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# Book Reviews

## *Design and Optimization of Laminated Composite Materials*

Zafer Gurdal, Wiley, New York, 1999, 352 pp., $89.95

The focus of this book is acquainting the practicing engineer with the techniques and tools needed to explore the optimal design of laminated composite materials. To this end, the book is divided into eight chapters, with Chapter 1 providing a discussion of the terminology associated with laminated composites.

In addition, Chapter 1 provides an introduction to the formulation of a design optimization problem by means of an introductory example problem. A discussion of stacking sequence optimization is included; however, some documentation from a historical perspective would have been a useful addition, particularly graphical notions. Chapters 2 and 3 make up approximately one third of the book and present a review of the macromechanics of laminate composite theory, including both mechanical and hygrothermal loading. Chapter 4 discusses optimization formulations for laminate in-plane stiffness design. This is a sound baseline starting point for the subsequent chapters because laminate in-plane design requires only a knowledge of the in-plane stiffness matrix.

Two simple integer programming techniques, enumeration and Miki's lamination parameter diagram, have been used. Chapter 5 presents two formal procedures for handling discrete optimization problems, namely integer linear programming and genetic algorithms, with several examples as an illustration of the techniques. Chapter 6 discusses the various failure criteria used for evaluating the strength or failure of laminated composites. Chapter 7 builds on the material presented in Chapter 6 by using Miki's graphical procedure for the strength design of composite laminates with stress or strain constraints. The final chapter is an introduction to the design of structural elements in which bending is the dominant response mode. The importance of the ply-stacking sequence in the design strategy associated with the flexural response of structural members is discussed. For such response modes, the flexural stiffness depends not only on the thickness of the laminate but also on the ply distribution and laminate geometry.

In summary, the emphasis of the book is on a graphical design technique introduced by Professor Miki, with the bulk of the material dedicated to the optimal in-plane design of structural laminates. However, the guiding elements and key principles associated with mathematical optimization procedures for composite laminates are presented and as such should prove to be very useful to the practicing engineer.

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## *Turbulence Modeling for CFD,* 2nd Edition

David C. Wilcox, DCW Industries, La Cañada, CA, 1998, 540 pp., $75.00 (*Solutions Manual*, 268 pp., $40.00)

This is the second edition of a book that was first published in 1993. Its main objective, as defined by the author, is the incorporation of important new advances since 1993 in the area of turbulence modeling by emphasizing models that "have stood the test of time." Although the layout and overall organization is similar to that of the first edition, this new textbook has been expanded and enriched considerably. For the benefit of those who have not read the first edition, I will start my review with a brief summary of the material presented in the eight chapters and five appendices of this book.

Chapter 1, the Introduction, has been revised and expanded substantially. It includes a general discussion of the physics of turbulence (definitions, scales, and spectral representation); a section on the law of the wall, which discusses both the standard logarithmic law and the more recent and still very controversial power law; and a brief history of turbulence modeling.

In Chapter 2, The Closure Problem, the author introduces the Reynolds averaging approach and applies it to derive the Reynolds-averaged mean flow equations and the transport equations for the Reynolds stresses. The chapter concludes with a section on the scales of turbulence that introduces the concept of turbulence intensities and discusses two-point correlation tensors and related scales; both of these topics are new additions.

The discussion of various turbulence modeling strategies begins with Algebraic Models in Chapter 3. The standard mixing-length approach is developed and applied to wakes, mixing layers, and jets. Popular modern variants of the mixing-length model, including the Baldwin–Lomax and Cebeci–Smith algebraic models and the $\frac{1}{2}$ equation Johnson–King model, are then introduced and applied to attached and separated boundary-layer flows. This chapter has been enhanced with the addition of more comparisons between model predictions and experiments for favorable and adverse pressure-gradient boundary-layer flows.

Differential, isotropic eddy-viscosity models are presented in Chapter 4, One-Equation and Two-Equation Models. The turbulence kinetic energy equation is derived, and one-equation models are discussed, including applications and assessment of their performance for boundary-layer and separated flows. Two-equation models, with emphasis on the $k$-$\omega$ and $k$-$\varepsilon$ models, are subsequently presented, and their performance is assessed for free-shear flows. Perturbation techniques are employed to analyze the behavior of these models in the viscous sublayer, the log layer, and the defect layer. Surface boundary conditions, including wall functions for smooth and rough walls and surface mass injection, are then discussed, and applications to simple wall-bounded flows are presented. Subsequently, low-Reynolds-number variants of the $k$-$\varepsilon$ model are introduced, and their performance is evaluated relative to the $k$-$\omega$ model for two-dimensional boundary layers with adverse pressure gradients. Finally, the applicability of various models to complex separated flows is discussed. The main additions to this chapter are sections discussing in more detail the influence of freestream boundary conditions on the uniqueness of model predictions and the role of cross-diffusion terms as the key difference between $k$-$\varepsilon$ and $k$-$\omega$ formulations. More test cases for model assessment have also been included.

Chapter 5, Effects of Compressibility, opens with the introduction of the Favre averaging and the derivation of the Favre-averaged equations. Closure models for the various terms in these equations are then developed, and various compressibility corrections for mixing-layer flows are discussed. The chapter concludes with a discussion of the compressible law-of-the-wall and applications to compressible boundary-layer flows with and without shock-induced separation.

Modeling strategies are presented in Chapter 6, Beyond the Boussinesq Approximation. The chapter starts with a discussion of the deficiencies of the isotropic eddy-viscosity assumption for modeling complex flows, followed by the presentation of nonlinear, algebraic, constitutive relations and full, Reynolds-stress transport models. Applications include homogeneous turbulence, free-shear flows, boundary layers, and channel and pipe flows, as well as two-dimensional separated flows. Given the fact that most recent work in the area of turbulence modeling has focused on the development and application of non-Boussinesq models, the additions to this chapter are disappointingly few. Some notable new contributions that have been omitted entirely include 1) work toward the development and application of quadratic[1] and cubic[2,3] nonlinear, algebraic, constitutive relations for the Reynolds stresses; 2) significant progress in developing near-wall Reynolds-stress transport models without wall orientation and/or proximity parameters,[2–4] a subject of utmost importance for predictions of complex, industrial flows; and 3) the first successful application of a full, near-wall, Reynolds-stress transport model (that developed by Shima[5]) to complex internal (transition ducts) and external (ship hulls) three-dimensional shear flows with vortices.[6–8] Instead, the author has elected to revise this chapter by introducing a new, yet untested in complex flows, Reynolds-stress transport model based on the $\omega$ equation.

Some fundamental aspects of computational fluid dynamics (CFD) techniques are discussed briefly in Chapter 7, Numerical Considerations, which focuses almost entirely on one-dimensional equations. Issues that are critical for successful simulations of complex engineering flows and that are at the forefront of ongoing research (such as the numerical implementation of stress-transport models, multigrid techniques for fast convergence on large-aspect-ratio grids, etc.) are not discussed. Chapter 8, New Horizons, presents a brief summary of recent developments in direct numerical simulation and large eddy simulation research. The book ends with five appendices. The first two present the fundamentals of Cartesian tensors and perturbation theory, respectively, and the remaining are dedicated to the description of the software that is included with the book.

Overall the book is well written and should be a useful reference for anyone interested in a first introduction to the most commonly used engineering turbulence models. A welcome new addition is the substantial increase (by 50%) in the number of homework problems at the end of each chapter. This extensive collection of problems, along with the software disk that is included with the book, should make this second edition a helpful supplement for a graduate-level course. However, a reader interested in a more comprehensive treatment of the subject, particularly in the area of advanced turbulence modeling for complex flows, should review the recent literature for an up-to-date assessment of the state of the art. The reader should also be aware of the fact that the author frequently tends to present the material in a manner that is revealing of his own bias and strong preference for his $k$-$\omega$ model. For example, in a rare, for this textbook, discussion of a case where $k$-$\varepsilon$ models performed well in predicting separated flow over a backward-facing step, the author comments that this good performance "is probably a lucky coincidence" (Chap. 6, p. 325, last paragraph). This personal bias is understandable and to some extent justified if one focuses attention on simple boundary-layer flows, as this book largely does. However, such statements are simplistic and are not helpful to the reader in sorting through a subject as difficult, as important, and as controversial as turbulence modeling for CFD.

## References

[1]Shih, T. H., Zhu, J., and Lumley, J. L., "A New Reynolds-Stress Algebraic Equation Model," *Computational Methods in Applied Mechanics*, Vol. 125, 1995, pp. 287–302.

[2]Craft, T. J., and Launder, B. E., "A Reynolds-Stress Closure Designed for Complex Geometries," *International Journal of Heat and Fluid Flow,* Vol. 17, No. 3, 1996, pp. 245–254.

[3]Craft, T. J., Launder, B. E., and Suga, K., "Development and Application of a Cubic Eddy-Viscosity Model of Turbulence," *International Journal of Heat and Fluid Flow,* Vol. 17, No. 2, 1996, pp. 108–115.

[4]Durbin, P. A., "A Reynolds-Stress Model for Near-Wall Turbulence," *Journal of Fluid Mechanics,* Vol. 249, 1993, pp. 465–498.

[5]Shima, N., "Prediction of Turbulent Boundary Layers with a Second-Moment Closure: Part I—Effects of Periodic Pressure Gradient, Wall Transpiration, and Free-Stream Turbulence," *Journal of Fluids Engineering,* Vol. 115, No. 1, 1993, pp. 56–63.

[6]Sotiropoulos, F., and Patel, V. C., "Prediction of Turbulent Flow Through a Transition Duct Using a Second-Moment Closure," *AIAA Journal,* Vol. 32, No. 11, 1994, pp. 2194–2204.

[7]Sotiropoulos, F., and Patel, V. C., "Turbulence Anisotropy and Near-Wall Modeling in Predicting Three-Dimensional Shear-Flows," *AIAA Journal,* Vol. 33, No. 3, 1995, pp. 504–514.

[8]Sotiropoulos, F., and Patel, V. C., "Application of Reynolds-Stress Transport Models to Stern and Wake Flows," *Journal of Ship Research,* Vol. 39, No. 4, 1995, pp. 263–283.

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