National Aeronautics and Space Administration

High End Computing Capability (HECC) Program Overview

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NASA Facilities Engineering and Real Property Conference

Nashville, TN *12 May 2011*

M&S Imperative for NASA R&D

Why NASA needs high-fidelity modeling & simulation

- M&S (digital experiments) and physical experiments are tradable
- In many domains, physical systems and experiments are expensive, dangerous (e.g., extreme environments), require long wait, offer limited sensor data
- In contrast, decades of exponentially advancing HEC technology enabled dramatic improvements in cost, speed, and accuracy of M&S – plus the predictive capability
- Numerous studies conclude simulation is key to progress in science and engineering, and level of complexity unattainable by strictly experimental or theoretical methods
- M&S provides a national advantage for economic competitiveness, education, national security, science and technology, energy and environment, transportation, etc.
- Aero R&D Plan and other agencies identify supremely challenging goals to greatly extend boundaries of human knowledge and technological achievement
- Earth and space sciences require orders of magnitude increases in M&S capability for extremely accurate predictions, data assimilation, and understanding the universe
- Space transportation and exploration (government and/or commercial) need M&S to accelerate R&D, reduce mission design cost, and mitigate risk

M&S essential to rapidly and cost-effectively advance Agency goals

HEC Characteristics

HEC required to be at leading edge of computing technologies

- Unlike org-wide IT infrastructure, HEC is fundamentally driven to provide a rapidly increasing capability to a relatively small but very diverse and critical set of customers
- Requires regular, frequent, highly-specialized hardware and systems software refreshes to leverage the latest technologies
- Requires regular, specialized application software R&D to optimally exploit new architectures to efficiently solve complex NASA problems
- Requires pain-free accessibility by remote collaborators and partners

NASA HEC strategy cannot solely rely on industry or market-driven advances in underlying technologies

- HEC must take advantage of multiple highly dynamic and somewhat speculative technology domains
- NASA requirements often drive new supercomputer architectures and technology advances that are being / will be developed by industry

Key characteristics of successful HEC governance in other parts of the Federal Government (DOE, DoD, NSF, etc.)

- “Corporate level” funding with built-in capital refresh budgets
- Robust customer program engagement in governance and management
- Strong infrastructure and facilities support

Purpose and Scope of HECC

Established as one of the first two SCAP assets in 2006

- SCAP goal was to ensure that vital NASA assets and capabilities shared by multiple Mission Directorates remained healthy and were sustained
- HECC cemented NASA's long-term commitment to supercomputing as an essential resource for broad mission success
- NAS has stellar history and international reputation as pioneer in the development and application of HEC technologies, products, and services

Governance Model

- Program Executive within HQ-SMD Earth Sciences Division
- Board of Advisors with one representative from each MD and concurrence from OCIO
- Allocation of resources among MDs based on historical usage, prior investments, and future requirements

Funding Structure

- Baseline funding at Agency level provides "free" resources and services (MDs select own projects, determine priorities, and distribute their share of resources)
- Marginal investments by MDs (from ARMD, ESMD, and SMD) demonstrate current model has strong support and buy-in
- Created collective action not dependent on individual budgets and organizations

Advantages of Current HECC Model

NASA owned and supported in-house supercomputing resources

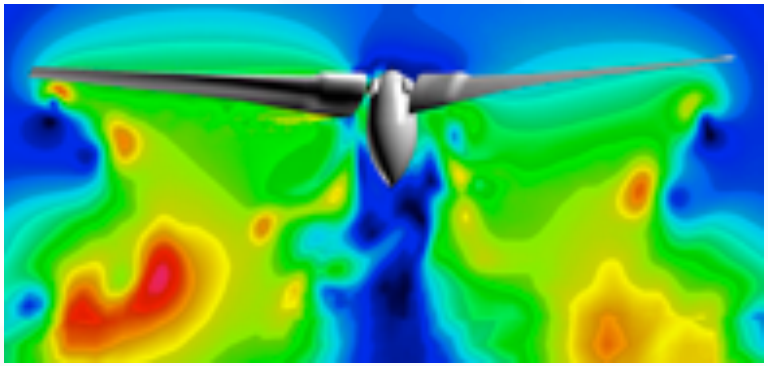
- Integrated support to NASA scientists and engineers, not just bare cycles as available from third-party external vendors of compute resources
- Multiple studies have shown this to be more cost-effective, reliable, secure, and best able to meet NASA's computational requirements
- Push the technology (and HEC vendors) to meet NASA's evolving modeling, simulation, and data analysis requirements via mostly COTS hardware and open-source software

NASA-wide consolidated supercomputing resources

- Leverage expertise to serve the entire Agency's supercomputing requirements – provides better support for acquisition and management of resources
- Balances demand and utilization across users from all NASA projects (meets dynamic peak demands of critical projects without having to maintain project-owned resources)
- Projects do not pay directly for baseline cycles and support (MDs control allocation according to their priorities), but still have option to augment resources if needed

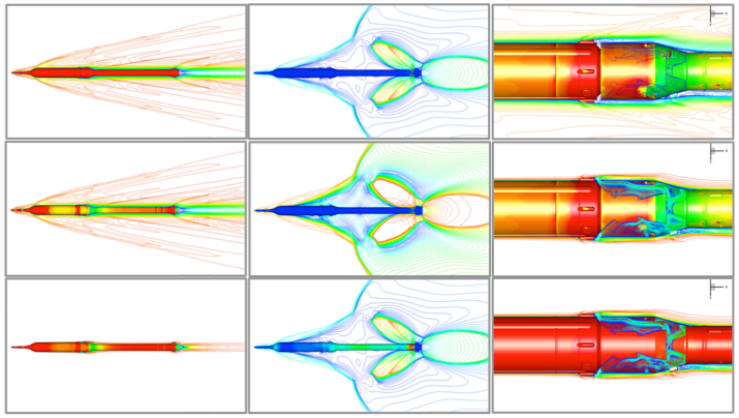
NASA's Diverse HEC Requirements

1) Engineering requires HEC resources that can handle large ensembles of moderate-scale computations to efficiently explore design space **(high throughput / capacity)**
2) Research requires HEC resources that can handle high-fidelity long-running large-scale computations to advance theoretical understanding **(leadership / capability)**

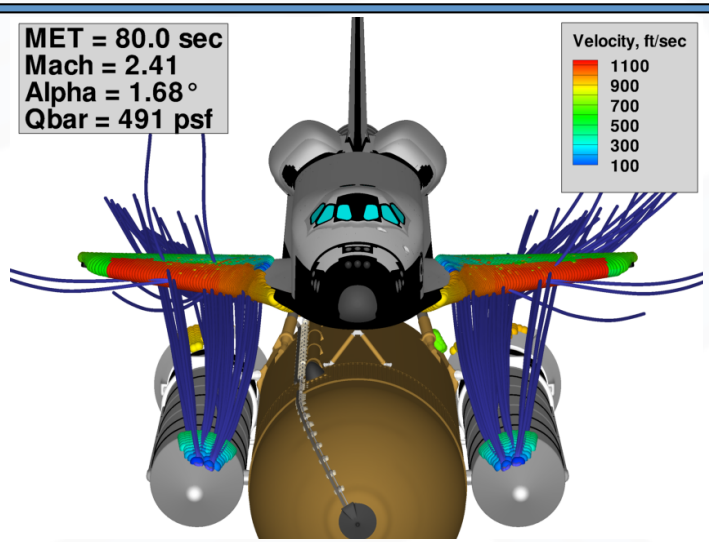


Rotary wing aerodynamics

3) Time-sensitive mission-critical applications require HEC resources on demand **(high availability / maintain readiness)**



Aerodynamic database generation



Space Shuttle debris transport analysis

High End Computing Capability

Four major technical areas

Supercomputing Systems

Provide computational power, mass storage, and user-friendly runtime environment through continuous development and deployment of management tools, IT security, systems engineering

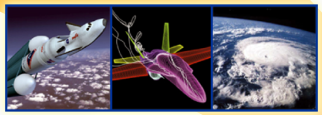
Application Performance and Productivity

Facilitate advances in science and engineering for NASA programs by enhancing user productivity and code performance of high-end computing applications of interest

HECC

Data Analysis and Visualization

Create functional data analysis and visualization software to enhance engineering decision support and scientific discovery by incorporating advanced visualization technologies and graphics displays



Networking

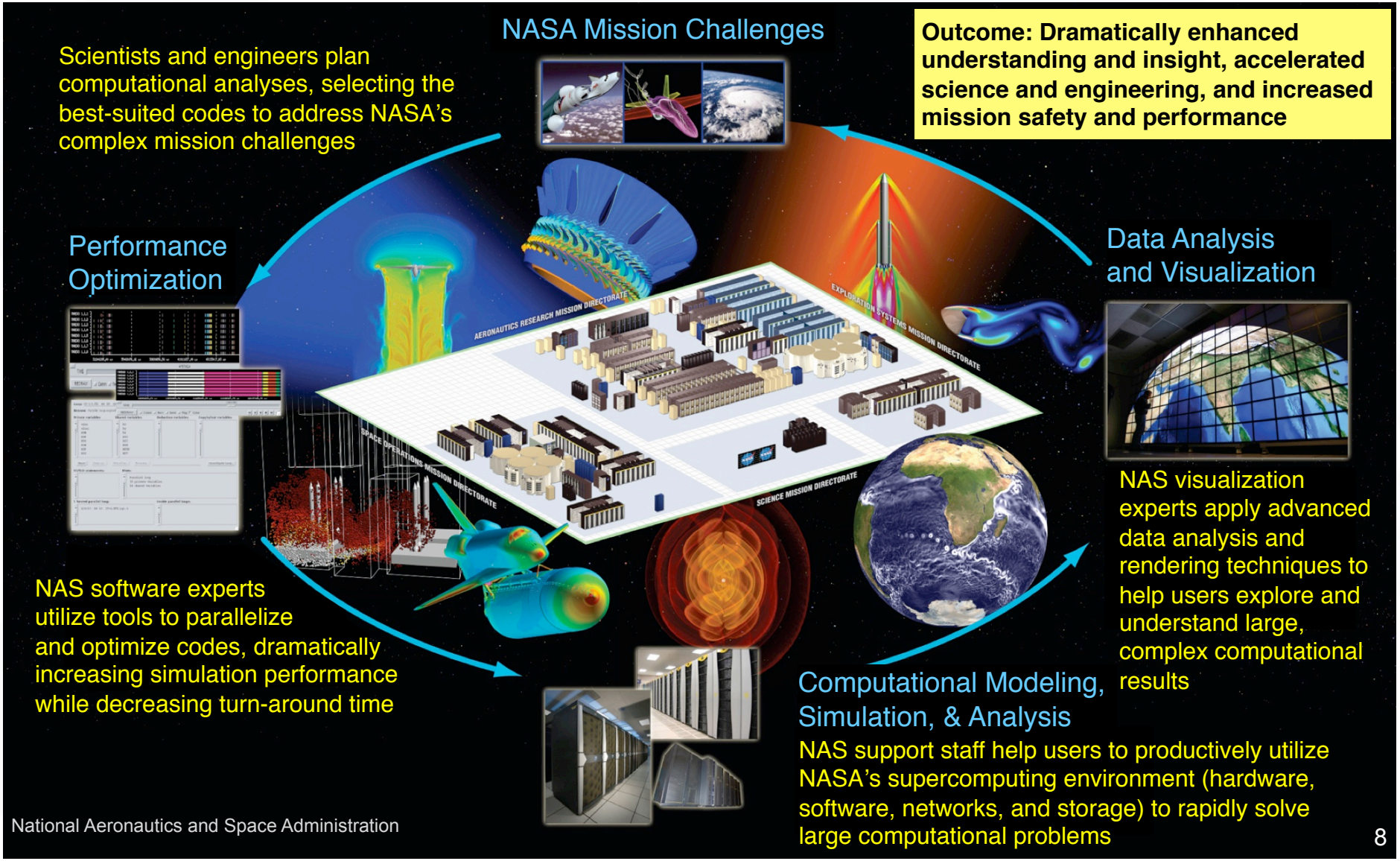
Provide end-to-end high-performance networking to meet massive modeling and simulation data distribution and access requirements of geographically dispersed users

Supporting Tasks

- Facility, Plant Engineering, and Operations: Necessary engineering and facility support to ensure the safety of HEC assets and staff
- Information Technology Security: Provide management, operation, monitoring, and safeguards to protect information and IT assets
- User Services: Account management and reporting, system monitoring and operations, first-tier 24x7 support
- Internal Operations: NAS Division activities that support and enhance the various HEC areas

Integrated Spiral Support for M&S

Develop and deliver the most productive integrated supercomputing environment in the world, enabling NASA to extend technology, expand knowledge, and explore the universe



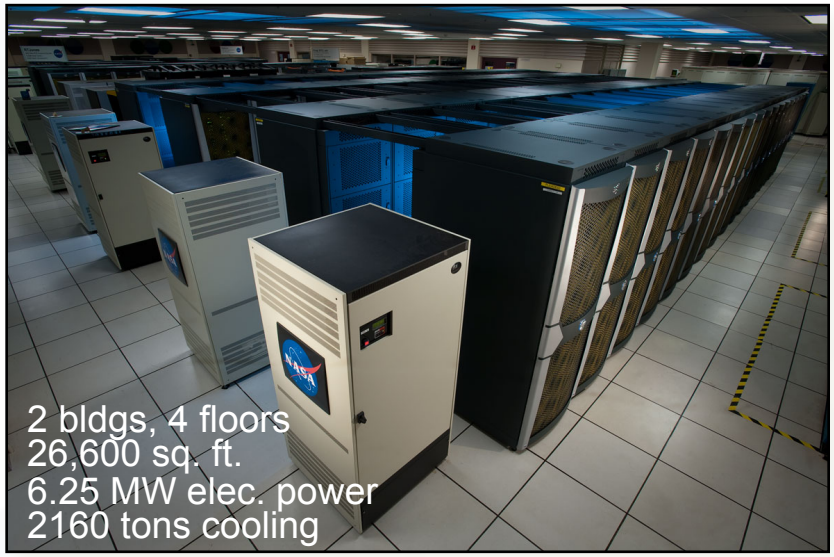
Supercomputing to Enable NASA Science and Engineering

Computing Systems

- Pleiades: 1.189 PF peak
  - 100,352-core SGI Altix ICE
  - 3 generations of Intel Xeon processors: Harpertown (4c), Nehalem (4c), Westmere (6c)
  - 168 racks, 182 TB of memory
  - Debuted as #3 on TOP500 in 11/08
  - 2 more racks with 768 Westmere cores and 64 M2090 GPUs soon to be integrated into system
- Columbia: 29 TF peak
  - 4,608-processor SGI Altix (Itanium2)
  - Debuted as #2 on TOP500 in 11/04
- hyperwall: 146 TF peak
  - 1,024-core (Opteron), 136-node GPU cluster
  - Large-scale rendering, concurrent visualization

Balanced Environment

- Storage: 10 PB disk; 50 PB tape
  - Archiving ~1 PB/month
  - Usage growth ~1.9X/yr since 2000
- WAN: 10 Gb/s to some Centers and high-bandwidth external peering
  - Transferring 150 TB/month to distributed users

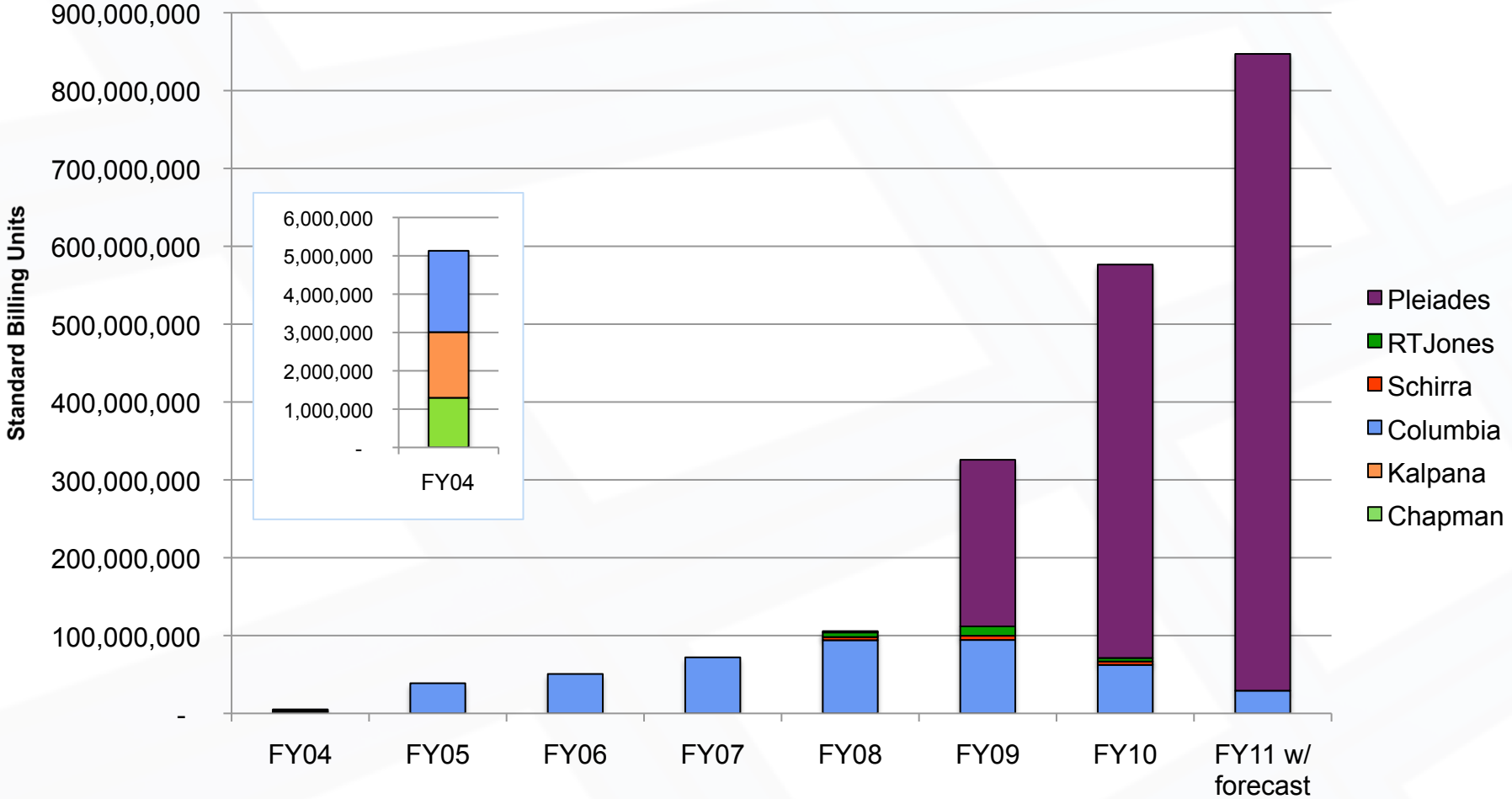


- Resources enable broad mission impact
  - MDs select projects, determine allocations
  - More than 500 science & engineering projects
  - Over 1,200 user accounts
  - Typically 300 to 500 jobs running at any instant
  - Demand for computing cycles extremely high
  - ~72 million core-hours delivered each month
- HEC demand & resources growing rapidly
  - NASA computational requirements projected to multiply by at least 4X every 3 years
  - Capacity growth ~1.8X/year since 1988

Advanced Visualization

- Supercomputer-scale visualization system to handle massive size of simulation results and increasing complexity of data analysis needs
  - 8x16 LCD tiled panel display (23 ft x 10 ft)
  - 245 million pixels
  - Debuted as #1 resolution system in world
  - In-depth data analysis and software
- Two primary modes
  - Single large high-definition image
  - Sets of related images (e.g., a parameter space of simulation results)
- High-bandwidth to HEC resources
  - *Concurrent Visualization:* Runtime data streaming allows visualization of every simulation timestep – ultimate insight into simulation code and results with no disk i/o
  - *Traditional Post-processing:* Direct read/ write access to Pleiades filesystems eliminates need for copying large datasets
- GPU-based computational acceleration R&D for appropriate NASA codes

Annual HEC Utilization at NAS
(FY2004 – FY2011)

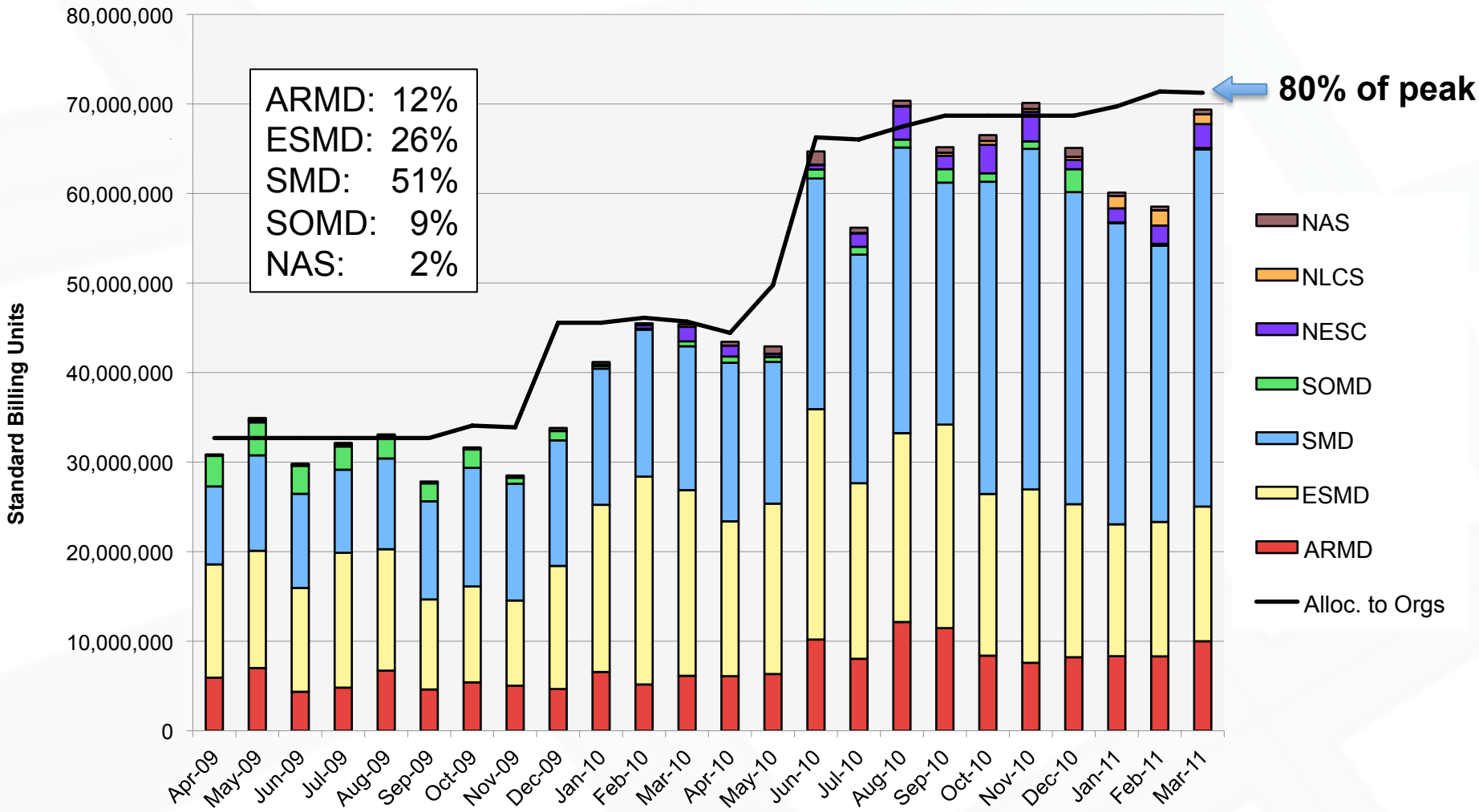


FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11 w/ forecast
5,131,127	38,732,080	50,656,990	72,001,157	105,674,460	325,772,284	576,543,944	847,108,388

SBU: Standard Billing Unit – used to normalize CPU-hours from different systems

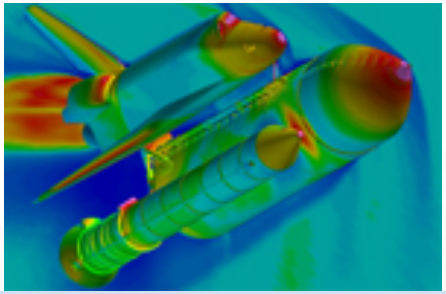
Overall HEC Utilization at NAS

(Last 2 Years Normalized to 30-Day Months)

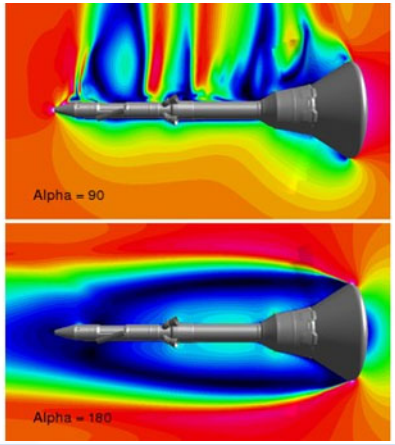


- **Total cost: $0.06 / SBU**
- **Marginal cost: $0.02 / SBU**

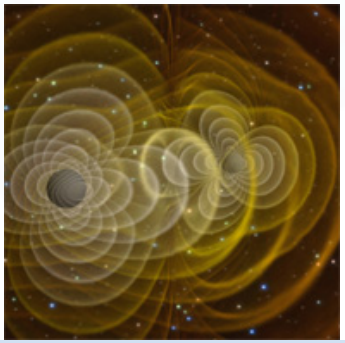
Strategic Support for all NASA MDs



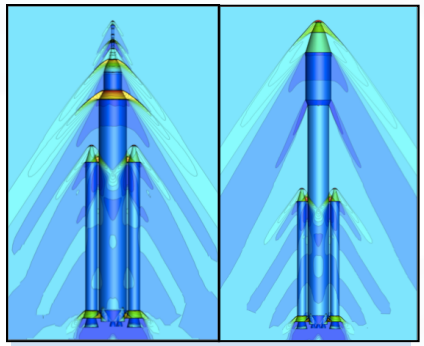
External tank redesign



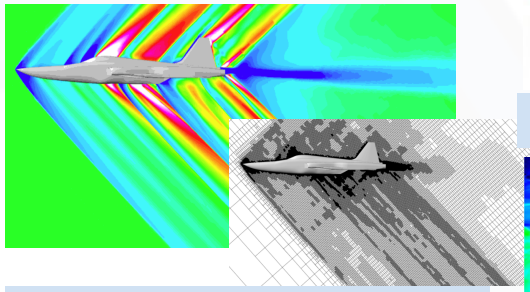
Launch abort system



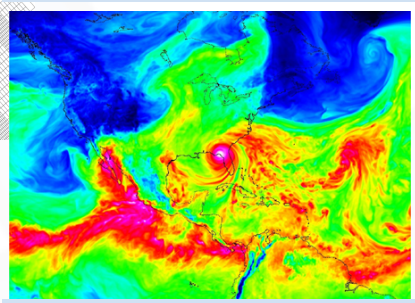
Merging black holes



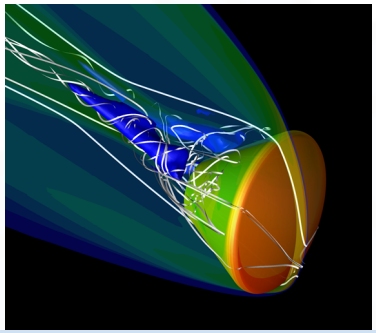
SLS vehicle designs



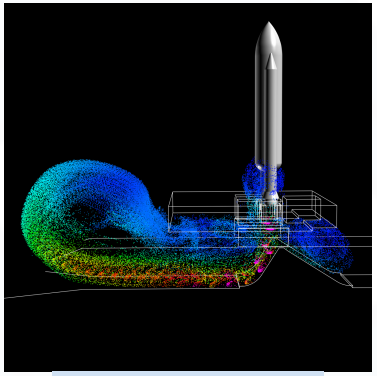
Sonic boom optimization



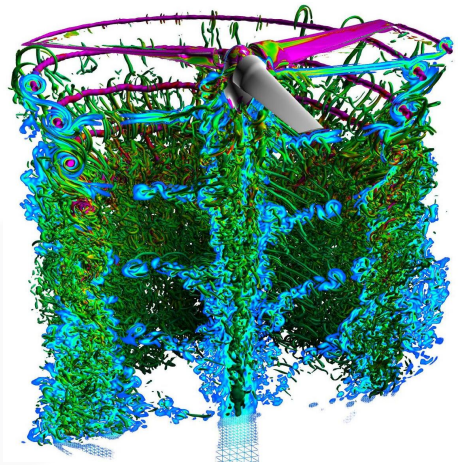
Hurricane prediction



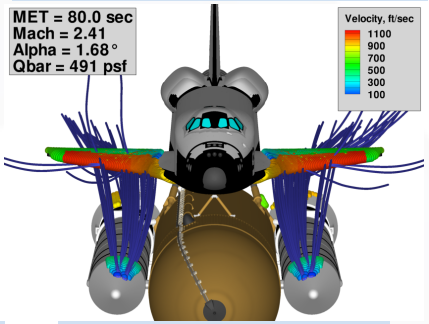
Orion/MPCV reentry



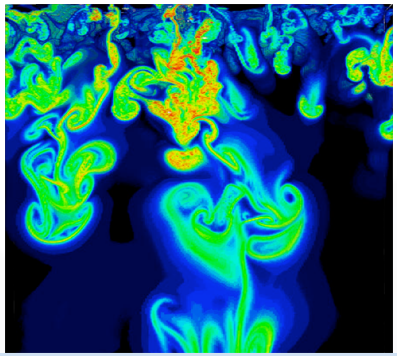
Flame trench



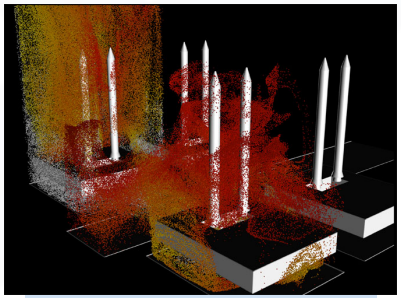
Rotary wing aerodynamics



Debris transport



Solar magnetodynamics



SRB burn in VAB

HECC: A Model for Success

- Provide an integrated environment and end-to-end support to a broad spectrum of users and their diverse requirements
- Focus on enabling NASA science and engineering discoveries and advances via supercomputing
  - Install and operate hardware that provides world-class cost performance in capability, capacity, and time-critical computing
  - Team with appropriate user communities to ensure that their models and application codes achieve optimal performance in targeted environment
  - Utilize a comprehensive set of tools that enables full understanding of and improvement in system and application performance, and user productivity
  - Provide data analysis and visualization tools and support that enable the exploration of huge data-sets, providing insights that were not previously possible
- Maintain close relationships with vendors, technology communities, and other HPC organizations to ensure correlation between NASA's future requirements and supercomputing roadmaps