Recent Advances in Numerical Methods for Fluid Dynamics and Heat Transfer

Computational fluid dynamics (CFD) tools are the key for modern understanding of many physical, electrochemical, and biological processes. They not only help explain complex events involving disparate temporal and spatial scales, but also allow us to peer at the heart of breakthrough science. This special section of the Journal of Fluids Engineering is a collection of select papers presented at the ASME 2004 Fluids Engineering Division Summer Meeting in Charlotte, North Carolina in the symposium on “Algorithmic Developments in CFD” sponsored by the Fluids Engineering and Heat Transfer Divisions. They represent an excellent cross section of research and developments crucial to issues both in fundamental progress and industrial applications. The symposium on algorithmic developments started in the 1990s and is intended to provide means for presenting novel and enhanced numerical algorithms for computational fluid dynamics (CFD) applications, direct numerical simulation, Monte Carlo methods, iterative and segregated solvers, shear interface algorithms, exploitation of parallel architecture, and adaptive techniques. Specific topics of interest include, but are not limited to, laminar and turbulent flows, reacting flows, compressible and incompressible flows, and non-Newtonian flows. The symposium is led by Subrata Roy from Kettering University, along with co-organizers Dhanireddy R. Reddy from NASA Glenn Research Center and Miguel Visbal from the Air Force Research Laboratory at Wright Patterson. The ongoing concurrent series of these symposia epitomize excellent cutting edge numerical research from an international representation of applied mathematicians, numerical physicists, fluid dynamicists, as well as industrial practitioners. The diffusion of knowledge that sprouts from the syntheses of ideas of these leading scientists and engineers usher in new technological breakthroughs and developments.

The seven papers selected for this collection are divided into two loosely formed groups. The first four papers present fundamental algorithm developments with underlying important practical applications. Three papers in the following group focus on novel implementations of developed numerical techniques for a wide range of flow simulations.

In the first group, Isa from Texas A&M University and Yao from Carnegie Mellon University develop a new numerical recipe for modeling the dynamics of the droplet-wall interaction and heat transfer mechanisms at subatmospheric to elevated ambient pressures, and for surface temperatures ranging from nucleate to film boiling. This has applications in a wide range of problems, including mist cooling of thin-strip casting, gas turbine airfoils, glass tempering, and electronic chips where misting jets show a better cooling efficiency and control of the material temperature. Simulation results for their method compares well against available test data for single stream of droplets at nonatmospheric conditions. The next paper is on multilevel Boundary Element Methods (BEM) for fast and accurate solutions of steady Stokes flows. A major problem dragging the progress of BEM is its high memory overhead and efficiency concerns for a general class of problems. The novel formulation proposed by Dargush and Grigoriev of the State University of New York at Buffalo shows promise in significantly overcoming that problem. For a test case in an irregular pentagon, the new formulation reduces the CPU times by a factor of nearly 700,000 while the memory requirements are shown to reduce by more than 16,000 times. The third paper in this category is the development of a meshless local Petrov-Galerkin control volume algorithm for fluid thermal system applications by Arefmanesh et al. from Islamic Azad University of Tehran. The accuracy and applicability of their method have been benchmarked for the transient heat conduction, potential flow over a block, and convection-diffusion-type non-self-adjoint problems. The Fourier series along with a modified upwinding relation has been utilized for optimal (artificial) diffusion in convective flow cases. The fourth paper by Celik et al. from West Virginia University investigates the limitations of the well-known Richardson extrapolation method focusing on the origin of oscillatory convergence in finite difference methods and demonstrates statistical performances of some possible remedies based on the modeled error equation. A new method based on the extrapolation of approximate error is also proposed.

The next set of papers begins with “An Adaptive Wavelet Method for Incompressible Flows in Complex Domains” by Wirasaet and Paolucci of the University of Notre Dame. They overcome the well-known difficulty of applying such a method for complex domains by using the Navier-Stokes/Brinkman equations, which take into account solid obstacles by adding a penalty term in the momentum equation. The method is based on interpolating wavelets and has been tested for incompressible flows over obstacles. Stolz from the Institute of Fluid Dynamics, Zürich, Switzerland has applied the newly developed high-pass filtered Smagorinsky models for large-eddy simulations of wall-bounded compressible flows. Specifically, the simulation of a spatially developing supersonic turbulent boundary layer at a Mach number of 2.5 and momentum-thickness Reynolds numbers at inflow of approximately 4500 is validated with experimental data. The numerical method uses entropy splitting along with a finite difference approximation for the diffusive flux. In recent days, there has been a flurry of research on the level set methods. The final paper in this anthology is by collaborators from Switzerland and the USA on the Streamline-Upwind/Petrov-Galerkin (SUPG) finite-element based level set method. Shepel and Smith from the Paul Scherrer Institut in Switzerland and Paolucci from the University of Notre Dame implemented the level set interface tracking method in the commercial FIDAP and CFX-4 codes. The procedure can be used for both structured and unstructured grids. Two formulations encompassing the single phase liquids and the coupled
motion of the gas-liquid phases are given and tested for large
density and viscosity ratios.

I would like to congratulate the authors of the papers in this
special section of the Journal of Fluids Engineering for their
staunch efforts in preparing and improving their manuscripts in
response to the reviews. The anonymous referees contributed a lot
of their time and expertise. They deserve special thanks. I also
thank Laurel Murphy for providing consistent support and help
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Subrata Roy
Associate Editor