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Book Reviews

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Verification of Computer Codes in Computational Science and Engineering

Patrick Knupp and Kambiz Salari, CRC Press, Boca Raton, FL, 2003, 160 pp., $79.95

On the back cover of this book a question is asked, "How can one be assured that computer codes that solve differential equations are correct?" This is a crucial question in the modern age of computational simulations covering essentially every field of engineering and physics. Neither this book, nor any other book, can answer that question comprehensively with absolute certainty, but this book makes an important contribution to the literature of methods for improving the quality of simulation software. Quite significantly, this is the first and only book published that deals entirely with assessing computer software reliability for the numerical solution of partial differential equations (PDEs).

Because there is a great deal of confusion and contradictory terminology in the field of verification and validation of computational models, the authors try to clarify what their book deals with in the first paragraph of the Preface. They state that the book specifically addresses the issue of "code order-of-accuracy verification (or verification, for short) in which one shows that the asymptotic order-of-accuracy exhibited by the code agrees with the theoretical order-of-accuracy of the underlying numerical method." Although I quibble with their statement concerning what the procedure actually does, their description focuses the reader's attention on the specialized topic of the book. To achieve the goal of order-of-accuracy verification, the book concentrates on a single, yet very powerful, technique usually referred to in the literature as the method of manufactured solutions (MMS). The authors do not think the MMS terminology is adequate, and so they invented a new term: order verification via the manufactured solution procedure (OVMSP). It is unfortunate they introduced new terminology for the same procedure, just when the MMS terminology was finally becoming widespread.

The book is written in the monograph style and still retains the tone of the corporate report from which it was derived. There are 10 brief chapters, most dealing with detailed design, implementation, and execution procedures for order-of-accuracy verification. Chapter 1 gives a brief history of the development of MMS, and the authors point out that "The idea is very natural and has been independently invented by numerous other investigators." Chapter 2 gives a short introduction to discretization methods for PDEs and terminology in code verification. Chapter 3 presents a step-by-step procedure for determining the order of accuracy of a code that solves differential equations. The method is based on calculating numerical solutions on different size spatial grids (or time steps) and comparing the sequence of solutions with the exact analytical solution to the differential equation. Knowing the exact solution and using a Taylor series expansion for the discretization error, one can explicitly evaluate the order of accuracy of each pair of solutions on different grids. Chapter 4 discusses how to design a suite of tests to identify logical paths through the code so that every line of code is exercised.

Chapter 5 explains that MMS belongs to the class of methods that solves the backward problem. MMS assumes a suitably complex solution to the original PDE of interest, and then a new PDE is analytically derived that satisfies the assumed solution. Chapter 6 discusses the types of coding errors that are found using the method, as well as those that are not found; specifically, robustness, efficiency, and formal errors. This chapter also discusses a clever blind test where errors were added to a code and the procedure was used to detect the errors. Chapter 7 very briefly discusses two related topics, numerical error estimation in solving PDEs, usually referred to as solution verification, and validation. Validation assesses the accuracy of the numerical solution relative to the physical world, i.e., experimental data. Chapter 8 presents four detailed examples of the code verification procedure applied to the steady and unsteady Burger's equations and the incompressible and compressible Navier–Stokes equations for laminar flow. Chapter 9 comments on advanced topics in order-of-accuracy verification, such as errors in lookup tables, nonordered approximations, and numerical damping terms for shock-wave capturing. Chapter 10 gives a brief summary and presents some conclusions.

The book is a welcome addition to the literature of methods for assessing the reliability of computational simulation software. However, some of the topics covered would benefit from a more careful discussion and a better description of the present state of the art of the procedure. For example, no in-depth discussion is presented for turbulent flow, shock waves, or applications in solid dynamics, and a number of open research issues remain. Some sections of the book are not very polished; for example, some of the descriptions are not clear or completely accurate, and some of the figures and tables are not easily understood.

The book could be used as a supplement in a graduate course on the numerical solution of PDEs and as a "how to" reference on code verification. In the latter instance, the text would be most valuable to code developers, especially in commercial software companies, corporations, and universities. High-consequence decision making based on computational modeling and simulation will ultimately be the beneficiary of implementing the procedures discussed in this book for improving code reliability.

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Heat Transfer in Single and Multiphase Systems

Greg F. Naterer, CRC Press, Boca Raton, FL, 2002, 640 pp., $129.95

The controversy over the nature of heat emerged in the 1700s, and subsequent contributions of natural philosophers, astronomers, and physicists of the past established a foundation for the transfer of energy, or heat transfer. Since that time, the field of heat transfer has been and continues to be critical to the advancement of technologies that benefit the public, such as energy generation and utilization, microelectronics and communication systems, airbreathing engines for transportation, and thermal protection systems for space exploration.

The development of the thermometer in 1709 led to heat transfer studies by numerous individuals, including Count Rumford, whose meticulous experiments, combined with the mathematical developments of Fourier, resulted in the field of conduction heat transfer. Fluid mechanicians such as Reynolds, Prandtl, Nusselt, and Grashoff contributed concepts and analyses that were the bases for the understanding of convective heat transfer. During that same time, physicists such as Planck, Stefan, and Boltzmann were investigating the phenomenon of energy transfer by radiation, resulting in the field of radiation heat transfer. These three modes of heat transfer—conduction, convection, and radiation—continue to be the basic areas of analysis in the discipline of heat transfer.

Numerous books have been written on the subject of heat transfer, some focusing on individual modes of heat transfer, others attempting to deal with the subject in its entirety, and yet others dealing with specific applications. Although each book is written with a slightly different focus, choices must be made as to what material to include and what aspects of the subject to exclude. The present volume endeavors to summarize the fundamentals of heat transfer and focus more on the multiphase aspects of heat transfer, along with applications to heat exchangers.

The introduction (Chapter 1) summarizes the fundamental concepts and definitions for heat transfer, Eulerian and Lagrangian systems, vector and tensor notation appropriate to the material presented, and transport properties. It also includes a cursory summary of the three fundamental modes of heat transfer: conduction, convection, and radiation. The first part of this book deals with the three primary modes of heat transfer, designated single-phase heat transfer. The section on conduction heat transfer (Chapter 2) provides a brief treatment of one-dimensional conduction, mentioning thermal contact resistance, fins, and extended surfaces. The chapter then addresses multidimensional heat conduction along with graphical and analytical solution methods and concludes with transient conduction and combined effects. The section on convection heat transfer (Chapter 3) addresses the traditional governing equations for conservation of mass, momentum, and energy; the velocity and thermal boundary layers; the nondimensional forms of the governing equations; and heat and momentum analogies. External forced convection, internal forced convection, and free or natural convection are presented with a focus on selected areas. The second law of thermodynamics is reviewed, as is turbulence modeling. A number of topics could be included to make the material more complete; however, the treatment of convective heat transfer does provide a reasonable introduction to the subject. The section on radiation heat transfer (Chapter 4) introduces the basic concepts of radiation between surfaces, with limited discussion of other aspects of radiation. Approximately half of the chapter is focused on solar radiation, including the design of solar collectors, their efficiency, and solar power generation. These chapters provide some examples but very few references to support the material selected or as sources for further study of the material.

The second part of the book focuses on multiphase heat transfer, including phase change, gas (vapor)–liquid systems, gas–solid (particles) systems, liquid–solid systems, and gas–liquid–solid systems. This section provides perhaps the major contribution of the volume. The presentation of phase change heat transfer (Chapter 5) gives fundamental definitions of boiling and condensation, solidification and melting, and evaporation and sublimation, with a few examples. Mixtures and two-fluid formulations are then considered, including the transport equations; mass, momentum, and energy equations; and the second law of thermodynamics. Interface tracking is then addressed with a focus on mass and momentum balances, energy balances, and entropy and the second law. The section on gas (vapor)–liquid systems (Chapter 6) addresses boiling heat transfer including pool boiling, film pool boiling, and critical and minimum heat fluxes and also pool boiling on inclined surfaces and boiling with forced convection. Condensation heat transfer is reviewed with laminar and turbulent films, outside single and multiple tubes, as well as condensation inside tubes. Thermosyphons and heat pipes, with wicking and entrainment limitations, are also considered. The discussion of gas–solid (particle) systems (Chapter 7) classifies the gas–solid flows and reviews the dynamics of gas particle interactions as well as convective heat transfer and radiative absorption and emission. These fundamentals are applied to fluidized beds with various flow regimes and velocity and pressure gradients, as well as heat and mass transfer. Spray drying is also considered. In the section on liquid–solid systems (Chapter 8), phase change materials and materials processing are addressed, including the fundamentals of one-dimensional solidification and melting, phase change with convection, and phase change with coupled heat and mass transfer. Specific applications are reviewed for cylindrical inward and outward conditions. The fundamentals of multidimensional solidification and melting are reviewed, as are the dynamics of liquid–solid flows. A number of applications are also considered, including various manufacturing processes, energy storage, and freezing in pipelines. Gas–liquid–solid systems (Chapter 9) are addressed in terms of combustion and spray deposition systems, including the fundamental equations of droplet flows with phase change. Case studies include atmospheric icing of structures and melt particularization; gas flows with solidification and melting, ablation shields, and free surfaces with phase change; chemically reacting flows; and multiphase byproducts of reacting flows with case studies for a blast furnace and steel production.

The performance of heat exchangers for both industrial and domestic applications is increasingly important as the demand for energy and energy exchange increases. The section on heat exchangers (Chapter 10) provides a very brief summary of tubular heat exchangers, including crossflow and shell-and-tube heat exchangers, as well as condensers and evaporators, and discusses the NTU-effectiveness method of analysis. There are heat exchangers that involve multiphase heat transfer; however, these have not been sufficiently addressed.

The final section of the volume deals with computational heat transfer (Chapter 11) and addresses finite difference methods that are appropriate for both steady-state and transient heat transfer problems and basic finite element methods for applications to heat and mass transfer, as well as time-dependent problems, hybrid methods, and other numerical methods that might be used for multiphase heat transfer problems. Although this chapter summarizes the techniques that might be used, it would have been helpful to include those techniques that would be appropriate for multiphase problems.

In summary, whereas the introductory material on single-phase heat transfer is limited, it does provide a foundation for the treatment of multiphase heat transfer, which appears to be the primary focus of the book. There is a wealth of material on multiphase heat transfer, with a logical progression of topics. Some of the chapters provide a comprehensive review of the material, whereas other chapters provide only a selected treatment of the material, focused primarily on the author's areas of interest. There are some examples in most of the chapters, and some chapters have a reasonable bibliography that may be pursued for additional information. There are problems at the end of each chapter, and the appendices provide selected material properties for use in working the problems. Overall, the book might be useful as a reference for graduate courses in multiphase heat transfer and for practitioners familiar with heat transfer who deal with multiphase systems.

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