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Book Reviews

The Finite Element Method in Heat Transfer and Fluid Dynamics, 2nd Edition

J. N. Reddy and D. K. Gartling, CRC Press, Boca Raton, FL, 2000, 469 pp., $119.95

This textbook is the revision of the original edition published in 1994. The focus remains an expansive presentation for the individual interested in finite element numerical methods for the study of heat transfer, fluid mechanics, and coupled phenomena of the authors' specific interest. It is organized into seven technical chapters, followed by a chapter on parallel processing issues. It concludes with three appendices, one containing a two-dimensional heat transfer code with expository details on numerical linear algebra appropriate for the discipline in the others. Each chapter is completed with suggested exercises and a listing of pertinent references.

Following the first edition, Chapter 1 presents forms of the conservation law statements of mechanics in a range of calculus and tensor notations, with expansions illustrated in cylindrical coordinates. A new section is added containing conservation law descriptions for a chemically reacting system and issues pertinent to phase change.

Chapter 2 is largely unchanged and presents a quite thorough exposition of formation of the classic Galerkin weak statement upon which a finite element discretization is constructed. It illustrates various implementations for simple elements. There follows a description of the available library of useful elements leading to the all-important transformations from local to global coordinates. Several simple examples complete the chapter.

The next chapter provides amplification on these issues for the conduction heat transfer problem class, including extension to three dimensions. Element-dependent computational procedures for determination of surface flux follow, wherein the authors fail to note that the weak statement itself provides a high-order-accurate flux determination. The problem class extension to unsteady time dependence follows, and associated semidiscretizations are developed with time carried in the expansion coefficient set (no time-space elements). The chapter is completed with the exposition of several quite specialized procedures for handling material nonlinearity, motion, and conductivity anisotropy.

Several example problems are then discussed at length. Compared with the first edition, the quality of the supporting graphical presentations is improved. However, as before, these are grayscale replications of the original color graphics, which compromises the visual interpretation support that could/should be there. (Interestingly, the original text had a color graphic on the cover; the same graphic is monochrome for this edition.) Another detraction, this time pedagogical, is that, whereas the first three chapters constitute ~40% of the page count, no exposition on the rich theory supporting the subject has yet been made. This is obviously an act of commission, not omission, as the first author is an authority on this subject.

The very lengthy Chapter 4 (over 100 pages) develops the subject for the incompressible, isothermal laminar flow Navier–Stokes equations, with a very modest commentary on turbulence in a latter section. After a few comments on the vorticity-streamfunction transformation, the issue of mass conservation forming a constraint on the momentum equation set leads to dual developments of mixed finite element and penalty function formulations. Interestingly, a most modest summary of the pressure projection concept, with the SIMPLE example, is tucked in later in the chapter among linear algebra issues.

The underlying theoretical issues for all constructions are completely ignored as "beyond the scope of the present study." This extends to the issue of stability, about which only a superficial discussion is presented in a latter section. Hence, chapter developments proceed directly to finite element matrix issues, a modest dialog on Newton and quasi-Newton iterations, and various time-integration schemes. Then occurs a quite thorough presentation on free surface tracking with associated computational issues. The chapter is completed with expository discussions on various benchmark problems (duct and slider flows, driven cavity, step-wall diffuser) followed by a couple of "practical" problems.

The short Chapter 5 extends the incompressible Navier–Stokes problem class to convective heat transfer, i.e., adds the energy equation. The resulting finite element and matrix algebra developments are a union of material in Chapters 3 and 4, with brief commentary on turbulent heat transfer. Numerical example discussions complete the chapter for various practical problem statements, also the thermal cavity benchmark, for which the high-Rayleigh-number streamline graphic looks pretty rough (same graphic as in the 1994 edition).

Chapter 6 addresses the added complexity of non-Newtonian fluids, by definition those fluids having a nonlinear constitutive equation. It is a combination of Chapters 6 and 7 of the first edition, addressing formulation and computational issues specific to inelastic and viscoelastic fluids, the latter exhibiting "memory" of the path followed. The development proceeds from a differential equation system to closure models, finite element construction, and associated nonlinear matrix iteration procedures for each problem class. After a very brief disclaimer on uniqueness and existence issues, numerous examples of applications complete the chapter.

Chapter 7 is totally new in addressing coupled problems, i.e., "computational continuum mechanics." Leaning on Chapters 4–6, the finite element completion is for solid mechanics using a nonvariational construction. The chapter then proceeds to Maxwell's equations, detailing the various issues pertinent to electromagnetics and associated simplifications. The chapter is completed with musings on various specific combinations followed by representative example computations. Chapter 8 is also new, presenting an overview description of organization of finite element matrix formulations for parallel processing.

Overall, the second edition represents principally an applications extension on the first edition. The reader interested in these aspects will find it a worthwhile expenditure of time and money. However, the significant detraction to the finite element developments in both editions remains the essentially complete absence of a sound theoretical basis for the methodology. Without this guidance, the user does not "know what to expect" regarding accuracy, convergence, stability, artificial diffusion, mesh (in)dependence, etc., and the developed examples do not address these matters. A decade ago, the American Society of Mechanical Engineers and AIAA "CFDers" got together and developed a firm technical strategy required for archival presentation of computational fluid dynamics results. The authors, with their strategy of "beyond the scope," have missed a fundamental requirement for the exposition of provably reliable computational mechanics simulations.

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Gas Turbine Heat Transfer and Cooling Technology

Je-Chin Han, Sandip Dutta, and Srinath V. Ekkad, Taylor and Francis, New York, 2001, 646 pp., $150.00

Gas turbines have been in use now for almost 60 years. First introduced in military planes, they have become the dominant propulsion system for large, and many small, aircraft and are used in surface transportation (ships, military tanks, etc.), and they are increasingly being used for land-based electric power generation. Their wide acceptability and use derives from their high thermal efficiency, providing excellent fuel consumption and low weight for aircraft propulsion. Their high efficiency in land-based electric power generation is evident particularly in a combined cycle (gas-turbine topping cycle and steam-turbine bottoming cycle) where overall thermal efficiencies now are of the order of 60%, a figure undreamed of several decades ago.

High thermal efficiency requires a high turbine inlet temperature, and new designs over the decades of gas turbine development have allowed significant increases in temperature. A colleague who worked in the development of gas turbines in the 1940s was asked then why he continued to work on cooling of turbine blades when it was clear that ceramic blades would soon be used, obviating the need for cooling. Even today, however, ceramic turbine blades are a thing of the future, though ceramic layers on airfoils for thermal barrier coatings are used in many high-temperature turbine stages. The temperature of the gas entering the first stage of some high-performance turbines is not only above any reasonable failure temperature of the blades, it may even be above the blade material melting temperature. Cooling methods must be designed and used.

The present volume serves as an excellent guide, not only on cooling systems for high-temperature gas turbines but also for important techniques used in research studies. It provides an update of the latest results, in particular of experimental observations, on a number of cooling methods. Written by one of the world's leaders in turbine cooling research, Je-Chin Han, and two excellent colleagues, Sandip Dutta and Srinath Ekkad, the book is a welcome addition to the literature. Although a number of volumes are available that cover various aspects of cooling in gas turbines, probably no other has the present book's coherence and uniform excellence, written consistently by the same authors throughout; most early works are compilations of the work of individual authors or groups.

The present volume covers many, if not all, areas of interest to researchers and designers of turbine cooling systems. Blade heat transfer, including film cooling, is covered well, as is internal cooling of turbine blades with jet-impingement, rib turbulators, pin fins, and the effects of rotation on internal cooling. The chapter on Experimental Methods, unusual in such a book, is a valued addition describing major techniques used in studying various aspects of heat transfer that would be of interest to experts as well as to budding researchers.

The book provides much material of value to any researcher, designer, or developer working with high-performance gas turbines and studying systems related to their required cooling. Though it includes the pioneering research done by the authors, it casts a wide net covering much of the relevant open research literature. Some subjects, e.g., combustor cooling and turbine-disk cooling, are not covered, as prime interest is centered on airfoil cooling, both internal and external, and related endwall heat transfer. The chapter on Numerical Methods, though providing interesting coverage of methods used in predicting blade heat transfer, is rather abbreviated, perhaps reflecting the authors' primary contributions to experimental studies.

The book is well organized and includes a useful reference list of publications at the end of each chapter. A well-written volume by highly acknowledged and excellent researchers, it belongs in the library of all of those interested in gas turbine heat transfer. It is sure to be the standard to which others will refer.

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