Modeling and Simulation of Turbulent Flows

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When, rather more than 10 years ago, Roland Schiestel sent me the manuscript for a new book on turbulent flows that he had written, I was delighted to see that, while rigorous in the development of traditional approaches to turbulence, these were used to serve the main theme of the work, namely the modeling of turbulence in a form suitable for use in CFD solvers. His invitation to write a preface was gladly accepted and the words I wrote then perhaps still merit repeating:

The fluid mechanics of the world we live in is overwhelmingly dominated by that chaotic, unsteady motion called turbulent flow. Whether it be the flow of air and water in the natural environment or the man-managed interior environment, heat, momentum and mass exchange is brought about by large-scale, irregular eddying motions rather than by molecular diffusion and the design of virtually all types of thermo-fluids equipment: pipes, boilers, compressors, turbines, IC engines, condensers, etc. are variously designed to cope with or exploit the fact that the fluids passing through or around them are in turbulent motion.

This is such a commonplace observation that the reader may feel it hardly deserves mention. Yet, if – instead of using our eyes to view the world about us – we formed our view of the nature of fluid motion by reading fluid mechanics textbooks, what a different impression would be gained! From such a study we would understand that for a great many problems fluid viscosity is an irrelevancy, in most others the flow remains perfectly laminar while, to handle that rather inconvenient (and apparently unimportant) state called “turbulence” we refer to tediously compiled experimental correlations.

This distorted view of the relative importance of different strands of engineering fluid mechanics underlines the extent to which academics base the syllabus of their courses on what they know, rather than on what is relevant. That, I suppose, is as inescapable a fact of life as turbulent flow itself.
At the research level, the computation of turbulent flows has long been a subject receiving greater attention than its scant coverage in textbooks would lead us to expect. Now the rapid growth of software companies marketing commercial CFD packages (coupled with a corresponding growth of users of such software) has helped bring home the need for more – and more systematic – instruction on the internal workings of these black boxes. The aspect of CFD software where questions most often arise and where, through the absence of textbooks, they are least easily handled is on turbulence modeling. There is, manifestly, a need for a comprehensive textbook treatment of engineering turbulence modeling, perhaps particularly one written by an active contributor to the continuing advance of the subject.

The above was the scene, as I perceived it, in the early 1990s when the first edition of Roland Schiestel’s book appeared to warm reviews. Over those intervening years, of course, the world of turbulence modeling has moved on, and with the first edition and then an enlarged second edition sold out, the author and publisher have concluded that the time has come for a new edition. The fact that the earlier editions had sold out was a good indication that the book was meeting a real need and that the structure and philosophy should remain intact – as it has. For example, the book rightly focuses on second-moment closure for it is only at this level that the subject can be developed formally as a branch of mathematical physics (having adopted that starting point, simpler levels of closure naturally emerge as particularly limiting cases that are applicable under increasingly restricted circumstances). Moreover, without recourse to modeling the unknown processes in the second-moment equations, an examination of the exact generation terms explains, at least qualitatively, so many of the paradoxes of turbulent shear flows. For example: why turbulent mixing typically results in twice as much heat flow at right angles to the mean temperature gradient as along it; why a secondary strain associated with streamline curvature whose magnitude is only 2% of the primary strain produces a 25% modification in the turbulent shear stress; or why, in orthogonal mode rotation, a relatively weak Coriolis force augments shear stress on the pressure surface by 10% whereas further increase in the rotation rate produces no further augmentation.

Thus, the fabric and style of the very successful original version are retained in this new edition. Among the several new additions, is the inclusion of new approaches to the economical handling of the near-wall region where “wall functions” are normally adopted to escape the crippling cost of a fine-scale resolution of the sublayer and buffer region. The usual log-law based wall functions had such a narrow range of applicability that alternative strategies were sorely needed. These are now included in a new presentation of this material. The number of references has also increased by some 30%, the great majority of which are to works appearing in the last five years. Thus, this new edition continues to serve admirably both those in industrial CFD needing to understand the physical basis of
their software as well as those engaged in or about to start their research in turbulence modeling.

In the foreword to the original edition I had written: “turbulence modeling is still seen by many as a black art founded on bad physics and capable of producing computed flow patterns in accord with measurements only by the arbitrary, case-by-case adjustment of a sackful of empirical constants and other less reputable fudges”. That perception is, happily, much less commonly found today. In France, Roland Schiestel’s previous editions have been a major contributor to the better-founded appreciation of turbulence modeling by the scientific and industrial communities. May this new edition continue the good work!

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