AIAA Journal
Vol. 36, No. 1, January 1998

Book Review

Advances in Numerical Heat Transfer, Vol. 1

Edited by W. J. Minkowycz and E. M. Sparrow, Taylor & Francis, Bristol, PA, 1997, 432 pp., $139.95

This monograph contains 10 chapters written mainly by academic authorities on broad issues central to numerical heat transfer. The contributions represent a cross section of current research topics in computational fluid dynamics (CFD) and heat transfer, with some extensions to multidisciplinary problems involving fluid–structure interaction and heat and mass transfer processes. Chapters 1 and 6–8 develop analyses focused on numerical mathematics issues, and Chapters 2–4, 9, and 10 discuss practical applications of current interest. Chapter 5 summarizes the state of the art in two-equation and second-moment turbulence closure modeling.

By and large, each chapter is well written, providing an informative summary of historic material, current state-of-the-art practice, and research topics for the future. Comments pertinent to each chapter's contribution follow.

The subject of Chapter 1 is progressively higher-order-accurate approximations for the convection operator in CFD, within a development framework of one-dimensional finite volume (FV) algorithm constructions. The review of current practice methodology is excellent, leading to the summary conclusion that many nearest-neighbor FV CFD codes can be easily modified to reduce the excessive numerical diffusion associated with first-order upwind methods. Cross-comparisons of methodology yield a transparent presentation. The introduction of Fourier analysis to characterize performance is informative, including comparison of incompressible with compressible flow methodology, e.g., MUSCL and various flux-limited schemes. The chapter is informative and even humorous at times.

Chapter 2 presents recent advances in CFD using the FV approach. A major part of the chapter is devoted to a presentation of FV methodology, which is quite standard, with extension to moving grids. Thereafter, for incompressible flow, the SIMPLE class of pressure resolution schemes is described, yielding a discussion of FV code and computer practice. Computational results follow, ranging from simple two-dimensional cavity natural convection to simulation of welding of a thin plate. An extension to compressible flow in a two-dimensional plane nozzle then leads to a turbulent compressor flow application. The chapter presents a comprehensive overview of the authors' applications to a broad problem class.

Chapter 3 continues in the same vein, proposing and developing a control volume/finite element method comparison for incompressible CFD on unstructured meshes of triangles and tetrahedra. The remainder of the chapter presents a fully detailed exposé on numerical implementation requirements. An extensive reference list concludes this chapter.

Chapter 4 presents comparative derivations of FV and finite element (FE) weak statement methodology for incompressible CFD algorithms. Extensive detail is presented on algorithm constructions, duplicating somewhat the material in the preceding chapter but in a notation found in the FE literature. Thereafter, discussion focuses on the action of pressure, including projection and pressure-based iteration methods, and nonstaggered meshing issues, ultimately leading to the SIMPLE algorithm class. No numerical results assess comparative performance.

Chapter 5 departs from the preceding chapters in presenting a summary of standard two-equation k–ϵ closure models, leading to advanced models for application to CFD. The subject of improved wall function boundary conditions and improved low Reynolds number k–ϵ models for detailed wall region resolution is presented. The issue of streamline curvature effects is discussed, leading to other two-equation models and the turbulent Prandtl number. There follows a discussion of Reynolds stress/flux transport models with nonisotropic algebraic stress models (ASM). No numerical results are included, but there is an extensive literature citation.

The next several chapters return to discussion of specific numerical methodology associated with computational heat transfer. Chapter 6 presents the concept of FV multiresolution, i.e., subgrid resolution using FV local mesh refinement within the global discretization. This leads to scale patching, done algebraically with standard FV methodology. Computational examples are presented for crystal growth simulation. The concept of scale resolution leads to a multiblock grid strategy, with resolution patching, all within the context of Cartesian FV cells and a staggered mesh resolution. An extensive literature list concludes this chapter.

Chapter 7 develops multigrid methods for compressible internal flows with heat transfer. Following a standard FV presentation, the multigrid algorithm is detailed for application in the SIMPLE class of CFD algorithms. Restriction and prolongation operators can be interpreted within the context of the preceding chapter. Computational experience for modest Reynolds number examples is given in ample detail, showing the advantage of multigrid. Complex geometries are broached, along with a modest application to turbulent reacting flow. The literature citation is extensive.

Chapter 8 backs up a few steps, treating conservation law forms for thermal problems. An analysis of formulation issues duplicates material presented in earlier chapters. The discussion then proceeds to a trans-FE approach, which again involves a comprehensive reformulation of the basic equations and numerical procedure. A range of rather elementary examples concludes the presentation, and a broad acknowledgment and reference list are given.

Chapter 9 presents an overview of numerical methods applied to phase-change problems involving solution of the energy equation with complicated thermodynamics. The construction encompasses both FV and FE forms, with both fixed and moving grid requirements developed. The numerical approach involves a predictor-correction methodology with tracking of the phase change interface in the process. The introductory numerical examples are geometrically simple, whereas the later ones are for more practical problems. Discontinuous thermal properties and fluid flow issues complete the chapter.

The summary chapter deals with inverse shape and boundary condition simulation requirements for optimization in heat conduction. The conservation law statement development is brief, leading to a boundary element method (BEM) solution process. The inverse problem is developed, followed by a brief summary of Tikhonov's regularization for ill-posed problems. Thereafter, results of the BEM algorithm for unknown thermal boundary conditions are summarized in two and three dimensions. The issue of temperature-dependent thermal conductivity concludes the chapter and introduces the idea of inverse shape design. An example is presented for a ceramically coated turbine blade airfoil.

In conclusion, this monograph presents a topically organized overview of current, predominantly FV, methodology for problems in computational heat transfer. The breadth of development compensates for the overlap that exists in FV formulation presentations. The monograph is recommended reading for those wishing to rapidly acquire an overview of these topics with excellent references to the current literature.

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(Required by 39 U.S.C. 3685)

1. Publication Title	2. Publication No.	3. Filing Date
AIAA Journal	0 0 0 1 - 1 4 5 2	10/1/97
4. Issue Frequency	**5. No. of Issues Published Annually**	**6. Annual Subscription Price**
Monthly	12	$65/$125

7. Complete Mailing Address of Known Office of Publication *(Street, City, County, State, and ZIP+4) (Not Printer)*
1801 Alexander Bell Drive, Reston, VA, 20191

8. Complete Mailing Address of Headquarters or General Business Office of Publisher *(Not Printer)*
American Institute of Aeronautics and Astronautics, 1801 Alexander Bell Drive, Reston, VA, 20191

9. Full Names and Complete Mailing Addresses of Publisher, Editor, and Managing Editor *(Do Not Leave Blank)*

Publisher *(Name and Complete Mailing Address)*
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PS Form **3526**, October 1994 *(See Instructions on Reverse)*

13. Publication Name	14. Issue Date for Circulation Data Below	
AIAA Journal	December 1997	
15. Extent and Nature of Circulation	**Average No. Copies Each Issue During Preceding 12 Months**	**Actual No. Copies of Single Issue Published Nearest to Filing Date**
a. Total No. Copies *(Net Press Run)*	3553	3502
b. Paid and/or Requested Circulation (1) Sales Through Dealers and Carriers, Street Vendors, and Counter Sales *(Not Mailed)*		
(2) Paid or Requested Mail Subscriptions *(Include Advertisers' Proof Copies/Exchange Copies)*	2855	2811
c. Total Paid and/or Requested Circulation *(Sum of 15b(1) and 15b(2))*	2855	2811
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e. Free Distribution Outside the Mail *(Carriers or Other Means)*		
f. Total Free Distribution *(Sum of 15d and 15e)*	69	69
g. Total Distribution *(Sum of 15c and 15f)*	2924	2880
h. Copies Not Distributed (1) Office Use, Leftovers, Spoiled	629	622
(2) Return from News Agents		
i. Total *(Sum of 15g, 15h(1), and 15h(2))*	3553	3502
Percent Paid and/or Requested Circulation *(15c / 15g x 100)*	80.3%	80.3%

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