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THE EVOLUTION OF PARALLELIZATION OF THE NOISETTE CFD CODE FOR SCALE-RESOLVING SIMULATIONS OF COMPRESSIBLE TURBULENT FLOWS

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Abstract. This work is about extending the parallelism of the computational fluid dynamics and aeroacoustics simulation code NOISEtte towards hybrid architectures and in accordance with the expansion of the set of involved numerical methods. The code is aimed at modeling of compressible turbulent flows using high-accuracy edge-based schemes on unstructured meshes and modern scale-resolving simulation approaches. Multilevel configurable MPI+OpenMP+OpenCL parallelization is in charge of the efficient use of various supercomputer architectures made of multicore CPUs, manycore devices, such as Intel Xeon Phi, graphics processors, such as GPUs of AMD and NVIDIA. The parallel algorithm and software implementation are presented in detail.

The evolution of high performance computing systems towards hybrid architectures requires appropriate adaptation of the parallel algorithm and its implementation. On the other hand, the evolution of numerical methods, the growing complexity of simulation technology, the involvement of more and more methods in a simulation also requires a certain parallelization upgrade.

In the present work, the NOISEtte code for scale-resolving simulations of aerodynamics and aeroacoustics problems is considered. The Navier–Stokes equations for compressible ideal gas are used as a mathematical model together with extra source terms and equations for turbulence modeling within one of the following approaches: Direct Numerical Simulation (DNS), Reynolds-Averaged NavierStokes (RANS), Large Eddy Simulation (LES) [1, 2], hybrid RANS-LES approaches, such as Detached Eddy Simulation (DES) [3]. The family of higher-accuracy edge-based schemes [4] is used for the spatial discretization on unstructured hybrid meshes. Explicit RungeKutta schemes (up to 4-th order) and implicit Newton-based schemes (up to 2-nd order) are used for discretization in time. The set of boundary conditions includes no-slip conditions for impermeable solid walls, Dirichlets conditions, characteristic inflow and outflow conditions. Examples of typical applications of the code are shown in Fig. 1.

Multilevel configurable MPI+OpenMP+OpenCL parallelization is in charge of the efficient use of supercomputers of various architectures, consisting of multicore CPUs, many-

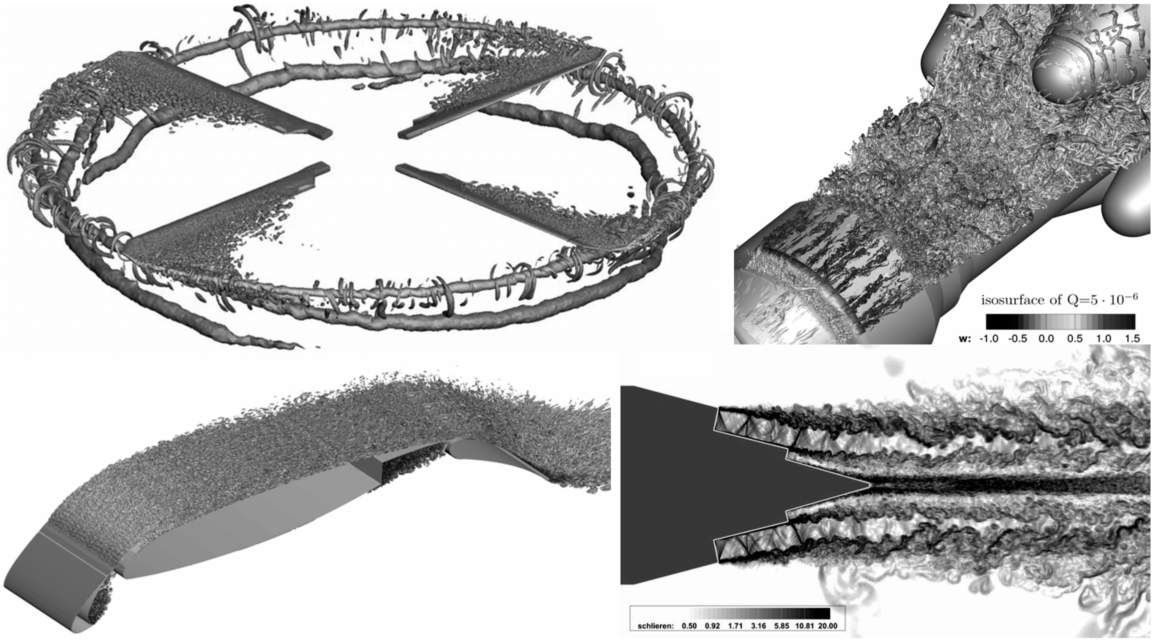

Figure 1: Typical examples of applications of the code in which aerodynamic and acoustic characteristics are determined: a helicopter rotor, a wing with high-lift devices, a space rocket, a jet of a turbofan engine

core devices, such as Intel Xeon Phi, graphics processors, such as GPUs of AMD and NVIDIA. MPI works at the upper level, it distributes the computing workload among supercomputer nodes. Inside the nodes, shared memory OpenMP parallelization takes care of manycore devices at the second level. The baseline MPI+OpenMP parallelization is presented in detail in [5]. The new parallel level uses OpenCL for massively-parallel accelerators.

The extension of the parallelism within the present work is twofold. Firstly, the use of sliding meshes for modeling rotating objects (such as flows around helicopter rotors or in rotor-stator configurations) complicated the parallel algorithm. Workload distribution and balancing for the sliding interface, which produces significant computational heterogeneity, have been introduced at the MPI decomposition stage. The MPI communication stage has been extended with dynamically changing connection topology between subdomains. In order to take into account the growing volume of data exchange, the MPI communications have been accelerated by multithreaded parallelization of packing send buffers and upacking receive buffers. Given the growing volume of data exchange, the MPI communications have been accelerated by multithreaded parallelization at the stages of packing outgoing messages and unpacking incoming messages. Several simulations with the sliding interface have been carried out, and its performance has been studied on up to 1400 CPU cores, as well as on up to 8 Intel Xeon Phi accelerators.

Secondly, the main extension consists in using the OpenCL standard for computing on GPUs and other massively parallel devices that support it. A specific infrastructure for debugging and testing kernels has been implemented in the code to simplify the porting process and ensure the correctness of the kernel code. The MPI communications have been extended with intra-node exchange between the CPU and OpenCL devices. Memory access via intermediate storage in local shared memory has been used in kernels to achieve coalescing of memory transaction and maintain compatibility of data structures with the CPU version. Computing kernels have been created so far for the explicit time integration algorithm with the edge-based EBR3 and EBR5 schemes [4]. Much remains to be done.

Detailed information on the parallel algorithm and its software implementation will be presented, as well as performance results on various devices, discussion and complaints about the hardships of heterogeneous parallelization.

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