REDUCING JET AIRCRAFT NOISE BY HARNESSING THE HETEROGENEOUS XK NODES ON BLUE WATERS

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EXECUTIVE SUMMARY:

Reducing the jet exhaust noise from commercial and military aircraft will improve airport efficiency (by increasing the rate by which aircraft land and take-off, especially at night), reduce noise-related environmental pollution near the airport, and reduce noise-related injuries to aircraft personnel. However, the source of the jet noise defies a simple engineering description so very large simulations to accurately model the turbulence-generated sound sources are needed. The spatio-temporal multiscale nature of turbulence found in jet exhaust requires computational resources that exceed current petascale capabilities. The heterogeneous XK nodes on Blue Waters are being used as prototype hardware on which to develop a computational fluid dynamics prediction code that can harness on-node complexity and parallelism at scale in preparation for forthcoming extreme scale (e.g., exascale) computers.

INTRODUCTION

Without a guiding theory, reducing aircraft noise has been left to expensive trial-and-error experiments and, more recently, simulations. The turbulence-induced sound is generated over a very large spatial region leading to a multi-scale nonlinear fluid dynamics problem where the relevant energy is contained over six to ten decades of spatial and temporal scales. Simulations that capture the full range of spatial and temporal scales are beyond current computing capacity but remain our best hope for quieter aircraft. A paradigm shift in computational science, enabled by the XK nodes on Blue Waters, is desperately needed to advance the fields of compressible turbulence and aeroacoustics to reduce the noise from jet aircraft.

The project has impact in three critical areas. By targeting our software development to the heterogeneous XK nodes on Blue Waters we are developing power efficient, high performance computational fluid dynamics codes that can run across thousands of heterogeneous nodes and thus contribute to the emerging programming models and numerical algorithms compatible with forthcoming hardware complexity at extreme scale. Second, the scale of Blue Waters enables the largest simulations of compressible turbulent jet noise ever done that will advance the science of flow-generated sound through carefully conducted simulations and guided post-processing of the 100s-1000s of TB of data generated. Third, new engine nozzle designs will be developed that have the potential to reduce turbulent jet noise and improve the quality of life of airport communities and military personnel.

WHY BLUE WATERS

The research on Blue Waters concentrates on the heterogeneous XK nodes. When using all of the XK compute nodes the aggregate theoretical peak performance is more than 5.5 petaflops. Harnessing all the performance of the XK nodes across the entire Blue Waters system requires significant research and development of new programming approaches that (a) incorporate node-level heterogeneity and (b) can be scaled across 1,000s of nodes. Single node examples of GPU acceleration are commonplace, but codes capable of effectively using massively parallel heterogeneous machines are not.

The research contains two components. The first is focused on algorithm development to take an existing large software application that has already demonstrated scaling up to 100,000 x86 cores on ORNL's Jaguar and transform it into a CPU-GPU application that runs across all 4,000+ XK nodes with the ability to simultaneously use the x86 CPU cores and Kepler GPUs that exist on the XK nodes. The code, which solves the partial differential equations describing a compressible, viscous fluid, is currently based on MPI. To map the code onto CPU-GPU nodes, MPI is insufficient to work at the GPU level. Emerging source-to-source transformation tools that can retarget code to different architectures are needed to (a) reduce repetitious code generation tasks and to (b) abstract away many of the challenges associated with computing on a GPU device connected to a host. CPU source-to-source transformations represent a significant research task because there will be considerable inter-dependence on the memory utilization and localization, task pooling and scheduling, and bus contention on the XK.

The second component of the research utilizes the CPU-GPU enabled code on the XK nodes to conduct fundamental research on the reduction of jet noise from commercial jet aircraft engines. By building on existing research support in this area from the Air Force Office of Scientific Research and the Office of Naval Research, the heterogeneous code run across all of the XK nodes, simultaneously using the CPUs and GPUs, permits the largest, most ambitious investigation into turbulent jet noise ever conducted and allows, for the first time, detailed links to be established between the jet engine nozzle shape, the turbulent noise sources and, ultimately, the radiated sound. The simulations are conducted in two parts: first we use the immense scale and i/o capability of Blue Waters to conduct the most detailed study of how turbulent jet noise is produced over the range of jet exhaust conditions (namely, velocity and temperature) most commonly encountered in aircraft. The databases for these simulations will approach 1 PB in aggregate and provide unprecedented detail into the physics of noise generation. We will make these databases publically available. The second objective of the simulations is to design a quieter jet engine nozzle using an adjoint-based inverse design approach. At Blue Waters scale this design will be a watermark in the development of reduced jet engine noise because both the nozzle and flow will be included simultaneously. Because of the computational cost involved in adjoint-based design of fully turbulent flows, no such calculation has previously been attempted. Even at Blue Waters scale only one jet condition can be considered, and we will choose a high-subsonic dual stream jet exhaust typical of modern gas turbines, with a cool outer stream and hot inner stream. This simulation's objective is to identify what nozzle modifications are best suited for aircraft jet noise reduction. The societal impact of environmental noise pollution reduction is critical around airports, and a pacing issue for the health of military personnel operating on naval aircraft carriers. There are no computational resources available where several petaflops of computing resource can be utilized for a single calculation.

In 2015 we used the Blue Waters XK7 nodes, with NVIDIA GPGPUs. Our software tool H-MxPA, developed originally by Professor Wen-mei Hwu (University of Illinois at Urbana-Champaign), has been extended by creating a node-level runtime system that (a) permits asynchronous, simultaneous execution of the same kernel written in OpenCL on multicore CPUs and many core NVIDIA Kepler GPGPUs and (b) can discover and optimize the work distribution between streams sent to the CPU cores and GPGPUs cores, taking into account host-device transfer latency and data transfer times.

The H-MxPA runtime will continue to be hardened within the proxy application that replicates the data structure complexity and parallel environment found in the target application, PlasComCM. Continuing into 2016 we will implement the runtime in PlasComCM, verify the correctness of the results generated by code compiled with H-MxPA, and apply it to a series of increasing complex jet exhaust noise simulations using grids with up to 2 billion grid points and 10 billion degrees of freedom.