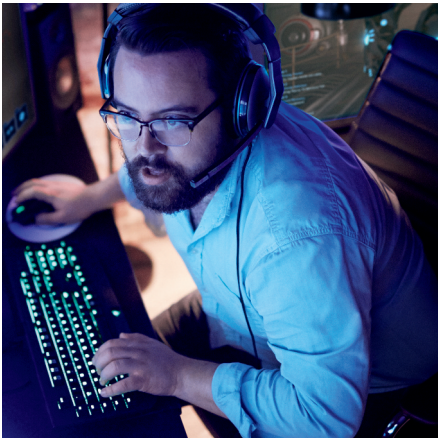# Rocketing the Development of Hypersonic Vehicles

Intel® Parallel Studio XE Cluster Edition, Intel® MPI Library
High-Performance Computing

Moscow Institute of Physics and Technology Creates Faster and More Accurate Computational Fluid Dynamics Software

The field of computational fluid dynamics (CFD) is a large branch of modern scientific computing that has four key elements:

- A real-life problem to be solved

- A set of partial differential equations (mathematical model) to represent the problem

- A numerical method

- A computer

The use of CFD complements both physical experiments and theoretical analysis and is often referred to as computational experiment. The theoretical results are inevitably limited to very simple problems. In practice, experimental studies have been the main approach. But these are time consuming and exceedingly costly. Also, many flow problems (e.g., weather predictions or space craft movements at high altitudes) cannot be studied experimentally.

Although CFD simulation cannot eliminate the need for physical measurements, it can significantly reduce the amount and overall cost of experimentation. In some cases—for instance, when analyzing a storm surge or chemical spill—computer simulation may be the only practical way to analyze the flows with predictive insights. CFD is also important in fundamental studies of flow phenomena, such as turbulence flows.

Computer calculations can effectively simulate flows that are too large or inaccessible for experimental approaches—or where simulations provide the needed answers with less effort and expense. For example, with computer-driven simulations, you can analyze thermal properties and model air flow in a data center. Using information about the size, content, and layout of the data center and its HVAC systems, CFD software can create a 3D mathematical model that can be rotated and viewed from different angles to help identify hot spots and see where cold air is being wasted.

In short, CFD is becoming increasingly important for modern science and engineering.

Swiftly Expanding the Frontiers of the Science of Computational Fluid Dynamics

"The use of Intel® software, such as Intel® Parallel Studio XE Cluster Edition, helps the MIPT Laboratory achieve excellent parallel scalability in solving complicated computational problems in the modeling of complex physical flows."

– Vladimir Titarev, PhD, Leading Researcher, Dorodnicyn Computing Center, Russian Academy of Sciences/ MIPT

The Challenge

CFD analyses are computationally intensive because the simulations have multiple dimensions (three spatial dimensions plus time). Other factors include the complexity of the governing partial differential equations, and mesh resolutions required to represent the complex geometry of flows of interest (e.g., flows over a complete civil airliner). This is the domain of high-performance computing.

Researchers are continually looking to design computing packages that generate more accurate results more quickly for complex simulation scenarios. CFD software must be:

- **Versatile** enough to handle the geometrical complexity and nonlinearity of extremely complex simulations

- **Flexible** to grow and expand as CFD simulations change

- **Portable** and easily modified to be used at different computer platforms

- **Efficient** to deliver answers with the least consumption of time and computing resources

The research laboratories at universities are at the forefront of some of the most exciting advances in CFD today. The Flow-Modellium laboratory of the Moscow Institute of Physics and Technology (http://www.flowmodellium.ru/en/), in Dolgoprudny, Russia, is one such laboratory.

The head of the Laboratory, Professor Sergey V. Utyuzhnikov, is a well-known expert in applied mathematics, numerical analysis in general, and CFD in particular. Since 2005, he has held a permanent academic position at the University of Manchester, UK. For more than 10 years, he was the leader of the Computational Aerodynamics Research Group in the Department of Computational Mathematics at MIPT and the principal investigator in numerous research projects.

Deputy head of the laboratory is Dr. Vladimir Titarev, a specialist in the field of CFD and parallel computing. He worked at the University of Trento (2005-2007) and Cranfield University in the UK (2007-2011) before joining the Dorodnitsyn Computing Center of the Russian Academy of Sciences as a highly published leading researcher.

The Laboratory has a branch in Central Aerodynamic Institute (TsAGI) led by Professor I.V. Egorov.

Professor Utyuzhnikov and his team are advancing the understanding of flow physics and control to apply it to real life. From a software development standpoint, the primary challenges of this mission are to:

- **Integrate** very different multiphysics libraries in the framework of a single code.

- **Support** efficient utilization of multi-CPU clusters (up to 1,000 cores so far)

- **Enable** optimal utilization of the latest Intel® hardware.[1]

The Solution

The lab members develop a number of applications for computational fluid dynamics, including mesh generation, flow visualization, and actual flow solver codes. The latter code is used for mathematical modeling of problems of high-altitude hypersonic aerodynamics of future space vehicles in the complete range of Reynolds and Knudsen numbers as well as unsteady turbulence modeling via a large eddy simulation (LES) approach.
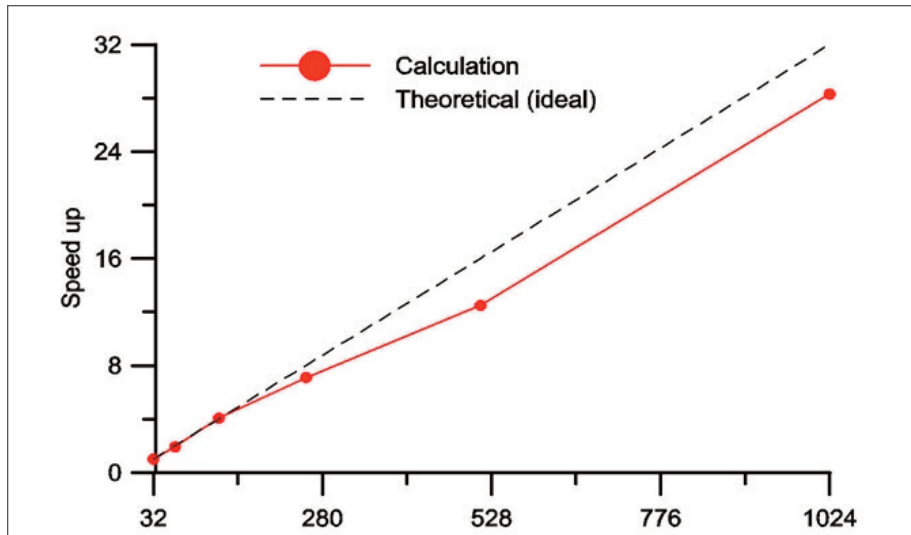
Figure 1. Flow solver code remains close to full theoretical efficiency even as it scales.

Intel provided training and sales support, as well as technical assistance via email or personal discussions. The computational package that grew out of this collaboration is known as the FlowModellium Solver*.

"The distinguishing feature of the code is its unique combination of accurate and efficient numerical methods, together with the inclusion of real non-equilibrium physics in the wide range of flow regimes of hypersonic vehicles," said Utyuzhnikov.

Results

"The use of Intel software such Intel® Parallel Studio XE Cluster Edition [formerly called Intel® Cluster Studio XE] helps the FlowModellium Laboratory solve complicated computational problems in the modeling of complex physical flows and to achieve excellent parallel scalability," said Titarev.

"The main compressible aerodynamics solver scales well up to 1,024 cores, with close to 80 percent parallel efficiency (relative to 32 cores) using mesh of from 5 to 50 million cells. High parallel efficiency enables us to carry out serial computations within very limited time scales," he said.

The Laboratory's second code, the Boltzmann* kinetic solver for rarefied gas dynamics simulations, achieves 95 percent parallel efficiency on 512 Intel® Xeon® processors and 70 percent on 1,024 processors.[2]

Benchmarking has been carried out on supercomputers of the Lomonosov Moscow State University, using four-core Intel Xeon processors and the Laboratory's own high-performance cluster, which uses more recent 12-core Intel Xeon processors.

This efficiency was arrived at after several iterations using different tools. The lab members considered alternative compilers—such as GNU Compiler Collection* (GCC*)/GFortran*—and alternative MPI implementations [the Message Passing Interface communications protocol for parallel computation], such as the chameleon freeware edition MPICH*. In the end, the combination of the Microsoft Visual Studio* integrated development environment and Intel Parallel Studio XE Cluster Edition with the Intel® MPI Library proved to be the most suitable on the grounds of convenience of development and speed.

Intel Parallel Studio XE simplifies the design, development, debug, and tuning of code that uses parallel processing to boost application performance. Intel MPI Library makes applications perform

better on Intel® architecture-based clusters with multiple fabrics.

The use of Intel software, such as Intel Parallel Studio XE Cluster Edition, helps the MIPT laboratory achieve excellent parallel scalability in solving complicated computational problems in the modeling of complex physical flows.

Conclusion

The work of the FlowModellium computing package and the MIPT Laboratory is focused on futuristic vehicles such as airplanes and spacecraft that travel at high speeds. However, CFD software has more down-to-earth applications as well. Quantitative simulations of fluid/gas flow enable research and engineering professionals to:

About MIPT

The Moscow Institute of Physics and Technology (MIPT) is the leading institute of higher education of the Russian Federation, training highly qualified specialists in various areas of modern science and technology.

The Laboratory for Mathematical Modeling of Nonlinear Processes in Gas Media was created at MIPT in 2011 under funding from the Russian government grant, "Measures to Attract Leading Scientists to Russian Educational Institutions" (contract No. 11.G34.31.0072).

Research interests of the laboratory include hypersonic flows, computational fluid dynamics, and the design of space vehicles and CAD systems. The laboratory actively cooperates with the Russian Academy of Sciences, Central Aerohydrodynamic Institute (TsAGI), University of Trento (Italy), Manchester University (UK), North Carolina State University (U.S.), and other institutions.

- **Design** more comfortable, safe, and energy-efficient living and working environments
- **Maximize** the yield from chemical and petroleum industry equipment and processes
- **Improve** the aerodynamics of vehicles for performance and fuel efficiency
- **More accurately** forecast the weather and predict natural disasters
- **Reduce** health risks from radiation, pollution and other environmental contaminants

Shared through dozens of journal publications and collaborative projects, the work of the MIPT team will ultimately inspire advancements in other areas of CFD to improve health, fuel economy, industrial efficiency, and economic vitality.

Intel® Parallel Studio XE Cluster Edition

The Intel® Parallel Studio XE tool suite simplifies the design, development, debug, and tuning of code that utilizes parallel processing to boost application performance. Get more application performance with less effort on compatible Intel® processors and coprocessors.

Intel® MPI Library

Intel® MPI Library focuses on making applications perform better on Intel® architecture-based clusters. It enables you to quickly deliver maximum end user performance even if you change or upgrade to new interconnects, without requiring changes to the software or operating environment.