J. Fluid Mech. (2003), *vol.* 497, *pp.* 440–443. © 2003 Cambridge University Press
Printed in the United Kingdom

BOOK REVIEWS

Generalized Riemann Problems in Computational Fluid Dynamics. By M. Ben-Artzi & J. Falcovitz. Cambridge University Press, 2003. 366 pp. ISBN 0 521 77296 6. £55 or $75.

J. Fluid Mech. (2003), *vol.* 497, DOI: 10.1017/S0022112003217067

In 1959, Sergei Godunov introduced a novel approach to computing approximate solutions to the Euler equations of gas dynamics that applies quite generally to compute shock wave solutions to nonlinear systems of hyperbolic conservation laws. The fundamental building block of Godunov's method is the solution to the Riemann problem, i.e. the given hyperbolic equation with piecewise constant initial data having a single jump discontinuity. The Riemann problem has a similarity solution consisting of a finite number of waves propagating at constant speeds, and its solution can typically be computed to arbitrary accuracy even for complicated nonlinear systems. In Godunov's method, the numerical approximation is viewed as a piecewise constant function, with a constant value on each finite volume grid cell. Solving the Riemann problem at the interface between grid cells gives a way to estimate the flux at the interface, and differencing these numerical fluxes gives a robust conservative shock-capturing method. This method is only first-order accurate, however, and introduces considerable numerical dissipation that tends to greatly smear out shock waves.

In the years since, a variety of different approaches have been developed to extend Godunov's method in order to achieve better resolution of shock waves, and better accuracy in general, while avoiding the appearance of non-physical oscillations that arise if a classical higher-order method is applied near a shock. One successful approach is summarized in this book.

The 'generalized Riemann problem' of the title refers to a generalization of the classical Riemann problem in which the initial data are taken to be piecewise linear rather than piecewise constant. This problem no longer has a similarity solution and cannot be solved exactly, but an approximate solution is developed that allows second-order accuracy to be achieved. In addition to solving the Riemann problem based on the states at the interface determined by the linear approximations in space, estimates of the time derivative of the interface flux can also be obtained and used in a Taylor series expansion to yield second-order accuracy in both space and time. Non-physical oscillations are avoided by a judicious choice of the slopes used in each cell to define the generalized Riemann problems. As in other high-resolution shock-capturing methods, limiter functions are used to modify the slopes based on the smoothness of the solution nearby.

The method is first developed for scalar conservation laws and then extended to the more complicated case of systems, where the authors focus primarily on the Euler equations of gas dynamics and some extensions, such as a reacting flow model used in combustion. The theory of these equations is reviewed, including detailed analysis of the Riemann solution for the Euler equations. The basic GRP algorithm is developed for problems in one space dimension, and is then extended to multi-dimensional problems via dimensional splitting. In this technique one-dimensional problems are solved alternately in the x and y directions. (Only the two-dimensional case is discussed in the book, though extension to three dimensions is straightforward.) Dimensional splitting is certainly the easiest way to extend one-dimensional methods to multidimensional problems and is remarkably successful for many problems.

A variety of specific test problems are discussed in detail and these case studies provide the reader with insight into many aspects of gas dynamics in addition to demonstrating how the GRP approach can be applied in specific situations. For example, nozzle problems are considered first by developing and solving the quasi-one-dimensional equations, and then by solving the two-dimensional equations. Comparisons of the results obtained with the two models are included as well as discussion of how to handle the source terms and boundary conditions that arise in the context of the GRP methods. Wave interaction problems and detonation waves are also discussed in detail. Other sections contain algorithmic extensions, including a brief discussion of moving grid methods for tracking singularities in one dimension and "moving boundary tracking" methods in two dimensions that include the use of cut cells to handle complex geometry on Cartesian grids.

While the GRP methodology is but one approach to extending Godunov methods to high-resolution, it shares many features with other approaches and this book gives the reader a good understanding of several common issues. It contains a nice summary of this approach and many interesting applications to gas dynamics, and is a welcome addition to the literature.

R. J. LeVeque

Introduction to Micrometeorology (2nd edition). By S. P. Arya. Academic Press, 2001. 420 pp. ISBN 0 12 059354 8. £53.95.

J. Fluid Mech. (2003), *vol.* 497, DOI: 10.1017/S0022112003227063

Dr Pal Arya's 420 page textbook, entitled *An Introduction to Micrometeorology*, is useful as a class text for undergraduate and graduate students, as well as a basic reference for researchers in the field. This second edition, dated 2001, represents a revision to the first edition, published in 1988. It is closely related to Dr Arya's 1999 text entitled *Air Pollution Meteorology and Dispersion.*

Dr Arya has been teaching classes on micrometeorology at North Carolina State University for many years and this book was developed from his lectures in those classes and his research in this area. His extensive experience with his classes and with his research have led to an excellent summary of historical research on micrometeorology. However, the long history has also led to an over-emphasis in the current book on decades-old publications: over 90% of the 240 references are over ten years old (pre-1993). Similarly, even though most of the figures are excellent, most of them are taken from publications that are about 30 years old. If a third edition is planned, it would be useful if Dr Arya could include more of the new information found in current publications in micrometeorology.

A highlight of the book is that several excellent problems and exercises are given at the end of each chapter. This reviewer wishes that a separate document were available containing the answers! The List of Symbols and the Index are also very complete and helpful to readers.

The book has been carefully edited and there are very few typos. I found only a handful, such as "atmosphere of submedium" on page 41.

Most figures are excellent. However, to save space, the publisher has reduced the size of some the figures so much that they are difficult to read (for example, the ΔG wind vector is hard to see in parts a and b of Figure 6.3).

The 15 chapters are structured in a logical way, and groups of chapters could be used independently as part of specialized courses. For example, the first six chapters discuss micrometeorology with emphasis on basic observations, without strongly referencing turbulence, and could be used as a comprehensive discussion of boundary layer fundamentals such as surface energy balances. The mathematical descriptions throughout the book are relatively simple, even after turbulence is introduced. Chapter 1 is an introductory chapter. The next three chapters cover the energy budget near the ground, including the surface radiation, conductive, and sensible heat fluxes. Thermodynamic and latent heat effects are discussed in Chapter 5, and winds in the Planetary Boundary Layer (PBL) are discussed in Chapter 6. Turbulence theories are covered in Chapters 7–9 and surface similarity theory in Chapters 10–12, which would represent the core of most micrometeorology courses. Specialized discussions on the marine boundary layer, non-homogeneous boundary layers, and vegetative canopies are given in the final three chapters. It is easy to find the parts of the text that have been updated since the first edition, such as the urban boundary layer discussion in Chapter 14.

Because of the deliberate separation of the chapters into groups, one of the more important parameters in micrometeorology, the surface roughness length, z_0, does not appear until page 189. This is because the earlier chapters discussed the boundary layer in basic concepts, and the specific logarithmic wind profile for the neutral surface boundary layer is not given until Equation 10.6. It would help the readers if there were more cross-referencing among chapters, such as stating in the early chapters that z_0 is an important parameter and it will be discussed in detail later in Chapter 10. Similarly, the theoretical discussions of various flows in Chapter 7 should be related back to general discussions of wind profiles in earlier chapters.

Anyone who has attempted to estimate PBL heights from observations of vertical profiles of temperature, winds, or other parameters realizes that the PBL height is often not as obvious nor as "easily detected" as described in basic texts, such as in Section 1.1.2. In many cases, there exist multiple minor inversion layers and/or more of a gradual top to the PBL.

The physical explanations in Chapters 1 and 6 are generally good and will be helpful to students. There are a few places where additional rationale could be given for stated conclusions, such as at the top of page 78, where it is stated that "Mixed layers are found to occur most persistently over the tropical and subtropical oceans". It could be added that this is due to the fact that the surface temperatures of the oceans at those latitudes are nearly always warmer than the air temperature, and that there are no nocturnal stable layers formed due to surface radiative cooling.

Chapter 7 contains a fairly complete discussion and derivations of several types of boundary layer flows, including solutions for such topics as the Ekman spiral and laminar boundary layers. The readers should be more strongly informed about which of these examples of boundary layer flows have the most application in the atmosphere.

Turbulent variances and fluxes are covered in Chapter 8, including basic concepts such as the use of Reynolds averaging and the statistical theory of turbulence. Under the discussion of turbulence intensities on page 152, it could be mentioned that turbulence intensities can be relatively large over rough surfaces, and that lateral turbulence intensities tend to increase as winds become light. Chapter 9, "Models and Theories of Turbulence", is one of the best chapters, covering the more widely used models, including direct numerical simulation, large-eddy simulation, ensemble-averaged models, and gradient-transport theories. An excellent overview of dimensional analysis and similarity theories is given in Section 9.3.

As stated earlier, Chapters 10–12 contain valuable applied formulas for momentum, sensible heat, and latent heat fluxes, and wind, temperature, and moisture profiles. Some updates are given in this second edition to account for recent observations of marine and urban boundary layers. Terms like "more recently" should be eliminated if they refer to 1985 references (page 208). A stronger statement could be made about the importance of being able to estimate these surface fluxes in relation to studying climate change.

Monin–Obukov similarity theory is presented in Chapter 11, where applied equations for the thermally-stratified surface layer are given. The use of sonic anemometers to measure fluxes by calculating eddy correlations is covered in Section 11.5.3, but the statement about them not being widely used, except in special research expeditions, needs to be updated. With advances in sonic anemometers and reductions in their cost, they are now being widely used in large numbers in many field studies. To complete the trio of related chapters, Chapter 12, "Micrometeorological Methods of Determining Evaporation", contains a comprehensive survey of the field with many example figures.

From its title, Chapter 13, "Stratified Atmospheric Boundary Layers" would appear to be similar to Chapter 11. It would help the reader if the difference could be stated in the first paragraph of Chapter 13. It appears that Chapter 11 deals with the surface layer, while Chapter 13 deals with the full depth of the PBL, and with detailed numerical models. There could be more cross-referencing in both chapters. A major contribution of Chapter 13 is a survey of mathematical models of the PBL (see Section 13.3), including first-order closure models, non-local closure models, turbulent kinetic energy (k) and $k - \epsilon$ closure models, higher-order closure models, and large-eddy simulations. I found this to be one of the more useful sections of the book, since this type of survey and comparison is not usually provided in other books and other publications. This section also contains more references to recent (i.e. less than 5 or 10 year old) papers.

Non-homogeneous boundary layers, which vary in space and are not necessarily in equilibrium with the underlying surface, are discussed in Chapter 14. Examples are coastal zones, urban regions, and rural areas with alternating fields, forests, and lakes. The basic theories for boundary transition zones from one surface to another are given, such as for abrupt changes in surface roughness and/or surface temperature. Other topics are thermal internal boundary layers at coastlines and air modifications over water surfaces. It is noted that current students may not consider the Raynor *et al.* (1975) paper as a "recent" paper (page 332), since most of these students were not born when the paper was published. The most up-to-date section is the one on urban boundary layers, where most of the references are less than ten years old. There are also sections on air modifications over urban areas and building wakes and street canyon effects. The subject of urban micrometeorology is receiving much attention at the time of this review. The chapter concludes with discussions of flows and stabilities around topography, which have been the focus of some of Dr Arya's research.

The final chapter (15) concerns "Agricultural and Forest Meteorology". Many of the equations are related to those in Chapters 10–12. Sections on energy balances, surface fluxes, radiation, and wind, temperature and moisture profiles are included. The final section addresses turbulence in and above plant canopies.

To conclude, I recommend this book as a text and as a basic reference. However, it would be welcome if the next edition were to update many of the figures and references to reflect current research.

STEVEN HANNA