Journal of Heat Transfer

Guest Editorial

Foreword to the Special Issue on Computational Heat Transfer

It is our great pleasure to present this Special Issue of the Journal of Heat Transfer which is being published in honor of Professor Suhas V. Patankar's 65th birthday in 2006. This issue not only highlights Professor Patankar's seminal contributions to computational heat transfer and fluid dynamics (CFD) research and pedagogy, but also gives us an opportunity to review the current status and future prospects of CFD.

We may argue about when CFD really began, whether it was with Lewis Richardson's work on the computation of creeping flow in 1910, or with the publication of the landmark paper by Courant, Friedrichs, and Lewy in *Mathematische Annalen* in 1928, or with Harlow and Fromm's 1965 *Scientific American* article, "*Computer Experiments in Fluid Dynamics*." There is little doubt though, that the last 40 years have been an exhilarating time for CFD. Professor Patankar has been an integral part of the evolution of modern CFD, and one of its most significant architects.

Professor Patankar was born on February 22, 1941 in Pune, India. He obtained his B.E and M.Tech degrees from Pune University. He obtained his Ph.D. from Imperial College, London in 1967 under Professor Brian Spalding, marking the beginning of a long and fruitful collaboration. He taught at the Indian Institute of Technology, Kanpur, from 1967 to 1970. He returned to Imperial College in 1970, and working with Professor Spalding, published a series of papers, including their landmark 1972 paper describing the SIMPLE algorithm, one of the most cited papers in the thermal-fluid sciences literature. Professor Patankar taught at the University of Waterloo in 1973–1974, and joined the Department of Mechanical Engineering at the University of Minnesota in 1974, which became his home for over 25 years until his retirement in 2000. He founded the CFD company Innovative Research Inc. in 1987, and now serves as its President.

Professor Patankar's career spans the arc of modern CFD, from its modest beginnings in the 1960s, to its near-ubiquity as an industrial analysis and design tool a scant 40 years later. The great majority of the computational work done in the 1950s and 1960s addressed either Euler flows or creeping flows. Professor Patankar's Ph.D. thesis on the computation of two-dimensional boundary layers marks one of the earliest attempts to resolve boundary layer growth through the use of a flow-conforming mesh. The generalization of 2D boundary layer computations to three-dimensional parabolic situations necessitated the invention of the SIMPLE algorithm in 1972 to compute pressure in incompressible flows. The remarkable computational economy afforded by SIMPLE facilitated the simulation of surprisingly complex fluid flows through the 1970s and 1980s, despite the relative paucity of computer resources. Over the years, the SIMPLE algorithm and its variants have become the mainstay of a vast variety of elliptic incompressible flow calculations, and today form the core solver engine of most commercial finite volume CFD codes.

Another critical advance in popularizing CFD was the development of boundary-fitted and unstructured finite volume schemes to address complex geometries. The path to their development was not straightforward, however. Early pressure-based schemes such as SIMPLE employed staggered storage of pressure and velocity to overcome difficulties with the occurrence of spurious pressure modes. To translate these staggered schemes to body-fitted meshes, grid-following co- and contravariant velocity systems had to be used. Professor Patankar and his students, as well as other researchers, developed this class of techniques in the early 1980s. However, these methods were still geometrically too cumbersome, and co-located or nonstaggered schemes were invented. Here too, Professor Patankar and his students developed one of the earliest co-located pressure-velocity formulations in the literature in 1980–1981, and variants and extensions of these ideas can again be found in many commercial CFD solvers today.

Ultimately, body-fitted meshes were themselves judged too inflexible for commercial use, and the remarkable expansion of CFD into the industrial arena could not occur without the development of unstructured finite volume techniques. Here too, Professor Patankar's imprint is clear. In the early 1980s, he and his students developed a class of unstructured finite volume techniques combining ideas of scalar conservation with finite-element-like shape functions. Triangular and quadrilateral elements were addressed in their early work. These techniques, called the control-volume finite element methods (CVFEMs), inspired the invention of cell-based unstructured finite volume solvers in the 1980s and early 1990s, which sought to simplify the geometric complexity of CVFEMs, and to generalize them to the arbitrary polyhedral cells necessary for true flexibility. These advances, combined with advances in solid modeling and unstructured mesh generation, finally made CFD versatile enough for routine industrial use.

Over the years, CFD textbooks and undergraduate and graduate curricula were developed to support the ever-expanding need for CFD practitioners in industry. Professor Patankar's contributions to CFD pedagogy are also significant. His excellence as a teacher is legendary. His 1980 textbook, *Numerical Heat Transfer and Fluid Flow*, remains to this day a model of simplicity and clarity, and one of most coherent explications of the finite volume technique ever written.

With all the success that CFD has enjoyed, what opportunities for future work remain? The greatest opportunities are, of course, afforded by the continuing expansion in computational resources. With the advent of petascale computing, many of the computational economies that drove the invention of SIMPLE and its variants may no longer be necessary. Thus, more robust (albeit more storage-intensive) pressure-velocity coupling schemes are already being developed and may soon become the mainstay of commercial solvers. Robust handling of more challenging physics, addressing turbulence, multiphase flows, chemically reacting flows, and other complexities, are necessary. In particular, simulation of turbulence has been radically improved through direct numerical simulation (DNS) and large eddy simulation (LES) of turbulence that provide spatially- and temporally-resolved calculations of the unsteady flowfield and do not require the modeling of the entire spectrum of turbulent fluctuations. LES tools are now increasingly being integrated into many commercial solvers, and it is anticipated that these tools will be further refined and utilized to a significantly greater extent by industry and academia in the next decade. Simulation itself will become more ubiquitous, significantly more multiphysics, multiscale, and design-oriented, and less and less the purview of experts. These trends inevitably demand better quantification of error and uncertainty propagation, and the development of expert systems to guide users.

The special issue consists of 17 full-length papers and five technical briefs representing a spectrum of topics in CFD from new methodologies and model developments to applications ranging from nano- to macro-thermal-fluid systems. The first paper in the issue is a review paper by Professor Patankar's students and associates and reviews the developments in CFD methodology, from SIMPLE-based methods to control-volume-based finite element methods (CVFEMs), in which Professor Patankar had a defining role. The remaining papers in the issue are contributed papers that have all been rigorously reviewed according to the Journal Heat Transfer standards.

We appreciate the overwhelming support of the heat transfer community, and the contributions of many experts in the CFD area that have made the special issue possible. On behalf of all the students and associates of Professor Patankar, we would like to thank him for introducing us to CFD and providing us the education and training that have helped us to build our own paths in industry or academia. We would also like to thank Professor Jaluria and the Journal of Heat Transfer for graciously agreeing to produce a special issue on computational heat transfer and fluids in honor of Professor Patankar.

On the occasion of Professor Suhas Patankar's 65th birthday, we ask you to join us in acknowledging his seminal contributions to CFD, and wishing him many more happy years of computing.

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