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Book Reviews

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Computational Fluid Dynamics

T. J. Chung, Cambridge University Press, New York, 2002, 1012 pp., $95.00

This book represents a monumental undertaking by the author, a Distinguished Professor at the University of Alabama in Huntsville, as the culmination of almost four decades of conducting fundamental and applied research in computational fluid dynamics (CFD). Over 1000 pages constitute 27 chapters, partitioned into 5 general topics, and 4 appendices. The scope covers the complete spectrum of finite difference (FD), finite volume (FV), and finite element (FE) theoretical approaches to the construction of CFD algorithms, for problem classes ranging from incompressible to hypersonic reacting flows to relativistic fluid dynamics.

Part One is 40 pages of preliminaries in two chapters. Following a section on book organization, a thorough comparison of FD, FV, and FE algorithms for a simple linear two-point boundary value equation is developed including boundary condition (BC) impositions, especially the Neumann BC. This part is concluded with an overview of the canonical forms for parabolic, elliptic, and hyperbolic equations, followed by presentation of the Navier–Stokes (NS) equations for the compressible laminar flow problem class.

Part Two, entitled "Finite Difference Methods" and constituting 200 pages in 5 chapters, starts off in Chapter 3 with an exhaustive development of FD stencils for first, second, and mixed spatial derivatives. This leads to a precise summary of the FD δ, δ^+, and δ^- nomenclature prevalent in the literature and concludes with a definition of FD order of accuracy. Chapter 4 briefly introduces standard matrix iterative methods, including ADI, approximate factorization (AF), and time-splitting and then develops a range of FD algorithms for a model unsteady parabolic PDE. Then follows a section on a first-order hyperbolic PDE leading to clear delineation among the many famously named algorithms, e.g., Lax, Lax–Wendroff, McCormack, Beam–Warming, and DuFort–Frankel. Hence follows a thorough presentation of coordinate transformation of the NS equations, with Neumann BC application, and example FD algorithm forms. The chapter is completed with some simple examples. Chapter 5 is very brief, first outlining artificial compressibility and SIMPLE algorithms for the incompressible NS equations, followed by a brief exposé on transformation to vorticity in two and three dimensions.

The truly substantive Chapter 6 (100 pages) develops in thoroughness FD algorithms for the compressible NS PDE system. A thorough presentation of the potential flow forms of NS, both irrotational and rotational, leads to transonic flow artificial viscosity, artificial density, and flux upwinding FD algorithms. Then follows, in the same absolutely transparent comparison basis, the litany of FD algorithms for the Euler equations. Table 6.2.1 lists all of the famous names associated therewith (those given earlier plus Godunov, van Leer, Roe, Osher, Yee, Boris and Book, Briley and McDonald, Harten, and Jameson), and the next 40 pages cleanly present and summarize the distinctions, and lack thereof, among the lot. The generalization Euler→laminar NS follows, whence is developed the matrix preconditioning algorithm for low Mach flows as recently refined by Merkle.

Section 6.5 contains the significant departure from the "reporting" of FD algorithms to the author's most recent innovation in CFD theory labeled flowfield-dependent variation (FDV) methods. FDV originated as a process to embed the "physics" involved in the ill-behaved thermodynamics of hypersonic flow interaction with a body; hence also the mechanics gray areas between incompressible and compressible flow and laminar flow transition to turbulent. Based on a time Taylor series semidiscretization of the NS PDEs, of Lax–Wendroff type, an approach to CFD algorithm construction is identified that the author claims can recover the (stabilizing) essence of the majority of FD Euler and NS algorithms summarized to this point. The FDV theory parameterizes the identified flux vector derivatives, added to the parent NS PDE system, with coefficients dependent on the local flowfield; hence the name. An FDV solution is illustrated for a hypersonic inflow, but mathematical support, hence validation, of the claim is deferred to the FE part of the text. The chapter is completed with BC application definitions. This FD section is completed with Chapter 7, a brief discussion of generation of FV CFD algorithms using FD techniques. The concept of a staggered mesh is introduced, with operator splitting and fractional step algebraic processes detailed.

Part 3, entitled "Finite Element Methods," constitutes nine chapters encompassing 190 pages of text. Chapter 8 briefly introduces in one dimension the essence of FE implementation of a weak statement, following identification of FE literature jargon. The FE matrix assembly process is still ascribed to Boolean rigor, when in fact it is no more than element matrix order augmentation to meet global matrix rank. The definition of FE error in terms of matrix and integral norms, including Sobolev norms, concludes the chapter.

Chapter 9 develops FE shapes for one, two, and three dimensions and hence the corresponding FE basis functions of both Lagrange and Hermite type for the usual range of polynomial completeness degrees. The associated coordinate transformations are detailed, including isoparametric elements, leading to Gauss quadrature formulas. It was with some humor that I found "stiffness matrix" in this middle section of a CFD text. (It also appears later!) Chapter 10 devotes 40 pages to linear problem statements: the key practical developments are the concept of a penalty term (for Stokes PDE) and conjugate gradient and element-by-element linear algebra definitions.

Chapter 11 contains 50 pages devoted to nonlinear model problems and hence the fundamental issue of FE algorithm stability for convection-dominated flows. The introductory paragraph highlights the large number of algorithms (buzzwords) associated with the subject. Taylor–Galerkin, Petrov–Galerkin, and least-squares modifications to the classic Galerkin weak statement are developed, and the associated numerical diffusion mechanisms are identified. Interestingly, all of these algorithms plus another dozen have been confirmed reproducible via a Lax–Wendroff-type Taylor series time semidiscretization, to which the author's FDV method belongs. This topic, a natural for this chapter, is not included. The chapter technical content is concluded with linear algebra issues, now including GMRES, whereupon comparative solutions for a traveling wave and the rotating cone are summarized.

Chapters 12 and 13 present the "meat" of the FE CFD content, respectively, for laminar incompressible and compressible NS systems and hence algorithms. As FE methods have made the most significant inroads for incompressible flow analyses, the 20-page Chapter 12 is particularly terse, amounting to no more than brief statements of options (in a book entitled "*CFD*"!). One example problem completes the chapter, with the briefest comparison to benchmark data. This probably reflects the author's primary interest in high-speed compressible flow, the chapter for which, however, is only 40 pages long. Therein, the statements focus on a continuous Petrov–Galerkin formulation and a discontinuous Galerkin form leading to a rather thorough presentation of the introduced FDV formulation. The FE implementation of the FDV NS system is followed by discussion of several verification and benchmark NS problem results using the FE–FDV construction.

Chapter 14 presents a rather thorough comparison of alternative weak-form implementations including spectral bases, least squares, and finite point (hence to "meshless"), leading to a range of example results. Chapter 15 connects the NS FV formulation (essentially a constant test function) to a Galerkin FE construction, and Chapter 16 repeats the process for the FD–FE connection, concluding with a brief investigation into boundary element (BEM), particle-in-cell (PIC), and Monte Carlo connections ending up on page 530.

The remaining half of the book addresses issues auxiliary to CFD theories but of particular consequence to actual computing practice. Part 4, 140 pages in length, addresses structured and unstructured grid generation, leading to solution-adaptive meshing strategies appropriate for both classes. These chapters are sprinkled with ample mesh graphics and illustrative solutions focusing on shock capturing local mesh refinements. The section is completed with an overview of computing strategies, specifically domain decomposition, multigrid, and associated parallel processing issues and is replete with appropriate graphics.

Part 5, entitled "Applications," constitutes about a third of the book at about 300 pages. The seven problem classes addressed focus on compressible NS topics, with each section first developing the appropriate PDE statements and then presenting computational results generated by one or more of the presented CFD algorithms. The first topic is modeling for turbulence and highlights time averaging, Favre averaging, and filtering approaches leading to mixing length, two equation (TKE; k–ω), algebraic Reynolds stress (ASM), large eddy simulation (LES) with subgrid model (SGS), and finally direct numerical simulation (DNS) closures. An expansive set of illustrative numerical results concludes the chapter.

Chapter 22 addresses chemically reacting flows with combustion. The PDE plus closure development for turbulence and thermodynamics is very complete, making it an excellent reference reflective of this topic being one of the author's main interest areas. Example computational results are comprehensive in scope and content, spanning transonic to hypersonic applications. Chapter 23 follows with an equally comprehensive development of PDE and closure systems for acoustics and detailed computational results.

Radiative heat transfer, multiphase and electromagnetic flows, and relativistic fluid dynamics are the subjects of Chapters 24—27. Each is shorter than Chapters 22 and 23, but nevertheless each again presents an excellently complete problem statement followed by particularly representative numerical results. Then follows the appendices detailing three-dimensional flux Jacobians, Gaussian quadrature, source term Jacobians for two-phase flow surface tension, and metric tensor, FDV flux, and source term Jacobians for relativistic fluid dynamics.

In summary, this book constitutes an extremely valuable contribution to the technical CFD literature. I would classify it as a monograph rather than a textbook, in both its organization and the fact that it is devoid of suggested problem exercises. That aside, it presents in a thoroughly uniform notation the details of FD, FV, FE, and now FDV algorithms for applications to incompressible and compressible Navier–Stokes problem statements. I highly recommend it for the library of any institution or individual conducting fundamental or applied research in CFD.

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Flow Control by Feedback: Stabilization and Mixing

Ole Morten Aamo and Miroslav Krstić, Springer-Verlag, New York, 2003, 198 pp., $99.00

The book covers a narrow albeit important area of the broad field of flow control: transition delay and mixing enhancement via feedback control. The authors have done original work in the subfield and have established a fine reputation. It is quite surprising that Aamo and Krstić seem willing to risk that reputation by producing the present poorly conceived and executed book.

Aamo and Krstić's stated goal is to provide a self-contained introduction to the Navier–Stokes equations for the benefit of control students, to review the basics of control theory for the benefit of fluid dynamicists, and to help nonengineers acquire knowledge about the emerging field of microelectromechanical systems (MEMS). Lofty goals indeed. In 198 pages and 6 chapters, the authors motivate the subject, derive the Navier–Stokes equations, introduce elements of linear as well as nonlinear control theory, explain several feedback control strategies to delay transition or to enhance mixing in four prototypical flows, and describe a number of microsensors and microactuators. The whole exercise, in the opinion of this reviewer, was done in vain and is a syndrome of what is ailing academic publishing today. I shall detour to that broader issue for the next paragraph as this will set the tone for the rest of the present review.

Academic institutions made it imperative for faculty to publish in order to survive and prosper. There is nothing wrong with that if quality and not quantity is emphasized. Unfortunately, the exercise deteriorated during the past 10–20 years into bean counting and the race to publish en masse began. Demand spurs supply. The number of mostly-for-profit publishers of books and journals mushroomed, and mediocrity crept into both venues. Journal pages have to be filled, and library bookshelves have to be stacked. Hopping from one journal to another until something is eventually accepted for publication became a pastime for some researchers. Book acquisition editors working for certain publishers showed up in scientific meetings and, swarming like timeshare condominium salesmen, convinced unsuspecting potential authors of how easy it is to publish a book out of a thesis or an internal report. With computers, a camera-ready manuscript can be prepared mostly by cutting and pasting from one's prior publications, or worse, from others', and in a few short months or even weeks, a book is born to be purchased by blind library contracts as well as by a few innocent bystanders. Profits rolled in, as the costs to publishers were minimal, even when only a few hundred copies were sold. Other than a casual review of a table of contents and perhaps a one-page summary, the completed manuscript is never reviewed or copyedited and the often dismal results are exemplified by such books as the present one. Having no peer review made it easier to publish a book than a journal paper. Witness the recent book by Stephen Wolfram, *A New Kind of Science*, in which the author, among other things, was self-anointed as the Isaac Newton of the 21st century. Such a grandiose claim would be unlikely to pass the peer review process of journals, even that of mediocre ones. (For a review of Wolfram's book, see *Applied Mechanics Reviews*, Vol. 56, No. 2, March 2003.) Back to the present book. In the Preface, the authors declare the book to be a research monograph. Three paragraphs later, they assert that the book can be used as a text in a stand-alone course on flow control, or as a supplemental text in courses on fluid dynamics or control of infinite systems. In reality, the present book is none of the above. The hodgepodge nature of the presentation makes it incomprehensible as a textbook. The lack of coherence between the disparate parts, of thoughtful analysis, and of meaningful physics makes the book less useful as a research monograph.

The first misspelling in the present book is spotted in the fourth line of the Introduction. The list of references is meant to be organized alphabetically but is not always so. Some references are incomplete and many are "to appear." In places, the authors refer to the book as "this report," thus hinting at a cut-and-paste job from a previously published report. These and similar irritants could have easily been avoided had a competent copyeditor glanced at the manuscript. The book is filled with meaningless equations without much discussion of the physics or of what the mathematics mean. The chapter on MEMS is 4.5 pages long—mercifully with no equations—and the discussion of rotating-disk actuators occupies three sentences. What can possibly be learned from such terse presentation of a fledging field that, in one decade, has spawned thousands of journal papers, hundreds of meetings, and dozens of books?

Fluid mechanics is a very visual as well as physical subject. The authors attempt to teach this rich field to the uninitiated with mere equations and without much reference to the subject strengths. The result is page after page of meaningless equations that do not inform, instruct, or illuminate but instead confuse, unsettle, and irritate. The authors are themselves quite confused when they do not seem to know the difference between stabilization of a transitional flow and relaminarization of a turbulent one. Perturbation and linearization are introduced as mathematical oddities. Without physical reasoning, those powerful tools are nearly useless to newcomers.

Computational fluid dynamics—a very rich subject as well as an important one for building control algorithms—is distilled into six pages of equations. Spectral, Fourier–Galerkin, and Chebyshev collocation methods are again Greek to the uninitiated. The chapter on control theory is nine pages long. My negative assessment of the introductory chapters might have been less critical had the authors not claimed those chapters to be suited for newcomers. How can a reader of the present material proceed to model a flowfield different from the canonical ones described in the book, to approximate a complex system of differential equations, to discretize those equations, and finally to design the relevant controller?

The authors' statement that developing reliable control algorithms is the remaining missing ingredient for turning flow control into a practical tool flies in the face of the enormous difficulties that still remain with developing reliable, inexpensive, durable, dense arrays of sensors and actuators for field applications, not to mention the inadequacy of today's computers to perform online integration of the nonlinear Navier–Stokes equations. Other imprecise, meaningless, or outright erroneous statements percolate throughout the book. Witness "This is the case, for instance, in combustion, where the quality of the fuel-air mixture is *essential* for power generation ...." [Italics are mine.] Wouldn't power be generated even with a less-than-ideal fuel–air mixture? Witness "The micromachining technology that was developed over the past decade or two, opens for fabrication of sensors and actuators on the micron scale." Doesn't something need to be opened first before the revolution begins?

In parting, this book is not recommended for either private or public purchase. At exactly $0.50 per page, the reader deserves considerably better book than offered here.

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