

A Look at the Impact of High-End Computing Technologies on NASA Missions

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Abstract

From its bold start nearly 30 years ago and continuing today, the NASA Advanced Supercomputing (NAS) facility at Ames Research Center has enabled remarkable breakthroughs in the space agency's science and engineering missions. Throughout this time, NAS experts have influenced the state-of-the-art in high-performance computing (HPC) and related technologies such as scientific visualization, system benchmarking, batch scheduling, and grid environments. We highlight the pioneering achievements and innovations originating from and made possible by NAS resources and know-how, from early supercomputing environment design and software development, to long-term simulation and analyses critical to design safe Space Shuttle operations and associated spinoff technologies, to the highly successful Kepler Mission's discovery of new planets now capturing the world's imagination.

Keywords

Information Technology and Systems; Aerospace; History of Computing; Parallel processors, Processor Architectures; Simulation, Modeling, and Visualization

The story of NASA's IT achievements is not complete without a chapter on the important role of high-performance computing (HPC) and related technologies. In particular, the NASA Advanced Supercomputing (NAS) facility—the space agency's first and largest HPC center—has enabled remarkable breakthroughs in NASA's science and engineering missions, from designing safer air- and spacecraft to the recent discovery of new planets.

Since its bold start nearly 30 years ago and continuing today, NAS has led the way in influencing the state-of-the-art in HPC and related technologies such as high-speed networking, scientific visualization, system benchmarking, batch scheduling, and grid environments. The pioneering achievements and innovations made possible by the organization's resources and know-how became the model for subsequent HPC centers around the world. Early supercomputing environment design, software development, and network and storage technologies were all driven by NAS's original purpose: to provide a computational capability that would radically change the U.S. aerospace research and development cycle from a slow and costly wind-tunnel-centric process to one using efficient simulation-based design and engineering methods.

This unique and ambitious model has always combined the expertise of aeronautics and aerospace engineers specializing in computational fluid dynamics (CFD) with software

development and computer technology. Through this approach, NAS has become a leader and partner in the ongoing development of high-fidelity modeling tools and applications critical to simulation and analyses for designing safer, more fuel efficient, and environmentally friendly aircraft and revolutionary space exploration vehicles. NASA's Space Shuttle program and associated spinoff technologies, including a life-saving heart assist device, were in large part enabled by NAS resources and expertise.

Today, in collaboration with government, industry, and university partners, NAS continues to push the bounds of IT limits within the HPC community. For example, the facility's football-field-sized computer room boasts the largest InfiniBand fabric in the world to connect its supercomputing, visualization, and storage resources. And the Pleiades supercomputer, an SGI Altix system based on Intel processors, combined with innovative data analysis and visualization tools, plays an essential role in the highly successful Kepler mission's discovery of new planets now capturing the world's imagination.

Rich History in HPC Sets Scene

Long before the visionaries who dreamed up the NAS concept broke ground in 1985 on the building that houses its supercomputing resources today, Ames Research Center had a rich history of pioneering work in CFD and HPC. Originally established in 1939 under NASA's predecessor organization, the National Advisory Committee for Aeronautics (NACA), Ames became a laboratory for wind-tunnel research on the aerodynamics of propeller-driven aircraft. When the idea of combining computer power with the emerging field of CFD arose in the late 1960s, Ames already had a lineup of science and technology experts on hand when it set up a CFD branch staffed by world-renowned scientists to make breakthroughs in numerical modeling for aeronautics applications. The team made enormous strides in computer programming, numerical methods, and turbulence modeling for aerospace and turbomachinery applications. The Baldwin-Lomax turbulence model used for high-speed flows with thin attached boundary layers, became one of the premier models in the world, and is still widely used today [1]. Converging with the arrival of the 256-processor ILLIAC IV in 1972 [2]—the first attempt at parallel computing—these efforts set the scene for pushing the envelope of CFD and supercomputing.

Fast forward through the years 1976 to 1983, when a band of determined researchers and CFD leaders in industry, government, universities won congressional approval for the Numerical Aerodynamic Simulation (NAS) Program [3]. This visionary team developed and championed the basic concept behind NAS: to create a national capability to ensure continued U.S. leadership in CFD and related specialties.

Early Environment and Innovations

The first decade of this unique effort brought about many "firsts" in IT technology, while at the same time enabling important science and engineering breakthroughs. These early innovations, the outcome of partnerships with both industry and other government organizations, leapfrogged the technologies of their time, and are the source of many of today's IT standards.

In 1983, NAS installed its initial hardware, two DEC VAX 11/70s named Orville and Wilbur, in its temporary home at the Central Computing Facility (CCF) at Ames, just down the hall from

the ILLIAC IV. Engineers designed a novel, net-centric environment—the first to put the UNIX operating system on production HPC systems. This was also the first time the TCP/IP protocol, developed by the Defense Advanced Research Project Agency (DARPA), was used for connecting to a supercomputing environment.

The next year, the NAS Program installed a single-processor Cray X-MP 12—Cray’s first customer installation of a UNIX-based system. At the same time, 25 Silicon Graphics Inc. (SGI) graphics terminals arrived, providing the opportunity for another first: the linking of supercomputers and UNIX workstations to distribute computation and visualization, today called the client-server model.

The first Cray-2 off the production line was installed at the CCF in 1985. This four-processor system, called Navier, later helped meet the program’s initial goal of attaining a sustained system performance rate of 250 megaflops per second (Mflop/s). NAS’s current Pleiades supercomputer, a 113,408-core SGI Altix ICE system running at a sustained rate of more than 1.09 petaflops, is more than four million time faster.

In 1988, a Cray Y-MP system called Reynolds, used by the Department of Defense for classified computing, reached the program’s performance goal of 1 gigaflops per second (Gflop/s) sustained performance for CFD applications. At the same time, a new 16,000-processor Connection Machine CM-2 initiated computer science studies in massively parallel computing. Rounding out its first 10 years of operation, NAS installed a 16-processor Cray C90 (15.36 Gflop/s peak), which arrived just hours after removal of the Cray-2. This new system, named von Neumann, allowed the facility to run many more multitasking jobs around the clock.

Moving into the Modern HPC Era

During its second decade of operation, NAS began and led a series of HPC advances, championing the single-system image (SSI) paradigm, in which a cluster of machines appears to be one system. Even during the late ’90s, when shuttle launches seemed routine and the agency reduced its investment in supercomputing capabilities and CFD research, NAS sustained its worldwide leadership in SSI. These advances increased NASA’s computing capability and influenced the agency’s venture into grid technologies.

In 1995, NAS (now called the Numerical Aerospace Simulation Division) installed a 64-processor SGI Origin 2000 system named Turing—the first of its kind to be run as a single system. When SGI next developed a 256-processor machine to meet NASA’s growing HPC requirements, the experience led to development of increasingly larger SSI systems that improved programmer productivity, ease-of-use, and system administration.

The world’s first 512-processor SSI supercomputer, an SGI Altix system named Kalpana, was critical to supplying time-critical analyses for determining the cause of the Shuttle Columbia accident in 2003. Kalpana also supported several joint projects among various NASA centers; for instance, the Estimating the Circulation and Climate of the Ocean (ECCO) [4] model dramatically accelerated the development of highly accurate analyses of global ocean circulation and sea-ice dynamics.

By mid-2004, the importance of supercomputing-enabled high-fidelity modeling and simulation for aerospace and other missions was clear. Expansions continued through the first decade of the new millennium, including installation of a 640-core IBM POWER5+ (Schirra) and a 2,048-core SGI Altix 4700, Columbia (13 Tflop/s peak), which was the largest SSI computer to date.

Columbia eventually grew to 10,240 processors, and in 2004 captured the second highest spot on the TOP500 list of the fastest supercomputers in the world. More importantly, with a ten-fold increase in HPC capacity, NASA was able to pursue its new space exploration mission and simultaneously conduct leading research in Earth science, astrophysics, and aerospace modeling. Through the years, NASA users relied heavily on Columbia for modeling flow features in the shuttle flowliner, validating numerical weather prediction capabilities, and designing next-generation exploration vehicles.

Today, NAS operates the 113,408-core Pleiades supercomputer, currently the 7th most powerful supercomputer on the TOP500 list [5]. Installed in 2008, Pleiades built on the previous work with SGI and Intel to significantly increase NASA's supercomputing performance and capacity. It allowed agency codes to run with minimal modifications, and was compatible with standard engineering workstations so users could easily migrate their codes. Among the key missions supported were extensive simulations of large computational problems for future space vehicle design, development of increasingly detailed models of large-scale dark matter halos and galaxy evolution, and running coupled atmosphere-ocean models to assess decadal climate prediction capability for the Intergovernmental Panel on Climate Change.

In June 2011, Pleiades reached an important milestone: a sustained performance rate of more than 1 petaflop/s, representing 83% of theoretical peak—an impressive feat, considering that it runs on three generations of processors and two generations of InfiniBand. Recently, the power and speed of this system enabled scientists at the University of California, Santa Cruz, and New Mexico State University to generate the largest and most realistic cosmological simulations of the evolving universe to date. The “Bolshoi” simulation code helps explain how galaxies and other very large structures in the universe have changed since the Big Bang [6]. Systems engineers also recently added 64 new Intel Xeon 5600 nodes with NVIDIA m2090 graphics processing units (GPUs), which will be used to accelerate both computation and visualization.

Network Technology Innovations

High-speed networking technologies have always been integral to the performance of NASA HPC systems. Since the arrival of the first Cray system at Ames, network and systems engineers have worked collaboratively to develop innovative approaches for improving network performance for the agency's unique applications and large data transfers. Today we take for granted the ubiquitous availability of network connections across the globe, but in 1985, the debut of NASnet [7], a specialized, long-haul communications subsystem connecting aeronautics researchers across the country to HPC resources at Ames was cause for celebration—it was the first time a supercomputer was connected to a TCP/IP network without using a front-end system. Six years later, engineers began building the second-generation NASnet, called AEROnet, which was the first high-speed wide-area network (WAN) connecting supercomputing resources to remote customer sites. In 1996, the NAS networking staff successfully connected AEROnet and

DARWINnet, a secure local-area network at Ames, to facilitate remote access to wind tunnel and other aircraft design testing facilities across the agency.

In 2005, NAS staff associated with the NASA Research and Education Network (NREN) worked with National Lambda Rail (NLR) and Level3 Communications, Inc., to establish the first 10Gb/s WAN capability between Ames and other NASA centers. Such high-speed connections were critical for optimal utilization of the Columbia supercomputer and for transferring the vast amount of data required to solve the agency's challenging problems.

Today, the largest InfiniBand fabric in the world interconnects Pleiades with RAID drives and archival storage systems through more than 65 miles of cabling. This high-speed local area network is composed of a 10-gigabit (Gb/s) backbone supporting HPC and visualization systems, and includes almost 900 Ethernet ports.

Meeting Mass Storage Demands

While data transfer, management, and archiving has always been a key component of NAS's model, the late '80s were banner years for the NAS storage environment. A partnership with DARPA and the University of California, Berkeley, produced the Redundant Array of Inexpensive Disk (RAID) project that led to the distributed computer data storage technology used today. Another storage-related innovation was the development of the first UNIX-based hierarchical mass storage system, NASstore. Comprising two StorageTek 4400 cartridge tape robots, each with a capacity of about 1.1 terabytes (TB), NASstore reduced tape retrieval time from 4 minutes to 15 seconds.

Since 2004, NAS has seen a steep growth in demands for data storage. Users' storage requirements have zoomed about 85% each year, putting a heavy load on existing archive file systems. This trend is largely due to the increasing resolution of simulation runs and larger-capacity, higher-throughput supercomputers such as Pleiades and Columbia. In 2004, users transferred data into the archive at an average rate of 1.8 TB per day—that number is now 25 TB.

Today's HPC environment includes a 45-petabyte (PB) archive storage capacity and 400 TB of online disk cache, plus about 10 PB of disk storage attached to NAS supercomputing and data analysis systems. Data stored on RAID is migrated to tapes as needed, and copies of users' data are written to tape media in silos located in two different buildings. Recently, NAS storage experts installed a new open-source Lustre filesystem with double the disk capacity and 10 times the I/O operations per second performance of the old filesystem.

Data Analysis & Scientific Visualization

Since the first SGI graphics terminals were linked to the Cray-2 in 1985, scientific visualization has been an essential component of the NAS HPC environment. The organization's experts in this arena continually research, develop, and apply innovative tools and techniques to greatly enhance the understanding of computational simulations and experimental data for science and engineering problems. For instance, the Graphics Animation System (GAS) was used to create animations of particle traces moving through flow fields in the Space Shuttle Main Engine

(SSME). The interactive 3D Virtual Wind Tunnel allowed users to explore and analyze complex structures found in fluid flow simulations, such as momentum and density characteristics on a Harrier jet model. NAS's multidisciplinary experts were the first to develop and distribute software for automatic detection and visualization of 3D flow field topology, such as vortex cores and separation lines. The Flow Analysis Software Toolkit (FAST [8]), a modular software environment for visualizing and analyzing CFD scalar and vector data, garnered the NASA Software of the Year Award in 1995.

In 2002, NAS developed the hyperwall, a graphics cluster connected to a wall of 49 LCD panels, which enabled scientists to view and explore complex datasets and computational results. The follow-up hyperwall-2 system, powered by 128 graphics processing unit (GPU)-based nodes, was the highest resolution display in the world when it went online in 2008. Recently, the hyperwall-2 was upgraded to Nvidia GeForce 480 GTX cards, with peak GPU performance of 136 Tflop/s and 1.5 PB of dedicated storage, plus access to all of Pleiades storage. As part of NAS's ongoing support for the agency's current Kepler mission in its search for other life-supporting planets, visualization experts have employed innovative techniques to improve both accuracy and performance of the tool used to discover and confirm planet candidates.

NAS has also developed a sophisticated multi-stream concurrent visualization method to process and display data in real time while applications run on its supercomputers. This important method makes it feasible to render and store animations showing every simulation timestep, allowing users to see rapid processes in their models—often for the first time. Concurrent visualization has proven crucial to, for example, understanding the complex nature of rotor wakes, enabling near-real-time tropical track and intensity forecasts (Figure 1), and generating large-scale, high-resolution animations of dark matter in Earth's galactic neighborhood.

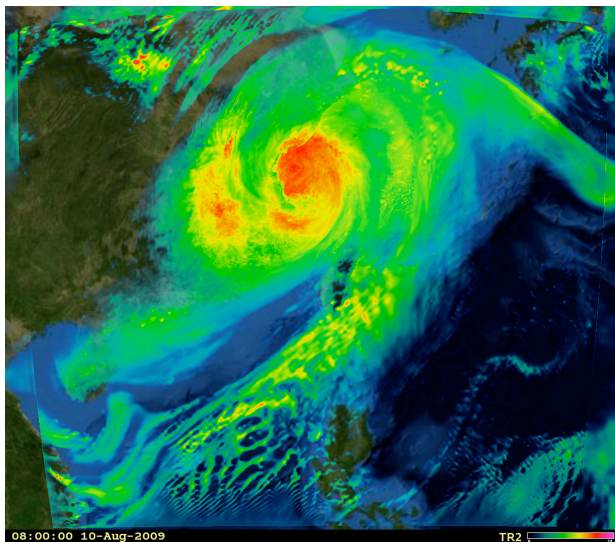


Figure 1. Image from 96-hour simulation of the 2009 Typhoon Morakot, done for atmospheric scientists at NASA Goddard's Mesoscale Dynamics and Modeling Group, as part of their research to improve accuracy of weather simulation. (David Ellsworth and Bryan Green, NASA/Ames; Wei-Kuo Tao, NASA/Goddard)

Other HPC-Related Achievements

While the NAS Division's other notable HPC-related achievements are too numerous to review, three bear mentioning: system benchmarking, system scheduling software, and grid technologies.

System Benchmarking: In 1991, a team of computer scientists unveiled the NAS Parallel Benchmarks (NPB) [9], developed in response to the program's increasing involvement with massively parallel architectures. These benchmarks mimic computation and data movement of large-scale CFD applications, and provide objective evaluation of parallel HPC architectures. The original benchmarks featured "pencil-and-paper" specifications, which bypassed many of the difficulties associated with standard benchmarking methods of the time for sequential or vector systems. The suite consisted of five parallel kernels and three simulated applications, in order to measure the true performance of real-world CFD applications used by scientists on NAS supercomputers. The NPBs quickly became an industry standard, and today's version is widely used to evaluate sustained performance of highly parallel supercomputers.

Scheduling Software: In 1994, NAS and Lawrence Livermore National Laboratory began alpha-tests of the Portable Batch System (PBS). Based on the earlier NAS Queuing System (NQS), the first batch queuing system for supercomputers, PBS improved batch job scheduling and resource management for massively parallel computers, clustered workstations, and traditional supercomputers. Success led to commercialization of PBS in 1998, and today PBS Professional (currently distributed by Altair Engineering) is used to schedule all computational jobs at NAS and other HPC facilities around the world.

Grid Technologies: As part of the effort to connect agency HPC resources, the NAS organization became an early proponent of grid technologies, and in the late '90s developed NASA's first distributed, heterogeneous computing infrastructure. The Information Power Grid (IPG) was designed to seamlessly blend computing systems, data storage, and analysis software connected through high-speed networks across the agency. This ambitious prototype was aimed at enabling users to spend more time on research and less time learning how to use the resources required to run their applications. The IPG project led to future work in integrating HPC resources at Ames and Goddard, and is considered a precursor to cloud computing.

Partnerships in Aeronautics

While over the years NAS has diversified its supercomputing-related work to include support for NASA mission areas in Earth science, study of the planets, and understanding the origins of the universe, it has never strayed from its original charter to provide a cutting-edge, multidisciplinary HPC facility for maintaining U.S. leadership in aeronautics. This includes applying supercomputing and CFD technologies to the design, development, and construction of aircraft, rotorcraft, spacecraft and their components.

In 1987, researchers at General Dynamics Corp. utilized the 4-processor Cray-2's large memory capacity to obtain Euler and Navier-Stokes solutions for a complete, high-resolution configuration of an F-16 fighter jet. The Cray-2 was also used to run CFD calculations to investigate vertical and short-takeoff and landing (V/STOL) flows to gain better understanding of the interaction of propulsive jets with V/STOL aircraft and the ground, and other flow

phenomena.

NAS computational experts also worked with the U.S. Navy and McDonnell Aircraft Company to demonstrate how CFD could speed up aircraft design and engineering processes by reducing the number of expensive, time-consuming wind tunnel tests. They developed numerical algorithms and coding methods demonstrating CFD's ability to predict aerodynamic loads on the F/A-18, a supersonic, all-weather fighter jet, and later employed the NASA-developed High-fidelity Multidisciplinary Analysis Process (HiMAP) software to understand the flow phenomena involved in abrupt wing stall incidents on the F-18 E/F.

Many of the complex physical phenomena associated with both aircraft and rotorcraft flight are still not well understood and difficult to predict accurately. In the rotorcraft arena, these include blade deformations, noise, vortical wakes, and blade-wake interactions. Over the last decade, CFD researchers have supported industry through development of improved physics-based computational tools that will lead to reduced rotorcraft noise pollution and better heavy-lift capabilities in situations where airports are not practical or available, such as rescue missions (Figure 2).

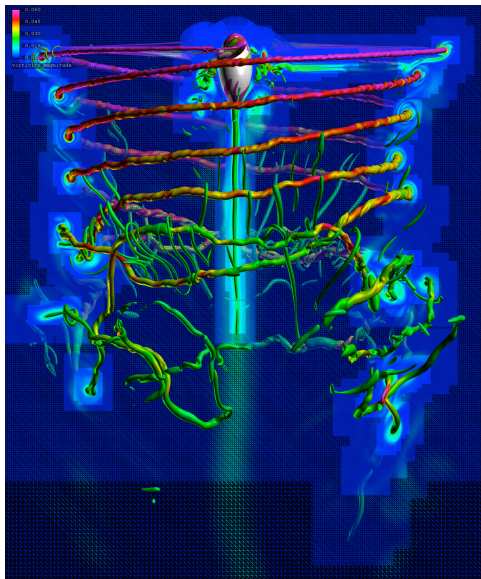


Figure 2. Navier-Stokes simulation of an isolated V-22 Osprey rotor in hover. Two levels of grid adaption improve rotor vortex resolution and predict the “Figure of Merit” within experimental accuracy. Magenta is high vorticity and blue is low vorticity. (Neal Chaderjian, Timothy Sandstrom, NASA/Ames)

Impacts on Space Shuttle

From the start, NAS computing cycles, modeling and simulation expertise, and visualization methods have played a critical role in improving the performance, reliability, and safety of NASA's most recognized and inspiring effort—the Space Shuttle Program.

Rewind to 1984. The Cray X-MP and Cray-1 systems at Ames were being employed by a team

of NASA researchers collaborating with Rocketdyne to generate CFD solutions for redesigning the SSME hot gas manifold in the powerhead [10]. The original three-duct hot gas manifold designed in the '70s (and used on the first shuttle launch in 1981) was replaced by a new two-duct design that improved overall SSME performance and reliability. Analysis using the INS3D flow solver [11] (developed at NAS, and winner of the 1994 NASA Software of the Year Award) showed that the two-duct design reduced pressure gradients within the system and lowered temperatures in the engine during operation, resulting in reduced stress on the turbopump and main injector. After extensive testing, the newly designed powerhead made its debut on Shuttle Discovery's 20th mission (STS-70) in July 1995, and was used on all subsequent missions.

NASA researchers also developed and enhanced a computational framework to design and analyze the entire fuel supply system of the SSME's liquid oxygen and liquid hydrogen turbopumps. This work, which began in 1985, included high-fidelity unsteady flow analysis that decreased design costs and improved engine performance and reliability.

These enhancements to the SSME were also applied to one of the most inspiring technology achievements coming from the NAS Division. In collaboration with MicroMed Technology, Inc., CFD experts, using HPC resources, improved the design of the DeBakey Ventricular Assist Device (VAD), winner of NASA's Commercial Invention of the Year in 2001. At that time, the life-saving VAD had been successfully implanted in more than 100 heart patients waiting for transplants, with no reported failures.

Along with important contributions to the Space Shuttle Program's success, the NAS facility became critical to supporting investigations of its tragedies. After the 1986 Challenger disaster, researchers at NASA Langley used HPC systems to understand and analyze what caused the accident, focusing on the O-ring. This work produced the largest 3D structural simulation in the world at the time. Starting in 2002, the computational framework was also used to investigate the root cause of cracks in the flowliner of the SSME fuel-line.

Immediately following the loss of Shuttle Columbia on February 1, 2003, NAS CFD experts began using their state-of-the-art codes to simulate flow fields around Columbia during ascent. Their simulations provided insight into the mechanism of debris shedding from the bipod-ramp region. These debris simulations and aerodynamic analyses were used in foam impact tests done for the Columbia Accident Investigation Board (CAIB). The resulting CAIB report concluded that the catastrophic accident was caused by damage sustained when a piece of foam insulation falling from the vehicle's bi-pod ramp on the external tank struck the leading edge of Columbia's left wing, piercing a reinforced carbon-carbon tile of the thermal protection system [12].

These simulations were enabled by the 512-processor, SSI system, Kalpana. In short order, more than 450 full simulations were run using about 600,000 processor hours. Researchers computed and delivered hundreds of CFD simulations of the Space Shuttle Launch Vehicle (SSLV) during ascent (Figure 3) using the highest fidelity SSLV model grid system ever produced. From this point on, NAS CFD expertise and HPC resources were at the forefront of critical safety analysis for shuttle missions for NASA's Return to Flight effort and all remaining launches.

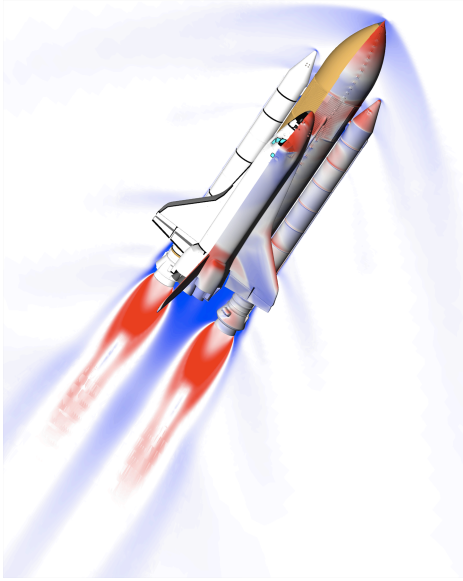


Figure 3. Surface pressures on the Space Shuttle launch vehicle and velocity in a plane through the External Tank and Solid Rocket Boosters, at Mach 1.40. (Reynaldo Gomez, NASA/Johnson; Stuart Rogers, NASA/Ames)

Next-Generation Space Vehicle Design

Over the last several years, the knowledge and understanding gained from using these advanced CFD software and HPC technologies for shuttle operations have been used for design analysis to improve the safety and reliability of next-generation space exploration vehicles. Since 2004, when NASA's then Constellation Program aspired to replace the aging shuttle vehicles to return humans to the moon, millions of processor hours have gone into supporting simulations for ground operations, risk analysis, and launch abort scenarios for future crewed missions to space.

Two extensive ground operations efforts involved the Vehicle Assembly Building (VAB) and the launch pad at NASA Kennedy. In the first case, the goal was to find out whether the VAB could safely handle storage of the significantly greater amounts of fuel required for next-generation vehicles. Experts implemented high-fidelity CFD tools to simulate and predict the effects of various VAB scenarios to determine the probability of a fire in one solid rocket booster (SRB) bay igniting any of the other three bays in the VAB, and to assess the resulting effects on other nearby structures. The fire scenarios, running for several minutes of "real time" with just a moderate level of detail, required 6 to 8 weeks of runtime on the Columbia supercomputer.

Additionally, NASA's simulation capability has been used to help determine whether the existing launch pad flame trench and deflector system used to launch the shuttle could withstand flow generated by next-generation launch vehicles. By combining engineering methods with high-fidelity aerodynamics simulations run on Columbia and Pleiades, NASA teams are using the OVERFLOW CFD code [13] and CART3D [14] (another award winning software package developed at NASA) to streamline the development of these vehicles. Work includes analyzing dozens of potential design shapes for launch and crew exploration vehicles, generating aerodynamic databases for each major design iteration, and conducting extensive probabilistic

risk assessment models for vehicle ascent.

More recently, modeling and simulation experts are collaborating with NASA industry partners to provide risk assessments of commercial spacecraft. As part of this work, NAS's engineering risk assessment (ERA) team delivered a series of analyses characterizing both the debris field generated by activation of the flight termination system during ascent and the resulting strike probabilities for an aborting capsule. They have also produced an Abort Assessment Guide [15], which documents current best practices for assessing the abort capabilities of potential designs for commercial crew launch systems, based on ERA methodologies.

Looking Forward

The original band of leaders who envisioned the ideal high-performance computing environment would still recognize their revolutionary model, despite the enormous technology shifts that have taken place over almost 30 years. Their winning formula is very much a part of the NAS environment looking forward, when NASA's supercomputing requirements are expected to continue to grow exponentially.

To keep pace with new, emerging HPC requirements needed support the 450-plus science and engineering projects that rely on its resources, the NAS Division is preparing for a significant technology refresh that will soon increase its HPC capacity another ten-fold. Storage will continue to expand in order to meet users' growing data storage needs, an expected 400% increase over the next three years. The organization is also delving into technology advancements such as large GPU clusters and streaming visualizations to remote users. Over the next few years, scientific visualization will continue to become more tightly integrated into the traditional environment of supercomputing, storage, and networks to offer an even more powerful tool to scientists and engineers.

Together with its partners, the NAS Division will continue supporting NASA's grand vision to conduct pioneering aeronautics research, design future crewed space vehicles, and gain a better understanding of the universe. This important IT work will be achieved through continuous innovations in HPC that expand scientific discovery and boost engineering productivity—helping ensure the success of America's space program for generations to come.

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John Hardman is a senior web developer with Computer Sciences Corp., working at the NASA Advanced Supercomputing (NAS) Division at Ames Research Center. He is responsible for a number of high-profile NASA websites and other media projects. With more than 20 years experience in electronic media, John is a national award-winning writer, designer, director, producer, and developer whose clients have included Apple, BMW, Capitol Records, Sports Illustrated, and Time-Warner. John holds a B.A. degree in philosophy from Santa Clara University.

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