

# Perm State University HPC-hardware and software services: capabilities for aircraft engine aeroacoustics problems solving

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**Abstract.** The present work is devoted to analyze high-performance computing (HPC) infrastructure capabilities for aircraft engine aeroacoustics problems solving at Perm State University. We explore here the ability to develop new computational aeroacoustics methods/solvers for computer-aided engineering (CAE) systems to handle complicated industrial problems of engine noise prediction. Leading aircraft engine engineering company, including “UEC-Aviadvigatel” JSC (our industrial partners in Perm, Russia), require that methods/solvers to optimize geometry of aircraft engine for fan noise reduction. We analysed Perm State University HPC-hardware resources and software services to use efficiently. The performed results demonstrate that Perm State University HPC-infrastructure are mature enough to face out industrial-like problems of development CAE-system with HPC-method and CFD-solvers.

## 1. Introduction

The present work is devoted to analyzing high-performance computing (HPC) infrastructure capabilities for aircraft engine aeroacoustics problems solving. We explore the ability to develop new structured and unstructured computational aeroacoustics methods/solvers for computer-aided engineering (CAE) systems to handle complicated industrial problems of engine noise prediction. Perm State University’s industrial partners, including leading aircraft engine engineering company “UEC-Aviadvigatel” JSC (in Perm, Russia), require that methods/solvers to efficiently optimize geometry of aircraft engine for fan noise reduction.

In 2010 Perm State University (<http://www.psu.ru>) was awarded the status of National Research University, justifying its reputation as one of the leading Russian universities. The Perm State University Strategic Development Program (2010–2019) has been worked out. The objective of the program is to update and develop Perm State University as a new type research university that integrates multidisciplinary R&D activities and advanced technologies for growing national economic competitiveness. The university participate in national and international activities used parallel and distributed computing (PDC) technologies. For example, Perm State University is:

- a participant of the University Cluster Program (<http://unicluster.ru>, since 2009),
- a full member of HPC Consortium of Russian Universities (<http://hpc-russia.ru>, since 2009),
- and a full member National HPC Technology Platform (<http://hpc-platform.ru>, since 2010).

The university designated by NVIDIA as a CUDA Teaching Center (2012-2015), CUDA Research Center (2014-2015), GPU Education Center (2015-2016), GPU Research Center (2015-2016). The Research-Education Center "Parallel and Distributed Computing (REC P&DC) of Perm State University was founded in 2009. The REC P&DC helps faculties to adopt wide usage of GPU-



computing and high-performance computing in general for solving a variety of problems in traditional and interdisciplinary scientific fields. The REC P&DC supports research and educational activities in advanced computing. The project "Development of Joint-Use Center of High-Performance Computing Resources – the REC P&DC" (supervised by this paper author) is a part of the Perm State University Development Program (2010-2019) as a national research university. For the project, Perm State University purchased HPC-systems with hybrid architecture including:

- NVIDIA Tesla S2050-accelerated cluster "PGU-Tesla" with 12 GPU entered the 14th-version (March 2011) of top 50 of all supercomputers in Russia and the CIS and ranked 1st in Perm Krai [1];
- NVIDIA Tesla K20-accelerated cluster "PGNIU-Kepler" with 16 GPU entered the 20th-version (March 2014) of top 50 of all supercomputers in Russia and the CIS and ranked the 1st in Perm Krai [2].

The supercomputers are using actively to solve super-complex computing problems with broad scope; an effective solution is possible only when using HPC-resources. The supercomputers also help to train highly competitive specialists with competences: to solve effectively problems in main areas of science and technology, and to develop critical and breakthrough technologies.

We computed a realistic fan noise emission/radiation problem by using the existing and developing CAE solvers. For example, engineer E.V. Koromyslov (with engineers M.V. Usanin and L.Y. Gomzikov) under supervision of Dr. A.A. Siner continue to develop solver code of GHOST CFD [3] for "UEC-Aviadvigatel" JSC. That code aimed to solve non-stationary Navier-Stokes equations by finite-difference schemes of high order of accuracy on the GPU. We plan to use the solver for task solving in the aerospace industry. This multi-GPU software is essential to perform a precise and robust numerical simulation that requires huge computational resources with Compute Unified Device Architecture (CUDA) [4] to design these eco-friendly engines.

Our vision for furthering the application and technology of GPU computing is fast growth. We believe in the broad opportunities of GPU-computing usage for solving a variety of problems in traditional and interdisciplinary scientific fields. In 2017 at Perm State University start project "Development and implementation of highly efficient computational algorithms for calculating the sound generation of the fan stage of an aircraft engine to reduce the impact of aircraft on the environment and humans".

## 2. Problem description

We start to use the existing and developing CAE solvers for realistic solving of fan noise emission/radiation problem, which involves both a full-3D exhaust geometry of aircraft engine and a typical fan noise modal content. To date, such modeling, despite its relevance, presents considerable difficulties due to the need for high-order schemes and high resolution (such as, for example, DRP (Dispersion Relation Preserving) schemes [5] for structured mesh and EBR [6] for unstructured ones), as well as detailed calculation grids, which leads to very high computational costs and difficulties in implementation. Previously, different well-known CAE systems (ANSYS CFX and Fluent [7], OpenFOAM[8]) with CFD-solvers already used at Perm State University supercomputers.

First, we considered as computational scheme for structured or unstructured 3D Cartesian meshes to solve the problems of noise reduction at fan stage of an aircraft engine. Second, we considered the problems of developing and effectively implementing of scalable computational algorithms for calculating the noise emission in the aircraft engine stage. We note that the choice of implemented algorithms and development tools determinate with characteristic properties of heterogeneous computing at the target computer architectures. We need to analyze Perm State University HPC-hardware resources and software services to efficiently use.

## 3. Theory and methods

We analyze modern high-performance architectures used for aeroacoustics task solving with large-scale computation. We consider architectures of high-performance clusters with homogeneous and heterogeneous nodes with multicore vector processors and manycore general-purpose computing for

graphics processing units (GPUs). We make an emphasis on CUDA capabilities of computational nodes with NVIDIA GPU. We consider software service that are and available at HPC target development platforms. We noted the software sets that are useful for CFD-code development. We use CUDA-enabled development tools, HPC-benchmarks, and CFD-codes interested by our industrial partners. We modernize HPC-infrastructure built on the base of NVIDIA GPU-accelerated hardware and CUDA-enabled software.

#### 4. Hardware and HPC-architectures

**Table 1.** Hardware description of HPC-systems at Perm State University

| Number of single precision (SP) / double precision (DP) floating point (FP) cores |                  |                  | Hardware of the parallel computing system                 |                                           | Performance at benchmark with DP FP, TFlops |       |
|-----------------------------------------------------------------------------------|------------------|------------------|-----------------------------------------------------------|-------------------------------------------|---------------------------------------------|-------|
| SP/DP FP vector CPU cores                                                         | SP FP CUDA cores | DP FP CUDA cores | Node processor numbers (type)                             | Networks types                            | High Performance Linpack[9]                 | Peak  |
| “PGU-Tesla” system                                                                |                  |                  |                                                           |                                           |                                             |       |
| 240                                                                               | 5376             | 2688             | 20 (2xXeon 5670 2.93 GHz 48 GB RAM) +                     | Infiniband QDR/                           | 4.88                                        | 8.99  |
|                                                                                   |                  |                  | 3 (Tesla S2050 1.15 GHz 4 GPUs x 3 GB RAM)                | Gigabit Ethernet/                         |                                             |       |
|                                                                                   |                  |                  |                                                           | IPMI                                      |                                             |       |
| “PGNIU-Kepler” system                                                             |                  |                  |                                                           |                                           |                                             |       |
| 128                                                                               | 39936            | 13312            | 8 (2xXeon E5-2680 [Acc: 2x Tesla K20] 2.67 GHz 64 GB RAM) | Infiniband FDR-10/ Gigabit Ethernet/ IPMI | 17.48                                       | 21.49 |
|                                                                                   |                  |                  |                                                           |                                           |                                             |       |

#### 5. Software services

The REC P&DC staff under supervision Assoc. Prof. A.G. Demenev deployed on the supercomputers and tested more actual versions OS Linux, MPI Libraries, GCC Compiler set, Intel Cluster Software Suite, NVIDIA GPU Drivers, CUDA Toolkit, PGI Accelerator Server.

To carry out calculations on “PGNIU-Kepler”, the following software is installed:

- Linux operating system (RedHat Enterprise Linux 7.3 64-bit);
- cluster file system (GPFS);
- set for managing tasks and resources (IBM Platform HPC 3.2, including IBM Platform LSF Task Scheduler);
- scripting languages (Perl, Python, bash);
- MPI execution environments (OpenMPI 1.5.4, MVAPICH2 1.6.3, IntelMPI 13.1, IBM Platform MPI 8.3.0);
- compiler sets (Intel 12, GNU 4.7, PGI Accelerator Server 14) for different programming languages (C / C ++, Fortran 77/90/95);
- HPC math libraries from NVIDIA (CUDA Toolkit v.6.0, 7.5, 8.0) and Intel (MKL 2017);
- tools for debugging and performance analysis (gprof 4, Intel® vTune 4, Intel® Thread Checker, IDB);
- version control systems (CVS, GIT, SVN) and data archiving tools (TAR, BZ2, GZ);
- SSH Terminal Services and remote desktop software (X2Go);
- file transfer software (SCP, SFTP).

The general difference of “PGU-Tesla” system software system:

- Linux operating system (CentOS 7.2 64-bit);
- cluster file system (PanFS);
- set for managing tasks and resources (OpenHPC 1.3, including PBS Pro 13).

We can install the existing and developing CAE solvers to compute a realistic fan noise emission/radiation problem. For example, Perm State University have academic licenses of well-known ANSYS CFX and ANSYS Fluent software.

## 6. Results and analysis

The “PGU-Tesla” system can simultaneously perform:

- up to 240 tasks on the Intel Xeon 5670 processor cores with SSE (Streaming SIMD Extensions) 4.2;
- up to 2688 subtasks with DP FP instructions or 5376 subtasks with SP FP instructions on the Nvidia Tesla S2050 CUDA cores with Compute Capability 2.0;
- up to 40 times faster data exchange between tasks over high-speed network QDR Infiniband than over conventional Gigabit Ethernet network.

Theoretical peak performance the “PGU-Tesla” system is up to 9.0 Teraflops as peak (in operations with DP FP). But real performance is up to 54.3 % of the peak performance on the High Performance Linpack. The tasks can use up to 960 GB DDR3 + 36 GB GDDR5 of the total amount of random access memory of computing nodes and up to 20 terabytes of data storage cluster with Panasas File System (PanFS).

The “PGNIU-Kepler” system can simultaneously perform:

- up to 128 tasks on the Intel Xeon E5-2680 processor cores with AVX (Advanced Vector Extensions) 1.0;
- up to 13312 subtasks with DP FP instructions or 39936 subtasks with SP FP instructions on the NVIDIA Tesla K20 CUDA cores with Compute Capability 3.5;
- up to 40 times faster data exchange between tasks over high-speed network FDR-10 Infiniband than over conventional Gigabit Ethernet network.

Theoretical peak performance of the “PGNIU-Kepler” system is about 21.5 Teraflops (with DP FP). But real top performance the “PGNIU-Kepler” is about 81.4% of the peak performance on the High Performance Linpack (with DP FP). The tasks can use up to 512 GB DDR3 + 80 GB GDDR5 of the total amount of random access memory of all computing nodes and up to 36 terabytes of data storage with IBM GPFS.

## 7. Conclusions

We analyzed Perm State University HPC-hardware resources and software services to use efficiently. We determined the characteristics of the architecture and the software of target computing platforms. We evaluated the upper limits of the actual performance expected for the CFD-solvers being developed. The expected performance of CFD-problems solving at the supercomputers is many times smaller for solving linear algebra problems with sparse matrix than for the HPL-benchmark. It may to verify on a suitable set of benchmarks (for example, HPCG benchmark [10]).

We ready to compute a realistic fan noise emission/radiation problem by using the existing and developing CAE solvers. The performed results demonstrate that Perm State University HPC-infrastructure are mature enough to face out industrial-like problems of development CAE-system with HPC-method and CFD-solvers.

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