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Book Review

Fundamentals of Turbulence Modeling

Ching-Jen Chen and Shenq-Yuh Jaw, Taylor & Francis, Bristol, PA, 1997, 292 pp., $49.95

The objective of this book is to provide engineers, researchers, and graduate students with an overview of some important aspects of turbulence modeling for flows of practical interest. The primary focus is on second-moment closures for the incompressible Reynolds-averaged Navier–Stokes equations, as the authors consider this approach to be the most promising and practical alternative for developing predictive computational fluid dynamics methods. The material included in the book will benefit mainly researchers interested in applying, rather than developing, second-moment closures. The authors favor a fairly extensive presentation of numerous applications of various models to two- and three-dimensional flows, whereas issues such as model realizability, coordinate-frame invariance, near-wall asymptotics, and so on are not addressed.

Chapter 1, entitled Introduction to Turbulence, starts with a brief overview of important historical developments in fluid mechanics research, followed by some comments on the validity of the Navier–Stokes equations for modeling turbulent flows and a summary of various averaging approaches, including Reynolds, ensemble, density-weighted, and conditional. Subsequently, the authors present the Reynolds-averaged Navier–Stokes and energy equations for buoyant incompressible flows along with the exact turbulence transport equations for the components of the Reynolds-stress tensor, the turbulence kinetic energy and its rate of dissipation, and the components of the turbulent heat flux vector. All equations are presented in Cartesian coordinates.

Chapter 2, Second-Order Closure Turbulence Model, opens with a discussion of the fundamental postulations on which Reynolds-averaged turbulence closures are based. The remainder of this chapter is dedicated to the presentation and calibration of a complete model for closing the transport equations for the Reynolds stresses, k, ε, and the components of the turbulent heat flux vector. The modeling strategies presented are based on progress made in the 1970s and 1980s. The chapter ends with a section on the determination of various model constants that demonstrates calibration procedures based on data from classical experiments with isotropic and nonisotropic turbulence with and without mean shear.

Chapter 3, Discussions of Turbulence Models, examines modeling alternatives that are simpler and, thus, computationally more efficient than full second-moment transport closures. Models discussed here include, in the order presented in the text, an algebraic Reynolds-stress model, the standard and various variants of the k-ε isotropic eddy-viscosity model, nonlinear two-equation models, a four-equation isotropic multiscale model, and a one-equation model based on the k equation. There follows an extensive section discussing predictions of turbulent free-shear flows, including plane and axisymmetric jets and wakes and mixing layers. The authors briefly review representative results from calculations using models ranging from full Reynolds-stress transport to standard k-ε. Subsequently they discuss the lack of a "universal" model for free-shear flows and point to the need for problem-dependent modifications of model constants even for second-moment closures. The chapter ends with a section on two-scale closures and their ability to improve predictions of turbulent round jets.

Issues related to Near-Wall Turbulence are discussed in Chapter 4, which opens with a section on wall functions for the mean velocity and temperature profiles, followed by brief comments on near-wall modifications for second-moment closures. Two-equation, low-Reynolds-number models are then summarized, with particular emphasis on two-layer models. The rest of this chapter presents representative applications of various models to two-dimensional and axisymmetric wall-bounded shear flows. The test cases considered include flow through a channel with asymmetrically roughened walls, wall jet flow, flat plate boundary-layer flow, and flow past axisymmetric afterbodies. The final section discusses in more detail near-wall modifications for Reynolds-stress transport models with emphasis on modeling strategies that account for wall-echo effects.

In Chapter 5, Applications of Turbulence Models, the authors review several calculations of complex two- and three-dimensional turbulent flows that were reported in the literature in the 1970s and 1980s. Emphasis is placed on two-dimensional and axisymmetric cases with flow separation, such as backward-facing steps and cavities. The three-dimensional cases considered include stress-driven secondary motion in a straight rectangular duct, pressure-driven secondary motion in a curved pipe and a curved rectangular open channel, and flow around a bluff body. In most of these cases, the authors have attempted to present results with more than one turbulence model so that the relative performance of various models can be readily assessed.

Chapter 6, Turbulent Buoyant Flows, presents a comprehensive review of Reynolds-stress transport and algebraic stress turbulence models for buoyant flows along with several applications to two- and three-dimensional flows.

In the Closure of the book (Chapter 7), the authors conclude on a very optimistic note. They predict that "in the future there will be a minicomputer loaded with a turbulence model and a numerical method, neither of which a practical engineer will need to know—just like the present-day pocket calculator that is loaded for logarithmic functions and hyperbolic tangent evaluation. The minicomputer will provide answers to the laminar and turbulent flow problems. The engineer will thus be free from analyzing and studying turbulence models and numerical technique and will be able to devote his or her time in tackling other engineering problems and other duties."

In summary, this is a useful book for anyone interested in numerical simulation of turbulent flows. However, because it focuses primarily on progress made in the 1970s and 1980s, it will be more effective if read in conjunction with recent literature on turbulence modeling. Important advancements in both model development and application to complex flows that took place during the first half of the present decade are not discussed in this book.

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