Book Review

Computational Modelling for Fluid Flow and Interfacial Transport
Wei Shyy, Elsevier Science Publishers, Amsterdam, 1993, 522 pp., $225.75.

The question was once posed, by Dr. Art Rizzi, whether computational fluid dynamics (CFD) was best regarded as a large problem or as a small science. The point is, I suppose, that a science, even a small one, aspires to precise statements and rigorous procedures. In CFD, the chief protagonists of the small science philosophy are the finite element practitioners, who would, if they could, pose all problems weakly in appropriate trial and test spaces, with a priori error bounds in optimal norms. Professor Wei Shyy clearly views CFD as a large problem. He takes a pragmatic attitude based on finite differences, and is happy to introduce any empirical device that helps.

I would not like to declare that either view is best. It is good that we have advocates for both, just as a democracy needs eloquent supporters of all political creeds. I will say, however, that the book under review displays both the strengths and some of the weaknesses of the large problem approach.

The first 110 pages are based on a beginning graduate course that Professor Shyy has taught at the University of Florida; this part might also be suitable for adventurous undergraduates. The aim is to familiarize the student with the basic concepts required for understanding CFD methods. Ideas of stability, consistency, convergence, local and global truncation error, stiffness, and boundary conditions are introduced intuitively and illustrated through well-chosen examples from ordinary differential equations. Following what has become a traditional manner of presentation, the major types of partial differential equations are then exhibited, and schemes for the model problems in each class described. These are well chosen, and make useful points, but it would perhaps have been helpful at this stage to see some samples of numerical solutions from typical schemes.

Those who take the small science view will find in this first part of the book several rather loose definitions. For example, consistency is defined through an operator $\mathcal{L}(U)$ acting on the exact solution U, and an operator $L(u)$ acting on the numerical solution u. The approximation is said to be consistent if $L(u) \rightarrow \mathcal{L}(U)$ as all mesh dimensions approach zero. Mathematical hackles will rise at this. A continuous operator and a discrete operator simply cannot be compared, any more than apples and oranges. A correct procedure depends on introducing the projection operator $P(V)$ that translates continuous functions into their discrete representations (such as point values, cell averages, or piecewise linear elements). Then the discrete operator is consistent with the exact operator if $L[P(V)] \rightarrow P[\mathcal{L}(V)]$ under mesh refinement. A purist might wish to refine even this definition, but omitting any mention of the projection operator makes it quite impossible to define accuracy. We must know what the calculation is supposed to yield before we can say how well the job has been done. There is also confusion between the accuracy of an operator and the accuracy of a scheme, two things that must be carefully distinguished to make sense of the Lax-Wendroff method.

In a textbook for engineers it may not seem appropriate to make pedantic distinctions. However, these particular chickens come home to roost in a later discussion of advection methods. Leonard's QUICK scheme is described as second-order accurate, because it contains a formula that can be recognized as a second-order approximation to a derivative. The operator is intended, however, to produce a flux balance across a cell, and if used in that way will yield third-order results, provided all other terms are treated in the same way (which may not be easy).

The topic just discussed can be used as a litmus test of the reader's philosophy. If you feel uneasy about building on doubtful foundations, you are a Small Scientist, and this is probably not a book for you. If you shrug your shoulders, and argue that creating real codes to solve real problems will always involve many inexact arguments, then you are a Large Problemist, and in this book you will find much practical and valuable information together with a good flavor of the underlying theory.

After the introductory material, Professor Shyy turns to the writing of complete codes. His next 160 pages deal with so-called pressure-based schemes of the type originally developed for incompressible flow. Key ingredients of these schemes are staggered storage for the pressure and the contravariant velocities, together with an advection scheme to update the velocities, and an elliptic solver to update the pressure. The approach that he takes to develop these schemes is interesting. A robust, but not very accurate, method (the 1976 TEACH code) is taken as a basis, and in fact the reader is assumed to be already familiar with it. Various aspects of the code are analyzed and criticized. Frequently, a model problem exhibiting the same difficulty is used to illuminate the situation, and then an improvement is suggested. Some of these improvements are at rather tentative stages of their development, but the general approach is a good way to orient the reader within the current research. Substantial discussion is given of composite grids, boundary conditions, multigrid strategies, and other matters. The section closes with impressively thorough and varied applications (a combustor, a discharge lamp, capillary flow under microgravity, and a complex duct), in all of which challenging difficulties have to be overcome. Readers of this journal, however, may find that in the simpler cases where comparison is possible, the results for strongly discontinuous flow fall short of the standards that they expect from modern finite-volume methods. The ancient division of CFD into compressible and incompressible camps is still with us, despite the best efforts of both parties to send emmisaries across the divide.

Finally, about 250 pages are devoted to flows where important effects arise from the presence of an interface. Professor Shyy observes correctly that this topic is not very prominent in previous CFD texts. He begins with a concise review of the dynamics and thermodynamics of interfaces. Next, he develops the various strategies for treating an interface numerically; mapping it to a coordinate line (in simple cases only), "volume of fluid" methods, marker particle tracking methods, and capturing of a phase variable. He then describes in detail an algorithm for tracking and using interface markers that permits interfaces to break and merge. Here I find the large problem approach impressive. The descriptions are very clear and specific, the methods ingenious, and the applications again varied.

However, I cannot close this review without commenting on the price charged by the publishers. The sum of $225.75 will deter most prospective purchasers, and I really cannot see the justification. The text seems to be prepared in LaTeX, presumably by Professor Shyy himself, many figures are clipped from other publications, and the subediting has been superficial. Within the past 12 months, the library in my own department has not paid more than $125.00 for any single-volume text, and would not do so unless the book were clearly in a class by itself. There is no doubt that this is a useful book, complementary to other CFD texts, but it is not flawless. If you can only afford one CFD book, Fletcher's is more comprehensive. If you are only interested in compressible flow, Hirsch's gives better methods. In a balanced library, Shyy's book would sit beside them. I hope that a price adjustment will allow it to do so.

Philip Roe
University of Michigan