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Book Reviews

Computation and Comparison of Efficient Turbulent Models for Aeronautics: European Research Project ETMA

Edited by A. Dervieux, M. Braza, and J.-P. Dussauge, Verlag–Vieweg, Wiesbaden, Germany, 1998, 581 pp., DM 298

There are two basic steps in any numerical simulation: i) construction of a mathematical model of the physical problem and ii) discretization of the mathematical model and a computer solution thereof. Both these steps engender errors—physical approximation errors and numerical approximation errors—which should be independently understood and possibly estimated a priori or a posteriori. Assessment of the physical approximation errors is called *validation*, and that of the truncation and round-off errors is called *verification*. Verification of the numerical method should precede the validation of the physical model in comparison with observation. In an area such as fluid-mechanical turbulence, which is extremely complex and varied and poorly understood, validation with experiment is both especially important and especially difficult. That is why undertakings like the Project Efficient Turbulence Models for Aeronautics (ETMA) Workshop on computation and comparison of efficient turbulence models for aeronautical compressible flows are important and their conclusions are worthy of study.

Following the 1980–1981 AFOSR–HTTM–Stanford Conference on Complex Turbulent Flows, the European Project ETMA selected a series of prototypical turbulent flows for which fairly extensive experimental data were available and invited researchers to solve these flows computationally with the numerical methods and turbulence models of their choice. This resulted in a workshop held at the University of Manchester Institute for Science and Technology on 14–16 November 1994, and this book is the proceedings of this workshop. Encompassing eight test cases and approximately 60 contributors who solved one or more of those test cases, this book gives a fairly comprehensive picture of the state of the art of turbulence modeling for aeronautical flows in the mid-1990s.

The large number of contributors is testimony not only to the importance of the turbulence modeling problem and the level of activity in turbulence research but also to the number and variety of test cases. The editors, who were the organizers of this endeavor, set for themselves a tremendous task in accumulating and consolidating this large amount of data. There are eight test cases, most of which are really categories of test cases, each containing several specific test cases. These include supersonic mixing layers, supersonic and low-speed axisymmetric and plane channel flows with backward-facing steps and other obstacles, various turbulent boundary-layer problems on flat plates, ramp flows, a transonic bump, shock reflections, and steady and unsteady airfoil problems. Taken together, these test cases cover a good range of the type of problems that are of practical interest in aeronautics and are within the capabilities of present-day computers to solve in a reasonable time.

The numerical algorithms chosen by the contributors cover most of the techniques in the mainstream of computational fluid dynamics work today. Though contributors often chose the finite volume approach, there are also finite difference and finite element computations, as well as computations based on boundary-layer equations. Both implicit and explicit time-stepping schemes are represented; there are standard Runge–Kutta schemes, total variation diminishing schemes, and other approaches typical of today's aerodynamic codes.

But the area where the variety is greatest is in the focus of this work, the turbulence models. The amount of effort that has been put into developing turbulence models over the years and the many different approaches researchers have developed to look at turbulence modeling are reflected in the number of turbulence models discussed in this book. One test case alone attracted computations employing over a dozen different models. The models employed by the contributors encompass virtually all of the standard types used today in fluid mechanics: algebraic models, half-equation models, one-equation models, two-equation models, and Reynolds-stress models. Most of the models used here have appeared previously in the literature, and many are standard: the Baldwin–Lomax model, various forms of the k-ε model, and so on. The emphasis here is more on assessing the state of the art than on developing new models. Some interesting new developments are discussed, however. The q-ζ model, for example, is based on the k-ε model but is reformulated in terms of $q = \sqrt{k}$ and its dissipation ζ. These new dependent variables are much better behaved near the wall, permitting improved resolution and reduced run times.

Each test case is introduced by a short chapter that describes the case and the reasons for including it and gives the parameters required for the participants to simulate it along with the experimental data against which the computations will be compared. Papers by the contributors of solutions for the test case then follow. A "synthesis" chapter concludes the discussion of the case, summarizing the results of the contributors and the strengths and weaknesses of their computations.

Overall, these summaries indicate that at least rough qualitative solutions to most of these problems are within present computational and modeling capabilities. Quantitative accuracy is achieved in some cases, but a model this accurate for one test case is rarely so successful for another case, even a similar one. The first test case, for example, the supersonic mixing layer, a free shear flow without wall complications, is arguably the simplest of the flows examined in this effort. And yet the results show quite clearly that models that work well for low convective Mach numbers do not work so well for high convective Mach numbers and vice versa. This and similar conclusions for the other cases indicate that compressible turbulent flows, even in simple geometries, involve physical phenomena too complex for any single existing turbulence model to simulate accurately a moderately wide range of problems.

The editors of this book undertook an arduous task, and they should be commended for having carried it out successfully. The book is a valuable resource for anyone involved in turbulence modeling, whether as a user or a developer, but certain caveats do have to be kept in mind when drawing conclusions from such a resource. Except in those cases where a single contributor evaluated the performance of several models with the same numerical algorithm, it is difficult to separate those differences in results that are due to model differences from those that are due to algorithm differences. It is also true that, in a comparison set up as this one was, the contributors know the answer they are supposed to get and they can refine their models, grids, and algorithms accordingly. There is nothing wrong with this; it allows us to see how close to the right answer the computations can get. But someone working in the dark would likely not be able to get so close.

The development of further such resources should be encouraged—conducted, ideally, in a focused manner in such a way as to make the conclusions drawn from the comparisons as definitive as possible. It might be desirable to evaluate turbulence-model predictions for a few benchmark flows in complex geometries or perhaps even to see how well current large-eddy simulations are able to compete with turbulence-model computations in the simulation of some basic benchmark flows.

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Computational Gas Dynamics

Culbert Laney, Cambridge University Press, Cambridge, England, United Kingdom, 1998, 605 pp., $110.00 (hardcover), $54.95 (paperback)

This book offers a comprehensive review of computational methods for the simulation of high-speed flows of gases, with an emphasis on problems of aerodynamic interest. The book is very well written and has an excellent balance between the mathematical aspects and physical concepts underlying modern computational methods. This book would make an excellent textbook for a course in computational fluid dynamics (CFD), and I plan to use it for my graduate course in CFD. It would also serve as an invaluable reference book for researchers and engineers working in the area of compressible gas dynamics.

The book is divided into five parts. First there is a brief review of compressible gas dynamics, with a clear analysis of the governing equations. The author makes a strong connection between the mathematical derivations and the compressible flow physics. This helps the reader understand the basis for the numerical methods to be derived later in the book. The analysis is also supported by excellent illustrations.

The second part of the book reviews computational methods for approximating functions. The emphasis is on polynomial and piecewise-polynomial approximations, with a good description of how to quantify the approximation error. These topics are not usually covered in CFD books, and this review is important because it clarifies many of the issues behind the computation of flows with discontinuities. Laney presents this complicated material in a careful and concise fashion.

Basic principles of computational gas dynamics are covered in the third part of the book. The usual topics of conservation, Courant–Friedrichs–Lewy condition, stability, and upwinding are addressed. The connection between the overlap of the computational and physical domains of dependence and the effect on stability are clearly illustrated.

The fourth part of the book concerns "first-generation" methods for computational gas dynamics. Methods for scalar conservation laws are discussed, and then these methods are extended to the Euler equations. An excellent discussion of boundary conditions is also included in this section of the book.

The final part of the book discusses solution-adaptive methods. The recent literature contains a huge number of methods in this class, but Laney has selected the most important of these for description in this section. He describes each method and shows relationships between apparently different methods. The author gives some subjective analysis of the different methods to give the reader a perspective on the relative usefulness of the large number of different methods discussed. He is straightforward about this, and I think the research community generally accepts most of his opinions. The only complaint that I have about the book is that its discussion of multidimensional flow simulations is very brief. However, given the depth of treatment of the methods for one dimension, this is hardly a fair criticism.

Throughout the book a series of test cases is used to evaluate the various methods developed. This permits a consistent comparison between the methods so that the reader can understand the strengths and weaknesses of each of the many methods described. The series of cases also shows how computational methods have evolved over the years. The book is carefully written and is surprisingly readable. Great care seems to have been taken to make sure that the algebra is correct. The choice of nomenclature is sensible and mainstream, and Laney has cited the most important papers in the literature. This is a very useful book, and I highly recommend it to anyone working in compressible flow computations.

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