HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS

HPCC
NASA

PROGRAM PLAN

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HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS
PROGRAM PLAN

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PROGRAM PLAN
HIGH PERFORMANCE COMPUTING AND COMMUNICATIONS (HPCC)

1 INTRODUCTION AND PROGRAM OVERVIEW

1.1 Introduction

This document is the Program Plan for the NASA High Performance Computing and Communications (HPCC) Program. This is the controlling document that defines the top-level technical and management structure of the Program. The Program described in this document has accelerated and will continue to accelerate the development of high-performance computing and computer communications technologies to meet the needs of the U.S. aerospace, Earth and space sciences, spaceborne research, and education communities. It will also accelerate distribution of these technologies to the American public. The technologies developed under this Plan will help maintain U.S. technical and economic leadership in the international arena of high-performance computing.

1.2 Background

The main objective of the Federal HPCC R&D program is to extend U.S. technological leadership in high-performance computing and computer communications. As this is accomplished, these technologies will be widely disseminated to accelerate the pace of innovation and improve national economic competitiveness, national security, education, health care, and the global environment. NASA's HPCC Program is a key contributor to four of the current federal program component areas:

- High-End Computing and Computation
- Large-Scale Networking, including the Next Generation Internet
- Human Centered Systems
- Education, Training, and Human Resources

The NASA HPCC Program is a critical element of the Federal IT R&D effort.

NASA's primary contribution to the Federal program is its leadership in the development of algorithms and software for high-end computing and communications systems which will increase system effectiveness and reliability, as well as support the deployment of high-performance, interoperable, and portable computational tools. As HPCC technologies are developed, NASA will use them to address aerospace transportation systems, Earth sciences, and space sciences research challenges. NASA's specific research challenges include improving the design and operation of advanced aerospace transportation systems, increasing scientists' abilities to model the Earth's climate and predict global environmental trends, furthering our understanding of our cosmic origins and destiny, and improving the capabilities of advanced spacecraft to explore the Earth and solar system. The HPCC Program supports research, development, and prototyping of technology and tools for education, with a focus on making NASA's data and knowledge accessible to America's students. These challenges require significant increases in computational power, network speed, and the system software required to make these resources effective in real-world science and engineering environments.

In support of these objectives, the NASA HPCC Program develops, demonstrates, and prototypes advanced technology concepts and methodologies, provides validated tools and techniques, and responds quickly to critical national issues. As technologies mature, the NASA HPCC Program facilitates the infusion of key technologies into NASA missions activities, and the national engineering, science and education communities, and makes these technologies available to the American public. The Program is conducted in cooperation with other U.S. Government programs, the U.S. industry, and the academic community.

1.3 Program Goal

This Program Plan describes the research and development that NASA is pursuing in the area of high-performance computing and communications. The goal of the NASA HPCC Program is to:

Accelerate the development, application, and transfer of high-performance computing and computer communications technologies to meet the engineering and science needs of the U.S. aerospace, Earth and space science, spaceborne research, and education communities, and to accelerate the distribution of these technologies to the American Public.

1.4 Overall Strategy and Approach

The NASA HPCC Program is planned and executed in cooperation with Federal agencies, industry, and academia to ensure that the most effective technologies are used to meet Program goals and to promote the rapid and effective transfer of technology products. Program success will require advances in application algorithms and software, system software, and high-performance computing and communications testbeds. NASA's strategy is to bring together collaborative teams consisting of government, academic, and private sector applications and computational methods developers, systems software developers, and high-performance computing and networking designers so that interdisciplinary solutions can be sought across the full spectrum of computational technologies from applications to hardware. Collaborations also support the emergence of a viable commercial market for high-performance computing and communications software and hardware.

1.5 Program Components

HPCC is a computing and communications research program that pursues technologies at various levels of maturity. Applications in the areas of Earth science, space science, aerospace technology, and education are used as drivers of HPCC's computational and communications technology research, providing the requirements context for the work that is done.

As a cross-cutting multi-enterprise initiative, the HPCC Program receives funds from the Aerospace Technology (AT), Space Science (SS), and Earth Science (ES) Enterprises, and the Office of Human Resources and Education.

The HPCC Program is coordinated through the Aerospace Technology Enterprise and is managed by NASA Ames Research Center. The Program has supporting work at nine NASA field centers and the Jet Propulsion Laboratory (JPL) and is organized into five Projects:

- Computational Aerospace Sciences (CAS)
- Earth & Space Sciences (ESS)
- Remote Exploration and Experimentation (REE)
- Learning Technologies (LT)
- NASA Research and Education Network (NREN)

1.6 Program Phasing: Phase I to Phase II

The 1999 Program Commitment Agreement (PCA) called for an evaluation of the Program in light of refocusing efforts within the federal information technologies activities and recent technical trends. The intent of this evaluation activity was to establish that the NASA HPCC Program continues to meet:

- NASA commitments to Federal information technologies activities
- Requirements of NASA's customer Enterprises and Headquarters Office:
    - Aerospace Technology Enterprise
    - Earth Science Enterprise
    - Space Science Enterprise
    - NASA Headquarters Office of Human Resources and Education

During Phase I the HPCC Program (FY92-FY99) successfully prototyped high-performance computing and communications technologies to enable pioneering advances in each of the HPCC Program's project areas:

- High-fidelity, multi-disciplinary simulations of complex aerospace systems:
  - First-of-a kind simulation of powered-lift aircraft in ground effect
  - Combined nonlinear aerodynamic-structures analyses
  - Complete combustor and compressor simulations over-night
  - Prototype frameworks for propulsion and vehicle design and optimization

- System software and hardware technologies enabling the timely and cost-effective use of high-performance computing in the Earth and space sciences:
  - Beowulf Parallel Linux, enabling inexpensive PC clusters running Linux
  - Parallel Adaptive Mesh Refinement (AMR) packages
  - Parallel/distributed visualization

- Commodity-based space borne supercomputing;
  - Commodity based embedded system with fault injection capability
  - Simple software-implemented fault detection and recovery mechanisms

- Networking technologies to support NASA missions:
  - Multicast Internet Exchange, enabling testing of new IP multicast technologies.

- Learning technologies to support NASA's education mission;
  - Portable webcasting technology, allowing webcast at low cost from land or sea at any point above or below the arctic caps (20 degrees latitude)
  - Wireless link technologies, allowing school campuses to communicate at medium to high speeds regardless of the age of the buildings or original construction
  - Over The Horizon Technologies, allowing the link-up of campuses and communities by reflecting data streams off of the Troposphere overcoming geographic obstacles

Each of these technologies, as well as many others, first developed in Phase I of the HPCC Program, are the technical building blocks of the Program's Phase II (FY00-FY06) work.

In Phase II (FY00-FY06), the HPCC Program enters the next natural phase in any technology development program: the generalization, refinement, and insertion of such technologies into the processes of most relevance to the Program's customers and stakeholders. For example, the prototype frameworks will be extended to support distributed space transportation design events, the Beowulf technologies will be refined to allow the cost-effective support of elements of the Earth and space science communities, and the multicast technologies will be further developed and infused in NASA applications. Implicit is a shift in focus from proof-of-concept studies to development of an effective technology legacy.

In addition to the natural maturation of the Program's work, there is always the need to adapt to relevant technical trends. In Phase II, the HPCC Program is explicitly addressing the following pervasive technical trends:

- Distributed, multi-disciplinary teams: In engineering, science, and education there has been a strong trend towards geographically-distributed interdisciplinary teams working together to address challenges of increasing complexity. Increasingly, the teams require complex software systems to enable distributed, multi-disciplinary simulations and collaborations. Recent progress in artificial intelligence techniques and process modeling (distinct from the discretization of differential equations) will lead to a broadening of the computational techniques which can make use of high-performance computing and communications technologies.

- Distributed computing, storage, and communications resources: Recently, the trend towards distributed computational, storage, and networking resources has accelerated. This is being driven in part by the distributed teams, and partly by striving to make use of the best resources at the lowest cost. This trend is being enabled, in part, by the explosive growth of internet technology, but there remains severe challenges to extending the internet philosophy to leading edge science and engineering activities.

- Software bottleneck: Since the beginning of the computer era, nearly a ten order-of-magnitude increase in the performance of computer hardware has been achieved, but there has been only modest gains in the pace at which software for these systems can be developed and verified. As a result, efforts to apply high-performance computing and communications to engineering and science challenges are often constrained by the ability to develop the needed software. This situation is being exacerbated by the trend towards inter-disciplinary teams working across distributed heterogeneous resources.

1.7 Scope of Program Plan

The HPCC Program Plan provides an authoritative, top-level management description of the program, and is the controlling document for program content and organization. This plan will be regularly updated to reflect program progress and strategic redirection. The main purpose of this Program Plan is to establish:

- Program requirements
- Program objectives and performance goals
- The management organizations responsible for the Program
- Program resources, schedules, and controls

The domain of high-performance computing and communications is highly dynamic. Technology breakthroughs occur frequently. In order to provide the highest quality deliverables while accommodating a dynamic environment, the HPCC Program needs to be adaptable. At every level within the HPCC Program, managers and researchers are required to continuously evaluate technical approaches in light of technology trends, while maintaining a clear focus on accomplishing the Program goals and milestones on time with acceptable risk.

2 PROGRAM OBJECTIVES

Of primary importance in meeting the goal of the HPCC Program is to enable the use of high-performance computing and communications technologies to improve the effectiveness of the HPCC Program's customers. Therefore, the highest level objectives of the Program are to support the customer impact objective indicated in Section 2.1. However, to meet the customer impact objective, it is necessary to achieve specific improvements in performance, interoperability, portability, reliability, resource management, and usability. The specific technical objectives and performance indicators in these areas are described in Sections 2.2 – 2.7.

To achieve the overall program goal (Section 1.3), the identified customer impact and technical objectives (Sections 2.1-2.7) must be accomplished. These objectives will be met if the indicated performance goals for each objective are met. The purpose of the performance indicators is to suggest characteristics of the ongoing work that would indicate that progress is being made towards meeting the performance goals.

2.1 Customer Impact Objective

Infuse HPCCP technologies in to mission critical customer Enterprise/Office processes, document discernable improvements in the customers' processes and, if possible, document discernable improvements in the final products as a result of the use of HPCCP technologies.

2.1.1 Aerospace Technology Enterprise

Performance Goals

Demonstrate or document the use of HPCCP technologies to support the reduction in the design cycle time of at least ten NASA or NASA-sponsored design events, from at least five distinct NASA Programs, contributing directly to the Aerospace Technology Enterprise goals. (CAS/NREN)

Demonstrate or document the use of HPCCP technologies to enable the analysis or simulation, as appropriate, of three distinct elements of the National Air Space contributing directly to the Aerospace Technology Enterprise goals. (CAS/NREN)

Performance Indicators

- Industry and NASA baseline metrics

- Availability of computational tools
- Infusion of HPCC Program technologies and applications into NASA communities

2.1.2 Earth Science and Space Science Enterprises

Performance Goals

Document twenty-five scientific research groups using applications supporting NASA science objectives operating at 10X improvement using negotiated science metrics over initial ESS Round-3 application baseline and 40% interoperating with stable Earth and space science frameworks impacting at least 5 scientific communities (2 or more applications per framework; 3 applications interoperating within a stable Earth System Modeling Framework).
(ESS)

Demonstrate an integrated spaceflight-ready commodity-based hardware testbed, system software, and application system capable of delivering 300 MOPS/watt with a reliability of 0.99 over 5 years (in a space environment) on at least 3 applications directly traceable to ongoing NASA space and Earth sciences research objectives. (REE)

Demonstrate or document the use of HPCCP networking technologies to enable the implementation or development of four projects/programs directly supporting the NASA Earth and space science research objectives. (NREN)

Performance Indicators

- Availability of computational tools
- Comparison of model output to satellite sensor data sets
- Comparison of integrated coupled model output to satellite sensor data sets
- Incorporation of HPCC technology into NASA spacecraft and aircraft platforms

2.1.3 Office of Human Resources and Education

Performance Goals

Demonstrate LT-developed, -enabled, or -inspired tools, techniques, and products to disseminate NASA Earth and space sciences and aerospace engineering data, tools, and knowledge to at least 10,000 educational points of contact including American schools, universities, and other formal and informal educational institutions. (LT)

Demonstrate or document the routine and persistent use of LT-developed, -enabled, or -inspired tools, techniques, and products to disseminate NASA Earth science, space science and aerospace engineering data, tools, and knowledge to at least 1,000 American formal and informal educational institutions. (LT)

Performance Indicators

- Infusion of LT tools, technology, and internet-based products into the formal and informal educational pipeline from pre-service to the classroom and beyond

2.2 Computational and Communications Performance Objective

Dramatically increase the computer and communications performance available for use in meeting NASA mission requirements.

Performance is defined as the rate at which a computer performs operations, or a network transfers data, or a storage system stores/retrieves data or an application and underlying computational system completes a task.

Performance Goals

Demonstrate the effective use on NASA aerospace systems, Earth and space sciences, or education challenges of computational or communications systems delivering:

- 250 Gigaflops sustained on applications, ground based (CAS/ESS)
- 300 MOPS/watt, space ready (REE)
- 1 Gigabits/second end-to-end sustained, ground based (NREN)

Demonstrate the effective use on NASA aerospace systems, Earth and space sciences, or education challenges of applications delivering:

- A complete vehicle analysis in one day (CAS)
- A complete propulsion system analysis in one day (CAS)
- Produce on a weekly basis, ensembles of one-year forecasts of climate events using a 1 degree atmosphere and a 1/3 degree ocean resolution (ESS)
- Assimilation of atmospheric data at 1/2 degree resolution at a rate of 30 days per day (ESS)

Performance Indicators

- Capability computing testbeds
- Development of low-cost platforms
- Performance analysis and monitoring tools

- Reduction of requirements through improved algorithms
- Implementation of new networking technologies and capabilities
- Use of revolutionary application across Next Generation Internet

2.3 Interoperability Objective

Dramatically increase the interoperability of application and system software operating on high-performance computing and communications systems available for use in meeting NASA mission requirements.

Interoperability is defined as the ability of software on multiple machines from multiple vendors to communicate.

Performance Goals

Demonstrate on NASA aerospace systems, Earth and space sciences, or education challenges technologies that enable:

- Interoperation among at least ten distinct computational simulation, data analysis, or other tools spanning at least three aerospace disciplines. (CAS)
- Interoperation among at least three applications in the Earth System Modeling framework, and two applications in at least four other Earth and space science frameworks. (ESS)
- High-performance Multicast protocols among five networks, and quality-of-service and traffic engineering capabilities among three networks. (NREN)
- Integration of a new computational simulation, data analysis, or other tool into an interdisciplinary framework in one day. (CAS/ESS)
- Integration of a new computing or storage system into a computational grid in one day. (CAS)
- Integration of a new networking protocol, methodology or tool into an integrated testbed in one day. (NREN)

Performance Indicators

- Industry-standard software design and coding practices
- Configuration management and interface agreements

2.4 Portability Objective

Dramatically improve the portability of application software and data to new or reconfigured high-performance computing and communications systems available for use in meeting NASA mission requirements.

Portability is defined as the ease with which a piece of software (or file format) can be "ported", i.e. made to run on a new platform and/or compile with a new compiler.

Performance Goals

Demonstrate on NASA aerospace systems, Earth and space sciences, or education challenges technologies that enable:

- Successful execution of a computational simulation, data analysis, communication, or other tool on a new computer, network, or storage system, or combination of these resources within one week. (CAS/ESS/NREN)
- Successful execution of a computational simulation, data analysis, communication, or other tool on a computer, network, or storage system, or combination of these resources within one day of a modification in the software or hardware configuration of these resources. (CAS/ESS/NREN)

Performance Indicators

- Use of software engineering techniques
- Software reusability

2.5 Reliability Objective

Dramatically improve the reliability of user-requested events executing on high-performance computing and communications systems available for use in meeting NASA mission requirements.

Reliability is defined as the probability that a given computer-based event (e.g., computational operation, data transfer or storage) will complete successfully.

Performance Goals

Demonstrate on Earth and space sciences space-borne applications the successful completion of 99% of the requested computational events over a 5-year time period. (REE)

Demonstrate on NASA aerospace systems applications the successful execution of 99% of the user requested computational events over a 24-hour time period on a distributed computational system including at least ten distinct resources, including at least one computer platform, one mass storage system, and one wide-area network. (CAS/NREN)

Performance Indicators

- Reliability testing
- Development of application algorithms designed to allow enhanced reliability
- Distribution of system software to enable enhanced reliability

2.6 Computational Resources Management Objective

Dramatically improve the ability to manage heterogeneous and distributed high-performance computing, storage, and networking resources available for use in meeting NASA mission requirements.

Resource management is defined as the ability to allocate compute, network, and/or storage resources to allow the most appropriate execution of an event request.

Performance Goals

Demonstrate on NASA aerospace systems, Earth science, and space science applications the ability to allocate compute, storage, and network resources to a requested computational event, including at least ten distinct resources, including at least one computer platform, one mass storage system, and one wide-area network. (CAS/NREN)

Performance Indicators

- Fielding of applications capable of effectively exploiting distributed resources
- Distribution of software to enable simple and timely allocation of resources
- Identification of a computing, storage, and networking resource pool which can be allocated

2.7 Customer Usability Objective

Dramatically improve the usability of high-performance computing and communications tools and techniques available for use in meeting NASA mission requirements.

Usability is characterized as the effectiveness, efficiency, and satisfaction with which users can achieve tasks in the user environment presented by a technology or integrated system of technologies. High usability means a system is: easy to learn and remember; efficient, visually pleasing and easy to use; and quick to recover from errors.

Performance Goals

Demonstrate visual-based assembly and successful execution of aerospace applications. (CAS)

Demonstrate a spaceborne computing environment that has the same usability as its contemporary commercial equivalent. (REE)

Provide the integration of networking enhancements into aerospace and Earth sciences applications codes that allow for a quantifiable improvement in user perceived performance. (NREN)

Demonstrate for NASA education applications, the ability to receive kinetic, auditory, and visual input and present multimedia information to students through full motion three-dimensional imaging and haptic feedback in an integrated format that allows for a quantifiable improvement in the effectiveness of the learning experience. (LT)

Performance Indicators

- Usability testing
- Identification of specific usability requirements
- Development of software modules or systems to enhance usability

3 CUSTOMER DEFINITION AND ADVOCACY

The HPCC Program is a cross-cutting technology activity that enables NASA's Enterprises, Offices, and Centers to deliver products and services to their customers more effectively and efficiently. HPCC research has the goal to reduce costs and development time, while increasing the capability to generate, access, analyze, and interpret engineering and science data.

Although the technology developed and demonstrated under the HPCC Program will enable the development of full-scale computing and communications systems, it is expected that the HPCC Program will not fund the actual acquisition of full-scale production systems. The implementation of full-scale production and operational systems is the responsibility of the HPCC customers.

Specific HPCC customers are other NASA Programs and organizations, selected segments of the U.S. aerospace manufacturing industry, academic research labs, other U.S. Government Agencies, the U.S. education community, and the information technology industry. Table 3.1 is a listing of customers by HPCCP Project.

The HPCC Program Executive Committee and the Executive Committee Working Group are the key interfaces to the sponsoring NASA Enterprises and Headquarters Office. Cooperative efforts with NASA mission engineers, scientists, and educators are the most essential technical interfaces with the key customer bases. Formal workshops and formal/informal communications have been and will continue to be utilized to maintain an interface with large cross-sections of the customer bases.

Advocacy for the HPCC Program within NASA is led by the Aerospace Technology (AT) Enterprise, with support from the other three sponsors: the Earth Science and Space Science Enterprises, and the NASA Office of Human Resources and Education. The Aerospace Technology Enterprise serves as the primary liaison for interactions with other federal agencies and for advocacy with OMB and Congressional representatives.

PROJECT	PRINCIPAL GOVERNMENT CUSTOMERS	PRINCIPAL INDUSTRY AND ACADEMIC CUSTOMERS
Computational Aerospace Sciences (CAS)	NASA Aerospace Technology Enterprise, researchers in applied computational aerospace sciences and computer science, engineers developing aeronautical and space transportation systems	Aerospace vehicle and engine manufacturers; Information Technology industry supplying commercial technology to aerospace community
Earth and Space Sciences (ESS)	NASA's Earth Science Enterprise, Space Science Enterprise, Government research labs performing scientific research in Earth and space sciences	University labs performing scientific research in Earth and space sciences
Remote Exploration and Experimentation (REE)	NASA's Earth Science Enterprise, Space Science Enterprise, NASA and DoD missions requiring spaceborne embedded high-end computing	Commercial satellite industry
Learning Technologies (LT)	NASA's Office of Human Resources and Education, Federal, State and Local Government Agencies and Departments involved in K-12 education	Information Technology industry supplying commercial technology for K-12 education
NASA Research and Education Network (NREN)	NASA's Aerospace Technology Enterprise, Earth Science Enterprise, Space Science Enterprise, and Office of Human Resources and Education, as well as other federal organizations requiring state-of-the-art networking	Information Technology industry supplying commercial technology to aerospace, Earth and space sciences and education communities

Table 3-1: HPCC Customers

4 PROGRAM AUTHORITY AND MANAGEMENT STRUCTURE

The overall program authority is established by the NASA Headquarters Program Management Council (PMC). The Program Commitment Agreement (PCA) represents the Agency-level agreement for the implementation of the HPCC Program. Although the Program is funded by three Enterprises and the Office of Human Resources and Education, the overall management of HPCC is formally within the Aerospace Technology Enterprise. Ames Research Center is the lead center, and the execution of the HPCC Program is managed by the HPCC Program Office located at Ames.

4.1 Organization

Figure 4-1 shows the management structure of the HPCC Program. The NASA Office of Aerospace Technology, Office of Earth Science, Office of Space Science, and Office of Human Resources and Education are the customers of the HPCC Program. Overall program objectives, requirements, and metrics are established by the NASA HPCC Executive Committee, composed of Associate Administrators of all of the NASA Agency Office customers and chaired by the Associate Administrator of the Office of Aerospace Technology. The NASA Office of Aerospace Technology is the NASA Headquarters focal point for coordinating the Program's Headquarters-level approvals, reviews, and customer advocacy.

The NASA HPCC Executive Committee Working Group, comprised of senior representatives from each Agency Office customer organization, works closely with both the HPCC Executive Committee and the HPCC Program office to ensure that the customers' requirements are addressed.

NASA Ames Research Center is responsible for the overall direction, control, and oversight of HPCC Program implementation. Under the direction of the Ames Center Director, the HPCC Program Office located at Ames is responsible for the overall management and execution of the Program, including the maintenance of program-level plans, coordination of program-level reviews, and the overall coordination of work across the Projects.

Cross-Project synergy is critical to the most effective execution of the HPCC Program. The Program Office sponsors, and each Project participates in, cross-cutting integration management teams chartered to review and recommend actions to improve the effectiveness of HPCCP application, system software, and testbed research, development, prototyping, and infusion into the customers' processes. Specific issues being addressed are greater cross-Project sharing of application techniques and algorithms, a concerted effort towards developing a technical legacy to support high-performance, interoperable, and portable applications, and the best use of all testbed resources to meet NASA's aerospace, Earth and space sciences, and education mission requirements.

The work of the HPCC Program is managed through five customer-focused Projects. The Computational Aerospace Sciences (CAS) Project focuses on developing advanced computing and communications technologies to improve the design and operation of aerospace transportation systems. The Earth and Space Sciences (ESS) Project is focused on bringing high-performance computing and communications systems to bear on improving the rate of progress in the Earth and space sciences. The Remote Exploration and Experimentation (REE) Project endeavors to bring high-performance computing to spaceborne platforms. The NASA Research and Education Network (NREN) Project pursues the development of high-performance communications technologies for NASA missions. The Learning Technologies (LT) Project represents the primary educational technology component of HPCC.

The execution of the NASA HPCC Program involves all NASA centers.

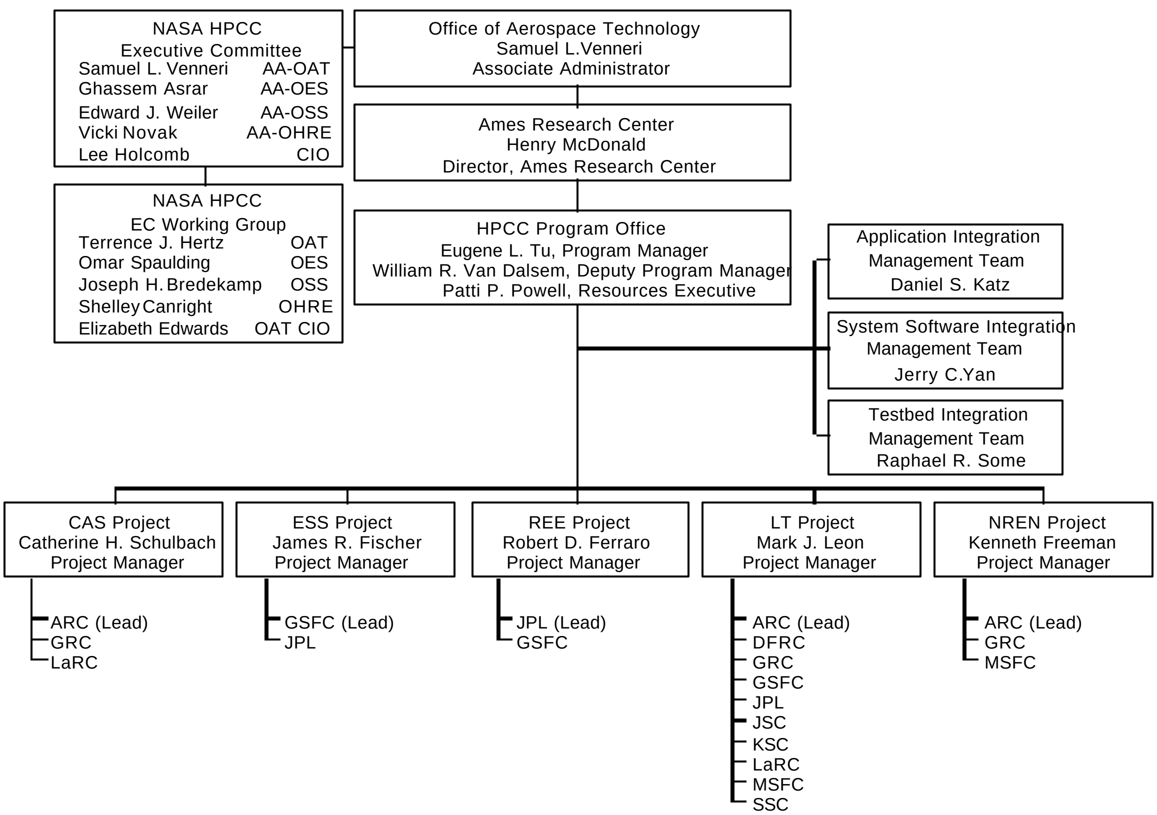


Figure 4-1: NASA HPCC Management Structure

4.2 NASA HPCC Program Executive Committee

The NASA HPCC Program Executive Committee (EC) establishes program objectives, requirements, and metrics and validates the strategic direction and plans of the program based on Agency policy and guidelines. The HPCC EC also approves the HPCC Program Plan, assesses program performance against requirements and customer expectations, and provides for cross-Enterprise coordination. All of the customer NASA Enterprises and Headquarters Offices (Aerospace Technology, Earth Science, and Space Science Enterprises and the Office of Human Resources and Education) are represented on the Executive Committee at the Associate Administrator level. The NASA Chief Information Officer is a member to ensure that Executive Committee has appropriate information regarding NASA and interagency information technology activities. The Associate Administrator for the Aerospace Technology Enterprise is the Chair of the HPCC Executive Committee.

The HPCC EC will meet at least twice a year to validate program objectives, requirements, and metrics. If required, the HPCC EC will meet more frequently. Specific processes and products of the HPCC EC are defined in the EC Charter.

4.2.1 NASA HPCC Program Executive Committee Working Group

In support of the HPCC EC, a working group has been formed consisting of representatives from the customer NASA Enterprises and Headquarters Offices (Aerospace Technology, Earth Science, and Space Science Enterprises and the Office of Human Resources and Education). The HPCC EC Working Group provides recommendations to the HPCC EC regarding program objectives, requirements, and metrics as well as approval of the HPCC Program Plan, assessment of program performance against requirements and customer expectations, and cross-Enterprise coordination.

The HPCC EC Working Group (WG) will typically meet on a quarterly basis. If required, the HPCC EC will meet more frequently. Specific processes and products of the HPCC EC WG are defined in the WG Charter.

4.3 Office of Aerospace Technology

The NASA Office of Aerospace Technology is the NASA Headquarters focal point for coordinating through the HPCC Program Executive Committee the Program approvals, reviews, and customer advocacy.

Specifically, the Office of Aerospace Technology will:

- Chair the NASA HPCC Program Executive Committee
- Provide a forum for the review of HPCC Program status on a quarterly basis
- Report HPCC Program status to the NASA Program Management Council
- Coordinate the Independent Annual Review process with the Chief Engineer's Office
- Facilitate the review and approval of HPCC Program Commitment Agreement, Program Plan, and other documents requiring NASA Headquarter's level approval
- Coordinate delivery of Program information for use by the Executive and Legislative Branches of the federal government

4.4 Ames Research Center

Ames Research Center is the lead center for the HPCC Program. The Ames Center Director is responsible for providing overall management of the implementation of the HPCC Program.

Specifically, the Ames Center Director will:

- Provide overall direction, control, and oversight of program implementation
- Appoint the Program and Deputy Program Managers and other key program office staff
- Maintain an HPCC Program Office
- Review HPCC Program performance, schedule, and cost status

4.5 Program Office

Consistent with the program objectives, requirements, and metrics established by the HPCC Executive Committee, and the overall direction, control and oversight of the Ames Center Director, the Program Office manages the execution of the HPCC Program and its Projects.

The Program Office will:
Execute the Program Plan:
- Execute the HPCC Program consistent with the approved and current Program Plan

Maintain approved and current Program documents:
- HPCC Program Commitment Agreement (PCA) document
- HPCC Program Plan which is consistent with the approved PCA

Approve Project Plans:
- HPCCP Project Plans which are consistent with and support the approved HPCC Program PCA and Program Plan

Report Program status to:
- Ames senior management on a monthly basis
- Office of Aerospace Technology on a quarterly basis
- Executive Committee and EC Working Group as required

Maintain outreach activities including:
- Publication of the HPCC Program Insights Magazine on a quarterly basis
- Maintenance of a current HPCC Program website (www.hpcc.nasa.gov)

The Program Office shall at all times strive to obtain the best possible synergy across the Program. These efforts will be supported by the Application, System Software, and Testbed Integration Teams which report to the Program Office

In addition, the Program Office is responsible for retaining current knowledge of:

- Technical trends in high-performance computing and communications
- Current and evolving requirements of HPCC Program stakeholders and customers
- Other NASA, federal government, private sector, and international high-performance computing and communications research and development activities

The Program Office shall insure that the HPCC Program continues to be as effective as possible in light of these evolving external factors.

4.6 Project Management

The HPCC Program Office is supported by the Project Managers for each of the five HPCC projects. The NASA centers that lead each of the HPCC Projects are responsible for designating a manager who will have project management authority.

HPCC Project Manager responsibilities include:

- Overall management of the assigned multi-center project, including cost, schedule, and technical performance
- Preparing and maintaining the project plan, specifications, schedules, and budgets
- Reporting project performance and status, including contracts, to the HPCC Program Office and as otherwise required
- Submitting project reports and preparing and presenting project reviews and technical advocacy materials
- Maintaining a current Project-level website linked to the HPCC Program website

4.7 Integration Management Teams

Three Integration Management Teams support the Program Office in insuring the Program is executed with good awareness of evolving technical trends and with as much inter- and intra-Program collaboration as is productive:

- Application Integration Management Team
- System Software Integration Management Team
- Testbed Integration Management Team

Each Integration Management Team will consist of at least one member from each of the NASA HPCC Program Projects (e.g., CAS, ESS, REE, NREN, and LT). The members will nominate a Team Manager from among themselves. The Team Manager will be responsible for overseeing the operation of the Integration Management Team, and the meeting of the Team's responsibilities.

Further details of the Integration Management Team processes and products are defined in the Team Charters.

5 PROGRAM REQUIREMENTS

The NASA HPCC Program is designed to support the overall Federal high-performance computing and communications goals while addressing agency-specific computational challenges beyond the projected capabilities of commercially-available computing and communications systems. These computational challenges have been chosen for their impact on NASA's missions, their national importance, and the technical challenge they provide to the NASA HPCC Program.

The science and engineering requirements inherent in the selected NASA applications require at least three orders of magnitude improvement in high-performance computing and networking capabilities over the capabilities that existed at the beginning of the program in FY1992. Of equal importance, significant advances in interoperability, portability, reliability, resource management, and usability are essential to the pervasive and effective application of increased computational and communications performance to NASA's goals. NASA's requirements in these areas are beyond the planning horizons of the commercial sector. NASA must develop new approaches and technologies and demonstrate their feasibility before the commercial sector can move aggressively into these areas and eventually meet NASA's requirements.

The Program has been organized into five customer-focused Projects which strive to develop, demonstrate, and infuse into customer processes integrated systems of application, system software, and testbeds which, in total, meet the overall HPCC Program goal identified in Section 1.3 and each of the customer impact and technical objectives identified in Section 2.

5.1 Computational Aerospace Sciences (CAS) Project

The Computational Aerospace Sciences (CAS) Project addresses the high-end computing needs of the NASA Aerospace Technology Enterprise and the extended aerospace community, including other government agencies, industry, and academia. The CAS goal is to:

Enable improvements to NASA technologies and capabilities in aerospace transportation through the development and application of high-performance computing technologies and the infusion of these technologies into the NASA and national aerospace community.

5.1.1 Overview

The CAS Project facilitates the transfer of technology developed in NASA aerospace and information technology research efforts to routine use by operationally-oriented or product-oriented programs within the NASA Aerospace Technology Enterprise. This will provide the aerospace community with key tools necessary to reduce design cycle times and increase fidelity in order to improve the safety, efficiency, and capability of future aerospace vehicles and systems. This has the additional benefit of establishing within the aerospace community a viable market for vendors of high-performance computing hardware and software. CAS, because of this relationship with the general computer science community, provides input and direction for developing technology for aerospace application.

The CAS Project works with NASA Aerospace Technology Enterprise Programs and the extended aerospace community to select high-priority areas that have bottlenecks or limits that could be addressed through the application of high-end computing. These challenging, customer-focused applications guide efforts on advancing aerospace algorithms and applications, system software, and computing machinery. These advances are then combined to demonstrate significant improvements in overall system performance and capability.

5.1.2 Technical Plan for CAS

CAS is organized into and supports work in three major areas:

- Aerospace applications and algorithms, providing the customer focus
- Computing testbeds, providing the laboratory of research hardware
- Systems software that forms the interface between the testbed and the user

In this way, the project brings together a collaborative team of developers so that the proper balance of activities can be orchestrated across the full spectrum of computational technology from applications to hardware.

The CAS customer-focused *Advanced Technology Applications (ATA's)* are aerospace problems that are selected because of their importance to NASA's Aerospace Technology Enterprise, their ability to drive high-performance end-to-end computational technology development, and their ability to cover the spectrum of the types of problems expected to be encountered by the aerospace community in the next 3-10 years. The ATA’s are selected through partnership with the Aerospace Technology Enterprise; and ATA research focuses on areas critical to the entire lifecycle of aerospace vehicles, from concept to operation, providing tools necessary to reduce design cycle times and increase fidelity to improve safety, efficiency, and capability of future aerospace vehicles and systems.

ATA efforts include improving and streamlining the analysis process (from set-up to post-processing), coupling the analyses of multiple disciplines and components, and integrating models and analyses for comprehensive analysis, design, and optimization. This will be done in ways to enable operation on HPCCP testbeds and to facilitate eventual transfer to other organizations through attention to performance, portability, interoperability, reliability, resource management and usability.

To exploit the potential for highly concurrent processing using large numbers of processors, whether in one machine or in many networked machines, CAS develops new tools for analysis and optimization that reflect the underlying physics and yet are tailored to the highly concurrent architectures. Algorithm innovations will be required to make best use of these highly concurrent architectures. For example, algorithms are needed that operate effectively on computing systems with long and/or non-homogeneous latencies between computing nodes. Algorithms must not only be latency-tolerant but must be latency-adaptive.

The CAS *Computational Testbed* effort is focused on providing a continuously evolving research testbed for the development of ATA's. In Phase I of the HPCC Program and the CAS Project, CPU speed and memory were the bottlenecks, and so CAS supported the acquisition and use of a series of high-performance parallel computing systems. CAS also supported the development and evaluation of cost-effective workstation clusters.

This focus on individual systems was important when the ATA focus was largely on improving the speed of computations for individual disciplines and/or components. While still important, aerospace problem solving now encompasses much more. It is likely to involve geographically-distributed teams, running 24-hours around the clock and requiring computing and experimental tools and data archives to simulate multi-disciplinary interactions between components. Ability to make use of all available resources and corporate knowledge and to have access to reusable components and tools play a vital role in reducing cost and risk as well.

In this environment, single systems (even massively parallel ones) are insufficient and/or cost prohibitive. Yet computing resources are everywhere. At the same time, speed and predictability of turn-around time are crucial for making use of distributed heterogeneous systems. A seamless interface to a reliable and predictable system is needed to limit the labor-intensive tasks of porting applications from system to system.

Fortunately, new nationwide efforts to develop computational grids provide promising technologies for improving turn-around time and throughput by providing the basis and infrastructure to retain/improve performance while enabling portability, interoperability, reliability, resource management, and usability. The key is to hide from the user the detailed components and architecture of the grid by providing services that remain unchanged regardless of changes to the underlying structure. An example is providing system-level services that improve scheduling capability through modeling, monitoring, prediction, load balancing, resource reservation and quality of service guarantees.

The CAS *System Software* effort takes system-level services (such as those mentioned above) and provides to the user the tools to enable improved and predicted turnaround and throughput. For example, tools must be provided to enable applications to be easily moved between systems with little or no human intervention. Tools must also be provided to create, maintain, and use modular application components that can interoperate; and users' efforts must be minimized through easy-to-use tools and a reliable system.

Just as CAS works with the aerospace community to identify problems and work on bottlenecks in the applications area, CAS also works with the information systems community and the NASA Research and Education Network (NREN) Project to transfer computing and communications technologies from the research to the operational environment. One aspect of this is for CAS to provide access to hardware and software testbeds to the wider aerospace community (not just to ATA-funded researchers) so that other scientists and engineers can have access to the new technology and so that they can provide a wider range of challenges to the testbed systems.

The results of the efforts in the three CAS work breakdown structure areas are brought together in demonstrations of new and improved capabilities such as:

- Multi-disciplinary, three-dimensional simulation of a complete propulsion system in one day
- High-fidelity, full-vehicle simulation of commercial aircraft or advanced concept vehicle in one day
- Multi-disciplinary analysis of a new space transportation vehicle for flight characteristics in one day, and optimization in one week
- Simulation of the national air transportation system for safety and/or capacity in one day

In the long term, the technologies developed in CAS will enable the entire life cycle of a new vehicle to be designed and deployed in virtual simulation. These technologies will be transferred to aerospace and information systems activities, specifically targeting those striving to meet NASA's aerospace technology goals, and, as appropriate, emerging efforts such as the NASA Intelligent Synthesis Environment Initiative. Through partnerships with the extended CAS community of government agencies, industry, and academia, additional bi-directional technology transfer will occur.

CAS will continually collaborate with the Learning Technologies Project to evaluate CAS technologies for broader application to the public interest. For example, simpler versions of applications (e.g., for aircraft or engine design) could be created in "education versions" as opposed to "engineering versions."

5.2 Earth and Space Sciences (ESS) Project

The goal of the ESS Project in the NASA HPCC Program is to:

Demonstrate the power of high-end and scalable cost-effective computing environments to further our understanding and ability to predict the dynamic interaction of physical, chemical, and biological processes affecting the Earth, the solar-terrestrial environment, and the universe.

5.2.1 Overview

The ESS Project is striving to enable the NASA science Enterprises and their field centers to meet increasing mission requirements more effectively and efficiently. Guided by the strategic plans of the Enterprises, ESS research increases NASA's capability to produce, analyze, and understand its science and mission data while reducing the investment in money, time, and human resources required to do so.

A primary ESS objective is to provide the necessary scalable computational technologies and software tools to further the development of a suite of multidisciplinary models, simulations, and analyses of data products by the NASA science community toward the goal of scalable global simulations coupling many disciplines and to the simulation of complex multiple-scale problems associated with space science. High resolution, multidisciplinary models are important for their predictive value and for their ability to extrapolate beyond our ability to measure and observe systems directly. For example, if the time scale of interest is on the order of one hundred years, systems must be simulated for thousands of years. Learning what the important interactions are, what their time scales are, and what controls exist in the system are important needs of the emerging Earth systems science and is an activity that requires computing power at the TeraFLOPS level or greater and networking capability in the gigabit per second range.

The advanced semiconductor and fiber optic technologies which are driving ground-based computing and communications advances are also migrating into flight instrument sensors, providing improved spatial and spectral resolution and resulting in higher data rates to the ground. Analysis of the data produced by these sensors requires data retrieval algorithms which may scale with the square of the data resolution. Ground-based computational systems must process and analyze this data at a rate that meets or exceeds the rates at which it reaches the ground. The volume of data to be obtained from next-generation space borne sensors will be so great that current and next-generation computing systems will be inadequate for the required modeling, data assimilation, and analysis tasks. Data from many sensor systems will be collected at frequent intervals over a period of many years, stressing mass storage systems, and enabling reprocessing projects which can again dramatically increase the throughput requirements on computing systems and their data I/O capabilities.

As a direct result of the initial phase of the HPCC Program, high-performance scientific codes have emerged as powerful tools for performing important work for NASA. These highly-capable scalable codes have exposed new issues that are as important as performance: code interoperability, portability of applications among the variety of high-performance architectures, and management of the complexity of resulting coupled models. It has become evident that additional performance, though necessary, is not sufficient to make a code useful for support of NASA research and missions. The cost to adapt existing high-performance research codes to function with suites of NASA research or production codes for evaluation and eventual adoption and use may be prohibitively high. This is because code interoperability, which often exists among code components within specific research groups, rarely exists between these groups, and there are many such groups. In some cases, several Agencies such as NASA, NSF, DOE, and DOD fund multiple research groups within a modeling community, all researching advanced models, but these models lack the ability to interoperate. This situation is not a significant issue when the primary products of the research groups are research findings shared through scientific papers, but with the emergence of powerful modeling and analysis codes as key tools of NASA science and mission support, preparation of these codes for ease of incorporation and use by NASA has become extremely important.

5.2.2 Technical Plan for ESS

The goal of the Round-3 CAN (FY00-04) of the ESS Project is to enable production-ready high-performance Earth and space science computational applications which analyze or interpret NASA Enterprise observational mission data The technical plan for Round-3 is organized into three major efforts focused on *applications, computing testbeds, and system software.*

ESS *applications* are selected because of their scientific importance, ability to drive high-performance end-to-end computational technology development, and diverse workloads representative of what might be found in an Earth and space science computing facility 3-5 years out. Applications research focuses on areas critical to NASA science: the coupling of advanced discipline models into scalable global simulations, providing realistic global change understanding; 3D simulation of plasmas and fluids; high resolution modeling of astrophysical systems; and the integration of models and analysis algorithms for processing, analyzing, and understanding the enormous volumes of data expected from the international missions planned in the next decade and beyond.

Round-3 is designed to have broad impact in the scientific community. Investigations are sought whose code products will be used by other groups, especially through an identifiable provider/customer relationship. Customers of Round-3 technology include NASA scientific research programs and flight missions that require mature high-performance codes for use in production and operational computing environments. Investigator Teams will be asked to advance the performance of proposed specific application codes and expand their interoperability with other related codes within self-defined multidisciplinary scientific communities. Development of an Earth System Modeling Framework (ESMF) will be a high priority. Desired outcomes include fostering reusability among software components and portability among high-end computing architectures; reduction in the time required to modify research application codes; structuring of systems for better management of evolving codes; and enabling of software exchange between major centers of research.

ESS *computing testbeds* provide Investigator Teams with access to significant computing resources and applications support to assist them in achieving their code improvement milestones. The development of ESS testbeds will ensure that high-end scalable computer systems evolve in a direction that leads to sustainable and usable TeraFLOPS for ESS applications. The ESS testbeds activity will be coordinated with those NASA projects which are customers of the ESS-developed software technologies so that production and operational platform capacity will more likely be available for their use once the ESS-sponsored research is delivered. ESS will actively facilitate restructuring and movement of codes to very inexpensive commodity-based high-performance systems which currently have high interprocessor latency, much less mature system software, little vendor support and little applications support. ESS plans to provide a capability computing testbed sized to meet the negotiated requirements of the selected Round-3 Teams. It will be leveraged with other HPCC projects that require high-end computing (e.g. CAS) to give ESS access to significantly more capability computing resource than it could otherwise acquire alone. Where appropriate, ESS will also seek to leverage capabilities from outside of the HPCC Program. ESS will also provide a commodity-based cluster running the Linux operating system sized by Investigator needs. ESS will give scientists from the broader Earth and space sciences community who receive NASA funding, but are not supported by ESS, access to the testbeds to assist them in preparing to use scalable parallel systems.

The goal of the ESS *systems software* research and development activities is to make high-end scalable computer systems an integral part of large-scale computing resources in the Earth and space sciences. In these science communities, applications are increasingly complex and in a continuing state of flux, evolving as the scientific understanding of the problems evolve, and moving through a series of computer systems because their life time exceeds that of high-end computer platforms. Primary computing system requirements include: tools and techniques that support achievement of interoperation among major code components with relative ease while simultaneously achieving high performance; tools that allow use of advanced high-performance computational methods by typical users; techniques that allow for rapid porting and tuning of evolving applications to the local architectures; and visualization tools accessible from remote locations capable of handling the data volumes associated with TeraFLOPS systems. ESS is focusing its system software R&D efforts on four major thrusts which address these requirements while leveraging other research groups and vendors to provide other software tools.

1) Facilitate evolution of an Earth System Modeling Framework - ESS has set an objective in Round-3 of facilitating movement of a critical mass of the NASA Earth system modeling community to a common modeling infrastructure (a step they have called for) by actively facilitating the joint definition of an Earth System Modeling Framework (ESMF) by this community and migration of their codes to this framework.

2) Provide practical parallel Adaptive Mesh Refinement (AMR) packages that do not require sophisticated knowledge to use - Adaptive mesh refinement (AMR) is an advanced numerical technique increasingly popular in the scientific and engineering communities for large-scale applications which cannot achieve the spatial resolution which they require with uniform grids. Use of AMR techniques can significantly improve computational and computer memory efficiency by devoting finite CPU and memory resources to computational regions where they are most needed, thus making it possible to compute an accurate numerical solution of a much larger problem than would be possible if using a global fine mesh.

3) Develop new methods to visualize massive data sets produced by ESS Applications – High end applications create new problems involving the analysis and visualization of the resulting datasets. 4D simulation and remote sensing datasets which are produced and consumed on these machines are often too large to be transferred to or stored at an investigator's local site in their entirety. ESS is enhancing low end workstation tools to make use of HPC technology. The data access, rendering, display, and user interface modules are developed to execute in a distributed environment.

4) Leverage the Linux operating system – ESS will bring very inexpensive high-performance parallel computing to the NASA science user environment by leveraging the Linux operating system and computer industry's investment in mass market technology. Parallel Linux clusters are moving to the production computing floor for some applications but much system software, taken for granted on commercial systems, is still needed to make them generally useful. In Round-3, ESS will stress test Linux clusters with Investigator codes, develop system software to overcome key shortcomings, and motivate the development of latency-tolerant computational techniques capable of achieving new levels of cost-effective high-performance computing. It is anticipated that Beowulf system vendors will rapidly incorporate system software innovations into their products.

ESS will perform evaluation throughout Round-3 to identify and understand the critical success factors for the selected Investigations. The characteristics of the codes that affect performance and interoperability as well as characteristics of the testbeds that affect performance and usability will be assessed. ESS will collaborate with groups performing basic research into next-generation computing systems to provide them with test codes and application characterizations from the Round-3 applications codes to ensure that their research addresses the computational requirements originating in NASA science.

ESS will collaborate with the HPCC Learning Technologies Project to transition ESS Investigator technologies into effective and timely spin-offs. ESS will identify ways for making materials and knowledge coming out of their Investigations available to the public or for use in primary and secondary education (K-12) in the U.S. ESS will also identify ways for making problem solving approaches, algorithms, modules or data products coming out of their Investigations useful to public organizations such as state and local governments or private industry.

5.3 Remote Exploration and Experimentation (REE) Project

The goals of the Remote Exploration and Experimentation Project are to:

Demonstrate a process for rapidly transferring commercial high-performance computing technology into ultra-low power, fault tolerant architectures for space.

Demonstrate that high-performance onboard processing capability enables a new class of science investigation and highly-autonomous remote operation.

5.3.1 Overview

NASA and DOD requirements for space-capable computing technology are becoming more demanding, especially with regard to available power and cooling, performance, reliability, and cost. The REE Project seeks to leverage the considerable investment of the ground-based computing industry by bringing supercomputing technologies into space within the constraints imposed by that environment. The availability of onboard computing capability will enable a new way of doing science in space at significantly reduced overall cost. This technology will embrace architectures scalable from sub-watt systems to hundred-watt systems that support a wide range of missions from Earth-observing missions to deep space missions lasting ten years or more. Earth-observing missions are typically conducted in a data-rich/power-rich environment with sensors capable of producing gigabits to terabits per second. In the future, Earth Observations will use families of instruments on spacecraft constellations which utilize low-power and low-mass systems found in the deep space missions. Deep space missions require ultra-low-power and low-mass systems capable of autonomous control of complex robotic functions. These space-based systems must be highly reliable and fault tolerant under extreme radiation conditions.

The REE Project will minimize or eliminate radiation-hardened components in the prototypes that are developed. This approach would allow shortening the technology insertion cycle for NASA missions from its current 3 - 5 years to 18 months. In order to accomplish this goal, significant fault-tolerant system software and algorithm development work needs to take place so that commercial architectures and components may be used reliably in space. It is this software-implemented, fault tolerance effort that is the highest risk/highest payoff and the legacy of the Project.

5.3.2 Technical Plan for REE

The technical plan for the REE Project is organized into three major efforts focused on *applications, system software, and computing testbeds.*

The REE *applications* have been selected based on their potential for stimulating technology development that enables smaller, cheaper missions. It is the achievement of dramatically-increased science return for the same or lower cost that is the reason for REE. Two technology themes dominate this consideration: miniaturization and performance. Space data systems must be dramatically reduced in mass, power consumption, and size in order to meet the requirements of missions in the Discovery, Surveyor, New Millennium, and other low-cost mission series. At the same time, these systems must meet new performance standards driven by the need for more autonomous, self-managing spacecraft and by high-rate sensors capable of producing one to ten gigabits of data per second. REE *applications* are defined and selected in partnership with end-product customers from the NASA flight codes for Space Science and Earth Science Enterprises to address the strategic interests of these Enterprises. These applications teams represent the future customer base for the REE Project deliverables and are crucial in assuring that REE is addressing the right problems the right way.

The REE *system software* must meet two important requirements. First, it must be capable of supporting fault-tolerant real-time (as opposed to "batch") operation. A high level of fault tolerance will be required, especially for mission-critical functions. Radiation-induced transient faults must be detected and corrected in real-time. Hardware component failure must result only in incremental (not catastrophic) reduction in performance. Among the HPCC Program elements, requirement of real-time operation is unique to REE. Second, *system software* must support an architecture that is scalable. This will permit it to support an array of mission needs and classes, ranging from high-performance Earth orbiters to long-lived missions to the outer Solar System. Scalability is an issue of importance to other HPCC Program elements as well. REE focuses on the fault tolerance issues of system software and services, but will rely on the other projects to cover the more mainstream scalable, parallel system software development.

The REE *computing testbeds* will be used to develop, test, and evaluate low-power embedded versions for space-based computing of new high-performance computing architectures. Initially, ground-based testbeds will be developed in partnership with industry to validate the ability to lower the power and improve the reliability of commercial high-performance computing architectures. In this environment, such issues as fault-tolerance, graceful degradation, scalability, testability, reconfigurability, and performance can be explored without the considerable investment of time and funding required for flight testing. The key to the success of these earth-based facilities is access. They must be remotely available to developers of the *applications* (i.e., users) and the *system software*. Flight testing of a hardware prototype is a crucial final element of the technical plan. For space-based evaluation, flight experiments for evaluating the early REE prototypes may be planned for the later launches in the New Millennium Program or other flight testing opportunities. These experiments may be viewed as *flying testbeds* where REE hardware and software prototype systems may be tested and evaluated in a realistic environment.

REE research will focus on two crucial technical issues: fault-tolerant high-performance and improvement in the performance-per-power ratio. It would be somewhat artificial to view these as distinct and unrelated. Indeed, ultimately they may be distinguished only in that they represent different implementations of the same scalable, architectural concepts. Moreover, they will not be pursued to the exclusion of major research efforts in the other technical areas discussed earlier. However, in choosing this focus, REE is paving the way for NASA to meet the most challenging of envisioned mission requirements, for example, providing an Earth-orbiting SAR processor capable of tens of GigaFLOPS or supporting an outer planet mission having less than a watt available for computing. Because the REE *applications* are chosen to represent computing problems typical of the space environment, they will be used to provide focus and direction to this research.

The REE Project works in close partnership with industry, academia, and government. Teams are formed to pursue the research and development goals described above. These partnerships will form a two-way path for the infusion of new off-the-shelf component technology from industry into NASA flight projects and for the transfer of REE-developed technology (fault-tolerance, packaging and miniaturization, architectures, etc.) back into the private sector for commercial use. The industrial, academic, and government members of these teams will be bona fide partners in the REE effort: between half and three-quarters of the Project's resources will be spent outside of NASA. The vehicle that will be used in forming these partnerships or teams will be the Request for Proposals (RFP).

Other federal agencies, particularly DoD and DARPA, are keenly interested in the directions that REE will pursue. REE is already coordinating its technical R&D activities with the Air Force Research Laboratory Improved Space Computer Program (ISCP). REE will coordinate investments with ISCP to avoid duplication in R&D, and to cover a broader range of spaceborne computing concepts than either program could afford separately.

5.4 Learning Technologies (LT) Project

The goal of the Learning Technologies Project is:

To research and develop products and services that use NASA information and that facilitate the application of technology to enhance the educational process for formal and informal education and life-long learning.

The goal supports the Office of Human Resources and Education goal for Educational Technology as seen at http://education.nasa.gov/implan/fig1.htm and directly contributes to National Priorities in Educational Excellence as noted on page 9 of the 1998 NASA Strategic Plan with 1999 Interim Adjustments:

We involve the educational community in our endeavors to inspire America's students, create learning opportunities, and enlighten inquisitive minds.

5.4.1 Overview

The NASA Learning Technologies (LT) Project uses NASA's inspiring mission, unique facilities, and specialized workforce in conjunction with the best emerging technologies to promote excellence in America's educational system. LT works to enhance the public's scientific and technical familiarity, competence, and literacy. LT accomplishes this by capturing the educational potential of NASA programs and by conducting and facilitating educational projects at all levels of the American educational system. LT will leave the American People with a legacy of education technologies and applications. To date, 51 educational projects have been established for the educational community to use on an ongoing basis.

It is known that the understanding of technology and computers has greatly affected people in the United States. This trend has enhanced economic growth and improved daily life. Unfortunately, the population is becoming stratified in its access to information. As a result, children of economically-challenged parents may never have the opportunity to see a computer in their own home. In this case the information age may actually be stimulating a further separation of the social classes. To help counter this effect, the LT Project is working with the Department of Education to establish staff positions and training tools in our libraries, and public buildings to help educate parents who need computer and technology skills. In doing so, they can further develop themselves and their children.

VISION: LT promotes effective use of NASA information and knowledge for education and life-long learning.

MISSION: LT is NASA's leader in the development of educational technology.

LT has a strong focus on multimedia, multisensory, interactive, internet-based technologies. It leverages off of innovative state-of-the-art science. Many of LT's high-level milestones will develop new capabilities from these sources.

LT is a multi-center activity managed by the HPCC LT Project Office at Ames Research Center. LT funds activities that use the National Information Infrastructure (e.g., Internet) and other technologies to foster reform and restructuring excellence in math, science, computing, engineering, and technical education. LT activities fall under the Educational Technology category of NASA's Education Program.

5.4.2 Technical Plan for LT

The technical plan for the Learning Technologies (LT) Project focuses on accomplishing the following objectives:

- Prototype breakthrough technologies that serve as a catalyst for learning environment use of engineering and scientific data by 9/00.
- Demonstrate integrated learning technology products in relevant educational environments by 9/01.
- Production-ready breakthrough technologies that serve as a catalyst for learning environment use of engineering and scientific data by 9/02.
- Solicit and implement LEARNERS II agreements with industry & academia by 9/03.
- Develop prototype of revolutionary multisensory multimedia technology for education by 9/04.
- Establish impact on NASA's education mission through the demonstration of prototype revolutionary multisensory multimedia systems for education by 9/05.

LT researches activities with these objectives to develop emerging technologies and develops them into high-quality and affordable learning environments, connecting educators with NASA missions. Special emphasis is placed on encouraging historically-underrepresented groups to pursue careers in science, mathematics, and engineering. LT supports these educators in their own educational goals, in the goals of the educational systems in which they work, and in their efforts to improve those systems. Our requirements come from the NASA Implementation Plan for Education and the NASA Strategic Plan.

Only a select few can afford to tackle the education challenges that LT has taken on. In the NASA LT Dissemination Plan FY1998, LT expressed the need to reach all of the over 100 thousand schools in the United States. LT is approaching dissemination to ten percent of this audience through the establishment of internal and external alliances, such as the NSTA "Building a Presence" initiative. LT will be developing robust technologies that can be used by both teachers and students with minimal guidance and limited computational resources. LT will outline the development of user friendly software and turn-key hardware to support newly-developed educational systems. In order to bring the educational experience of NASA's new technology to the student, LT must effectively close the gap between the rapidly evolving world of the scientist and the challenging environment of the student. A comprehensive integration of Academia and NASA technology will be required to generate the prime interface to students.

Implementation of these objectives occurs largely through the sponsorship, often in the form of Cooperative Agreements, of numerous activities across all of the NASA Centers and in the external community. Guidance in soliciting, selecting and evaluating these activities comes from a steering committee comprising the InterCenter Working Group (ICWG) and the LT Advisory Board. The general role of the LT Advisory Board is to examine Learning Technologies programs, products, and services and offer independent advice and guidance.

This process ensures that the highest-quality activities, with a balance of both near- and long-term impacts, are supported to meet NASA Educational Technology program goals, objectives and actions. It also assures that these activities meet the milestones of the Learning Technologies Project and the HPCC Program Goals, including one of the primary HPCC goals of disseminating audience-appropriate and quality technologies to the American Public.

5.5 NASA Research and Education Network (NREN) Project

The goal of the NASA Research and Education Network Project is to:

Extend U.S. technological leadership in computer communications through research and development that advances leading-edge networking technology and services, then apply these enhanced capabilities to NASA mission and educational services.

5.5.1 Overview

The goal of the NASA Research and Education Network (NREN) Project is to provide a next-generation network testbed that fuses new technologies into NASA mission applications. The capabilities that are realized by these new technologies will enable new methodologies for achieving NASA science goals. Moreover, these networking technologies will provide NASA missions with the advantages of enhanced data sharing, interactive collaboration, visualization and remote instrumentation. NREN will meet these goals through technology integration and collaborations within the multi-agency Next Generation Internet program.

The NASA Research and Education Network (NREN) Project is the primary NASA part of the Federal Next Generation Internet (NGI) initiative. The Next Generation Internet initiative is a multi-agency Federal partnership with industry and academia to develop significantly higher-performance networking technologies and systems-enabling, next-generation distributed applications between scientists, engineers, and computing resources.

5.5.2 Applications

NREN is tightly aligned with multiple NASA efforts. NREN's partners include other HPCC Projects, NASA Enterprises, NASA Centers, and other Federal agency NGI partners. NREN's strategy to integrate advanced networking technologies into NASA applications is outlined below:

- Evaluate emerging network technologies that promise to enable future NASA applications
- Prototype selected technologies using the NREN testbed
- Extend the NREN testbed to key NASA application sites
- Prototype next-generation NASA applications on the NREN testbed, using the advanced technologies, and validate successful approaches

Advanced network technologies will contribute different types of functionality to various HPCC/NASA mission activities. Emphasis is focused on using advanced networking technologies to enable applications that involve the geographical distribution of computing facilities and/or people.

Applications in the following areas are being pursued: support of virtual collaboration and remote instrumentation for the Astrobiology Institute; efficient and timely distribution of large volumes of data for Earth Sciences; creation of virtual reality settings for Aerospace; and tele-seminars and education outreach for the education community. These application areas are intended only as a sample of current and planned activities.

5.5.3 Technologies

Through collaboration with key organizations within government, academia, and industry, NREN will focus on the following technologies to enhance HPCC/NASA's missions:

Quality of Service (QoS): QoS technologies address the commitment of resources to specific applications, to ensure that the performance parameters such as bandwidth, latency, jitter, and packet loss stay within an acceptable range. The ability to provide QoS to end-user applications will enable efficient sharing of network resources among multiple users, while providing preferential treatment to selected applications during conditions such as scarce resources and varying delay. NREN will investigate various approaches to QoS, including shaping traffic as it enters the network, reserving network resources (e.g., ReSerVation Protocol , RSVP), utilizing different queuing strategies within the routers, and labeling selected network flows and then providing preferential treatment to those flows within the network backbone (e.g., differential services).

Multicast: Multicast, point-to-multipoint transmission, is the primary technology that enables collaborative applications. Multicast was initially introduced into the Internet by creating virtual multicast tunnels within the unicast infrastructure. Tunneling, however, is only an interim solution, as it is extremely inefficient. NREN is taking the lead in deploying native multicast in wide area networks, thus enabling very high bandwidth multicast.

Multicast is inherently unreliable transmission, since it is based on the unreliable UDP (User Datagram Protocol) transport protocol. While most audio and video transmissions are tolerant of a small level of packet loss, file transfer and imaging applications typically are not. Reliable multicast is required for these latter activities, i.e., native multicast must be augmented by appropriate mechanisms to add reliability. Different strategies for achieving reliable multicast have been proposed, including the use of forward error correction. NREN will evaluate the strengths and weaknesses of these strategies in the context of specific NASA applications.

Adaptive Middleware: NREN will prototype network technology to enable the creation of a middleware-enhanced internetwork to support a very high-performance geographically distributed heterogeneous information and computational capability. The middleware will address scheduling and other QoS issues as well as security issues. Such a platform has the potential of transforming NASA missions in the 21st century.

Gigabit Networking: Several NASA Enterprise Programs are developing applications that will involve interactive visualization of large data sets; these applications will require ultra-high-bandwidth network connections. To support these applications, NREN will partner with the National Transparent Optical Network (NTON), a 10+ gigabit/second optical network.

Hybrid Networking: Many NASA applications require access to remote sites or to sites that do not have high-speed terrestrial connectivity. To support such applications, a combination of satellite and terrestrial networks must be used. Traditional network protocols (designed and tuned for terrestrial networks) may require modification to enhance performance in this high-latency, lossy network environment. NREN will work with NASA Glenn Research Center personnel and with commercial satellite partners to enable high-performance NASA mission applications over hybrid networks.

Traffic Engineering: Traffic engineering is a natural follow-on to NREN's Quality of Service activities. The objective of traffic engineering is to enhance network performance by distributing traffic evenly across network resources. Specific traffic-engineering capabilities which NREN will investigate include assigning traffic to specific network routes, providing rapid traffic adaptation to changes in network topology, and incorporating administrative policies in the routing process. These traffic-engineering capabilities will enable more efficient utilization of system resources. This translates into improved services, in terms of both increased throughput and reduced delay, for NASA applications.

Other network technologies are certain to emerge during the time span of this project plan. NREN will evaluate other emerging network technologies and new paradigms for collaborative interactions as they arise, and prototype these technologies as it is deemed appropriate.

6 PROGRAM SCHEDULE

The currently active HPCC Program milestones are given in Section 6.1. The metrics and target success criteria for each milestone are also listed. All of the HPCC Program milestones (active and completed) are given in the Appendix.

The HPCC Program operates under 8 PCA milestones, supported by 44 Program milestones. The chronological flow of Program milestones into PCA milestones is represented graphically following the milestone list.

The Program has been designed to encourage cross-Project synergy when effective, especially in the development of domain-independent technologies. As a consequence, approximately 25% of the active Program milestones are addressed by multiple Projects.

To retain tractability, whenever feasible, distinct output metrics are identified for each Project contributing to a Program milestone. As a result, even in cases where multiple Projects may be working together to exceed a specific Program milestone, the target success criteria for each individual Project is documented. This allows the determination of, for example, whether a specific Project has met its target success criteria for a milestone, independent of other Projects.

6.1 HPCC Program Milestones and Output Metrics

Milestones	Due Date	Output Metrics
PCA-1 Develop component technologies for performance	**9/01**	
1.1 Establish high-performance testbed for application performance (CAS/ESS/NREN)	9/00	CAS/ESS/NREN: Integrated hardware and software to provide a computing and communications testbed for HPCC applications capable of 250 GFLOPS (benchmarks) and 3 locations with Gigabit WAN capability.
1.2 Establish 1st generation scalable embedded computing testbed (REE)	6/01	REE: Computing testbed capable of 30 MOPS/Watt and scalable to at least 50 nodes.
1.3 Develop and apply technologies to measure and enhance performance on high-performance testbeds (CAS/ESS/NREN)	9/01	CAS: Software tools to reduce parallelization time from months to one week while maintaining 50% application performance compared with manual parallelization. Tools to benchmark testbed performance in computing capability, database manipulation, and scheduling to evaluate alternate scheduling strategies and choose optimal approaches to reduce variability and improve predictability of turnaround time. 3 relevant application codes parallelized; 3 data analysis codes parallelized; documented evaluation of parallelization tools. ESS: 90% of Round-3 codes with capabilities for automated performance monitoring and characterization. 30% of ESS Round-3 applications operating at 3X improvement using negotiated science metrics over baseline at the start of Round-3. NREN: Automated quality of service data collection tool capable of measuring 2 service classes and scalable to at least 5 nodes. 3X performance in 1 application each for aerospace and Earth sciences through the integration of networking enhancements

		into application codes.

Milestones	Due Date	Output Metrics
PCA-2 Develop component technologies for reliability and resources management	**6/03**	
2.1 Develop real-time reliability for spaceborne computing (REE)	3/02	REE: 3 applications with 99% availability, 99% reliability over 5 years, and less than 50 msec latency.
2.2 Develop embedded tools and services for autonomous resurce estimation/request of local and distributed ground based systems (CAS/ESS/NREN)	12/02	CAS: Tools for broadcasting local system status for utilization on distributed systems. 3 applications with tools for automated submission and management of multiple jobs; 3 applications with tools for utilization of new or modified resources on a distributed computing system within 1 day. Tools for job execution management on distributed systems; integration of new computing or storage node into distributed computing system within one day. ESS: Production-ready commodity-based cluster computing runtime and development environments portable to three Linux-based testbeds from different vendors. NREN: 3 applications with quality of service guarantees based on resource management of 5 network nodes. 50 Mbps throughput improvement in 3 applications with the embedded capability to automatically estimate and request WAN resources.
2.3 Develop tools for reliability of ground-based computing systems (CAS)	6/03	CAS: Application tools to detect, classify and adapt to faults on distributed computing nodes and networks; 99% availability on distributed computing systems (10 distinct resources including one each of

		computing node, mass storage and wide area network).

Milestones	**Due Date**	**Output Metrics**
PCA-3 Develop component technologies for interoperability and portability	**9/03**	
3.1 Tools and techniques for interoperable and portable applications in aerospace, Earth science and space science communities (CAS/ESS)	3/02	CAS: Distributed debugging capability on 6 distinct platforms; adapt codes for interoperability within 1 week. ESS: Prototype Earth and space science frameworks impacting at least 5 scientific communities with interoperability among 2 or more applications per framework. 3 applications interoperating within a prototype Earth System Modeling Framework. Integration of new module into framework within 1 day; portability to new computing system within 1 week. Two portable parallel latency-tolerant adaptive mesh refinement packages.
3.2 Interoperable and portable networking technologies (NREN)	9/02	NREN: 100% of external NREN multicast connections via high-performance Multicast protocols among 5 NGI networks. Establish quality of service and traffic engineering capabilities among 3 NGI networks.
3.3 Interoperable and portable systems, services and environments (CAS/ESS)	9/03	CAS: Interoperability of 3 tools pre-processing CAD geometry data for application input; interoperability of 10 tools spanning 3 aerospace disciplines and including high-fidelity analysis; integration of new tool into interoperability framework within one day. ESS: Portable production-ready Earth System Modeling Framework incorporating 5 disciplines.

Milestones	Due Date	Output Metrics
PCA-4 Develop component technologies for usability	**9/04**	
4.1 Prototype/establish advanced technologies that serve as a catalyst for learning environment use of engineering and scientific data (LT)	9/00	LT: 5 prototype technology or application advances providing internet-based multimedia interactive tools addressing national education standards.
4.2 Production-ready breakthrough technologies that serve as a catalyst for learning environment use of engineering and scientific data (LT)	9/02	LT: 5 production-ready technology or application breakthroughs providing internet-based multimedia interactive tools addressing national education standards.
4.3 Develop tools to improve usability of aerospace simulation capabilities (CAS)	3/04	CAS: Visual-based assembly capability applied to 3 aerospace applications to speed the problem set-up, reduce learning time, and reduce set-up errors.
4.4 Develop prototype of revolutionary multisensory multimedia technology for education (LT)	9/04	LT: Prototype technology for education with visual, auditory, motion and haptic interfaces and utilizing digital libraries and artificial intelligence.

Milestones	Due Date	Output Metrics
PCA-5 Demonstrate integrated HPCC technologies	**9/02**	
5.1 Demonstrate embedded applications on 1st generation spaceborne computing testbed (REE)	9/00	REE: 3 applications with 10X improvement (per processor) in throughput over the 1999 RAD6000, sqrt(n) processor scalability, and 50% of ideal speedup.
5.2 Demonstrate integrated learning technology products in relevant educational environments (LT)	9/01	LT: LT-developed interactive multimedia technologies distributed to 10,000 learning environments such as schools, museums and science centers, community centers and aerospace education organizations.
5.3 Demonstrate improvement in time-to-solution for aerospace applications (CAS)	12/01	CAS: Improvement in aerospace applications: Complete combustor and compressor simulation in 3 hours each; high-fidelity space transportation vehicle analysis in 1 week and optimization enabled; S&C database generation for aerospace vehicles within 1 week; demonstration of improvements in 4 NASA-sponsored design events.
5.4 Demonstrate embedded applications using fault-tolerant techniques (REE)	6/02	REE: 3 applications with 10X improvement (per processor) in throughput over the 1999 RAD6000, sqrt(n) processor scalability, and 50% of ideal performance speedup.
5.5 Demonstrate significant improvements in Earth and space science application codes (ESS)	9/02	ESS: 10X improvement using negotiated science metrics over baseline at start of Round-3 in 50% of all applications while interoperating among 2 codes. 20 high-performance modules compatible with existing frameworks.
5.6 Demonstrate end-to-end networking capabilities on NASA mission-oriented applications (NREN)	9/02	NREN: 3 applications interoperating on multiple QoS enabled networks; 50 Mbps (aggregate internal) multicast; gigabit performance between 2 NASA sites; 2 applications utilizing enhanced hybrid networking. Gigabit capability (end-to-end) between 2 NASA sites; Application-embedded traffic engineering enabling query and efficient priority utilization.

Milestones	Due Date	Output Metrics
PCA-6 Demonstrate significant engineering, scientific, and educational impacts from integrated HPCC technologies	**9/05**	
6.1 Establish impact on Earth and space sciences through the demonstration of a production-ready high-performance Earth and space science computational simulations validated by NASA Enterprise observational mission data (ESS/NREN)	9/03	ESS: 25 scientific research groups using applications supporting NASA science objectives operating at 10X improvement using negotiated science metrics over baseline at start of Round-3; 10 groups interoperating with stable Earth and space science frameworks impacting 5 scientific communities (2 per framework; 3 for Earth System Modeling framework). NREN: 2 Earth and space science applications across high-performance end-to-end networks with gigabit performance and QoS enhancements.
6.2 Establish impact on space mission through the demonstration of a flight-ready integrated system software, testbed, and application system (REE)	6/04	REE: 3 applications achieving 300 MOPS/Watt on flight-qualified testbed with scalability to 50 nodes, scalability of sqrt(n), availability of 99%, reliability of 99% over 5 years, real-time latency of less than 50 msec and price-performance of 8 MOPS/$K (100X). Capability for insertion time of less than 18 months into flight vehicle.
6.3 Establish impact on aerospace design and operations through the demonstration of integrated systems of applications, tools, services and resources which enable the high-performance execution of interoperable aerospace applications across distributed heterogeneous testbeds (CAS/NREN)	9/05	CAS: Utilize distributed heterogeneous computing system (10 components) for: 3D steady-state multidisciplinary propulsion system analysis in 1 day; high-fidelity full-vehicle simulation of aircraft in 1 day; high-fidelity space transportation vehicle analysis in 1 day and optimization in 1 week. Document improvements in 6 NASA-sponsored design events and impact to 3 elements of the national airspace system. NREN: 3 aerospace design applications across high-performance end-to-end networks with gigabit performance and QoS enhancements.

6.4 Establish impact on NASA's education mission through the demonstration of prototype revolutionary multisensory multimedia systems for education (LT/NREN)	9/05	LT: Established classroom-ready prototype technologies for education with visual, auditory, motion and haptic interfaces and utilizing digital libraries and artificial intelligence. NREN: Distance-learning application utilizing adaptive networking technologies.

Milestones	Due Date	Output Metrics
PCA-7 Establish sustainable and wide-spread customer use of HPCC Program technologies	**9/06**	
7.1 Establish sustained price-performance improvements for Earth and space science applications (ESS)	9/04	ESS: Demonstrate 50 Gigaflops sustained applications performance at $250K for 50% of Round-3 Investigations.
7.2 Establish sustained utilization of commercial computing technologies for spaceborne applications (REE)	9/05	REE: Technology selected for flight mission price-performance of at least 8 MOPS/$K (100X).
7.3 Enable sustained use of LT technologies by educational community (LT)	9/05	LT: Technologies or applications shall be infused as a tool to enhance the learning in a content area or multidisciplinary setting in at least 1,000 learning environments such as schools, museums and science centers, community centers and aerospace education organizations.
7.4 Establish sustained use of CAS tools and techniques towards meeting Aerospace Technology Enterprise goals and objectives (CAS)	9/06	CAS: Survey demonstrating infusion of production-ready applications and system software tools into NASA Aerospace Technology programs, aerospace engineering industry and high-performance computing communities.
7.5 Transfer NREN technologies to NASA's operational WAN (NREN)	9/06	NREN: Infusion of multicast, QoS, and traffic engineering technologies into NASA operational WAN.

PCA and Program Milestones	Due Date
PCA-1 Develop component technologies for performance	**9/30/01**
1.1 Establish high-performance testbed for application performance (CAS/ESS/NREN)	10/3/00
1.2 Establish 1st generation scalable embedded computing testbed (REE)	6/30/01
1.3 Develop and apply technologies to measure and enhance performance on high-performance testbeds (CAS/ESS/NREN)	9/30/01
PCA-2 Develop component technologies for reliabili and resources management	**6/30/03**
2.1 Develop real-time reliability for spaceborne computing (REE)	3/29/02
2.2 Develop embedded tools and services for autonomous resource estimation/request of local and distributed ground-based systems (CAS/ESS/NREN)	12/31/02
2.3 Develop tools for reliability of ground-based computing systems (CAS)	6/30/03
PCA-3 Develop component technologies for interoperability and portability	**9/30/03**
3.1 Tools and techniques for interoperable and portable applications in aerospace, Earth science and space science communities (CAS/ESS)	3/29/02
3.2 Interoperable and portable networking technologies (NREN)	9/30/02
3.3 Interoperable and portable systems, services and environments (CAS/ESS)	9/30/03
PCA-4 Develop component technologies for usabilit	**9/30/04**
4.1 Prototype/establish advanced technologies that serve as a catalyst for learning environment use of engineering and scientific data (LT)	9/30/00
4.2 Production-ready breakthrough technologies that serve as a catalyst for learning environment use of engineering and scientific data (LT)	9/30/02
4.3 Develop tools to improve usability of aerospace simulation capabilities (CAS)	3/31/04
4.4 Develop prototype of revolutionary multisensory multimedia technology for education (LT)	9/30/04
PCA-5 Demonstrate integrated HPCC technologies	**9/30/02**
5.1 Demonstrate embedded applications on 1st generation spaceborne computing testbed (REE)	9/29/00
5.2 Demonstrate integrated learning technology products in relevant educational environments (LT)	9/28/01
5.3 Demonstrate improvement in time-to-solution for aerospace applications (CAS)	12/31/01
5.4 Demonstrate embedded applications using fault-tolerant techniques (REE)	6/28/02
5.5 Demonstrate significant improvements in Earth and space science application codes (ESS)	9/30/02
5.6 Demonstrate end-to-end networking capabilities on NASA mission-oriented applications (NREN)	9/30/02
PCA-6 Demonstrate significant engineering, scientifi and educational impacts from integrated HPCC technologies.	**9/30/05**
6.1 Establish impact on Earth and space sciences through the demonstration of a production-ready high-performance Earth and space science computational simulations validated by NASA Enterprise observational mission data (ESS/NREN)	9/30/03
6.2 Establish impact on space mission through the demonstration of a flight-ready integrated system software, testbed, and application system (REE)	6/30/04
6.3 Establish impact on aerospace design and operations through the demonstration of integrated systems of applications, tools, services and resources which enable the high-performance execution of interoperable aerospace applications across distributed heterogeneous testbeds (CAS/NREN)	9/30/05
6.4 Establish impact on NASA's education mission through the demonstration of prototype revolutionary multisensory multimedia systems for education (LT/NREN)	9/30/05
PCA-7 Establish sustainable and wide-spread custon use of HPCC Program technologies	**9/29/06**
7.1 Establish sustained price-performance improvements for Earth and space science applications (ESS)	9/30/04
7.2 Established sustained utilization of commercial computing technologies for spaceborne applications (REE)	9/30/05
7.3 Enable sustained use of LT technologies by educational community (LT)	9/30/05
7.4 Establish sustained use of CAS tools and techniques towards meeting Aero-Space Technology Enterprise goals and objectives (CAS)	9/29/06
7.5 Transfer NREN technologies to NASA's operational WAN (NREN)	9/29/06

7 PROGRAM RESOURCES

The Program will be accomplished within the budget allocations and resources listed below. The presented HPCC Program budget is consistent with the President's FY2000 budget as enacted by Congress.

7.1 Funding by Enterprise

R&D NOA PY $,M	Prior	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY05	BTC	Total
Total HPCC	**400.4**	**47.5**	**69.4**	**74.9**	**76.2**	**67.0**	**56.5**	**29.4**	**14.6**	**835.9**
Aerospace	241.6	20.6	24.2	24.2	25.5	27.3	27.4	25.4	14.6	430.8
Space Science	10.4	8.4	19.5	24.9	24.9	13.9	13.9	0.0	0.0	115.9
Earth Science	131.4	14.5	21.9	21.8	21.8	21.8	11.2	0.0	0.0	244.4
Education	17.0	4.0	3.8	4.0	4.0	4.0	4.0	4.0	0.0	44.8

The following program codes are assigned to HPCC funds:

Code R - Office of Aerospace Technology
509-10 Computational Aerospace Science Project
509-10-41 NASA Research and Education Network Project

Code Y - Office of Earth Science
625-20 Earth and Space Sciences Project
625-20 NASA Research and Education Network Project
625-40 Learning Technologies Project

Code S - Office of Space Science
626-30 Remote Exploration and Experimentation Project
626-30 NASA Research and Education Network Project

Code F - Office of Human Resources & Education
332-41 Learning Technologies Project

7.2 Funding by Center

R&D NOA PY $,K	FY 99	FY 00	FY 01	FY 02	FY 03	FY 04	FY05
Total HPCC	**47,500**	**69,400**	**74,900**	**76,200**	**67,000**	**56,500**	**29,400**
ARC	17,409	26,488	16,177	17,352	17,885	19,395	16,495
DFRC	150	150	150	150	150	150	150
GRC	5,223	6,138	5,813	5,955	6,668	5,870	5,870
GSFC	10,950	12,245	20,410	19,730	19,730	9,430	1,530
JPL	9,499	19,646	27,230	27,910	16,910	16,610	310
JSC	215	215	215	215	215	215	215
KSC	17	8	50	50	50	50	50
LaRC	3,737	4,410	4,505	4,488	5,042	4,430	4,430
MSFC	250	50	300	300	300	300	300
SSC	50	50	50	50	50	50	50

7.3 Workforce by HPCCP Project

Project	Center	FY 1999	FY 2000	FY 2001	FY 2002	FY 2003	FY 2004	FY 2005
HPCC Program		108	120	119	120	123	122	107
Project	**Center**							
Computational Aerosciences		85	92	92	93	95	95	95
	ARC	24	24	25	25	25	25	25
	LaRC	12	17	13	14	16	16	16
	GRC	49	51	54	54	54	54	54
Earth and Space Sciences		12	15	15	15	16	15	0
	GSFC	12	15	15	15	16	15	0
	JPL	0	0	0	0	0	0	0
Remote Exploration And Experimentation		0	0	0	0	0	0	0
	ARC	0	0	0	0	0	0	0
	GSFC	0	0	0	0	0	0	0
	JPL	0	0	0	0	0	0	0
NASA Research and Education Network		6	7	6	6	6	6	6
	ARC	6	7	6	6	6	6	6
Learning Technologies		5	6	6	6	6	6	6
	ARC	2	3	3	3	3	3	3
	DFRC	0	0	0	0	0	0	0
	GSFC	0	0	0	0	0	0	0
	JPL	0	0	0	0	0	0	0
	JSC	1	1	1	1	1	1	1
	KSC	0	0	0	0	0	0	0
	LaRC	0	0	0	0	0	0	0
	GRC	2	2	2	2	2	2	2
	MSFC	0	0	0	0	0	0	0
	SSC	0	0	0	0	0	0	0

8 CONTROLS

The process for controlling changes of the HPCC Program and the subordinate Projects is hierarchical and described in this section.

8.1 Program and Project Changes

The Program Commitment Agreement (PCA), the Program Plan, and each Project Plan (CAS, ESS, REE, NREN, and LT) are controlled documents. The retention, updating, and approval of these documents is controlled as follows:

Document	Retains Approved Documents	Preparation of Updated Documents		Approves Documents
		Primary	**Supporting**	
Program Commitment Agreement	NASA HQ Program Office	HPCC EC	Program Office	Administrator
Program Plan	Program Office	Program Office	Project Offices	HPCC EC AA – (Codes F,R,S and Y)
Project Plans	Project Offices	Project Offices	Task Managers Performing Orgs.	Program Manager

Any change to the HPCC Program or an HPCC Project which alters the commitments within a controlled document must be approved by the approving official(s) for all levels of documents impacted by the proposed change. The PCA and Program Plan include change logs which document all changes from the beginning of the HPCC Program to the date of the latest approved change.

8.2 HPCC Computing and Networking Testbeds

All participants in the NASA HPCC Program must comply with current NASA security policies regarding access to networks and computers.

8.3 Sensitive Technology

NASA center management, working with industry and NASA HPCC researchers, are responsible for identifying sensitive technologies. These technologies are handled in such a way that their dissemination to foreign persons, companies, laboratories, and universities is restricted.

Sensitive information that is generated under formal cooperative research agreements between NASA and non-Federal parties is protected by the amended (October 1992) NASA Space Act of 1958. Data produced under such an arrangement will be protected from Freedom of Information Act (FOIA) requests for a period of 5 years after the date of dissemination.

Negotiated License Agreements are used to restrict access to privately-developed technology performed under the auspices of the NASA HPCC Program. These agreements provide NASA with limited rights to use proprietary data or designs in NASA in-house or cooperative research projects. These agreements specify limits on the distribution and use of the proprietary data by NASA and NASA-licensed entities.

Some software and information developed solely within the NASA HPCC Program may be subject to protection under the Export Administration Regulations (EAR) or the International Traffic in Arms Regulations (ITAR), which are export controls established by law. The participants in the HPCC Program will follow applicable export control laws. These regulations establish lists or categories of technical data and/or products that may not be exported without an approved export license. (Note that the definition of “exported” includes “disclosed” and “discussed” as well as published.)

9 RELATIONSHIPS TO OTHER PROGRAMS AND AGREEMENTS

The NASA HPCC Program is an element of the national HPCC activities, as coordinated by the National Coordination Office (NCO) for IT R&D (see http://www.ccic.gov/).

The National Coordinating Office (NCO) coordinates the federal multi-agency research and development activities. The NASA HPCC Program is engaged with the strategic planning, coordination, and reporting activities of the NCO. Through the NCO, the NASA HPCC Program is in touch with the latest trends in federal IT R&D strategies and meets the NASA HPCC commitments to the federal IT R&D activities. By participating in NCO reporting activities, the NASA HPCC Program receives high-level review through inclusion in such documents as the IT R&D Annual Report and IT R&D Implementation Plan.

Specific interactions between the NASA HPCC Program and the NCO include:

- Interactions with the NASA IT R&D Subcommittee and working group representatives
- Evaluation of PITAC findings for relevance to NASA HPCC Program planning and execution
- Active involvement with NCO planning and coordination activities
- Active support of NCO reporting activities

The HPCC Program contributes directly to the goals of the NASA Strategic Plan, as well as contributing to the effectiveness of other NASA Programs which utilize high-performance computing and communications technologies in their support of the NASA Strategic Plan. As other NASA Programs rely on CoSMO, SOMO, and NISN for production, high-performance computing and communications resources, CoSMO, SOMO, and NISN are customers of the successful technologies demonstrated by the HPCC Program.

Internal agreements:

1. NREN and NASA Integrated Services Network (NISN): Memorandum of Understanding on internal technology collaboration and transfer to NASA operational networks, May 1997.

External agreements:

1. National HPCC Software Exchange. NASA and other Federal HPCC agencies, working in concert with academia, have developed a National HPCC Software Exchange to provide an infrastructure that encourages software reuse and the sharing of software modules across organizations through an interconnected set of software repositories. This multiagency effort was initiated in FY1992 and continues through FY2001.

2. Office of Management and Budget "Terms of Reference," revised annually. Commitments between OMB and Secretaries/Administrators of participating federal agencies who sit on the National Science and Technology Council (NSTC). This document is used to develop a planning framework, program priorities and budget options for consideration by the individual agencies, OMB and ultimately the President.

3. NREN and Computing and Interdisciplinary System Office (CISO)/GRC: Memorandum of Understanding on hybrid technology collaboration and advanced application demonstrations, November 1997.

4. Next Generation Internet: NGI Implementation Plan (available at http://www.ngi.gov), Feb. 1998.

5. MOU between NASA and Silicon Graphics Inc. for collaborations in high-end computing, May 1999.

Reference documents: (available at http://www.ccic.gov/)

1. High Performance Computing and Communications: FY 1998 Implementation Plan, September 3,1998. Commitments between senior executives of participating federal agencies who sit on the NSTC Committee on Information and Communications (CIC). The Implementation Plan is used to annually review program goals, objectives, technical approaches, management approaches and milestones.

2. Information Technology Research: Investing in Our Future: February 24, 1999 Report to the President of the President's Information Technology Advisory Committee (PITAC) on future directions for Federal support of research and development for information technology.

3. Next Generation Internet Initiative: February 1998 Implementation Plan. Summarizes the goals, resources, management, and time line of the NGI Initiative.

4. PITAC Review of the Next Generation Internet Program and Related Issues: April 28, 1999 Report to the President of the President's Information Technology Advisory Committee (PITAC) on the implementation of the NGI Initiative.

5. Information Technology for the Twenty-First Century: A Bold Investment in America's Future: June 1999 Proposed in the President's FY2000 Budget.

10 ACQUISITION STRATEGY

Free and open competitive procurements will be used to the maximum extent possible. Among the procurement vehicles that are expected to be put to use in the NASA HPCC Program are NASA Research Announcements (NRA), NASA Cooperative Agreement Notices (CAN), and Requests for Proposals (RFP). These vehicles will result in grants, cooperative agreements and contracts. Cooperative Agreement Notices (CAN) will be used to the maximum extent possible for the incorporation of technology and applications into the Program. Existing vehicles, such as the Scientific and Engineering Workstation Procurement II (SEWP II) contract, may also be used. Interagency agreements for joint R&D endeavors and the utilization of early prototype systems will also be used.

11 COMMERCIALIZATION OPPORTUNITIES

Commercialization opportunities will be exploited through Space Act Agreements, Cooperative Research Agreements and Memoranda of Understanding with industry. Joint projects in high-risk areas will be pursued on a cost-sharing basis with industry and in close collaboration with government laboratories and academia. NASA will foster horizontal partnerships between NASA and multiple companies within the aerospace sector. The NASA HPCC Program Office will also foster the vertical integration of collaborative teams between hardware suppliers, third-party software vendors, and members of the U.S. aerospace community. Lastly, the NASA HPCC Program sponsors and conducts technical meetings and workshops and promotes the publication of scientific and technical papers to maintain the flow of technology from NASA to industry and academia.

12 TECHNOLOGY ASSESSMENT

HPCC is a computer research program that pursues technologies that are between five and twenty years of maturity. Applications in the areas of earth science, space science, and aerospace transportation systems are used as drivers of HPCC's computational technology research, providing the requirements context for the work that is done.

HPCC conducts TRL 2-6 research activities intended to prove feasibility, develop and demonstrate computing technologies for eventual introduction into NASA operations through operational entities like CoSMO, NISN, SOMO and EOS. For example, HPCC work in spaceborne COTS parallel computing systems is now at the TRL 2-3 stage, but is planned to attain TRL 6 in 2004. In addition, HPCC conducts education technology outreach demonstrations that are essentially at TRL 7-8. Appendix D includes a description of TRL 1-9.

13 DATA MANAGEMENT

The HPCC Program does not execute science missions and, therefore, does not create science data in the sense that would need to be addressed in this section.

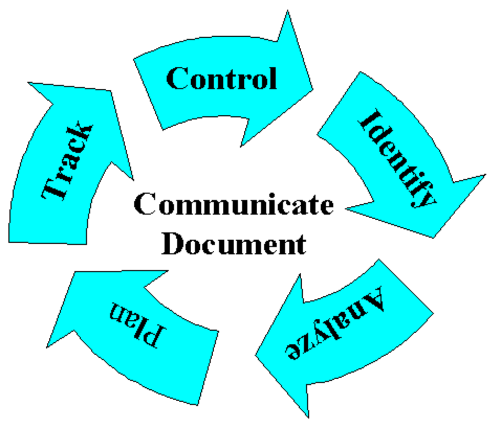
14 RISK MANAGEMENT

14.1 Overview

Risk is inherent in the research and development of new technologies, particularly in the highly dynamic area of high-performance computing and communications. Example identified risks for the HPCC Program, the impact and probability of these risks, and the associated risk probability mitigation strategies, are presented in Section 14.3. The risk mitigation process is fully documented in the HPCC Program Risk Mitigation Plan.

14.2 Risk Management Process

An ongoing risk management process is employed in the HPCC Program:



Identify
Risks are identified at all levels of the Program on a continuous basis. An example current list of Program-level risks is included in Section 14.3. Project specific risks are identified in the five HPCC Project Plans. Program-level risks, as well as Project-specific risks, are reviewed on at least an annual basis concurrent with the review of the Program's controlled documents (see Section 8.1). Program reviews, identified in Section 17, as well as Project-level boards, such as the LT Advisory Board (see Section 5.4.2), are essential elements of the risk identification sub-process.

Analyze
A three-level risk exposure analysis has been applied to the current Program-level risks. The impact and probability of the risks are rated low, medium, or high. This results in nine distinct values of risk exposure, allowing for a ranking of risks.

Plan

In general, Program-level risks must be monitored continuously, and action is required on a continuous basis to achieve mitigation. Risk probability mitigation actions are identified for each example Program-level risk in Section 14.3.

Track

Risk impact and probability are tracked. In addition, progress towards milestones is used as a risk indicator for the Program. Due to the milestone hierarchical structure (e.g., multiple task milestones enabling project milestones, multiple project milestones enabling program milestones, multiple program milestones enabling PCA milestones) progress towards milestones provides effective warning of risk probability in not meeting schedule commitments.

Control

Risk-specific indicators may trigger, for example, a review of more aggressive risk impact and risk probability mitigation and/or risk contigency plans. Any foreseeable delay of Program or PCA milestones triggers the review of appropriate Program-level risk mitigation and/or risk contigency plans. Risk indicators triggered at the task- or project-milestone level are addressed with mitigation actions at the Project level.

Communicate

Risk management processes are reviewed on an annual basis concurrent with the review of the Program's controlled documents (see Section 8.1).

14.3 Risk Identification, Analysis, and Mitigation

Examples of Program-level risks are presented below. For each risk, the impact and probability of the risk are identified. In addition, ongoing processes to reduce the probability of the risk are presented. The Project-specific risks are addressed in the 5 HPCC Project Plans.

Risk	**Risk Impact**	**Risk Probability**	**Risk Probability Mitigation Processes**
Most critical current applications not addressed	High	Medium	• Engage HPCC EC WG in selection processes • Periodically review selection criteria and selected projects with HPCC EC and EC WG • Review, and if necessary, realign application foci on a periodic basis
Program does not remain current with evolving customer technical requirements	High	Medium	• Involve customers in the technical implementation, from concept through delivery • Monitor potential changes in customer requirements • Design approach to adapt to customer changes
Partners do not meet resource commitments	High	Medium	• Formal MOU/MOAs • Periodic management review • Formal joint plans/teams
Reduction/loss of funding	High	Medium	• Advocate benefits to customers/stakeholders • Identify opportunities for expanded customer base
Technical projects do not meet performance or schedule commitments	Medium	Medium	• Monitor progress towards all milestones in hierarchical milestone structure • Regularly-scheduled reviews of technical progress and status • Identify and utilize leverage opportunities by redirecting technical approaches among the various activities
Technical project duplicative and/or not coordinated with a different HPCC project	Medium	Low	• Facilitate inter-project integration and coordination • Re-allocate resources to reduce inappropriate technical duplication
Changes in technical project activities adversely affect a different HPCC	Medium	Low	• Facilitate inter-project integration and coordination

project			
Unavailability of major computational facilities	Medium	Low	• Establish partnerships with other programs and organizations • Formalize relationships through agreements

15 LOGISTICS

The HPCC Program is a research and technology development program, not a systems development program. As such, there are no logistics considerations.

16 TEST AND VERIFICATION

Architectures and software will be evaluated using performance benchmarks based on real applications in the areas of aerospace transportation systems, and Earth and space sciences. Formal methods for software test and verification may be applied to aid in performance prediction and architectural design.

17 REVIEWS

Each of HPCC's five projects reports technical, cost and schedule status on a monthly basis to the Program Manager. In-depth reviews of each HPCC Project are conducted annually by the Program Manager. Typically, these consist of end-of-year site reviews at the lead project centers.

The Program Manager reports performance monthly to the Director of Ames Research Center and the Ames Management Council. The Program Manager reports performance quarterly to the Office of Aerospace Technology consistent with the requirements of the NASA Program Management Council. Members of the HPCC Program Executive Committee and Executive Committee Working Group are invited to these quarterly reviews by the Office of Aerospace Technology. The Office of Aerospace Technology reports Program status quarterly to the NASA PMC.

Reviews of Program plans and strategic directions are conducted annually by the HPCC Executive Committee (see Sec. 4.3).

HPCC is subject to reviews by the Independent Annual Review (IAR) committee. These reviews are typically conducted during the last quarter of each fiscal year.

HPCC routinely generates the following reports:

- HPCC Program Annual Report
- HPCC Program Quarterly Report

18 TAILORING

This Program Plan conforms to the NASA Program and Project Management Processes and Requirements (NPG 7120.5A), with adaptations appropriate to an ongoing and relatively small activity. Sections on acquisition strategy, commercialization opportunities, technology assessment, risk management, logistics, test and verification, and reviews are tailored to the nature of this technology program.

19 CHANGE LOG

19.1 Changes From Program Inception (1992)

1. January 1994. Additional CAS work content was added in response to expressed need from aeronautics airframe and propulsion industry. Information Infrastructure Technology and Applications (IITA) milestones were realigned to reflect budget stretch and IRM reductions.

2. March 1996. Combined similar CAS and ESS milestones. Included out-year milestones. Eliminated IITA milestones due to funding cuts.

3. February 1997. Responded to Presidential initiative to develop NGI. Developed new NGI milestones and replanned $25M in FY98-00 to meet the milestones.

4. September 1997. IITA Project ends due to funding cuts.

5. October 1997. LT Project initiated. IITA education activities and milestones transferred to LT.

6. April 1999. REE FY99 and FY00 baseline milestones rescheduled to adjust for diversion of REE funds to the federally-mandated NREN/NGI effort.

7. April 1999. NREN milestone (NR8) wording and due date changed to more accurately reflect network improvements and NGI application selections.

8. April 1999. New milestones for CAS, ESS, LT and NREN added for out-years.

9. April 1999. New milestone added for the Program to re-evaluate program and project plans with respect to upcoming Agency IT Strategic Plan. Milestone recommended from HPCC EC meeting of 12/15/98.

10. April 2000. Phase II organization and program objectives updated. Baseline milestones established.

20 APPENDIX A — GLOSSARY

ARC	Ames Research Center
AT	Aerospace Technology
ATM	Asynchronous Transfer Mode
CAN	Cooperative Agreement Notice
CAS	Computational Aerospace Sciences
CIC	Computing, Information and Communications
CLCS	Checkout and Launch Control System
CORE	Central Operation of Resources for Educators
CoSMO	Consolidated Supercomputing Management Office
COTS	Commercial Off The Shelf
DARPA	Defense Advanced Research Projects Agency
DFRC	Dryden Flight Research Center
DoD	Department of Defense
DoE	Department of Energy
EAR	Export Administration Regulations
EB	Executive Board (for Aerospace Technology Enterprise)
EC	Executive Committee (HPCC multi-Enterprise)
EOS	Earth Observing System
EPA	Environmental Protection Agency
ES	Earth Science
ESS	Earth and Space Sciences
FOIA	Freedom of Information Act
GFLOPS	Billion Floating Point Operations Per Second (GigaFLOPS)
GRC	Glenn Research Center
GSFC	Goddard Space Flight Center
HPCCP	High Performance Computing and Communications Program
HQ	Headquarters

IAR	Independent Annual Review
ICWG	InterCenter Working Group
IITA	Information Infrastructure Technology and Applications
IRM	Information Resources Management
ISCP	Improved Space Computer Program
IT	Information Technology
ITAR	International Traffic in Arms Regulations
JPL	Jet Propulsion Laboratory
JSC	Johnson Space Center
KSC	Kennedy Space Center
LaRC	Langley Research Center
LEARNERS	Leading Educators to Applications, Research and NASA-related Educational Resources in Science
LSN	Large-Scale Networking
LT	Learning Technologies
MOA	Memorandum of Agreement
MOPS	Million Operations Per Second
MOU	Memorandum of Understanding
MSFC	Marshall Space Flight Center
NCO	National Coordinating Office
NGI	Next Generation Internet
NHSE	National HPCC Software Exchange
NISN	NASA Integrated Services Network
NIST	National Institute of Standards and Technology
NPG	NASA Procedures and Guidelines
NRA	NASA Research Announcements
NREN	NASA Research and Education Network
NSA	National Security Agency
NSF	National Science Foundation
NTSA	National Science and Teachers Association

OMB	Office of Management and Budget
PCA	Program Commitment Agreement
PI	Principal Investigator
PITAC	President's Information Technology Advisory Committee
PMC	Program Management Council (NASA HQ Level)
QoS	Quality of Service
R&D	Research and Development
R&T	Research and Technology
REE	Remote Exploration and Experimentation
RFP	Request for Proposal
S&C	Stability and Controls
SEWP	Scientific and Engineering Workstation Procurement
SOMO	Space Operations Management Office
SS	Space Science
SSC	Stennis Space Center
TFLOPS	Trillion Floating Point Operations Per Second (TeraFLOPS)
TRL	Technology Readiness Level
WBS	Work Breakdown Structure

21 APPENDIX B — COMPLETED PROGRAM MILESTONES

Milestones	Due Date	Status
FY 93		
Interconnects to NSFnet at 45 Mbps	6/93	Complete
Initial development testbeds installed using available high-performance hardware (1-10 Giga-FLOPS sustained)	9/93	Complete
FY 94		
Install 10-50 GigaFLOPS sustained testbed (scalable to 100 GigaFLOPS) for Grand Challenge teams	6/94	Complete
Demonstrate T-3 (45 Mbps) Level 3 HPCC interconnects	9/94	Complete
FY 95		
Demonstrate satellite-based gigabit applications using the Advanced Communications Technology Satellite (ACTS) and associated ground terminals	6/95	Complete
Evaluate initial K-12 digital educational material	9/95	Complete
Demonstrate initial remote sensing database (RSD) applications over the National Information Infrastructure	9/95	Complete
FY 96		
Install 50-100 GigaFLOPS sustained scalable testbed	9/96	Complete
Demonstrate portability and scalability of software components and tools to TeraFLOPS systems	9/96	Complete
FY 97		
Demonstrate integrated, multidisciplinary applications on TeraFLOPS scalable testbeds	9/97	Complete
FY 98		
Install 100-250 GigaFLOPS sustained scalable TeraFLOPS testbed	6/98	Complete
Provide mature remote sensing data applications over the National	9/98	Complete

Research and Education Network		
Distribute mature K-12 curriculum products over the National Information Infrastructure	9/98	Complete
Demonstrate results of mature DLT Projects	9/98	Complete

Milestones	Due Date	Status
FY 99		
Establish next generation internetwork exchange for NASA to connect Grand Challenge universities' principal investigators to NASA high-performance resources	10/98	Complete
Demonstrate 200-fold improvements over FY1992 baseline in time to solution for Grand Challenge applications on TeraFLOPS testbeds	6/99	Complete
Evaluate HPCC program and project plans towards meeting objectives and goals of the Information Technology Initiative	8/99	Complete
Demonstrate portable scalable distributed visualization of multi-terabyte 4D datasets on TeraFLOPS scalable systems	9/99	Complete
Complete the initial efforts of HPCC by demonstrating improvements for aerosciences, Earth science, and space science applications	9/99	Complete

22 APPENDIX C — Funding by Enterprise per HPCC Project

Project	Code	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
CAS		*16,500*	*19,766*	*21,250*	*22,400*	*24,200*	*24,300*	*22,300*
	R	16,500	19,766	21,250	22,400	24,200	24,300	22,300
ESS		*11,600*	*19,667*	*20,900*	*20,900*	*20,900*	*10,300*	*0*
	Y	11,600	19,667	20,900	20,900	20,900	10,300	0
REE		*7,400*	*18,167*	*24,900*	*24,900*	*13,900*	*13,900*	*0*
	S	7,400	18,167	24,900	24,900	13,900	13,900	0
LT		*5,000*	*3,800*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*
	Y	1,000	0	0	0	0	0	0
	F	4,000	3,800	4,000	4,000	4,000	4,000	4,000
NREN		*7,000*	*8,000*	*3,850*	*4,000*	*4,000*	*4,000*	*3,100*
	R	4,100	4,434	2,950	3,100	3,100	3,100	3,100
	S	1,000	1,333	0	0	0	0	0
	Y	1,900	2,233	900	900	900	900	0
PROJECTS TOTAL		***47,500***	***69,400***	***74,900***	***76,200***	***67,000***	***56,500***	***29,400***

	Project	FY1999	FY2000	FY2001	FY2002	FY2003	FY2004	FY2005
R		*20,600*	*24,200*	*24,200*	*25,500*	*27,300*	*27,400*	*25,400*
	CAS	16,500	19,766	21,250	22,400	24,200	24,300	22,300
	NREN	4,100	4,434	2,950	3,100	3,100	3,100	3,100
S		*8,400*	*19,500*	*24,900*	*24,900*	*13,900*	*13,900*	*0*
	REE	7,400	18,167	24,900	24,900	13,900	13,900	0
	NREN	1,000	1,333	0	0	0	0	0
Y		*14,500*	*21,900*	*21,800*	*21,800*	*21,800*	*11,200*	*00*
	ESS	11,600	19,667	20,900	20,900	20,900	10,300	0
	LT	1,000	0	0	0	0	0	0
	NREN	1,900	2,233	900	900	900	900	0
F		*4,000*	*3,800*	*4,000*	*4,000*	*4,000*	*4,000*	*4,000*
	LT	4,000	3,800	4,000	4,000	4,000	4,000	4,000
TOTAL		***47,500***	***69,400***	***74,900***	***76,200***	***67,000***	***56,500***	***29,400***

23 APPENDIX D — NASA Technology Readiness Levels (TRLs)