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Book Reviews

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Computational Fluid Dynamics for Engineers

Edited by T. Cebeci, J. P. Shao, F. Kafyeke, and E. Laurendeau, Horizon Publishing, Long Beach, California and Springer, New York, 2005, XIV +396 pp., $129, includes CD-ROM

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In the Preface the authors state that "This book is an introduction to computational fluid dynamics with emphasis on the solution of conservation equations for incompressible and compressible flows with two independent variables." Any introductory book to a large and still evolving field such as computational fluid dynamics (CFD) has to make some difficult choices with regards to the breadth and depth of coverage. An additional challenge is to explain the material that is covered in a way that is accessible to a person who is starting his or her studies in the area and to guide the reader toward further inquiries in the literature for topics that are not covered due to space constraints. Last, this book is intended for use in the classroom, as the textbook for a two-semester course for advanced undergraduate and first-year graduate students. This introduces additional constraints on the design process, because accessibility of the material is now linked to the expected mathematical and physical background of senior-level college students. Moreover, the availability and appropriateness of problems and exercises become an essential part of the overall evaluation of the book.

Do the authors succeed in creating an introductory *text*book, guiding readers, especially students, toward a better understanding of CFD and its numerous applications in modern engineering? The answer seems to be "maybe," because several positive aspects of the delivery are marred by a roughly equal number of problems, some of which could be easily solved by a carefully revised second edition.

The book covers only finite-difference methods. Finite-volume techniques are mentioned briefly in two sections (one in Chapter 5, the other in Chapter 12), but the exposition is limited to rectangular grids and reverts back to pseudo-finite-difference coverage almost immediately. I doubt that a reader who is not familiar with CFD would appreciate why finite volumes are used in engineering practice. Finite elements and spectral methods are not covered at all. Only one- and two-dimensional problems and techniques are introduced. The authors make room for a brief discussion of turbulence models and for the solution of the Orr–Summerfeld equation and the e^n method of estimating transition to turbulent flow. However, the coverage of basic definitions, methods, stability results, and model equations is much too short and would have to be heavily supplemented by a classroom instructor. Moreover, when covering some of the introductory material, the authors occasionally fall into a (very common) trap: they talk to their peers, forgetting to define important terms, and taking for granted that readers are already familiar with some of the same CFD concepts that should have been explained as part of this book's mission.

The quality of this book is marred by some unfortunate editorial choices, first and foremost the editing of some of the figures. Some of them end up being almost incomprehensible without colors (e.g., Fig. 1.19a on p. 19, also probably Fig. 11.8 on p. 346), others are of poor quality (e.g., Fig. 1.24 on p. 22, Fig. 9.17 on p. 289, Fig. 11.5 on p. 344, and Fig. 11.9 on p. 347), and a few lack some essential information (e.g., what is the variable whose contours are shown in Fig. 1.21b on p. 21?). A Nomenclature section would have been most welcome. Alternatively, the authors should have defined all of the symbols used in the text. Then there are the typos, and the list is rather long, too long for this review. Suffice it to say that the references to previous equations have a significant chance of being incorrect throughout the volume. Finally, *caveat emptor*: the book comes with a CD-ROM that includes some FORTRAN codes and PC executable files that supplement very nicely the material in Chapters 4 and 5. However, an *additional* CD-ROM for the examples in Chapters 6–12 has to be purchased *separately*, from the publisher's Web site, for a listed price of $90.

A summary of the material covered in each chapter follows, with additional comments. Chapter 1, Introduction, is arguably the best chapter in the book. It is intended to show CFD applied to very challenging and realistic problems of interest to the aerospace and mechanical engineering fields, such as multi-element wings, shape design optimization, icing, and aerodynamics of ground-based vehicles. However, this chapter is also the hardest to follow for the uninitiated: I confess that I myself had trouble with some of the more esoteric comments, which will surely be appreciated by people who specialize in wing design. Will a student walk away from this chapter excited by the realization that CFD can be used to solve real problems, or will he be baffled and confused by the exposition?

Chapter 2, Conservation Equations, summarizes the most common sets of partial differential equations that are used to model fluid flow problems. It includes both differential and integral forms of the Navier–Stokes equations, both incompressible and compressible, the transformed and vector-variable forms, and the Reynolds-averaged equations. Inviscid flows, boundary layers, and stability equations are also introduced. Classification of conservation equations is mentioned, albeit limited to the brief analysis of one second-order linear partial differential equation (PDE) in two variables. Boundary conditions, especially for shear layers, are discussed. The chapter ends with 22 problems, featuring a good range of difficulty and breadth. A few minor comments are in order. The sum-over-repeated-index convention is used without comment, some typos and notation changes obscure the discussion of heat addition and heat conduction, and Fourier's law is used without attribution.

Chapter 3, Turbulence Models, introduces a selected few zero-, one-, and two-equation models. Also discussed are initial conditions needed for the solution of the transport equations. The authors have made numerous significant contributions to this field, and unfortunately this shows in unintended ways. Several key variables are not defined (H, even y^+, which is then defined in Chapter 12), and others are defined several pages after they have been first introduced (u_τ). Unfortunately, this chapter does not include any problems.

Chapter 4, Numerical Methods for Model Parabolic and Elliptic Equations, introduces the reader to the basics of finite-difference discretization applied to the unsteady one-dimensional heat conduction equation and the steady two-dimensional Poisson equation. Explicit and implicit methods are discussed, including Crank–Nicholson and Keller' box. Direct methods are detailed, based on the solution of block tridiagonal systems of linear equations, as well as iterative strategies of the Gauss–Seidel persuasion. A section on multigrid methods and 16 problems complete the coverage. The Thomas algorithm is presented as a numerical "recipe," without a derivation. The boundary conditions for the Poisson equation are presented in excruciating detail, showing all the modifications to the standard discretization that occur at the (rectangular) boundaries. The rate of convergence of an algorithm is mentioned without a definition. Barring a typographical error, there is *no difference* between the V-cycle and the μ-cycle multigrid methods, as listed on page 130. The entire discussion of multigrid methods is unsuitable for beginners.

Chapter 5, Numerical Methods for Model Hyperbolic Equations, introduces the reader to the wave and Burger's equations. The one-dimensional unsteady Euler equations are used as an example of systems of hyperbolic equations and treated to a brief eigensystem analysis. The Lax–Wendroff and MacCormack explicit algorithms are discussed and the Briley–McDonald (and/or Beam–Warming) implicit discretization(s) is (are) presented without derivation. Upwind methods are covered in some depth, and a brief discussion of finite-volume methods is found here. A discussion of convergence and stability (von Neumann version), an introduction to artificial viscosity, and 22 problems end the chapter. The one worked example in the finite-volume section deals with the steady *one-dimensional* convection/diffusion equation, and there are no problems on finite volumes in this chapter.

Chapter 6, awkwardly titled Inviscid Flow Equations for Incompressible Flows, deals with the Laplace equation in polar coordinates and the Hess–Smith panel method, applied to both single-element and multi-element airfoils. The coverage of the panel method is very thorough. Note that the reader is assumed to be familiar with the concept of circulation. This chapter makes constant references to material "available" or "given" in Appendix B (e.g., listings of programs, airfoil coordinates in tabular form), however Appendix B simply refers the reader to the premium CD-ROM, sold separately. Six problems end this chapter, including three in-depth analyses of airfoils that would benefit greatly from the availability of the premium software.

Chapter 7, Boundary-Layer Equations, introduces the reader to standard, inverse, and interaction problems involving the two-dimensional, incompressible boundary-layer equations. The discretization leads the discussion to Newton's method for nonlinear equations. The algorithm employed is Keller's box method, which brings this writer back to his days in graduate school [it was the algorithm introduced in (then Assistant) Professor Saad Ragab's course at Virginia Tech, circa 1988]. A computer program, "given" in Appendix B (you know the drill by now, and it continues for the rest of the book …), is introduced for the standard problem and applied to self-similar laminar flows, ellipses, and airfoils. Six problems end the chapter, including an introduction to Richardson's extrapolation technique.

Chapter 8, Stability and Transition, solves the Orr–Sommerfeld equation and introduces the e^n method for predicting the onset of turbulence. The eigenvalue procedure for finding nontrivial solutions is presented in depth, discussing in detail variational equations with respect to three sets of two of the four parameters involved. Transition predictions for a flat plate and a NACA 0012 airfoil are introduced. Three problems end the chapter, all virtually requiring the premium software.

Chapter 9, Grid Generation, introduces the reader to some basic concepts of mostly structured grid generation and mapping. Algebraic grid generation using unidirectional, multidirectional, and transfinite interpolation is presented. Differential equation methods using the Poisson equation are summarized, and conformal mapping methods, including the parabolic and wind tunnel functions, are presented. A qualitative discussion of unstructured grid generation ends the chapter. No problems are provided. Unfortunately, both algebraic and conformal mapping sections require some previous exposure to these techniques.

Chapter 10, Inviscid Compressible Flow, introduces the reader to the Rankine–Hugoniot jump conditions, shock capturing methods, and the transonic small disturbance equation. A brief discussion of the full potential equation leads the reader to MacCormack's method applied to the compressible Euler equations with examples including the unsteady one-dimensional shock tube problem and a steady quasi-one-dimensional nozzle. The Beam–Warming implicit method is also reintroduced and applied to the same two examples. Five problems end the chapter, four of which require premium software or a significant amount of programming. This chapter has a significant number of blemishes: "expansion waves are unphysical" (surely we mean "expansion shocks"); "halo" cells are usually called ghost cells; the symbols for forward, backward, and central differencing operators are used for the first time here, instead of Chapter 4; the second-order implicit artificial dissipation operator is presented as a fourth-order operator; one panel of Fig. 10.18 should be replaced by a panel in Fig. 10.17; the CFL number and inlet Mach number employed in the discussion do not always match those shown in the figures.

Chapter 11, Incompressible Navier–Stokes Equations, introduces the artificial compressibility method to solve the steady, two-dimensional version of the Navier–Stokes equations. The upwind discretization strategy is employed for the inviscid fluxes and central differences for the viscous fluxes. Approximate Jacobians are also introduced and discussed, and the overall convergence strategy to the steady solution is presented, featuring the alternating direction implicit method nested within a pseudotime step procedure. Model problems are then presented and detailed, including a laminar sudden expansion duct flow, flat plates, and a three-element airfoil. The latter employs an overset chimera grid approach, which is mentioned here for the first time, instead of in Chapter 9, without any explanation. Four problems end the chapter, three of which ask the reader to complete the derivation of some of the results shown in the presentation. The fourth one is among the favorites of the incompressible two-dimensional flow literature: the driven cavity problem. This chapter borrows heavily from the authors' published work, including references to CPU run time on Cray C90 and YMP machines. Of some concern are the sudden expansion duct flow results, whereby Tables 11.3 and 11.4 show that a 16-fold mesh refinement has absolutely no effect on the conservation of mass error. No explanation is provided in the text.

Chapter 12, Compressible Navier–Stokes Equations, ends the book by applying the MacCormack and Beam–Warming methods to the two-dimensional version of the Navier–Stokes equations. Finite volumes make another very brief appearance, and the fourth-order explicit Runge–Kutta time integration algorithm is introduced. The single model problem shown is *incompressible*, the same laminar sudden expansion duct flow that was employed previously. Again, extremely detailed and somewhat repetitive instructions on how to modify the discretization in regions close to the boundaries are provided, this time in a five-page appendix. Ten problems end the chapter: three derivations of Jacobian matrices, four supersonic flat plate runs, and three driven cavity applications.

In summary, this book provides a solid introduction to CFD, at least from the point of view of finite differences. A second edition, carefully revised, and containing the additional CD-ROM, could serve as a reference to the reader willing to investigate CFD applications and might be used as a textbook for an introductory course in CFD. However, I am hesitant to recommend the present edition, with the notable exception of practitioners of CFD applied to airfoil design.

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