Parallel Computational Fluid Dynamics—New Frontiers and Multi-Disciplinary Applications

Edited by K. Matsuno, A. Ecer, J. Periaux, N. Satofuka, and P. Fox, Elsevier, Amsterdam, 2003, 604 pp., $120.00

The breadth of the subject topic, parallel computational fluid dynamics (CFD), presents a challenge for a single publication to adequately represent every possible research area. This book contains the proceedings of the Parallel CFD 2002 Conference held in Kansai Science City, Japan, on 20–22 May 2002. As such, this compilation represents a snapshot in time of the evolution of CFD research in a variety of coupled CFD and parallel computing areas. The contributed papers from a cross section of international scientists and engineers contain current CFD research on various parallel computing architectures.

Innovations in computing architecture and increases in computing performance continue to enable "new frontiers" in numerical simulation. The significant influence of high performance computing (HPC) was highlighted when the Japanese ultra-high-speed vector parallel computing system known as the "Earth Simulator" became operational on 11 March 2002 just prior to the conference. The Earth Simulator combines three key components of state-of-the-art HPC: vector processing, shared memory multiprocessing, and distributed memory cluster computing. Specific sessions related to the Earth Simulator were included. The growing availability of HPC systems, from simple clusters with a few nodes to the performance-leading Earth Simulator, fosters innovations in the computational approach, numerical algorithms, and scientific applications. This book presents research in all of these areas.

The proceedings are grouped into seven chapters as follows (the number of papers in each chapter is shown in parentheses): Invited Papers (5), Earth and Space Global Simulations and Earth Simulator (11), Parallel Environments (12), Parallel Algorithms (17), Mesh Strategies (10), Multi-Disciplinary Simulations (15), and Tutorial Paper (1). One of the highlights of this publication is the concluding tutorial paper that presents a survey of parallel evolutionary algorithms (PEAs) and illustrates the methodologies with a series of simple nozzle optimization problems. The review discusses the most advanced research in the field and investigates the newly developed PEA tools for multicriteria, CFD dominant optimization problems.

Several invited papers focus on key research in turbulent flow simulations based on developments in the use of large eddy simulation (LES), the lattice Boltzmann methods (LBM), and the discontinuous Galerkin (DG) formulation. The maturing concept of using grid computing to provide access to vast amounts of computational resources is also reviewed.

The papers in the Earth and Space Global Simulations and Earth Simulator category provide an early indication of the value that the Earth Simulator will provide to global climate and weather analysis. Atmospheric general circulation models (AGCMs), ocean general circulation models (OGCMs), and magnetohydrodynamic (MHD) simulation results from the Earth Simulator were provided only two months after operations began. The computational and memory capacity of the Earth Simulator enables one-day simulations with grid refinement down to 5-km resolution. Its impact on parallel CFD will be significant for many years to come.

The Parallel Environments papers show the diverse range of hardware (from a network of heterogeneous workstations to conventional supercomputers to distributed clusters) being used for computational research. The use of a lower-cost, commodity component cluster computing environment, as described in 9 of the 12 papers, is consistent with the growing acceptance and reliance on cluster hardware. The widespread use of cluster systems provides the basis and justification for the research and development being performed to improve the computational performance of distributed memory architectures. Parallel environment characteristics such as processor speed and network interconnection speed influence the load balancing between the computational elements. Methods to automatically monitor and adjust the computational load are demonstrated, and the requirements for parallel I/O and massive data storage are outlined.

In the categories of Parallel Algorithms and Mesh Strategies, the papers investigate unstructured, Cartesian, and Chimera (overlapped, structured) grid topologies and adaptive mesh refinement techniques designed to accelerate convergence and/or improve the accuracy of the results. In the majority of the papers, the methods are developed, implemented, and tested on distributed memory architectures. The ratio of time spent in the numerical algorithm to time spent in message passing is a key to overall computational efficiency because it affects the elapsed time of every iteration step.

A balanced distribution of computational work between the compute elements optimizes the time utilized by the numerical algorithm. The ratio of total computational nodes to boundary condition nodes must be equally distributed, and the amount of boundary data to be passed should be minimized. Automation of the grid generation, mesh adaptation, and domain decomposition is discussed. The scalability of the computations as the number of compute elements is increased is also studied.

For most of the methods, the message passing interface (MPI) is implemented for communication between the computational elements. The use of MPI, even on shared memory systems, provides reasonable performance. However, the proper integration of an OpenMP application program interface for shared memory intranode communication and MPI for distributed memory internode communication to provide better overall efficiency is also successfully used.

The practical application of Multi-Disciplinary Simulations is the focus of the next category. Several papers discuss the use of genetic algorithms (GAs) for design optimization studies. Other presentations investigate the effects of unsteady flow and dynamic systems. All of the multidisciplinary research studies are aided significantly by the increased performance of parallel computing.

As mentioned earlier, a valuable element of this publication is a tutorial on PEAs with a series of simple nozzle optimization problems that illustrate the methodologies. Even someone new to PEAs will find this tutorial easy to follow and understand. The survey provides extensive references and a summary of the basic characteristics for each of four PEA model types: single population master–slaves, island or coarse-grained parallel, cellular or fine-grained parallel, and hybrid or hierarchical parallel. The review of PEA model types is followed by a discussion of PEA computational algorithm advances with specific references for each algorithm. An overview of the INGENET (Industrial Design and Applications using Genetic Algorithms and Evolution Strategies Network) database including key test cases from the aerodynamics area is provided, and detailed studies from the database are summarized.

An inverse nozzle design problem is described in detail with results presented for a conventional single population GA model and two hierarchical GA models with two different characteristics for a three-layer multiple model. A multi-objective nozzle design problem using an asynchronous evolution strategy demonstrates how the "compromise" design is derived using the multiple objective functions. A further discussion of Nash strategies and combining Nash equilibrium with GAs is outlined. This combined strategy is demonstrated on another multi-objective nozzle design problem. The combined Nash–GA strategy produces a solution in equilibrium between the multiple-nozzle-design objectives. This implies that new solutions can evolve that are different from the target objectives and not necessarily just a "compromise" between these objectives.

A minor deficiency of this book is the small size or loss of clarity for some of the figures. As a result, it can be difficult to understand portions of a paper that rely on the graphical information. This may be the result of the poor quality of the original figures or be caused by a size reduction or black-and-white reproduction of color figures in generating this publication.

In conclusion, *Parallel Computational Fluid Dynamics–New Frontiers and Multi-Disciplinary Applications*, edited by K. Matsuno et al., will serve as an important survey of key research in parallel CFD and the corresponding state of HPC. This book is especially valuable for the tutorial on PEAs, the sample optimization problems provided, and the extensive references. Basic design optimization and multidisciplinary optimization are areas that will benefit from continuing advances in parallel CFD and HPC.

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