid (UC3M) and Technical University of Madrid (UPM). The structure of the book has been enriched by contributions from students who used [35] and its previous versions. This book can be used as a teaching aid and as a reference for lecturers. More than 40 exercises are included in the book, which can be used to design the continuous evaluation of the learning process, as required by the European Higher Education Area (EHEA). The book is meant to be a first contact with finite volume methods and aims at providing the necessary background to study more specific works, some of them introduced in the book, and at providing the skills to use commercial programs or open source software within the framework of Computational Fluid Dynamics (CFD). As the background of graduate students, in areas relevant to this book, tends to be rather varied, the author aims to develop the understanding of common terminology, with a balance between mathematical rigour and the physical intuition that characterizes the very origin of finite volume methods.

Since 1989 the author has been engaged in the application and development of finite volume methods to solve hyperbolic conservation laws, first as a mathematics Ph.D. student, then as a researcher and lecturer. The contents of this book are not her own contributions to this methodology but draw on her experience in learning these methods as a graduate student, as a researcher and as a lecturer. The first part of the book is an introduction to systems of hyperbolic conservation laws. The objective of this part is to study and illustrate with examples, the type of possible solutions of conservation laws. A good understanding of what is expected from the equations will enable the reader to develop sound criteria for assessing the correctness of approximate numerical solutions of such problems. The second part of the book is devoted to applications of finite volume methods. Concepts are presented via the simplest problem, namely the numerical solution of the scalar transport equation. The degree of difficulty increases gradually by introducing different ways of solving the Riemann problem. We study the exact solution of the Riemann problem and the Godunov method. We also study different approximate Riemann solvers and associated numerical methods for solving nonlinear one-dimensional problems, such as for example, the first-order upwind scheme and flux splitting methods. Finally, the third part contains MATLAB/Octave codes developed by the author to solve all the exercises in the book and for the implementation of all the numerical methods presented. The codes also allow the reader to assess the practical performance of the various numerical methods presented, for solving the transport and Burgers equations with different initial and boundary conditions.

Regarding the bibliography at the end of the book, I would like to share with the readers my *gratitude* to the authors of all the works referenced, especially monographs, which helped to consolidate the finite volume methodology in the temporal scale of Mathematics. As Toro remarks in [30], *in 1917 Richardson made the first reported attempt to forecast the weather by solving partial differential equations numerically, by hand!. It is generally accepted that this work marked the beginning of Computational Fluid Dynamics*. In representation of all the authors listed here, I have chosen three researchers who have made outstanding contributions to the topics of this book, and I have produced a brief biographical review for each of them: P. Lax, S. Godunov and E.F. Toro. Every time I read their works I learn something new. I had the privilege of direct personal contact with them, in lectures and discussions in Santiago de Compostela, Oxford and many other places in the world. In addition, I would like to share with readers my admiration for them, both as researchers as well as human beings. In the biographical review of each of them, I follow a precise timeline and give links to their publications and most important research on the subject, including new lines of research in the mathematical field. I note that the lives all three scientists I have mentioned above have been marked by turbulent historical events of their times, but nonetheless they remained enthusiastic about scientific research. I consider awareness of these personal experiences to be of educational value, especially for young researchers who begin their research careers.

I would like to thank two admired colleagues in the Department of Applied Mathematics at USC for reviewing a manuscript of the book that resulted in a much improved version. O. Lopez Pouso reviewed the Spanish version [35] and contributed with very relevant observations. A. Bermúdez was my teacher of numerical analysis, the supervisor of my Ph.D. and the director of the research group in Mathematical Engineering (http://www.usc.es/ingmat/?lang=en) I am part of; he gave me the opportunity to learn about this theme and is the co-author of my first and now, as I write this preface, my latest work on finite volume methods [1, 2]. The challenge of making this book suitable for engineers, physicists and mathematicians has facilitated discussions with co-authors of scientific publications from other disciplines, especially with collaborators such as J. Puertas and L. Cea from the University of A Coruña, and P. Garcia-Navarro and P. Brufau from the University of Zaragoza. My friend M. Gómez Marmol and collaborators from the University of Sevilla, who have followed the Spanish version [35] as teachers and students, respectively, have enriched it with valuable contributions, corrections and suggestions. In addition to all of those who helped me to improve [35], it has to be mentioned that I have been using it as teaching aid for more than eight courses by now. This fact allowed me to improve it by reducing errors and analysing which aspects required more detail to enhance the learning of the concepts and methods studied. I am deeply grateful to Eleuterio Toro for his work in reviewing formal and conceptual aspects of this book, which has helped significantly to improve the final version of the work. The convergence of [35] to this book is the result of a proposition by Francesca Bonadei (Springer) in 2011. I thank her for her encouragement and her ability to help during the entire process. The translation from Spanish to English has been done by two former students of the above-mentioned courses, L. García and M. Cobas. We considered this translation work as an opportunity to discuss again concepts and analyse the best way to present them. I would like to thank them both for their involvement in the project and the professionalism with which they carried out their work.

I would not conclude without a few words to challenge those readers who are also students. I hope the book will serve as a tool to get closer to the methodology of finite volume methods, helping to understand the basic concepts and some of the important contributions from people who once faced problems to which they did not know the solution. You are probably now the same age as the three scientists I mentioned above, when they first produced new contributions to the field. The admiration that these pioneers inspire should act as a stimulus to you to solve the problems you will face, thus contributing to the growth of the great *mandala of knowledge* in which each layer builds on the previous one. We may think that our contribution to the thickness of this layer might be negligible, but with contributions from all of us, its area will continue to increase.

Loyal to my parents' teachings, I declare myself directly responsible for all the mistakes made in this book. Although it has been my goal to minimize them, in every iterative process it is also necessary to introduce a stopping test to provide an

approximate solution to the reader, and this is what you have in your hands. From these lines I propose a critical reading that will help in learning and contributing to increase the accuracy of subsequent editions. I will especially appreciate your remarks, suggestions and corrections. These will be a relevant indicator of this open project, and I promise to address them all and, as I have done with the Spanish version, will incorporate them in the future editions.

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January 2015

http://www.springer.com/978-3-319-14783-3

Solving Hyperbolic Equations with Finite Volume Methods

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2015, XVII, 188 p. 55 illus., 43 illus. in color., Softcover
ISBN: 978-3-319-14783-3