11th World Congress on Computational Mechanics (WCCM XI)
5th European Conference on Computational Mechanics (ECCM V)
6th European Conference on Computational Fluid Dynamics (ECFD VI)
July 20 - 25, 2014, Barcelona, Spain

DIRECT NUMERICAL SIMULATION OF TURBULENT FLOWS WITH PARALLEL ALGORITHMS FOR VARIOUS COMPUTING ARCHITECTURES

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Key Words: *Parallel algorithms, CFD, turbulent flows, MPI, OpenMP, OpenCL, GPU.*

The purpose of the work is twofold. Firstly, it is devoted to the development of efficient parallel algorithms for large-scale simulations of turbulent flows on different supercomputer architectures. It reports experience with computing on massively-parallel accelerators including graphics processing units (GPU) of AMD and NVIDIA and integrated core (MIC) architecture accelerators Intel Xeon Phi. Secondly, it represents new series of direct numerical simulations (DNS) of incompressible turbulent flows with heat transfer.

Parallel finite-volume CFD algorithms for modeling of turbulent flows on hybrid supercomputers are presented. A multilevel approach that combines different parallel models is used for large-scale simulations on computing systems with massively-parallel accelerators. MPI is used on the first level within the distributed memory model to couple computing nodes of a supercomputer. On the second level OpenMP is used to engage multiple CPU cores of a computing node. The third level exploits the computing potential of massively-parallel accelerators. The hardware independent OpenCL standard is used to compute on accelerators of different architectures within a general model for a combination of a central processor and a math co-processor. The represented algorithms in their “classical” MPI+OpenMP parallel implementation [1,2] were designed to scale till the range of up to 10^5 CPU cores. The hybrid OpenCL-based extensions have been developed in order to exploit the computing potential of modern hybrid machines. This work summarizes our experience with adapting the computational algorithms for different accelerator architectures. The specific scheduler infrastructure [3] for automated management of OpenCL tasks has been chosen to simplify the implementation of MPI and host-accelerator communications overlapped with computations.

The recent DNS simulations performed using the high-order finite-volume symmetry-preserving spatial discretization [4] are to be presented. The cases include a flow around an infinite square cylinder at Reynolds number 22000 (based on the height of the obstacle). The flow has been computed using the 4-th order scheme on a grid with around 300 millions of nodes on 800 CPU cores of MareNostrum supercomputer (BSC, Spain). Another case considered is a natural convection flow inside a closed air-filled (Prandtl number 0.71) differentially heated cavity of height aspect ratio 3.84 and depth aspect ratio 0.86. The

Rayleigh number (based on the cavity height) is 1.2×10^{11}. This configuration resembles the experimental set-up performed by D. Saury et al. [5]. The simulation has been carried out on a grid with 48 millions of nodes using MVS-10P supercomputer (JSC RAS, Russia). Examples of instantaneous flow fields are shown on fig. 1.

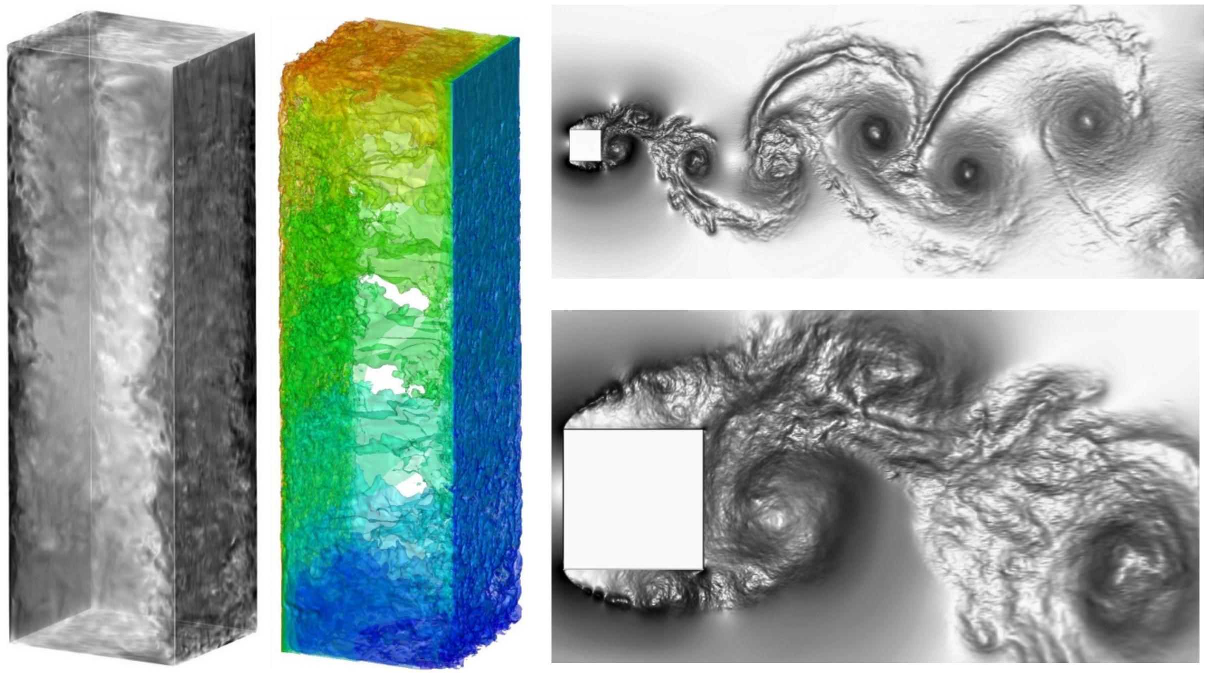

Figure 1. Examples of instantaneous snapshots from DNS cases considered. Left – DNS of a differentially heated cavity (module of velocity and isosurfaces of temperature are shown); right – DNS of a flow around a square cylinder (pressure field in the mid-plane is shown).

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