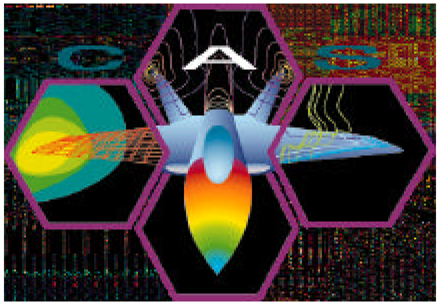
Independent Assessment

High Performance Computing & Communications Program

Computational Aerospace Sciences



Project Overview

Catherine Schulbach, Project Manager

Patti Powell, Program/Project Analyst

June 21-23, 2000

NASA Ames Research Center

Presentation Outline

- Vision
- Mission
- Goals
- Project Objectives
- Changes in Project Objectives from Phase I to Phase II
- Project Implementation Approach
- Project Organization
- Phase I Milestone Mapping
  - Done
  - Accomplished since last IAR
  - Rolled over into Phase II
- Phase I Milestones--Accomplishments
- Phase II Milestones
  - Executability by PCA/Program Milestone
  - Phase II accomplishments
- Resources

CAS Vision

Enable US leadership in flight

In the air

In space

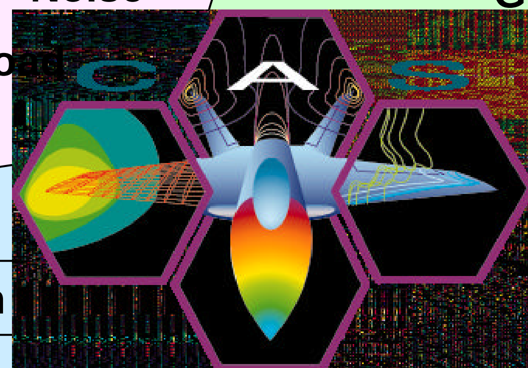
CAS Mission

Aerospace

- Max Mach #
- Mission Radius
- Cl_{max}
- Noise
- Drag counts
- Paylo
- Emissions

High Performance Computing

- File server
- GFLOPS
- Gbytes
- Gbits/sec
- Interface
- Java
- Plugin



Research

- Idealized problems
- Individual efforts
- Satisfy curiosity
- Publish paper
- Individualized tools
- Large, scalable platforms
- Soft deadlines

rams & Projects

- SMPs
- Real-life, hard problems
- Standard tools
- Provide results
- Group efforts
- Hard deadlines
- Build a vehicle

CAS Goal

- **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**

CAS Objectives

- **Customer Impact**
  - **Complete vehicle analysis in one day**
  - **Complete propulsion system analysis in one day**
- **Performance**
  - **Testbed with 250 GFLOPS sustained on applications**
- **Interoperability**
  - **Interoperation among at least 10 distinct tools spanning at least 3 aerospace disciplines**
  - **Integration of new tool into interdisciplinary framework in one day**
  - **Integration of new computing or storage system into "grid" in one day**
- **Portability**
  - **Execution of tool on new resource(s) within one week**
  - **Execution of tool on modified resource(s) within one day**
- **Reliability**
  - **Successful execution of 99% of user-requested computational events in 24-hour period on distributed system of at least 10 resources**
- **Resources Management**
  - **Ability to easily allocate resources (from set of at least 10) to requested computational event**
- **Usability**
  - **Visual based assembly of aerospace applications**

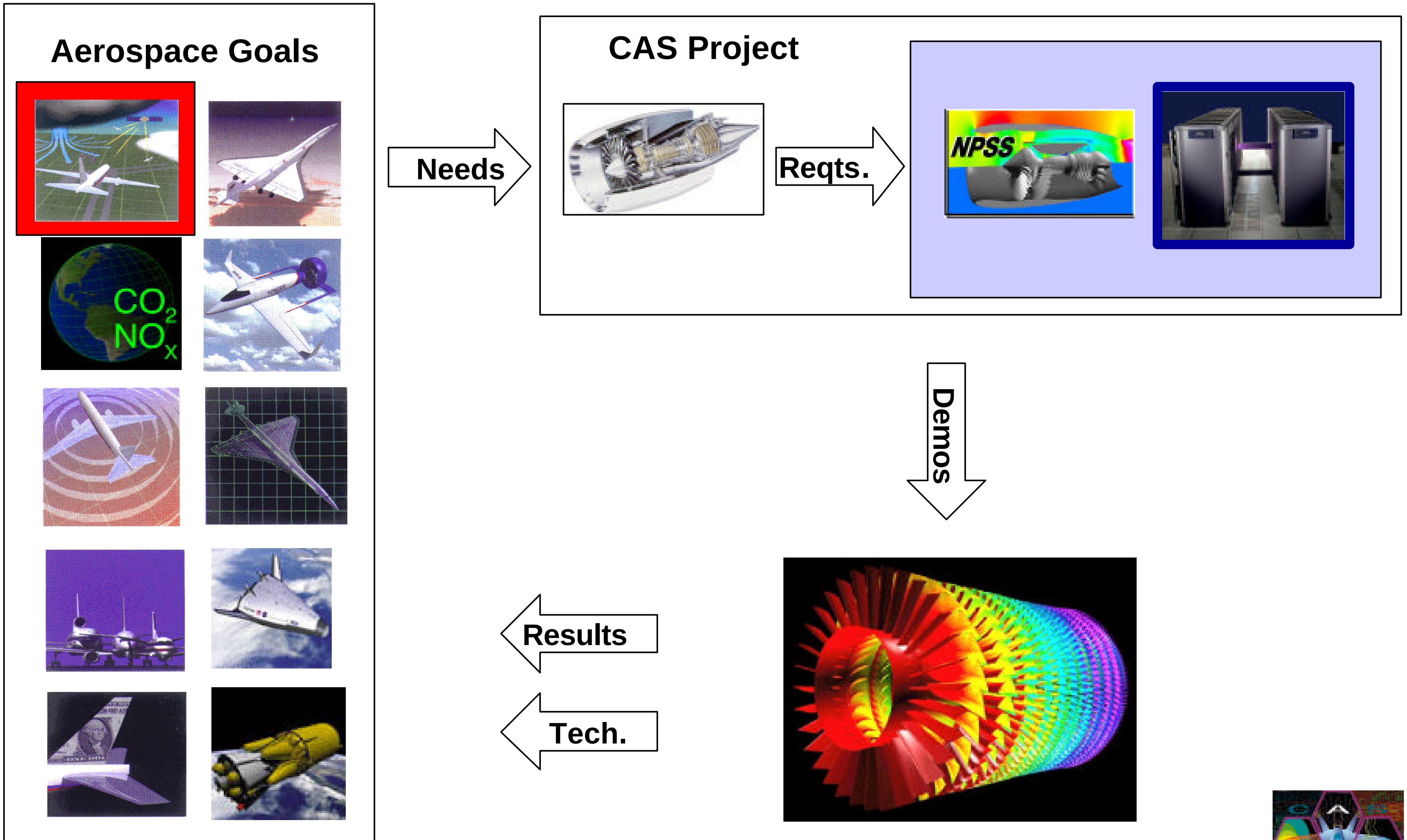
Phase I Objectives

- Develop computational methods and techniques representative of those that will be used in future design practices (e.g., multidisciplinary modeling of aeroscience problems)
  - Enhancements in design cycle environment for ASCT
  - Identify and support improvements in applications software that will lead to selection of HPC as cost-effective "host of choice" in daily design cycle of US aerospace industry
  - Spur design methodology development using HPC
  - Develop a full-featured design and analysis system that employs cost-effective computing platforms (NPSS)
  - Find better, more efficient parallel algorithms and parallel implementations
- Support accelerated development of cost-effective, high-performance computing machinery from domestic vendors to benefit the aerospace industry
  - Create "beta-test" TFLOPS computing facility and evaluate functionality and robustness of associated system software
  - Create prototype networked workstation cluster to provide the environment to develop and test the software necessary to make clusters an alternative to the traditional supercomputer
- Enable and facilitate the efficient and cost-effective execution of grand challenge applications on parallel and distributed supercomputers
  - Reduce effort and elapsed time required to design, implement, and test applications software
  - Reduce the effort and elapsed time required by application codes to computationally investigate phenomena or parameters of interest
  - Study the feasibility of relatively long-term major (revolutionary) advances enabled by the unexpected availability of new technology or concepts
- Assure competently trained individuals for future computational aeroscience work

Changes in Project Objectives from Phase I to Phase II

- **Support broader spectrum of Aerospace Enterprise**
  - **Include Access to Space and National Airspace Operations & Safety**
  - **Expand beyond design-cycle time reductions**
- **Increase focus on customer impact**
  - **Specific execution time objectives rather than relative improvements**
  - **Specific testbed performance objectives**
  - **Specific technologies needed to deliver efficient, cost-effective execution**
- **Demonstrate customer impact**

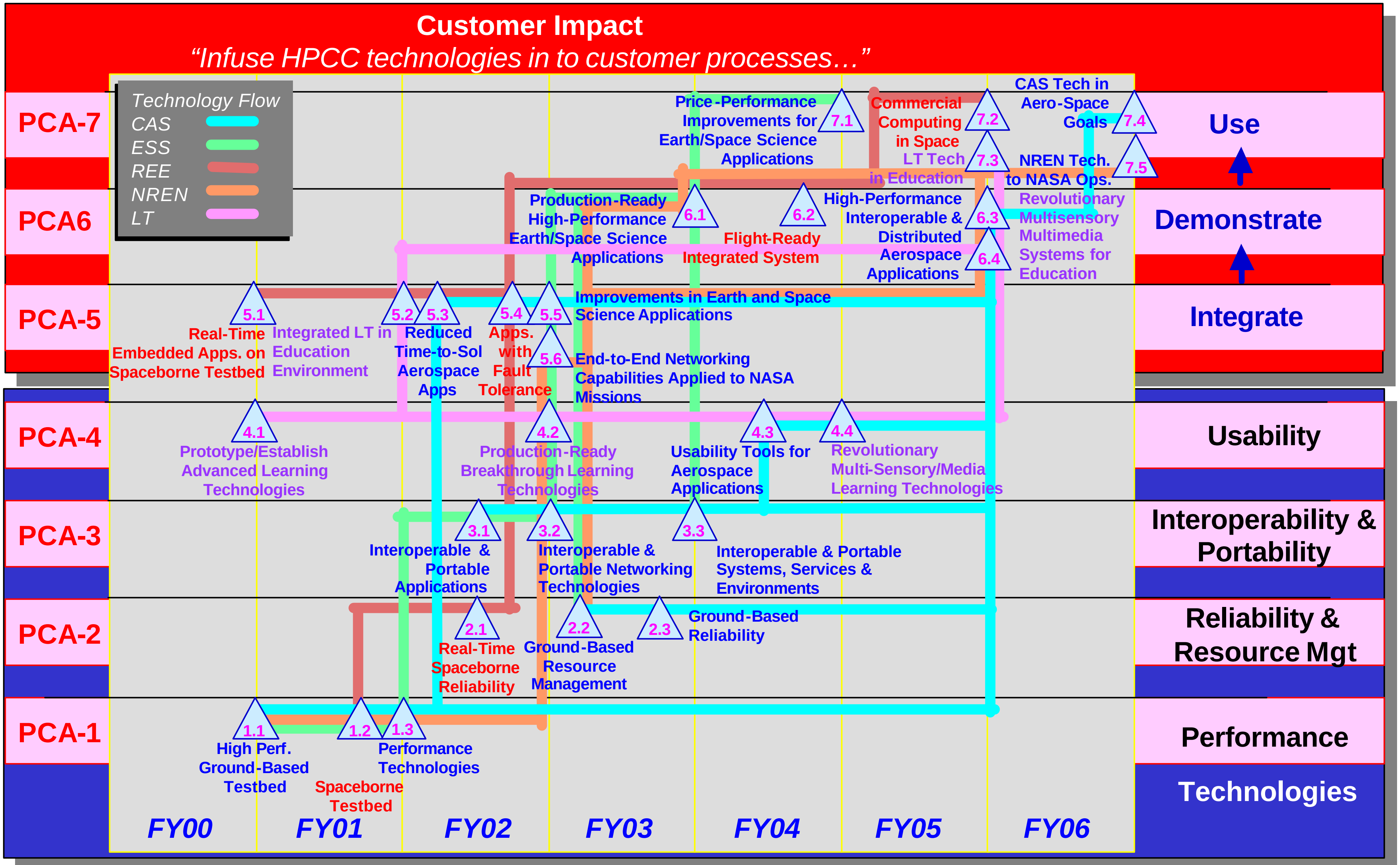
CAS Project Implementation Approach



CAS Project Organization

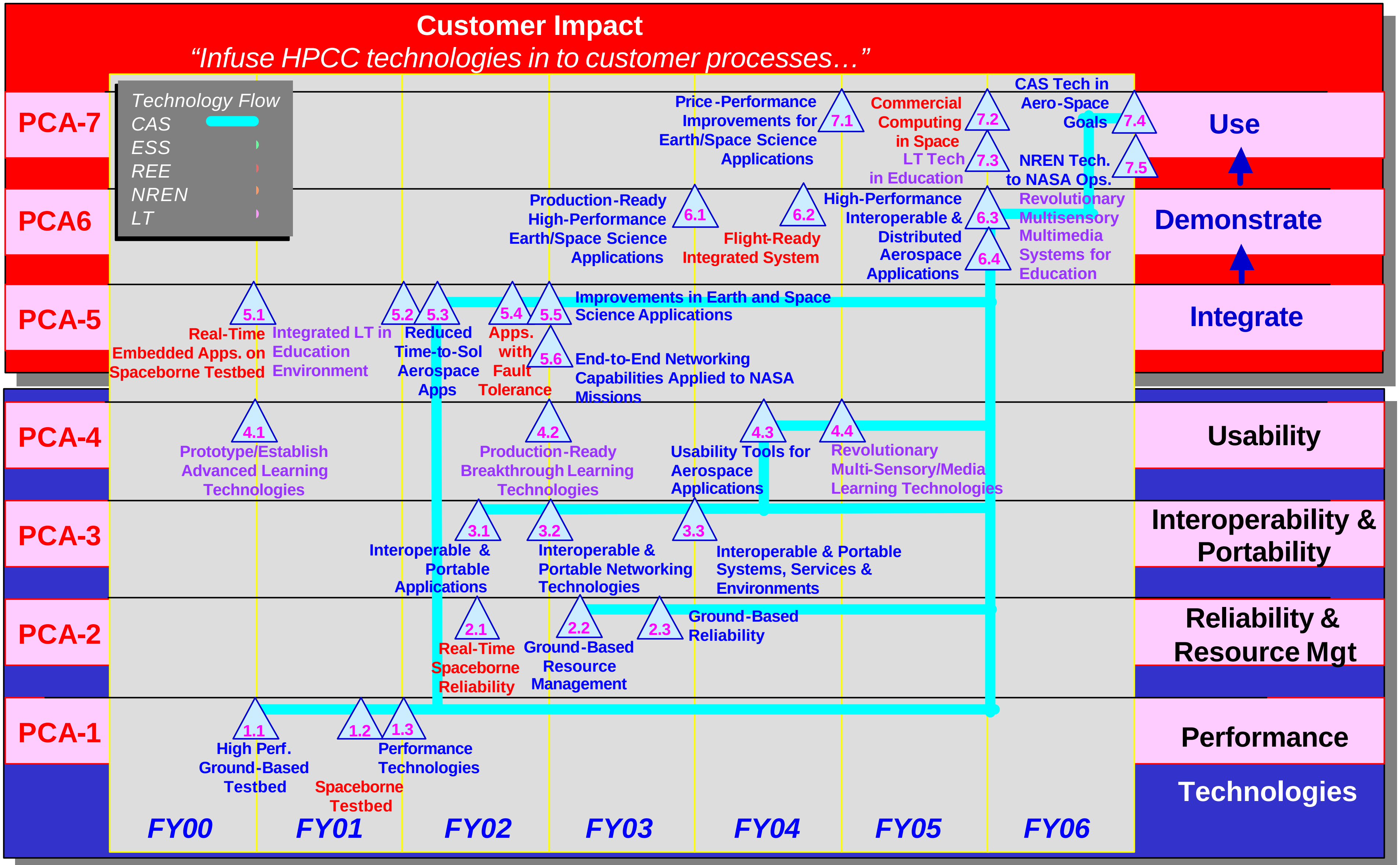
- **Catherine Schulbach**, CAS Project Manager
  - **Mary Livingston**, Associate CAS Proj. Mgr., Ames Research Center
    - **Goetz Klopfer** – Advanced Tech. Appl.
    - **Jerry Yan** – Systems Software & Tools
    - **Leigh Ann Tanner** – Testbeds
    - **Dochan Kwak** – BRHR
  - **John Lytle**, Associate CAS Proj. Mgr., Glenn Research Center
    - **Joe Veres** – Advanced Tech. Appl.
    - **Greg Follen** – Systems Software & Tools
    - **Isaac Lopez** – Testbeds
    - **John Lytle** – BRHR
  - **Jaroslaw Sobieski**, Associate CAS Proj. Mgr., Langley Research Center
    - **Joe Rehder** – Advanced Tech. Appl.
    - **Piyush Mehrotra** – Systems Software & Tools
    - **Dave Rudy** – Testbeds
    - **Dave Rudy** – BRHR

HPCC Program Technology Flows

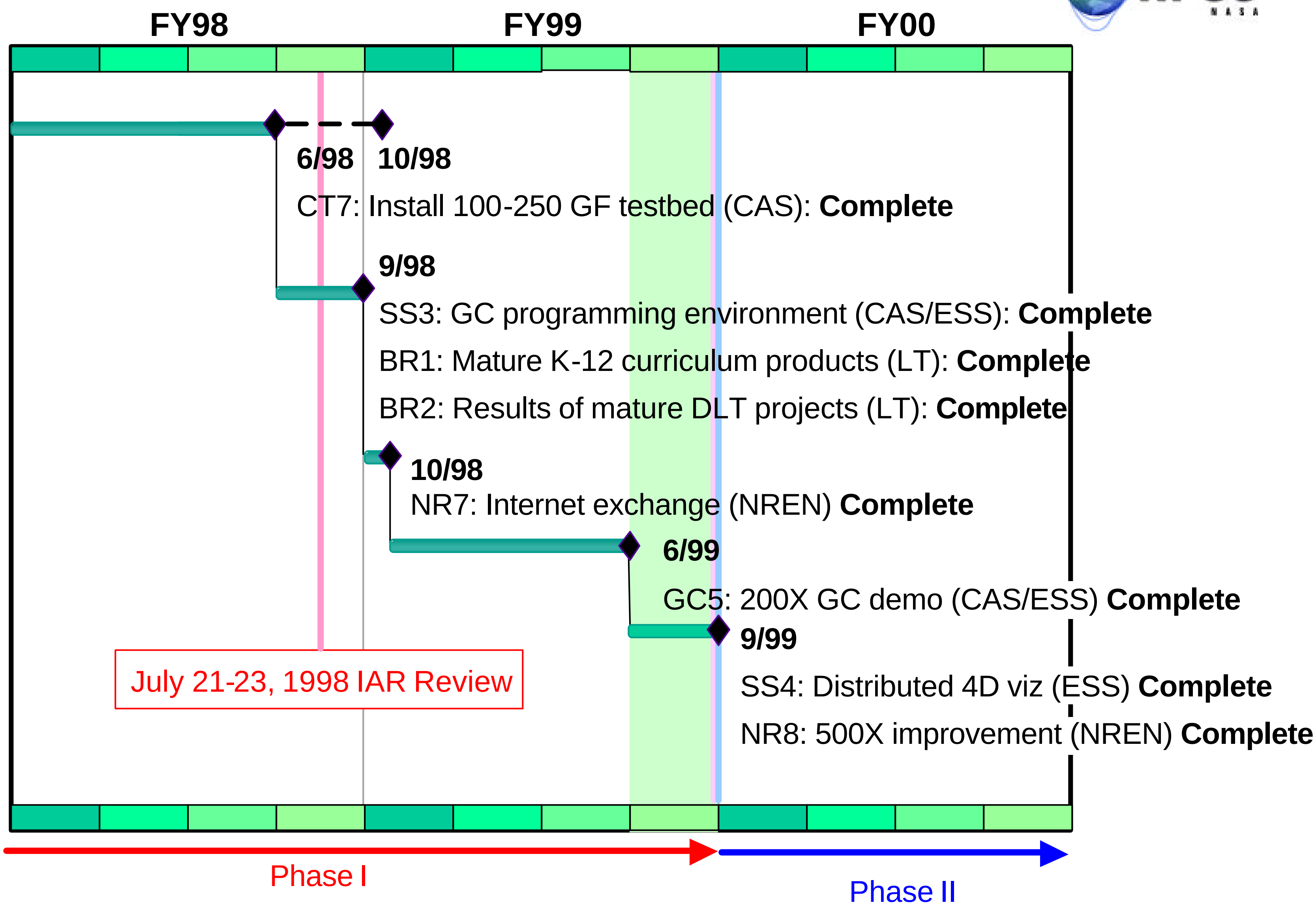


HPCC Program Technology Flow

- CAS -



Phase I Program Milestones
- FY98 IAR through FY99 -



Phase I Program Milestone Status and Cross Walk

(Extracted from January 1997 Program Plan as updated by April 1999 PCA)

HPCC NASA

Grand Challenge Milestones

#	Due Date	Comp Date	IAR Review
GC1	6/93	6/93	Prior IAR
GC2	9/96	9/96	Prior IAR
GC3	9/97	9/97	Prior IAR
GC4	9/97	9/97	Prior IAR
GC5	6/99	3/99	IAR 2000-Phase I
GC6	3/00	Open	IAR 2000-Phase II
GC7	9/01		IAR 2000-Phase II
GC8	9/03		IAR 2000-Phase II
GC9	9/03		IAR 2000-Phase II

NASA Research and Education Network Milestones

#	Due Date	Comp Date	IAR Review
NR1	6/93	6/93	Prior IAR
NR2	9/94	12/94	Prior IAR
NR3	6/95	9/95	Prior IAR
NR4	9/95	9/95	Prior IAR
NR5	3/96	3/96	Prior IAR
NR6	9/97	9/97	Prior IAR
NR7	10/98	10/98	IAR 2000-Phase I
NR8	3/00	3/00	IAR 2000-Phase I
NR9	9/02		IAR 2000-Phase II
NR11	6/04		IAR 2000-Phase II

Computing Testbeds Milestones

#	Due Date	Comp Date	IAR Review
CT1	12/92	12/92	Prior IAR
CT2	9/93	9/93	Prior IAR
CT3	6/94	6/94	Prior IAR
CT4	9/96	6/97	Prior IAR
CT5	12/96	12/96	Prior IAR
CT6	9/97	9/97	Prior IAR
CT7	6/98	10/98	IAR 2000-Phase I
CT8	12/99	Open	IAR 2000-Phase II
CT9	9/00		IAR 2000-Phase II
CT10	6/02		IAR 2000-Phase II

Information Infrasstructure Technology and Applications Milestones

#	Due Date	Comp Date	IAR Review
II1	12/93	12/93	Prior IAR
II2	9/95	9/95	Prior IAR
II3	9/94	8/94	Prior IAR
II4	9/95	9/95	Prior IAR
II5	9/96	9/96	Prior IAR
II6	9/94	8/94	Prior IAR
II7	9/95	9/95	Prior IAR

Basic Research and Human Resources Milestones

#	Due Date	Comp Date	IAR Review
BR1	9/96	9/96	Prior IAR
BR2	9/97	9/97	Prior IAR
BR3	Yearly	Yearly	Prior/Phase I

System Software Milestones

#	Due Date	Comp Date	IAR Review
SS1	9/96	9/96	Prior IAR
SS2	9/97	9/97	Prior IAR
SS3	9/98	9/98	IAR 2000-Phase I
SS4	9/99	9/99	IAR 2000-Phase I
SS5	9/00		IAR 2000-Phase II
SS6	3/01		IAR 2000-Phase II
SS7	9/01		IAR 2000-Phase II
SS8	12/01		IAR 2000-Phase II

Learning Technologies Milestones

#	Due Date	Comp Date	IAR Review
LT1	9/01		IAR 2000-Phase II
LT2	9/02		IAR 2000-Phase II
LT3	9/03		IAR 2000-Phase II
LT4	9/04		IAR 2000-Phase II
LT5	9/05		IAR 2000-Phase II

Statistics	
34 Milestones Completed	
9%	**Completed Ahead of Schedule**
88%	**Completed Ahead of or on Schedule**
12%	**Completed After Schedule (Average slip < 1 Quarter)**

CAS Phase I to Phase II Milestone Mapping

CAS Milestones			
Phase I #	Phase I Due Date	Incorporated into Phase II #	Phase II Due Date
CT9	9/00	1.1	9/00
SS7, GC7	9/01, 9/01	1.3	9/01
SS7	9/01	2.2	12/02
SS7	9/01	2.3	6/03
SS7	9/01	3.1	3/02
SS7, GCX	9/01, 9/05	3.3	9/03
SS7, GCX	9/01, 9/05	4.3	3/04
CT9, SS7, GC7	9/00, 9/01, 9/01	5.3	12/01
GCX	9/05	6.3	9/05
BR3	Yearly	C7.4.3	Yearly

Note: PCA from 4/99 has no CAS milestone beyond 01. GC9 is ESS. Also a PCA milestone with due date 9/05 is referenced, but it has no program milestones listed in the Appendix of the PCA document.

Summary of Phase I Technical Accomplishments

- **Completed**
  - **GC5: Demonstrate 200-fold improvements over FY1992 baseline in time-to-solution for grand challenge applications of TFLOPS testbeds (6/99)**
  - **CT7: Install 100-250 GFLOPS sustained scalable TFLOPS testbed (6/98)**
  - **SS3: Demonstrate a portable, scalable programming and runtime environment for grant challenge applications on a TFLOPS scalable system (9/98)**
  - **SS4: Demonstrate portable, scalable distributed visualization of multi-terabyte 4D datasets on TFLOPS scalable systems (9/99)**
  - **BR3: Provide Graduate & Post-Doctoral Support for High Performance Computing Research (yearly)**
- **Incorporated into new plan**
  - **GC7: Demonstrate 1000-fold improvements over FY1992 baseline in time-to-solution for grand challenge applications on TFLOPS testbeds (9/01)**
  - **SS7: Demonstrate portable, scalable debugging and test environment for grand challenge applications on a full TFLOPS system (9/01)**
- **Note: In the 4/99 Ver of PCA it is not clear that SS4 no longer applies to CAS**

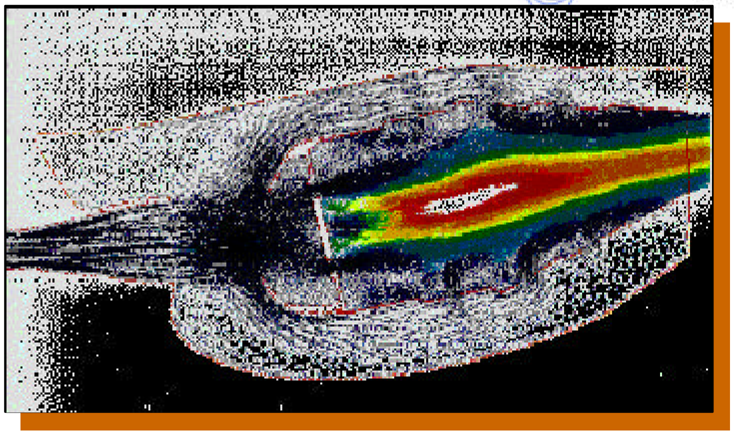
Phase I Accomplishments: Milestone GC5

- **Level 1 milestone, CGC5, "Demonstrate 200-fold improvements over FY92 baseline in time to solution for GC applications on TFLOPS testbeds," was completed on 9/98 (due 6/99).**
- **Accomplishments:**
  - **Full combustor simulation achieved a 200:1 reduction in time to solution in 9/98. Additional improvements have resulted in a 307:1 reduction (6/99) and 320:1 reduction (9/99).**
  - **Overnight turnaround of 13 hours was achieved for full combustor simulation.**
  - **Average-Passage Code (APNASA) demonstrated 400:1 reduction in time to solution.**
  - **Overnight turnaround of 15 hours was achieved for a full compressor simulation using APNASA.**
- **Metrics (Combustor):**
  - **Portability: IBM, SGI, HP, SUN, PC/Linux**
  - **Scalability: Yes, has been used on up to 96 processors of the IBM SP-2**
  - **Speedup: 25.5 (80% efficiency for 32 processors on CAS Testbed III)**
  - **Performance improvement: 307:1**
- **Metrics (Compressor):**
  - **Portability: Cray, HP, IBM, Linux, and SGI**
  - **Scalability: Yes, can use 12 processors for single blade row, 121 for 18 blade rows.**
  - **Speedup: 40 (95% efficiency using 42 processors on an SGI Origin 2000)**
  - **Performance improvement: 400:1**

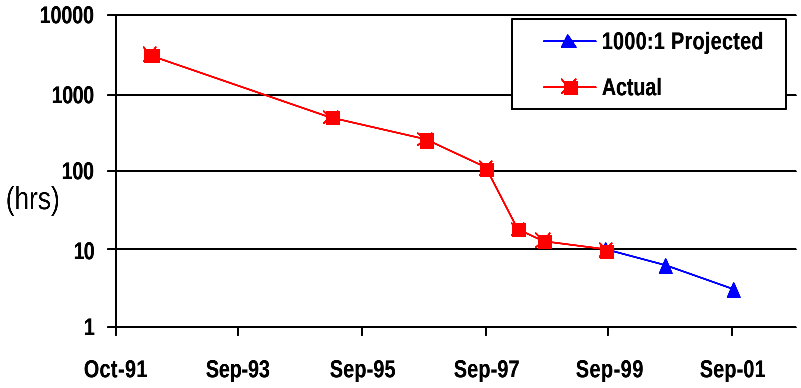
Full Combustor Simulation Reduced 307:1 Relative to 1992 Baseline

Significance

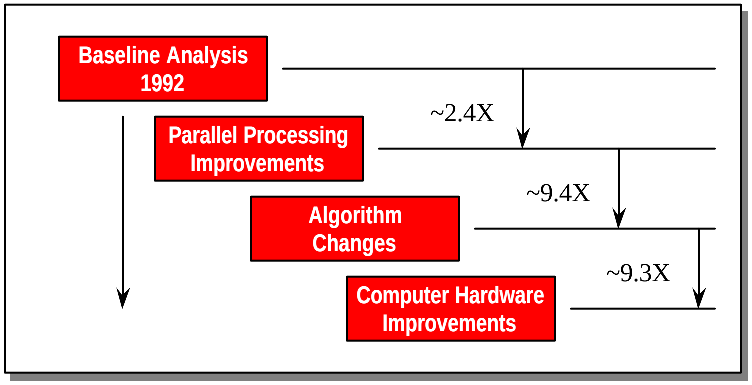
This improvement to the National Combustor Code will contribute to: (1) a significant reduction in aircraft engine combustor design time and cost by reducing the need for combustor rig testing by 1/3 and resulting in savings of $2.0M, and (2) the accomplishment of the national goal to reduce aircraft engine emissions.



Estimated Reduced Turnaround Time



Multidisciplinary Approach to Reducing Turn Around Time

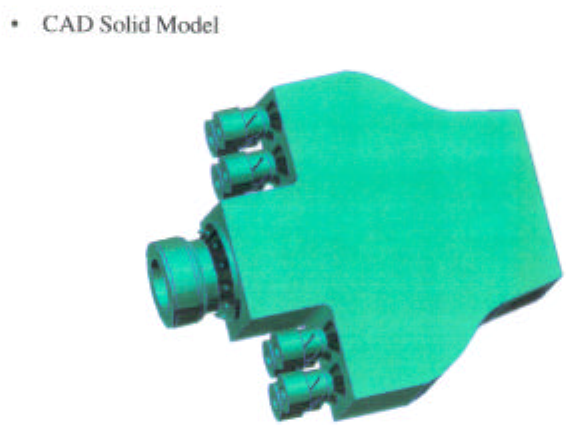


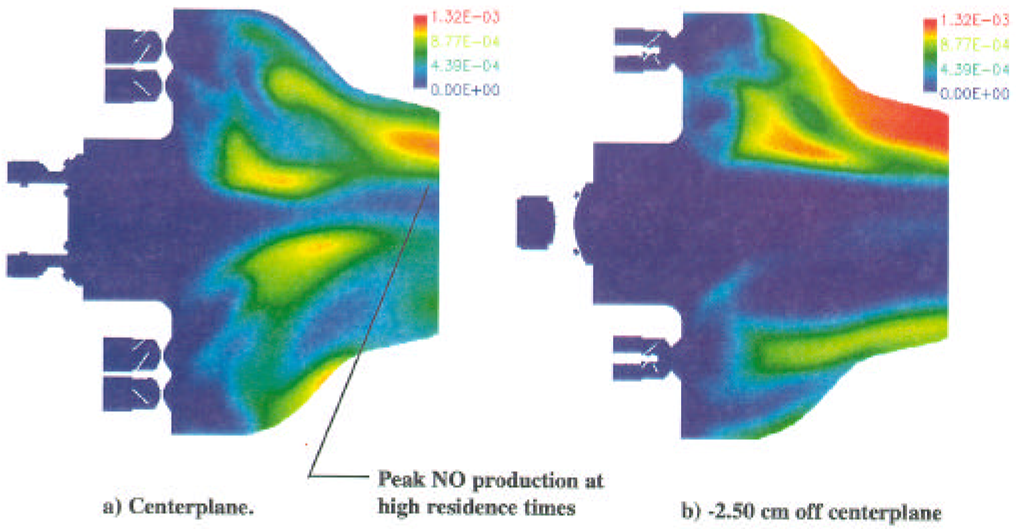
Full Combustor Simulation Reduced 307:1 Relative to 1992 Baseline

- **Shown (clockwise from upper right):**
  - (1) velocity vectors colored by temperature from simulation of full combustor from exit of compressor to inlet of the turbine, (2) approximate impact on turnaround time achieved by addressing the various factors that influence turnaround time, and (3) overall estimated reductions in turnaround time over an 8-year period.
- **Accomplishments:**
  - In 9/98, achieved 200:1 reduction in turn-around time on full combustor simulation from compressor exit to turbine inlet using CORSAIR_CCD by 9/98 (9 months early)
  - In 6/99, achieved 307:1 reduction in turn-around time; 320:1 reduction by 9/99.
  - Reduced turn-around time from 3174 hours (estimated on Intel Paragon) to 13 (10 in 9/99) hours (on SGI Origin 2000)
- **Significance:**
  - Reduces the need for combustor rig testing by 1/3—a savings of $2.0M
  - Key step in ability to perform complete engine simulation overnight
  - Aids accomplishing the national goal to reduce aircraft engine emissions
- **Metrics:**
  - Portability: IBM, SGI, HP, SUN, PC/Linux
  - Scalability: To 96 processors on IBM SP-2, 56 processors on Origin 2000
  - Speedup: 45.8 (82% efficiency for 56 processors on Origin 2000)
  - Performance: 2.3 GFLOPS
  - Performance Improvement: 307:1

National Combustor Code Simulation

Exploring Advanced Concepts for NOx Reductions
in order to meet HSR emission goals

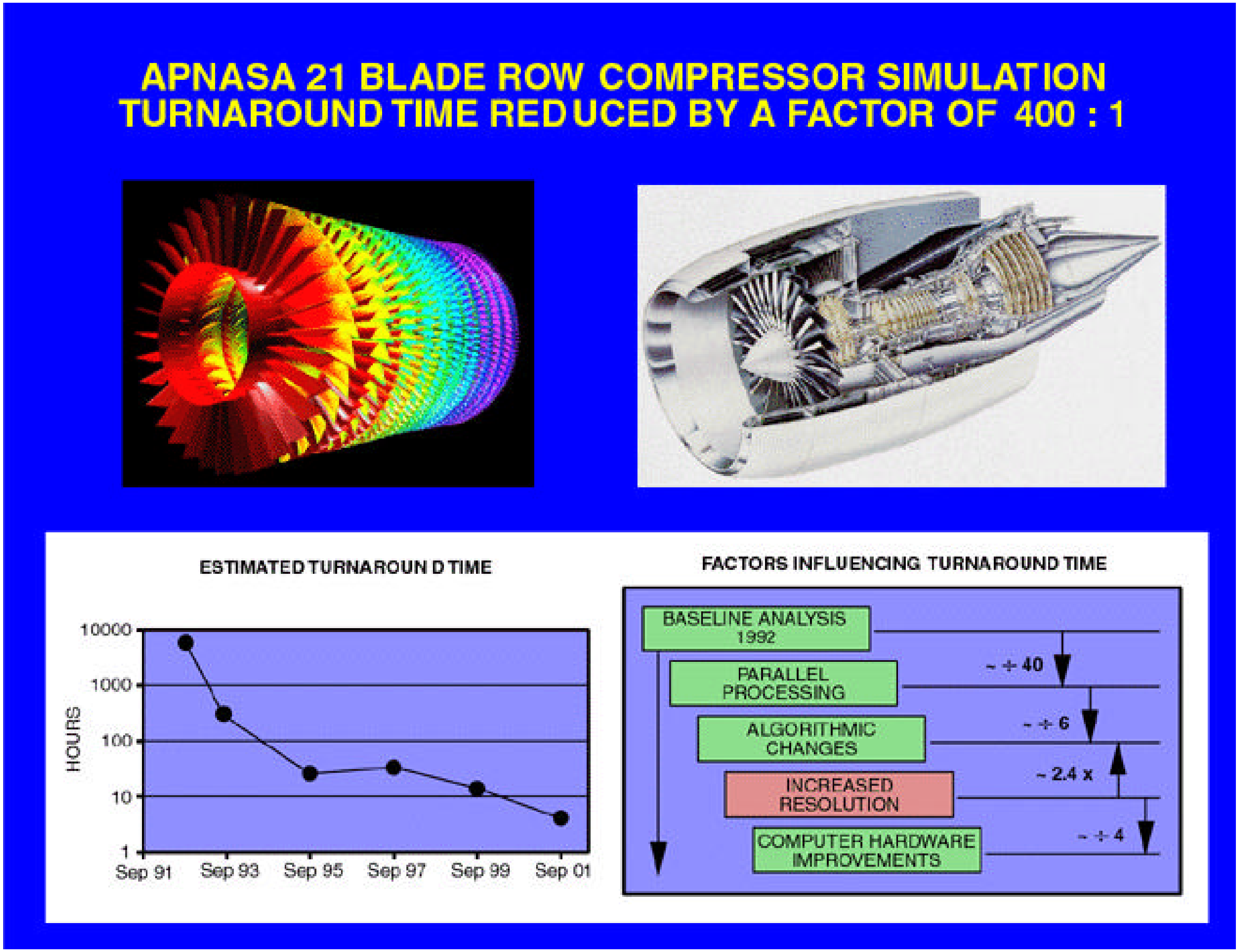




Contours of NOx Mass Fraction

Lean Direct Injection-Multi Venturi Swirler (LDI-MVS)
combustor calculation with the automated simplification
of full chemical kinetics module on SGI Origin 2000

Compressor Analysis Time Reduced 400:1 Relative to 1992 Baseline



Compressor Analysis Time Reduced 400:1 Relative to 1992 Baseline

- **Shown: (clockwise from upper left):**
  - Results of 21 blade-row compressor simulation by APNASA (Average-Passage Code—a Navier-Stokes solver for multistage turbomachinery flows)
  - Cut-away of full 3-D GE90 engine that uses the compressor
  - Approximate impact on turnaround time achieved by addressing the various factors that influence turnaround time
  - Overall estimated reductions in turnaround time over an 8-year period
- **Accomplishment**
  - On a 21 blade compressor, APNASA has by June 1999 reduced the time required to do a full compressor simulation to overnight turnaround (15 hours). This represents a 400:1 improvement over the 1992 baseline. This allows APNASA to be integrated into a design system and used to quickly provide a high fidelity analysis of a turbomachinery component prior to fabrication, resulting in a reduction in the number of test rigs and lower development costs. It demonstrates that a combination of improvements in hardware, software and applications can result in significant improvements to providing next generation design tools to increase design confidence and cut development cycle time by 50%. Either APNASA or the methodology on which it is based has been incorporated into the design systems of six gas turbine manufacturers
- **Metrics:**
  - Portability: Cray, HP, IBM, Linux, and SGI
  - Scalability: Yes, can use 12 processors for single blade row, 121 for 18 blade rows.
  - Speedup: 40 (95% efficiency using 42 processors on an SGI Origin 2000)
  - Performance improvement: 400:1

Additional Code Improvements

- **ENSAERO_MPI demonstrates 67X speedup from 1992.**
  - **The performance of the optimized version of ENSAERO_MPI on the NAS O2K machine steger is approximately 20 GFLOPS. This is 67X the performance (295 MFLOPS) of the Intel iPSC/860.**
- **OVERFLOW demonstrates 20 GFLOPS on O2K.**
  - **On a 256-processor O2K, a 33-million-grid-point high wing transport simulation ran at 20 GFLOPS using OVERFLOW/MLP version. Code enhancement (especially multigrid) can also speed the convergence by a factor from 1-4. This results in an improvement over 1992 of from 25-100 depending on the application. OVERFLOW scales nearly linearly with number of processors.**

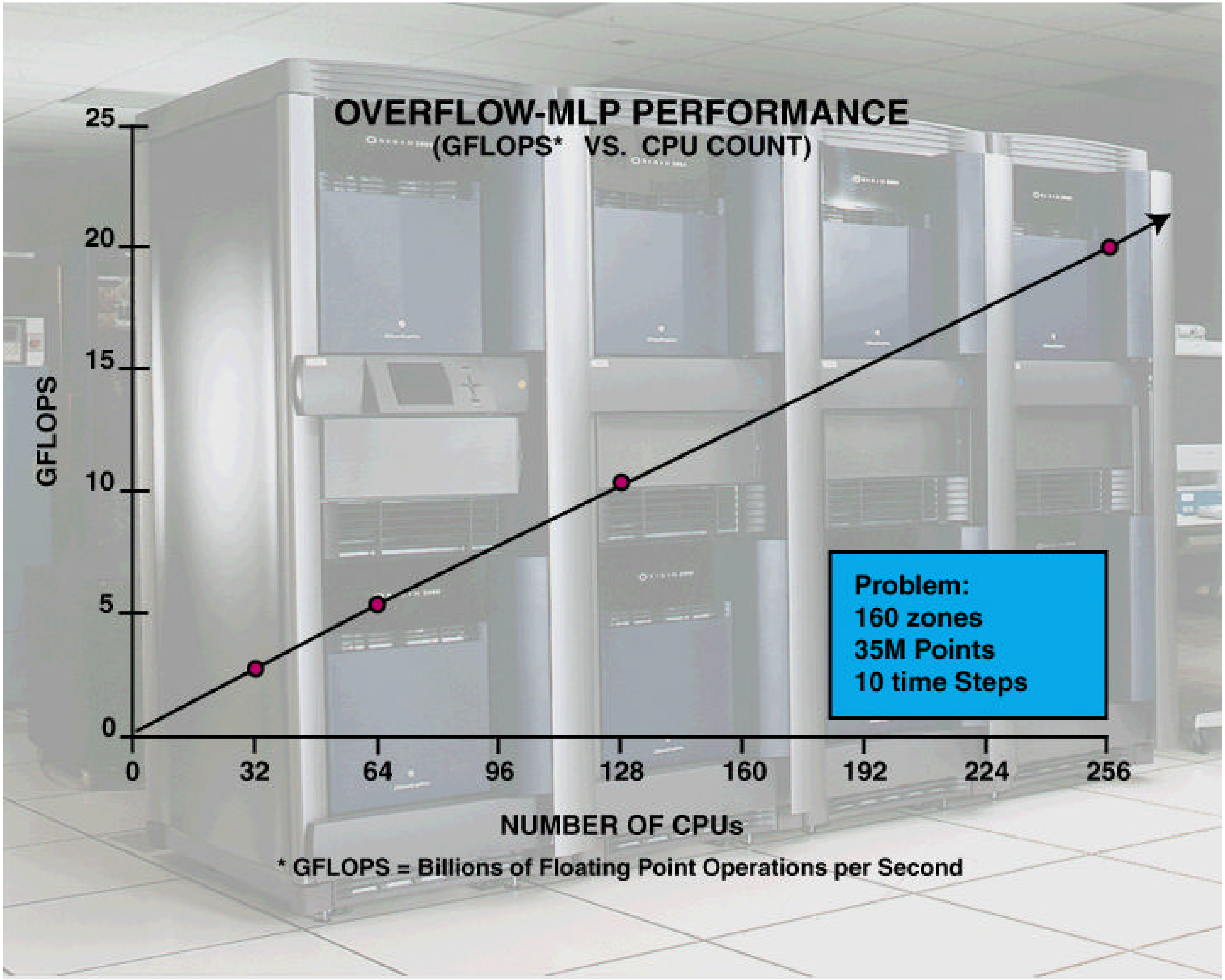
Phase I Accomplishments: Milestone CT7

- **Level 1 milestone, CT7, "Install 100-250 GFLOPS sustained scalable TFLOPS testbed," was completed on 10/98 (due 6/98 but later revised to 12/98).**
- **Accomplishments:**
  - **The 256-processor SGI Origin2000 system (named steger) at NASA Ames performed 101 GFLOPS on a LINPACK benchmark using a matrix size of order 76,800.**
  - **Under a Memorandum of Understanding, NASA Ames partnered with Silicon Graphics Inc. to configure two 128-processor Origin2000 systems (installed in April 1998) into a 256-processor Origin2000 system with global shared memory, the largest machine of its type.**
  - **The partnership focused on four areas: hardware development, operating system development, single computational fluid dynamics application scalability, and workload scalability.**
  - **The Ames-SGI teamed reached its initial goal of a working 256-processor system in October 1998.**
  - **LINPACK demonstration was completed shortly afterwards.**
  - **In November 1998, the DOE's Blue Mountain system achieved 1.6 TeraFLOPS on a Linpack benchmark, almost 16 times the performance of the Ames system. The Blue Mountain system is composed of 48 128-processor Origin2000 systems organized to behave as a single computer. The peak speed of this system of 6144 processors is over 3 TeraFLOPS.**
- **Metrics:**
  - **Performance: 100 GFLOPS on parallel benchmark (101 GFLOPS achieved)**
  - **Scalability: Maximum configuration > 10X installed (A configuration almost 16X installed demonstrated by DOE)**

NASA Ames 256-Processor Origin 2000 System Exceeds 100 GFLOPS

- 256 MIPS 250MHz R10000 Processors
- 64 Gigabytes of Main Memory
- IRIX 6.5.2 Single System Image (SSI) OS
- 1.3 Terabytes Fibre attached RAID Disk
- Custom 256-Processor Meta-Router Interconnect
- HiPPI, FAST Ethernet

- **Under a Memorandum of Understanding, NASA Ames partnered with SGI to configure a 256-processor Origin 2000 system with global shared memory, the largest machine of its type.**
- **The partnership focused on four areas: hardware development, operating system development, single computational fluid dynamics application scalability, and workload scalability.**
- **The Ames-SGI team reached its initial goal of a working 256-processor system in October 1998.**
- **LINPACK performance on this 256-processor system (Single System Image OS) was 101 GFLOPS. A matrix size of order 76,800 was selected for this test. This completes HPCCP/CAS Level 1 Milestone CT7.**

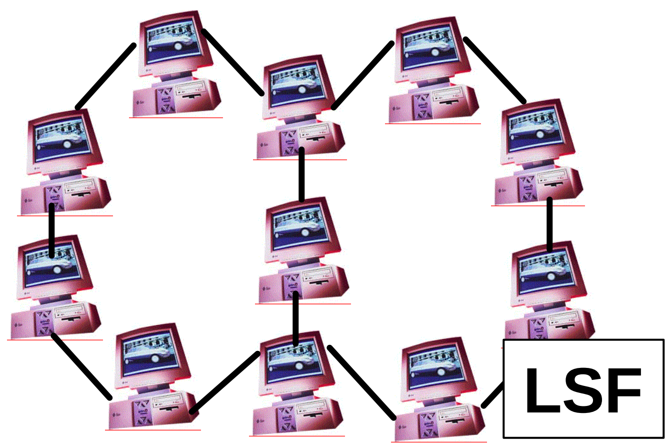


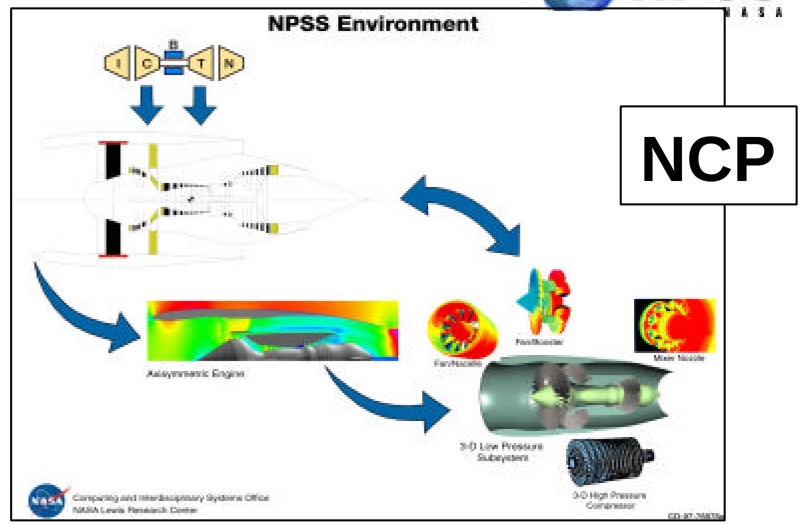
OVERFLOW-MLP PERFORMANCE
(GFLOPS* VS. CPU COUNT)
GFLOPS
0
5
10
15
20
25
0
32
64
96
128
160
192
224
256
NUMBER OF CPUs
Problem:
160 zones
35M Points
10 time Steps
* GFLOPS = Billions of Floating Point Operations per Second

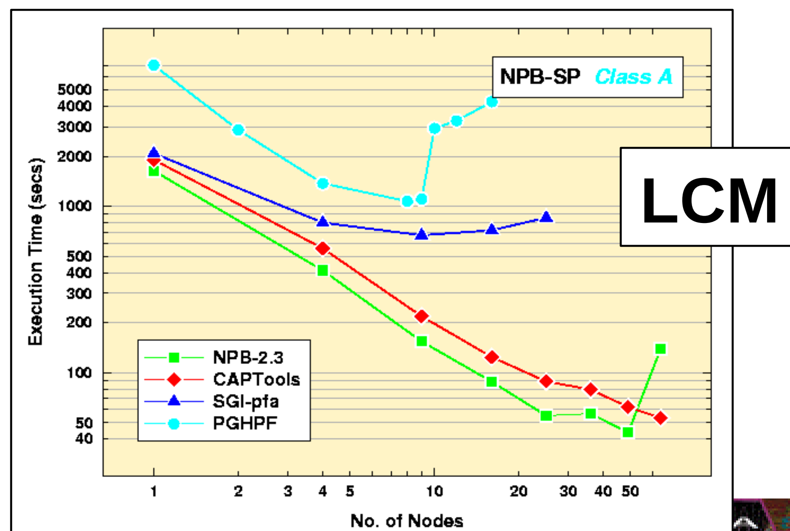
Phase I Accomplishments: Milestone SS3

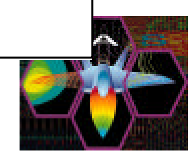
- **Level 1 milestone, SS3, “Demonstrate a portable, scalable programming and runtime environment for grand challenge applications on a TFLOPS scalable system,” was completed on 9/30/98 as scheduled.**
- **Accomplishments:**
  - **Runtime environment for NPSS/NCP Version 1 completed and delivered to industry partners 8/25/98**
  - **Evaluation of automated legacy-code parallelization tools, job management systems, and Distributed Computing Environment (DCE) completed**
  - **Parallel System monitoring and debugging tools developed (AIMS, P2D2, MPI I/O, Chant)**
  - **Distributed System management tools developed (MetaCenter)**
- **Metrics:**
  - **Demonstrated portability to SGI, HP, SUN, IBM testbeds (metric: all testbeds)**
  - **Demonstrated linear scalability to maximum number of nodes available on testbeds (metric: ln or better)**

Completion of Level 1 Milestone SS3







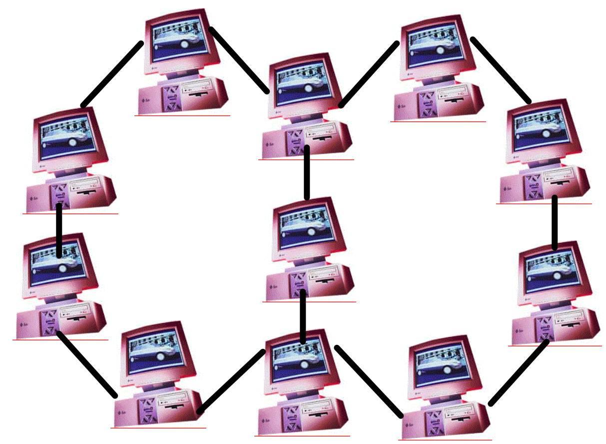


AHPC Demonstrates Significant Reduction in the Cost of Computing

One Node of Cray C90

$3.5 Million

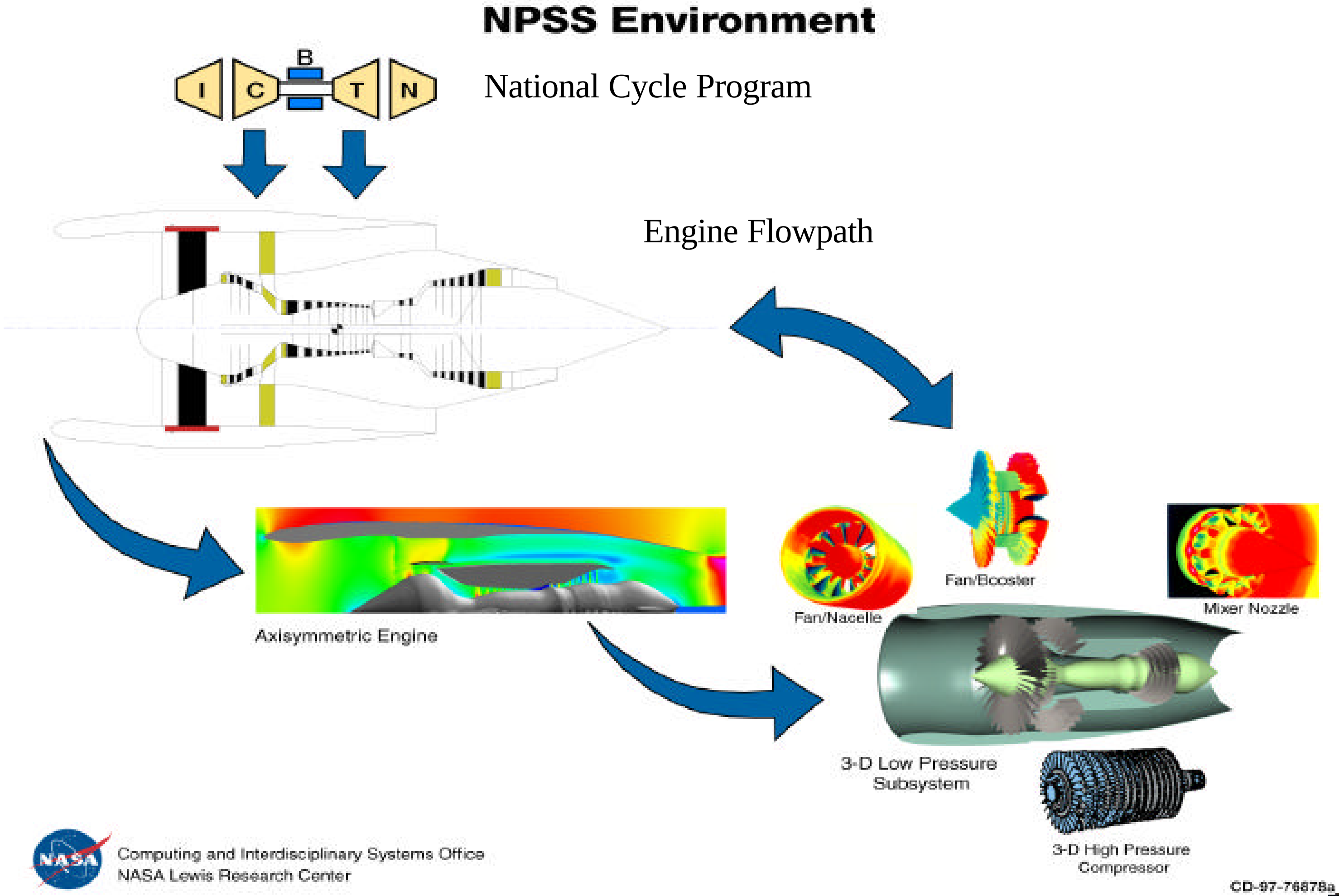
Ten SUN Ultra2 Workstations



$265 Thousand

Same 5 GFLOPS Performance Level
Same 99% Reliability Level

Numerical Propulsion System Simulation (NPSS) National Cycle Program (NCP)



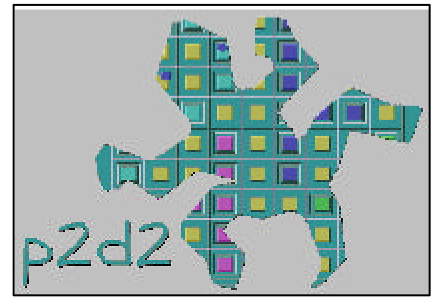
Computing and Interdisciplinary Systems Office
NASA Lewis Research Center

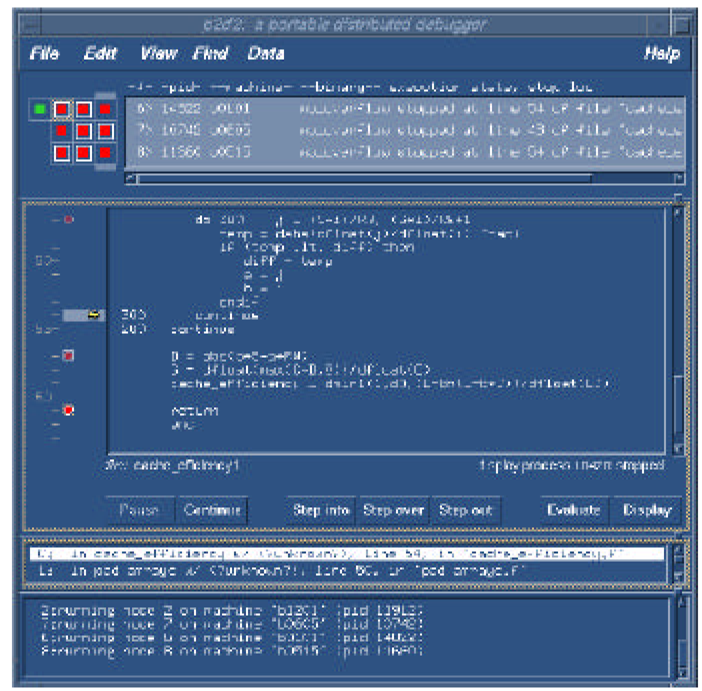
NCP (NPSS Version 1) Technical Accomplishments

- **Accomplishemnts:**
  - Completed Beta Version in 7/97. Validated by HSR and adopted for use in engine cycle design and analysis.
  - Completed development by 9/98 of NCP/NPSS Version 1 highest priority requirements (data reduction, transient, initial zooming, usability, performance).
  - Trained 60 people from NASA and industry.
  - Estimated savings to industry is $50M/year through improved productivity.
  - NCP/NPSS used by GEAE and NASA for derivative engine studies.
- **Metrics:**
  - Portability: Sun, SGI, HP, NT (near term)
  - Acceptability: All U.S. aircraft engine manufacturers and Boeing plan to use NCP to reduce engine design and development time
  - Customers: GE Aircraft Engine, Pratt & Whitney, Boeing, AlliedSignal, Allison, Williams International, Teledyne, DOD/AEDC, DOD/WPAFB, NASA Lewis, HSR
  - Speedup: Performance improvements resulted in a factor of 2 reduction in execution time

Portable Parallel/Distributed Debugger (p2d2)

- **Goals**
  - Provide a consistent user interface across all platforms, thus reducing the amount of effort required to learn how to use a debugger,
  - Provide a powerful enough set of standard operations to be considered complete by users who currently employ debuggers, including: breakpoints, data watchpoints, single-stepping, data displays
  - Provide user interface abstractions that scale to a large number of processes,
  - Permit debugging of distributed programs irrespective of the communication library used (PVM, MPI, ...).
  - Provide debugging information at the same level of abstraction as the program source (eventually even for HPF programs),
  - Provide debugging abstractions tailored to the CFD programming community (such as algorithm animation via solution visualization at breakpoints)





Preliminary Results on Automating Parallelization of Legacy Code (Legacy Code Migration)

Three tools providing methods of automating the parallelization of legacy code were examined:

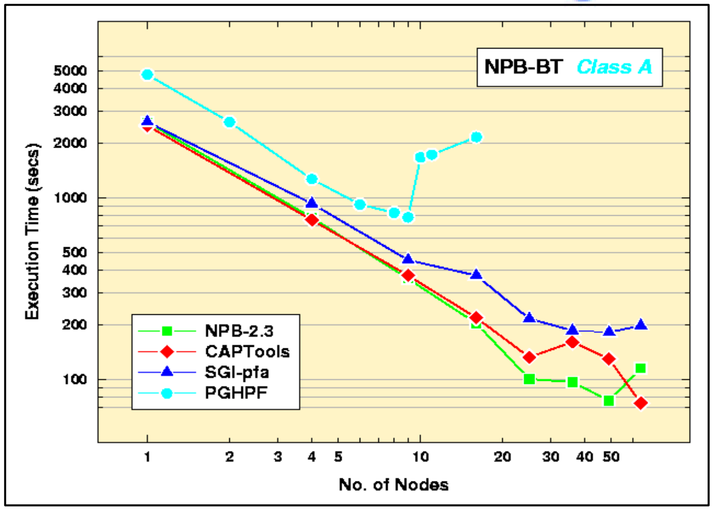
- **CAPTools**: U. of Greenwich's interactive parallelization tool
- **SGI-pfa**: SGI's performance analyzer
- **PGHPF**: the Portland Group's version of HPF

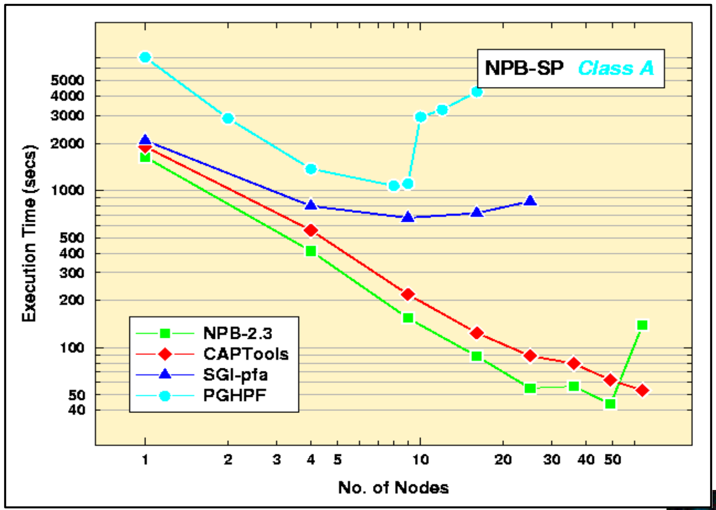
These tools were compared to the performance of NAS Parallel Benchmarks version 2.3 (NPB-2.3), implemented in MPI.

The graphs compare results for parallelization of the NAS BT and SP benchmarks.

- **The upturns in the graphs for PGHPF are due to a problem with Portable Batch System (PBS).**

While the automatic tools compare well on these charts, it may not necessarily follow that good performance can be easily obtained on user codes. Considerable work is often needed to clean up the codes before the automatic tools will work, and automatic tools may have limitations.

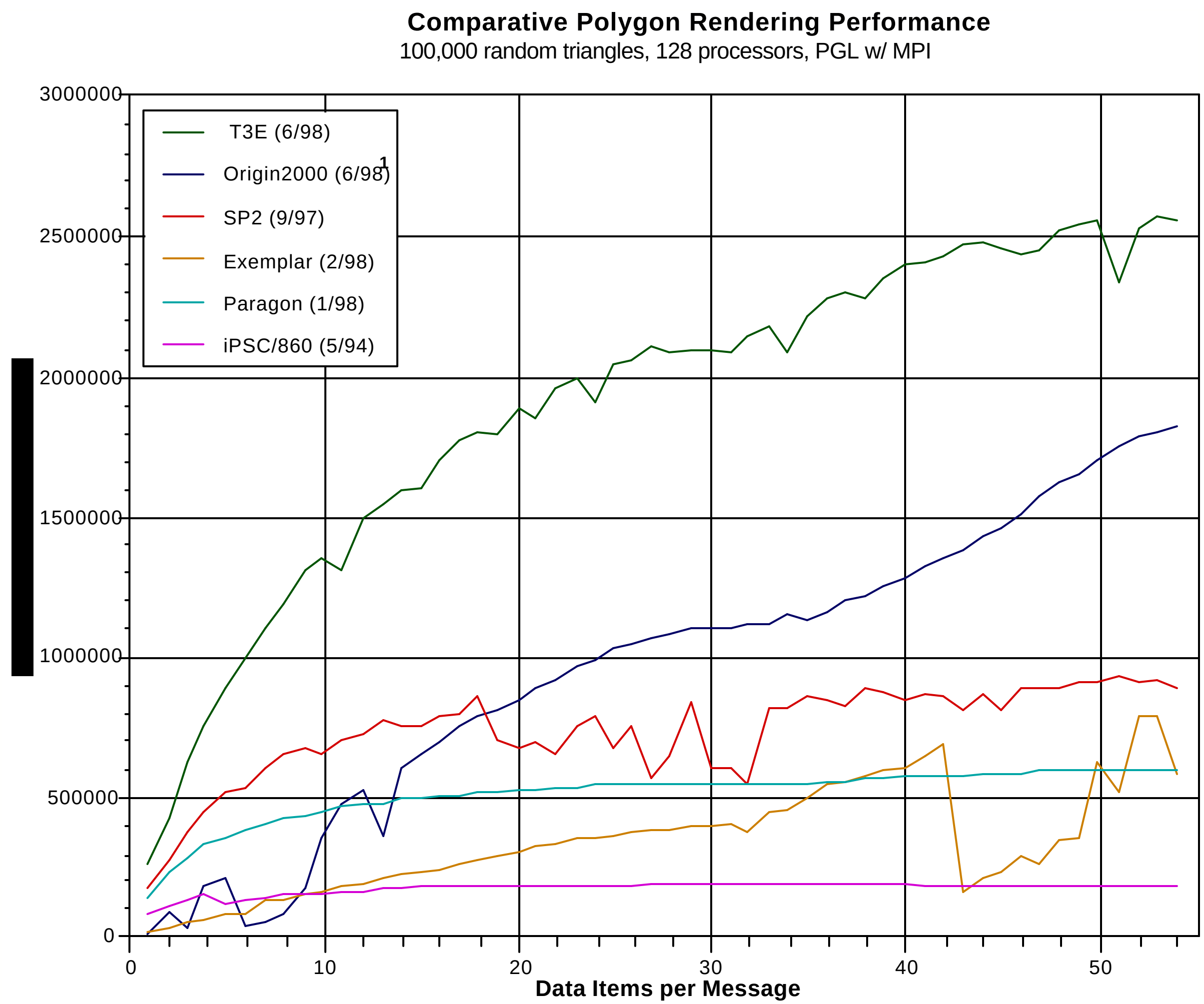




Phase I Accomplishments: Milestone SS4

- **Level 1 milestone, SS4: "Demonstrate portable, scalable distributed visualization of multi-terabyte 4D datasets on TFLOPS scalable systems" was completed on 9/99 as scheduled.**
- **Accomplishment:**
  - **PGL (Parallel Graphics Library) ported to HP Exemplar, SGI Origin2000, Cray T3E, workstation networks.**
  - **Extended parallel graphics capabilities to a wider audience, and provided support for newer architectures.**
- **Metrics:**
  - **Demonstrated portability to IBM, Intel, HP, SGI, T3E testbeds (metric: all testbeds)**
  - **13X parallel performance increase over 4 generations of architecture: faster processors, better compilers, improved algorithms.**
  - **44X uniprocessor performance increase over same set of architectures implies communication support is lagging badly.**
  - **MPI performs poorly on large ccNUMA architectures (Exemplar and Origin 2000).**
  - **Parallel performance/scalability is good on distributed memory systems with up to 128 processors. (metric: ln or better)**

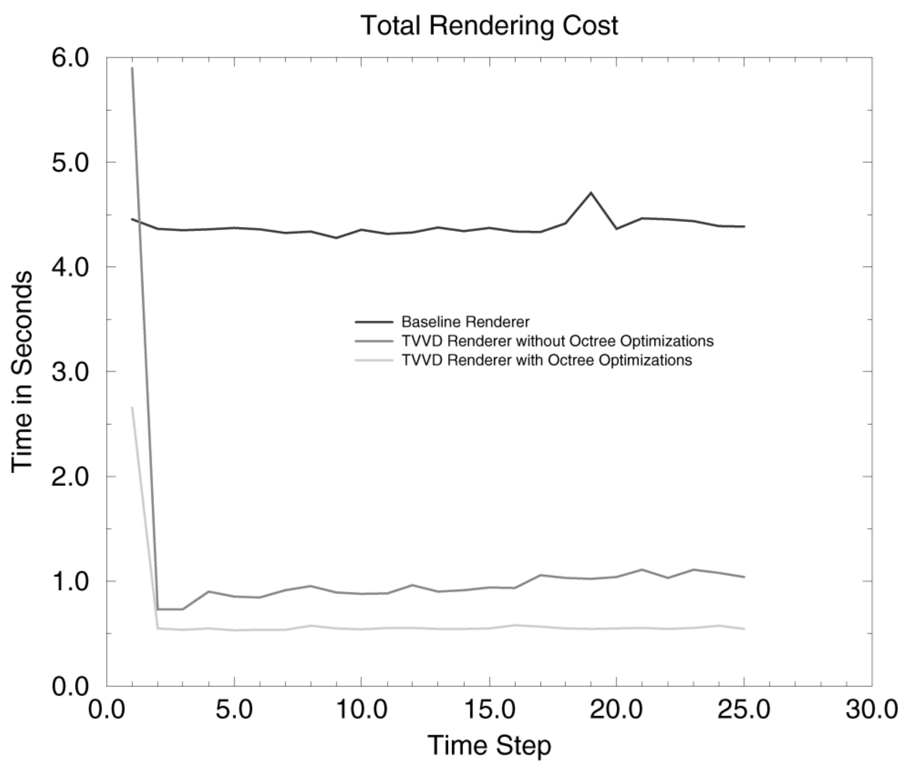
PGL Performance History

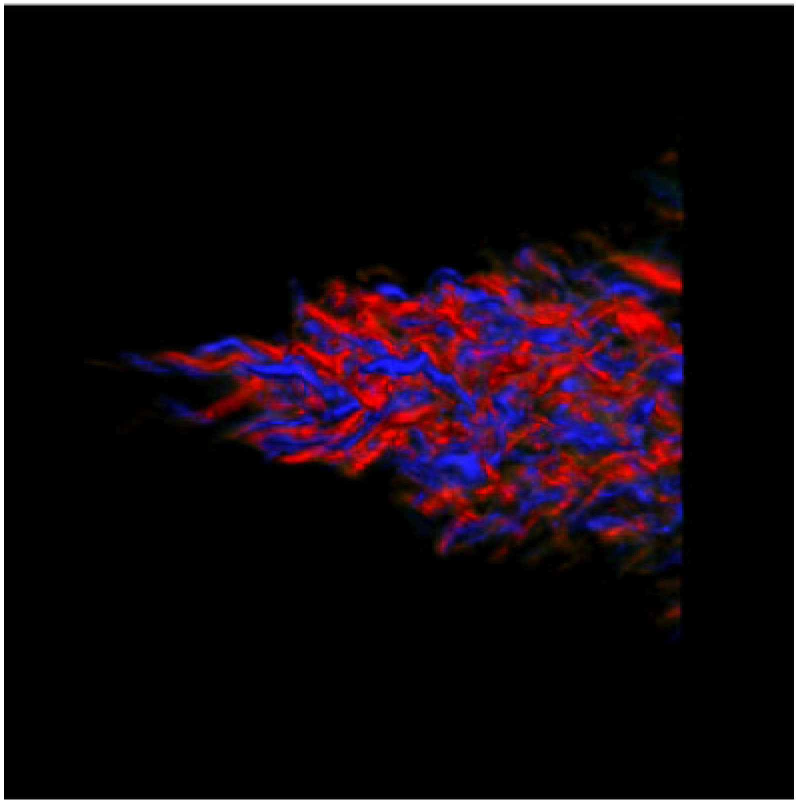


[1] Preliminary result w/ 120 PEs

6/98 data

Efficient Encoding and Rendering of Time-Varying Volume Data





Rendering cost and image of time-varying turbulent jet data

Phase I Accomplishments: Milestone BR3

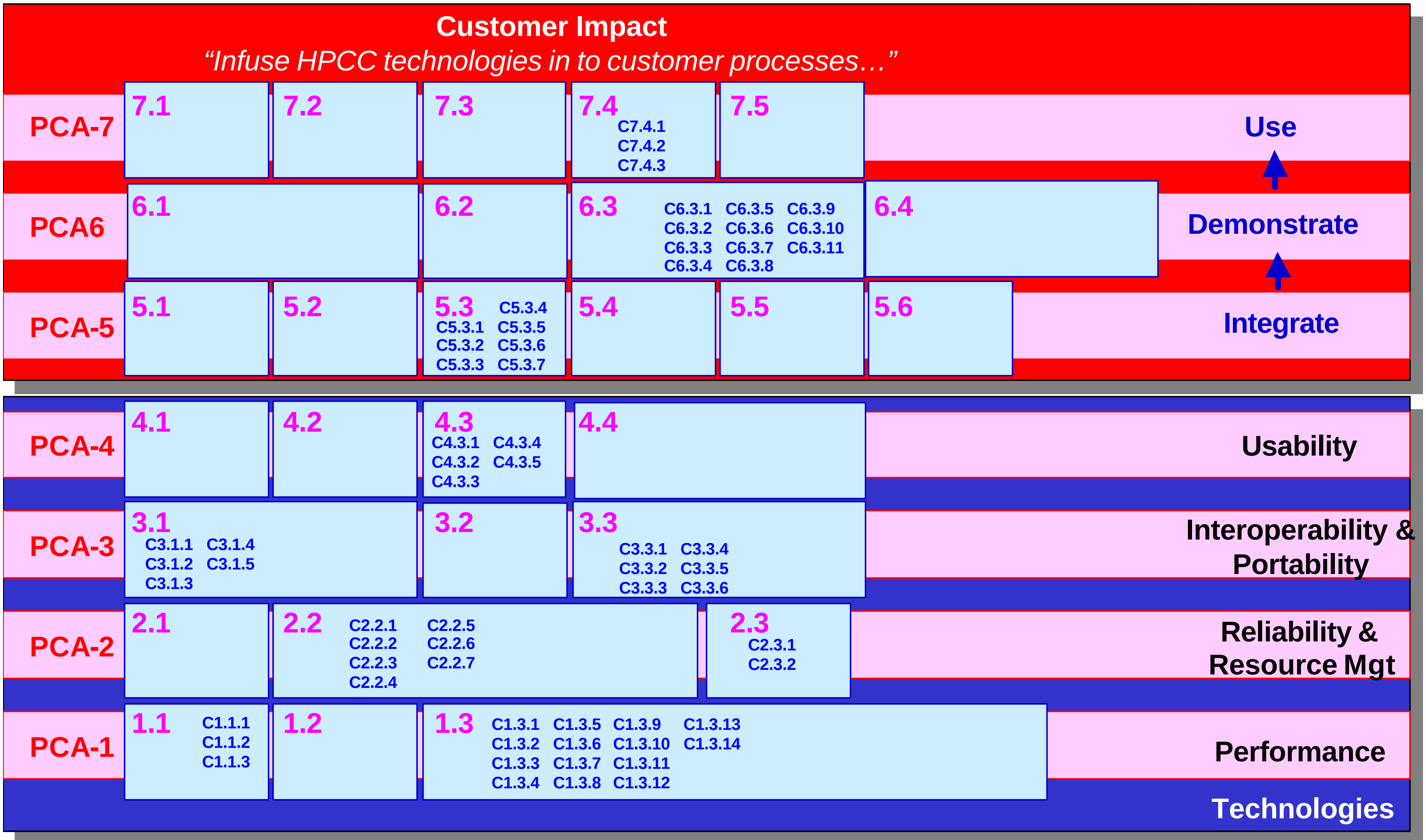
- Level 1 milestone, BR3, "Provide graduate & postdoctoral support for high performance computing research (yearly).
- Accomplishments:
  - Contribute to other elements of the CAS project: computer science; integrated design methods and tools; methods for distributed computing; data management methods and tools, multidisciplinary design optimization.
  - These basic research activities are conducted at universities and in-house primarily to train graduate students and post doctoral researchers in computer science and computational aerospace science.
- Metrics:
  - Total of 13 graduate students and 2 full-time NRC post-doctoral fellows are being supported under BRHR (metric: 10 new students/postdocs trained per year)
  - Additional graduate students supported under other elements

BRHR Support FY98, FY99, FY00

Title	PI	No. of Grad Students	No. of Post Doc and Faculty	Papers and Reports
Prophesy: A hierarchical tool for modeling and analyzing parallel, scientific applications	Taylor, Valerie Northwestern Univ.	1	1 (faculty)	2 (Conf. Paper)
Compiler Technology for Effective Parallelization of NASA Codes	Mellor-Crummey Rice Univ.	2	4 (3 PD, 1 faculty)	
Integrating Legacy Applications Within a Middleware Environment	Fatoohi, Rod San Jose State Univ.	2	1 (faculty)	
Desgin space exploration for MDO on a teraflop computer	Grossman, B. VPI	1	1 (faculty)	4 (Conf. Paper)
Design space exploration for MDO on a teraflop computer	Haftka, Raphael Univ. of Florida	1	1 (faculty)	2 (Conf. Paper)
Data compression for storage and transmission	Lee, D. NRC at Ames		1 (full time PD)	3 (Conf. Paper)
Efficient parallel algorithm for Inviscid and viscous flow simulation	Hafex/Chattot UC Davis	2	3 (1 PD, 2 faculty)	
Parallel hybrid-grid method for IDS application	Delanaye, Michel NRC at Ames		1 (full time PD)	2 (Conf. Paper)
Development of an Innovative Algorithm for Aero-Structure Interaction Using LB Method	Mei, Renwei U. of Florida			
Evolution in Denentralized Emergent Computation Algorithm to Structural Analysis and Design	Hajela, Prabhat Rensselaer Poly. Inst.			
Novel Scalable algorithms for Aerospace Design Optimization on MP Computers	Chattas, Omar Carnegie Mellon Univ.			
Achieving Application Performance on the Information Power Grid	Su, Alan UC San Diego	1		

HPCC Program Milestones

- Mapping from PCA to Program to Project Milestones -

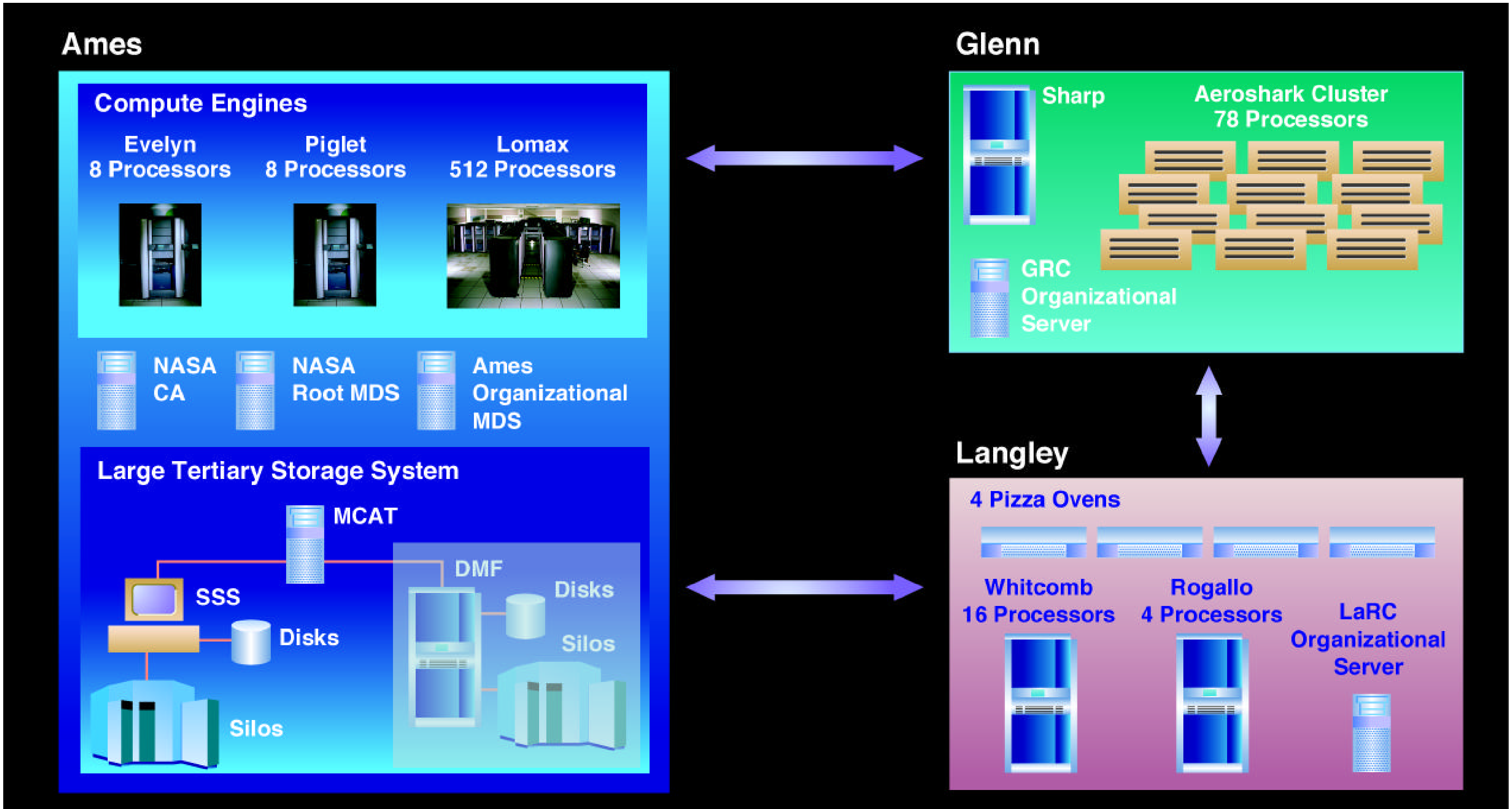


CAS 1.1: 250 GFLOPS Testbed

PCA 1	Develop Component Technologies for Performance	9/01
HPCCP 1.1	Establish high-performance testbed for application performance	9/00

- **Implementation Plan**
  - Release 512-processor O2K to user community
  - Integrate 512-processor O2K into testbed
  - Demonstrate 250 GFLOPS on benchmark
- **Current Status**
  - Built 512-processor SGI Origin 2000 (lomax) as a single system image
  - Achieved 242 GFLOPS on the Linpack Benchmark
  - Exceeded 55 GFLOPS on OVERFLOW_MLP on a a high fidelity 35 million point problem simulating a transport aircraft configured for landing
  - Released lomax to the general user community May 1, 2000
  - Integrated lomax into testbed May 1, 2000

CAS Computing Testbeds

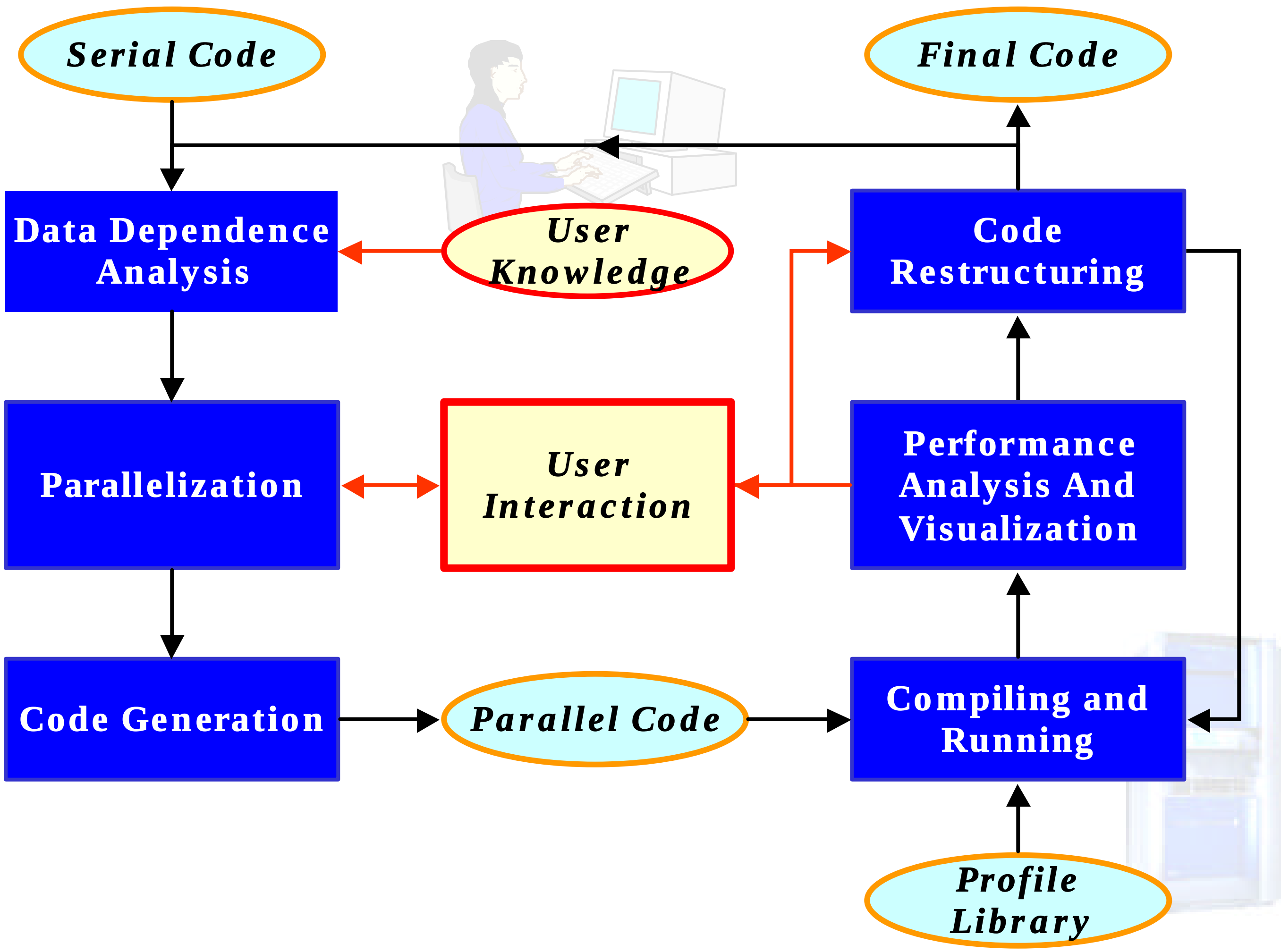


CAS 1.3: Component Technologies

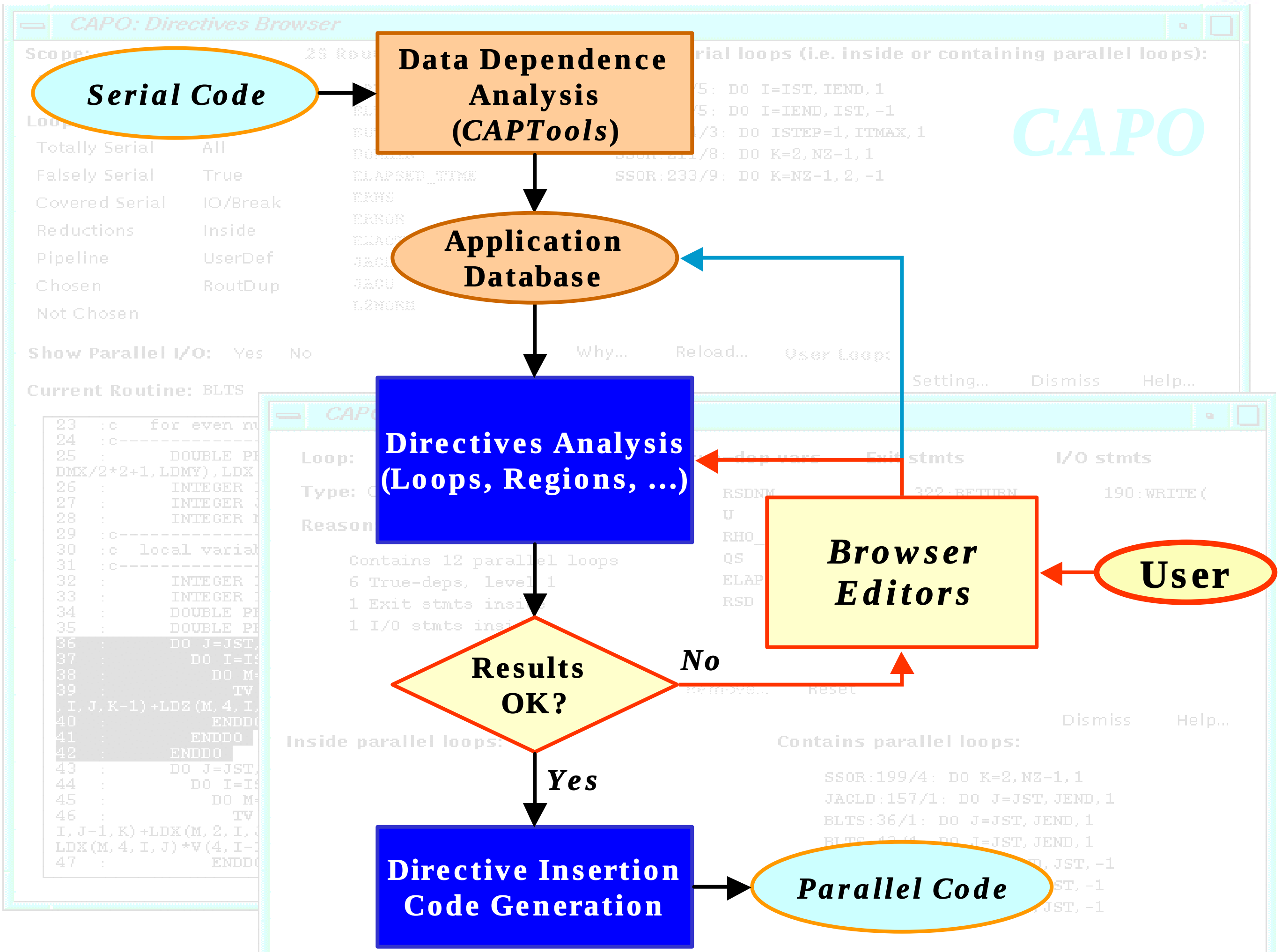
PCA 1	Develop Component Technologies for Performance	9/01
HPCCP 1.3	Develop and apply technologies to measure and enhance performance on high-performance testbeds	9/00

- **Implementation Plan**
  - Evaluate performance of automated parallelization tools
  - Develop benchmarks for measuring execution, database manipulation, and scheduling
  - Parallelize applications and enhance parallel codes
  - Investigate high-performance algorithms
- **Current Status**
  - Initial evaluation of parallelization tools
  - Testing new programming paradigms w/NPB
  - INS3D parallelization and enhancement

Parallelization and Tuning Process

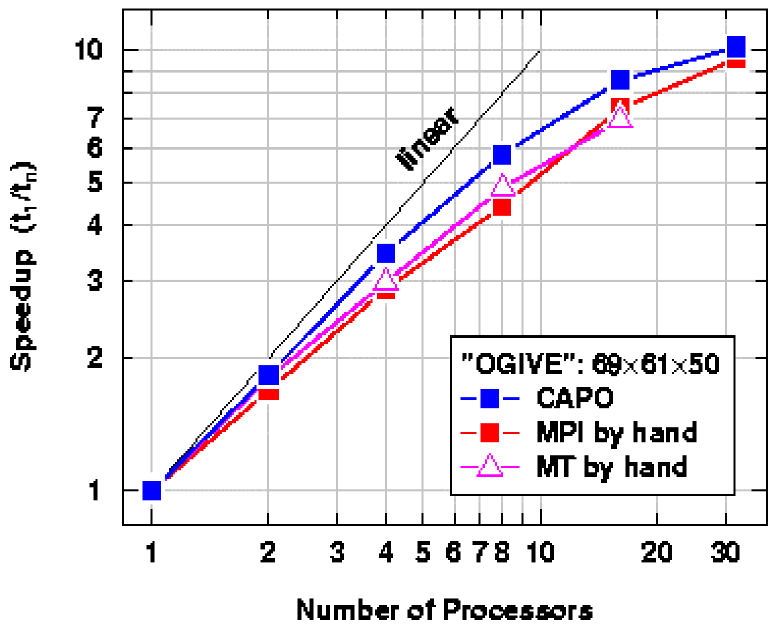


Generating OpenMP Parallel Code with CAPTools and CAPO



Performance Comparison

- Three versions of OVERFLOW
  - ⇒ OpenMP from CAPO
  - ⇒ MPI by hand
  - ⇒ Multi-Tasking by hand



SGI Origin2000, 195MHz

- Statistical "**pcsamp**" data, 16 cpus

MT version (secs1) **OMP version** (secs2)

Low threshold: 1%, ratio cutoff: 0.8

function	secs1	secs2	ratio	error
BCH0X	**1.45**	**0.04**	**36.250**	**18.373**
BCCNVV	**1.79**	**0.07**	**25.571**	**9.852**
CVSUTH	**2.32**	**0.12**	**19.333**	**5.724**
BCVELX	**0.56**	**0.03**	**18.667**	**11.062**
BCPX	**0.52**	**0.05**	**10.400**	**4.869**
BCQX	**0.78**	**0.08**	**9.750**	**3.620**
BCAXAV	**1.36**	**0.19**	**7.158**	**1.753**
FOMOL	0.37	0.10	3.700	1.319
CBCFIL	0.79	0.31	2.548	0.540
RCFLL	0.38	0.29	1.310	0.323
RDJSAL	0.42	0.33	1.273	0.296
SPE2JK	0.46	0.37	1.243	0.275
RHFSAJ	0.54	0.53	1.019	0.197
VFLL	0.57	0.57	1.000	0.187
Sum	**8.78**	**0.58**	**15.138**	**2.052**
Total	**36.06**	**27.20**	**1.326**	**0.034**

Conclusions

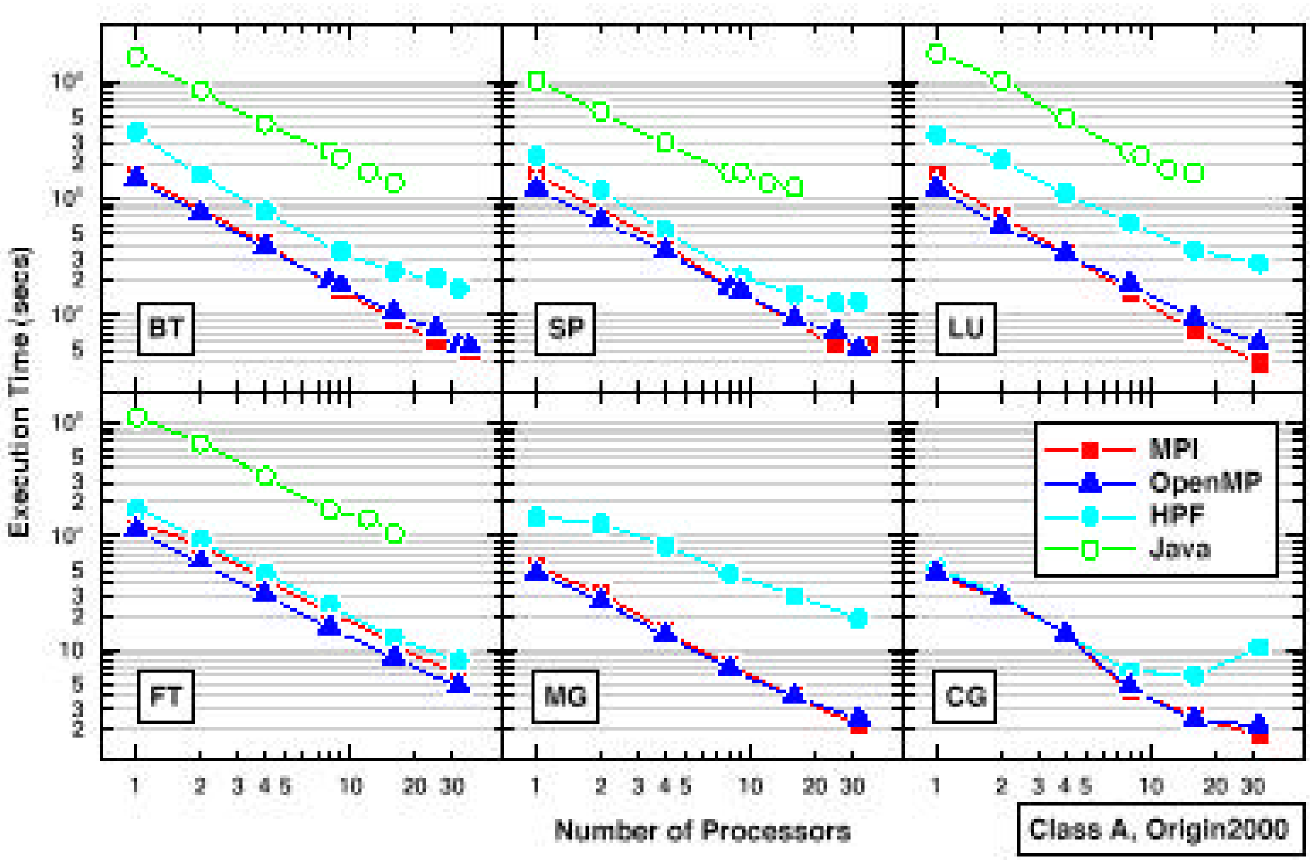
Application	*OVERFLOW*	*INS3D*	*TLNS3D*
Code size	851 routines, 100K	256 routines, 41K	117 routines, 27K
Code analysis*	25 hours	42 hours	16 hours
Testing	3 days	1 week	1 week
Code restructure	No	Yes, four routines	Yes, three routines
Performance	good	reasonable	reasonable
Improvements needed	Handle multi-zone	Reduce serial code, handle multi-zone	Higher-level parallelization? Multi-zone

* **Code analysis**: performed on a Sun Enterprise 10000, no user time

- **User interaction** is still necessary, but small

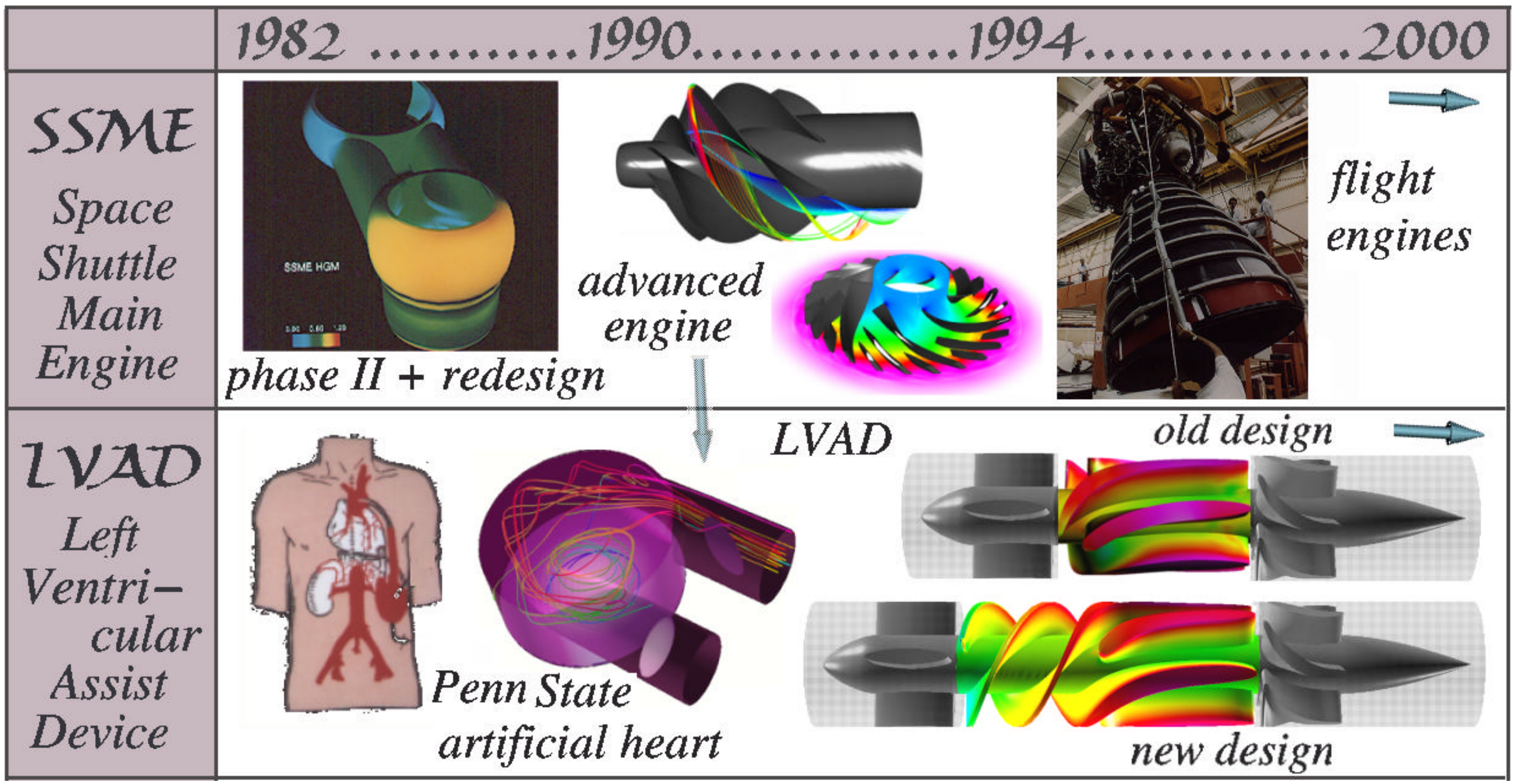
Comparison of NPB Performance with Different Programming Paradigms

- NPB1 pencil and paper specification--vendor implementation
- NPB2 source code implementation--Fortran and C, MPI parallelization
- NPB3.0 multi-language implementation--OpenMP, HPF, Java

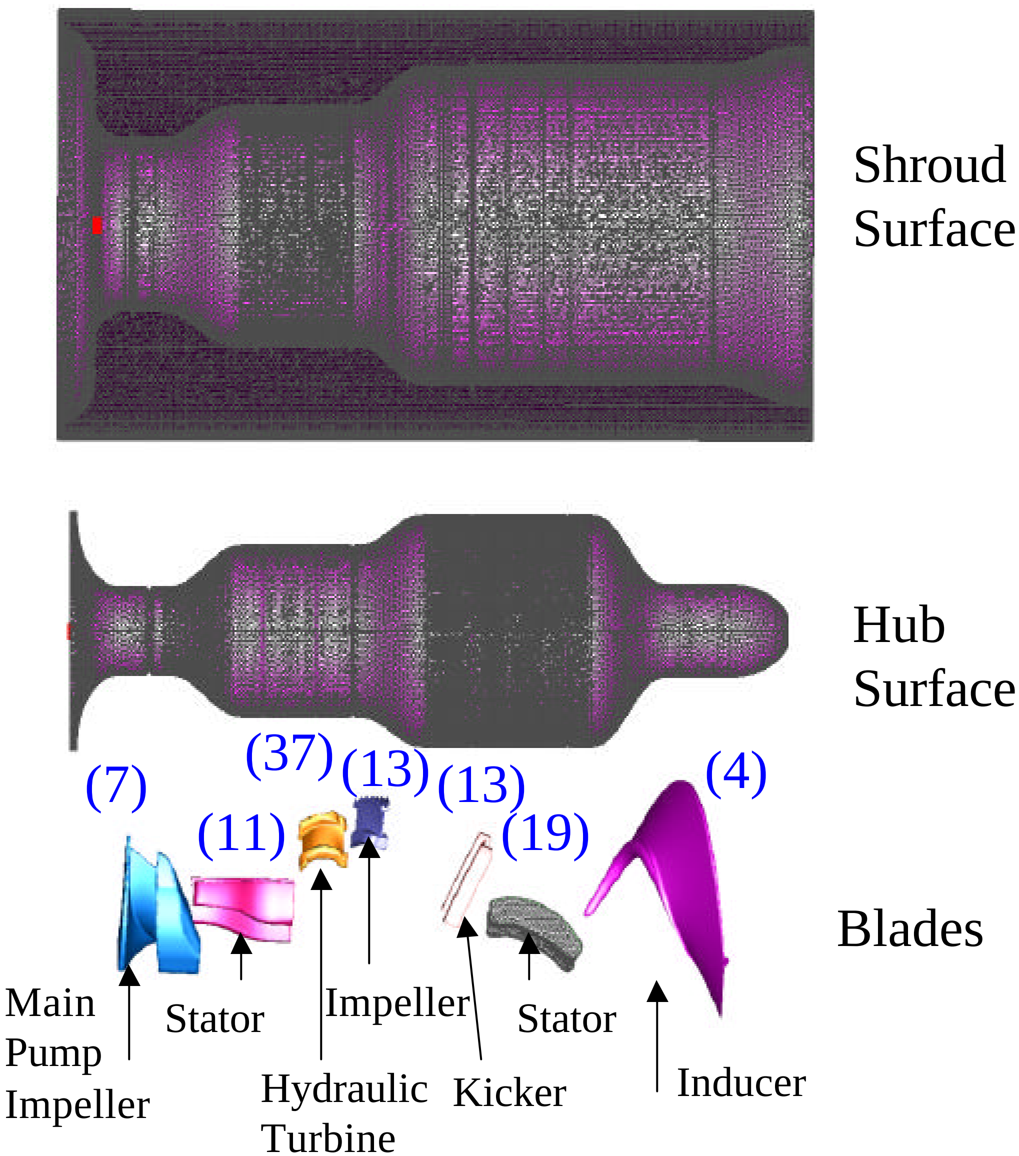


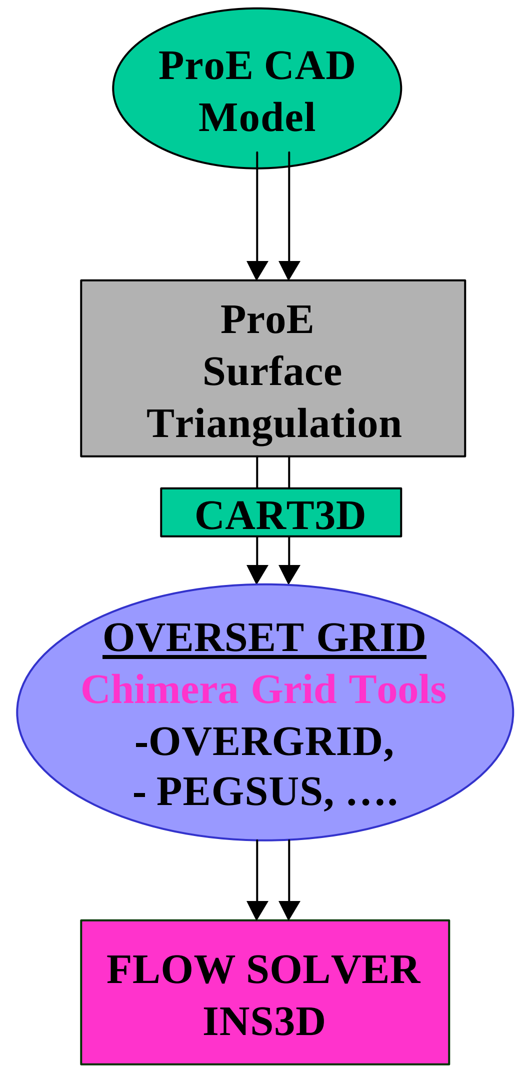
INS3D Parallelization Objectives

- To enhance incompressible flow simulation capability for developing aerospace vehicle components, especially, for simulating unsteady flow phenomena associated with high speed turbo pump.

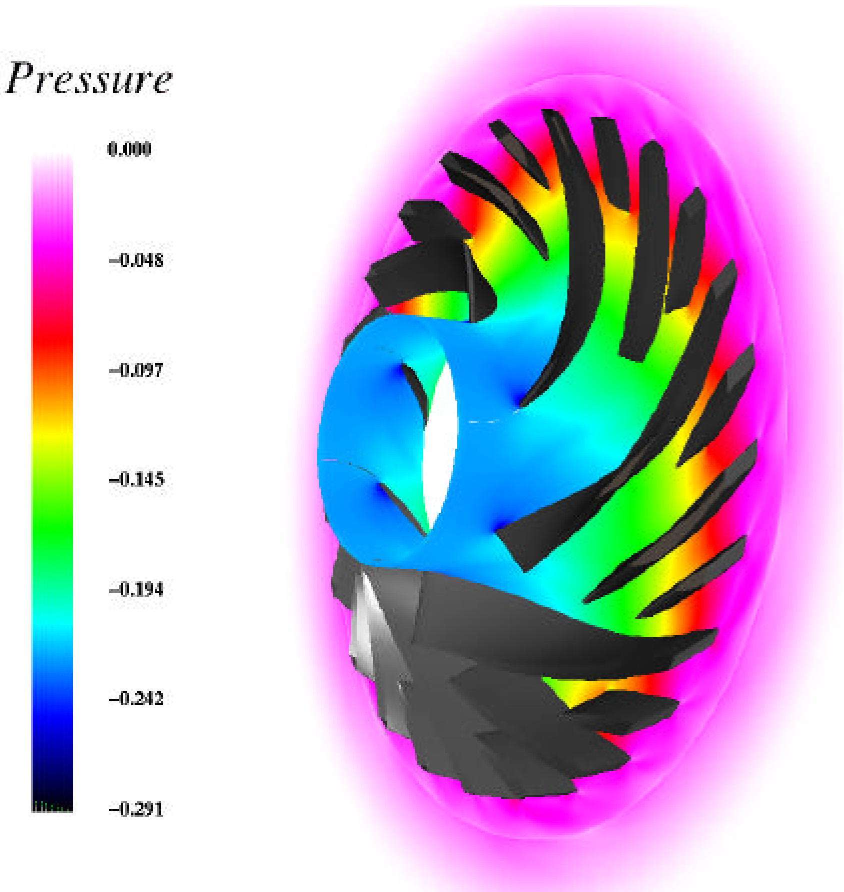


Boost Pump Computational Model





INS3D Parallelization



INS3D-MPI - coarse grain

First release

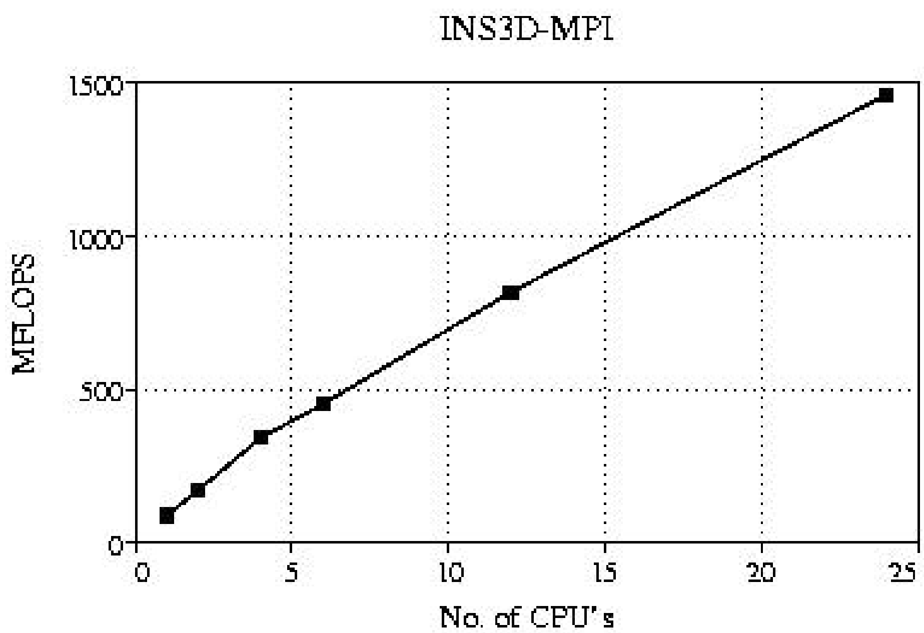
T. Faulkner & J. Dacles

MPI course grain + Open MP

Debugging stage

H. Jin & C. Kiris

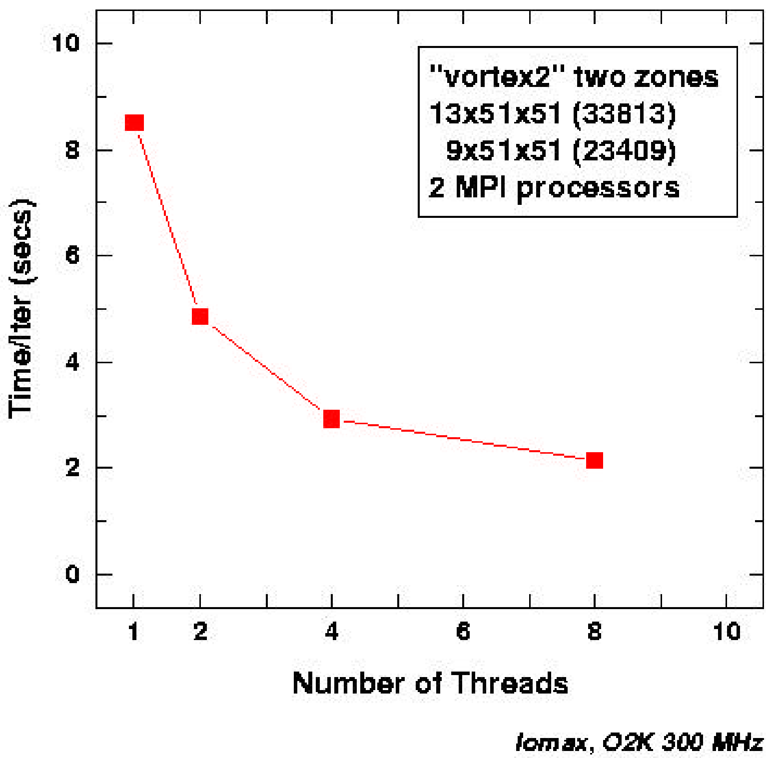
MLP (studying OVERFLOW-MLP)



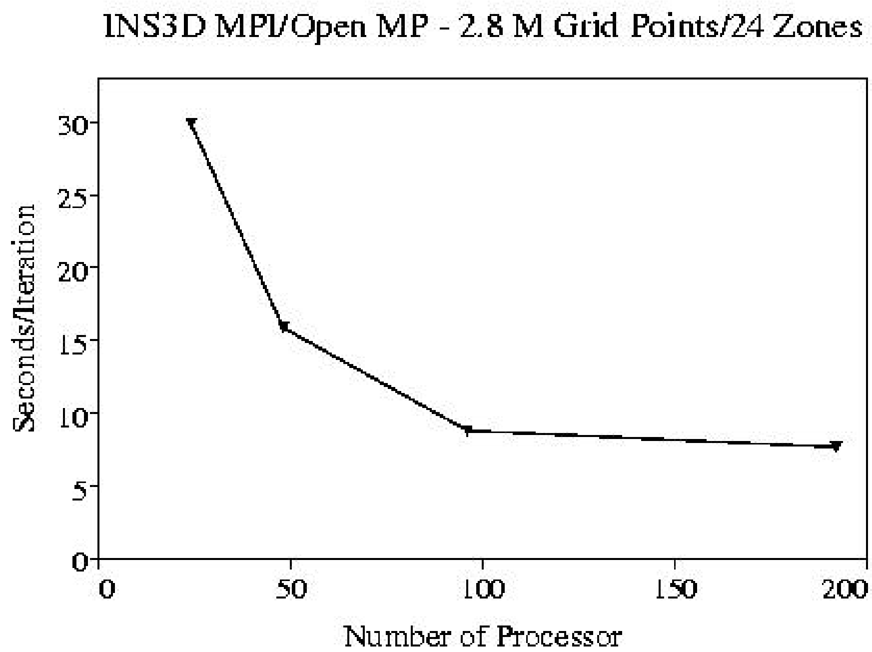
INS3D Parallelization

MPI coarse grain + Open MP

TEST CASE : 2 Zones Vortex



TEST CASE : SSME Impeller



Time-Accurate Formulation

- Time-integration scheme

Artificial Compressibility Formulation

- Introduce a pseudo-time level and artificial compressibility
- Iterate the equations in pseudo-time for each time step until incompressibility condition is satisfied.

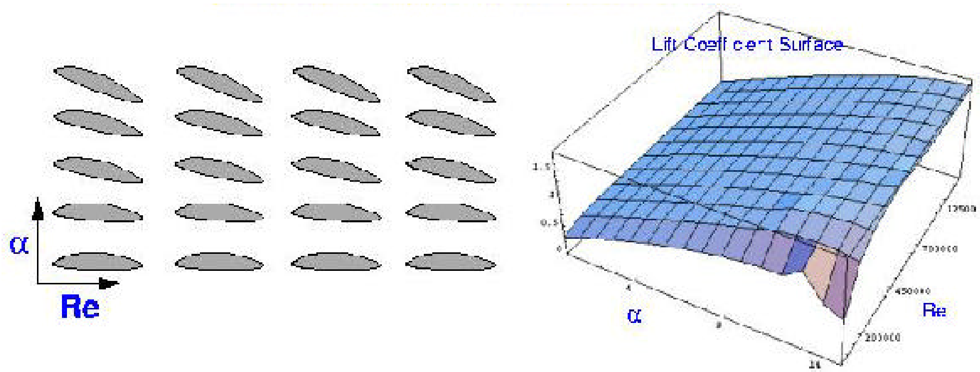
Pressure Projection Method

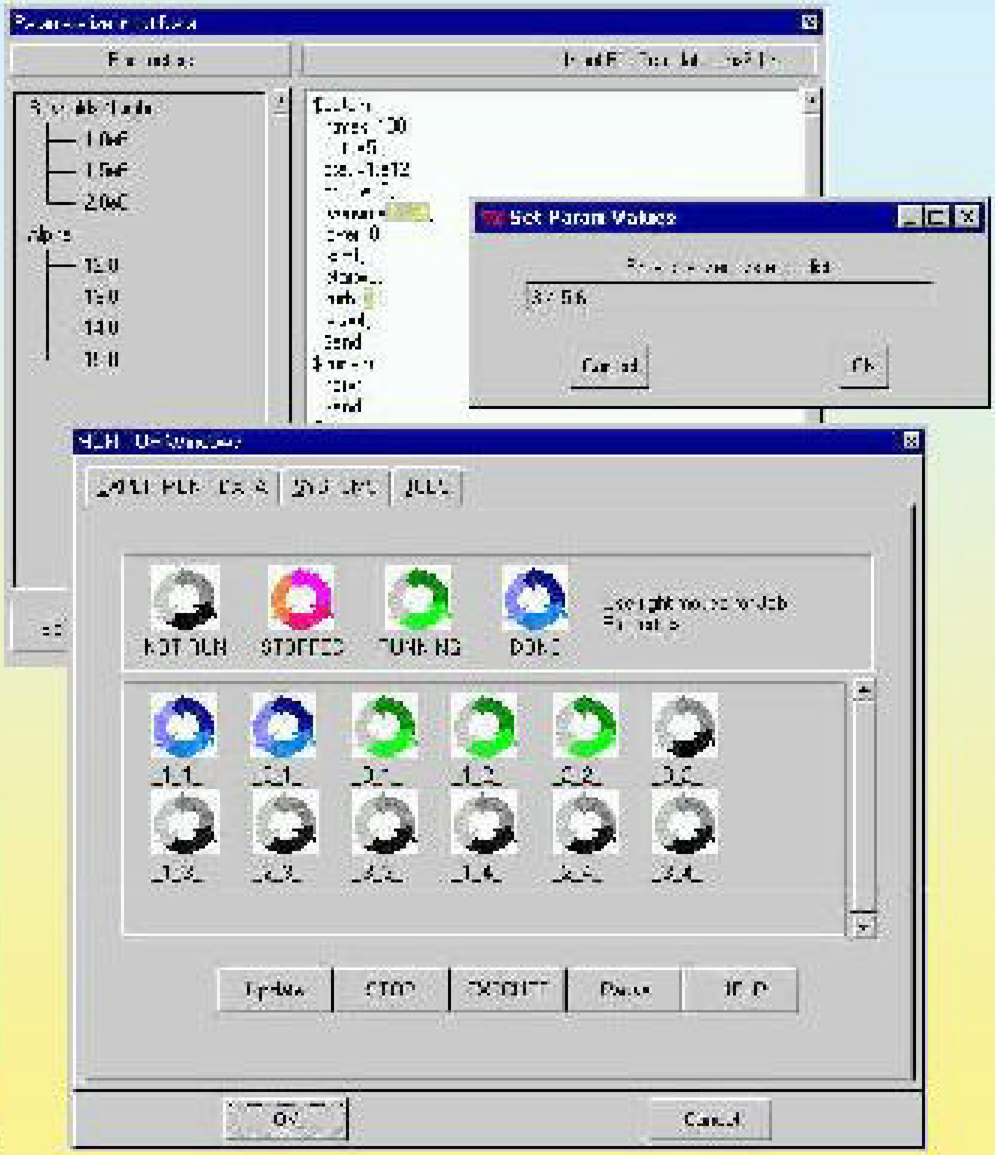
- Solve auxiliary velocity field first, then enforce incompressibility condition by solving a Poisson equation for pressure.

CAS 2.2: Resource Management Tools

PCA 2	Develop component technologies for reliability and resources management	6/03
HPCCP 2.2	Develop embedded tools and services for autonomous resource estimation/request of local and distributed ground based systems	12/02

- **Implementation Plan**
  - Provide services for job queueing, job tracking, job monitoring, and resource status
  - Prototype resource management, scheduling, and automated job submission systems
- **Current Status**
  - ILAB





ILab : The Information Power Grid Virtual Laboratory

- Parameterization made simple and easy
- Generates and submits scripts to execute parameterized jobs
- Absolutely no programming or scripting required
- Several Job Models, including Globus, PBS, MPI, local or remote
- Real-time monitoring of job status
- Organization and archiving of all "Experiment" data
- MRU and complete "history" secretarial features
- Built with Object-Oriented programming model

FUTURE :

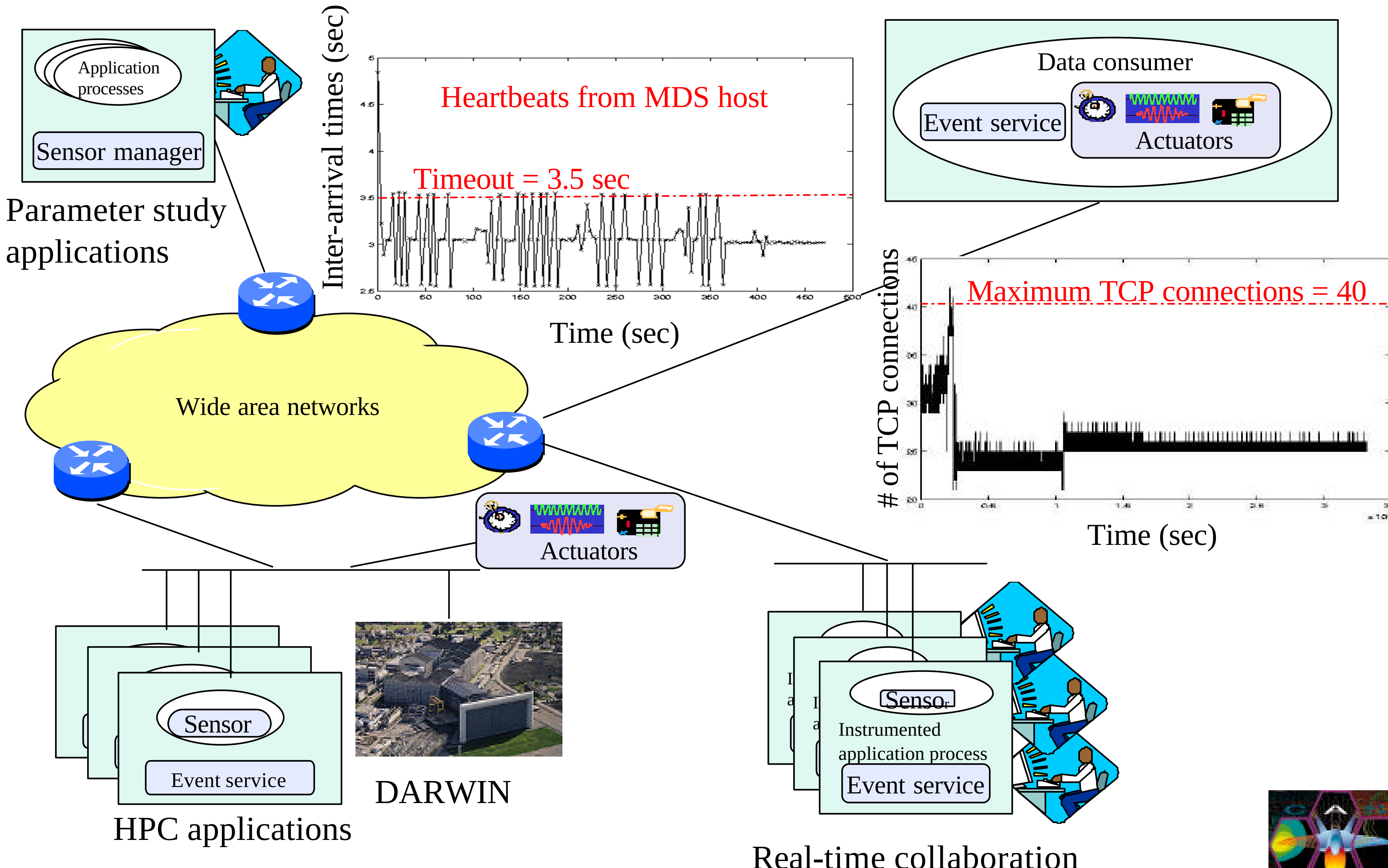
- CAD-based complex process specification;
- Additional Job Models : Condor, Legion, PVM

CAS 2.3: Reliability Tools

PCA 2	Develop component technologies for reliability and resources management	6/03
HPCCP 2.3	Develop tools for reliability of ground-based computing systems	6/03

- **Implementation Plan**
  - Prototype tools to detect, classify, and adapt to faults
  - Demonstrate use of tools to provide 99% availabilty
- **Current Status**
  - Fault Management Infrastructure for Grid Computing

Fault Management Infrastructure for Grid Computing



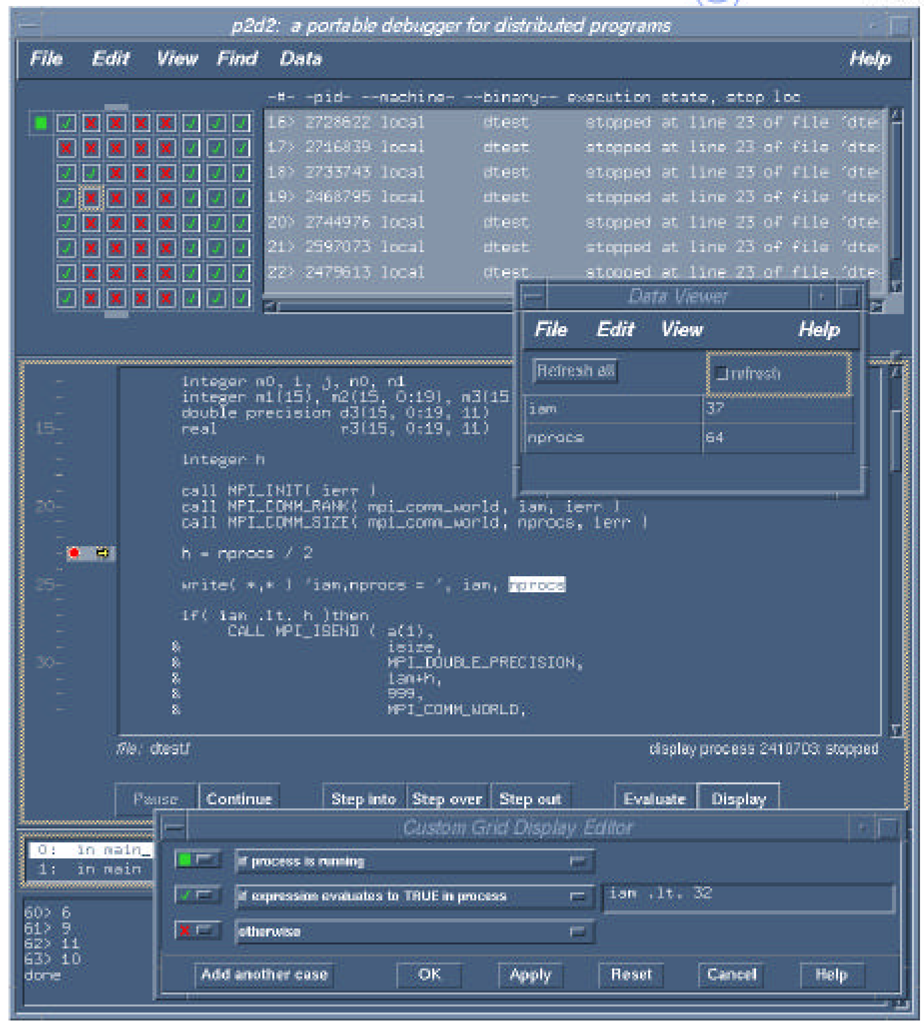
CAS 3.1: Interoperability and Portability
Tools and Techniques

PCA 3	Develop component technologies for interoperability and portability	9/03
HPCCP 3.1	Tools and techniques for interoperable and portable applications in aerospace, Earth Science and space science communities	3/02

- **Implementation Plan**
  - **Evaluate CORBA interface to distributed systems**
  - **Demonstrate parallel debugging on distributed systems**
  - **Develop tools to automate derivation of interfaces to CORBA environments and wrap legacy codes in CORBA**
  - **Evalute security services in distributed system environment**
- **Current Status**
  - **Demonstrated p2d2 debugging 64 and 128 Globus processes**
  - **Using CORBA and Globus to coordinate multi-disciplinary applications**
  - **Developing CORBA-based distributed scientific applications from legacy Fortran programs**

Demonstrated p2d2 Debugging 64 and 128 Globus Processes

- **Shown:**
  - **Screendump of 64 processes running under the Globus system. The processes are spread across 3 of the SGI Origins at NAS.**
  - **Debugging a very simple MPI program that has the following behavior when run on 2n processes:**
    1) each process i with ID in the range [0 ... n] sends a message to process n+i
    2) all 2n processes execute an MPI_Barrier
    3) step #1 is repeated
- **Although the application program is very simple, all of the Globus and mpich-g ".o" files (about 300 total) were compiled -g. The resulting a.out file is approximately 1.6MB on disk.**

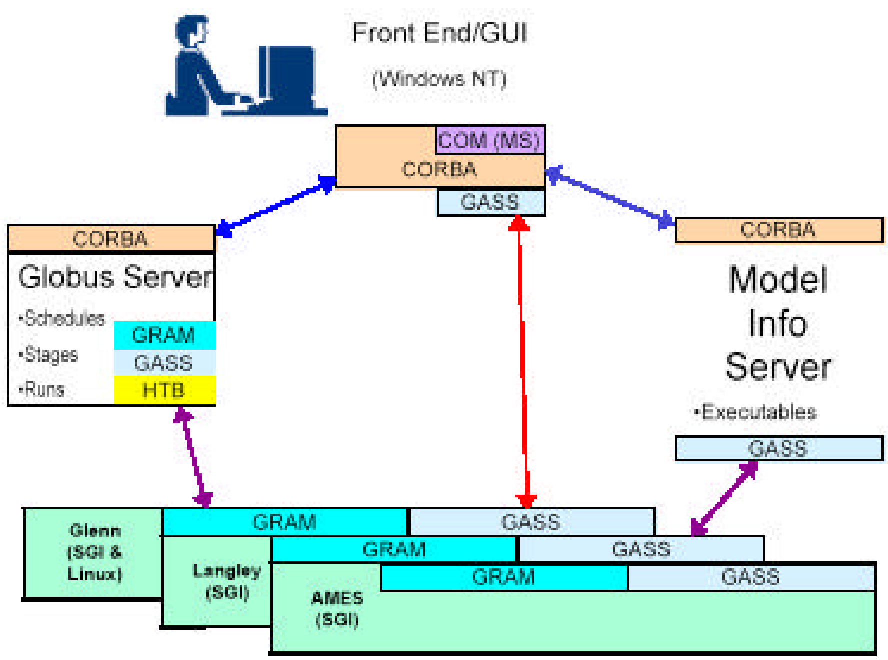


http://science.nas.nasa.gov/Tools/p2d2

Using CORBA and Globus to Coordinate Multi-disciplinary Aeroscience Applications

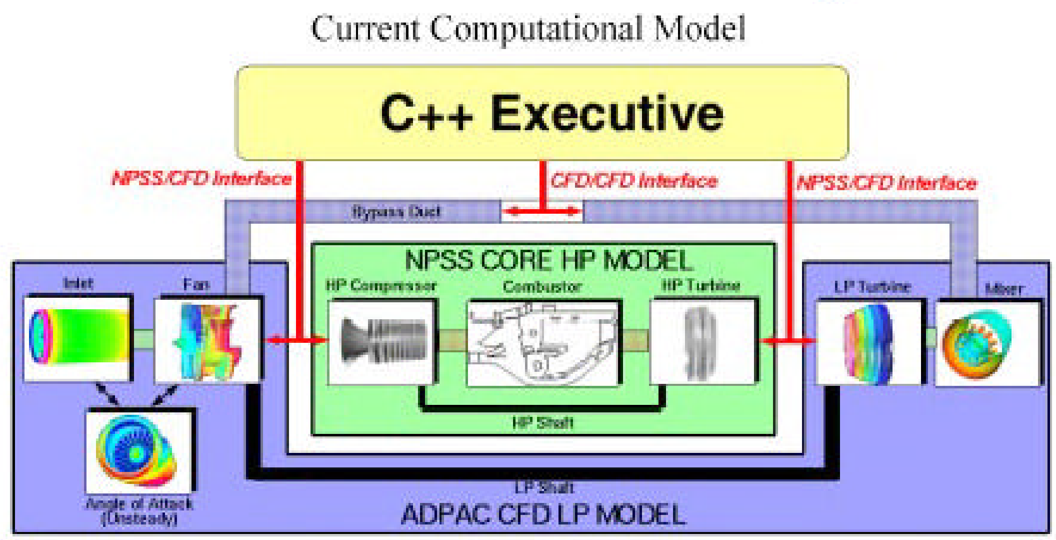
- **Time to port**
  - **Most time spent creating the ModelInfoServer**
- **Execution time**
  - **Sluggish. The focus was on functionality rather than speed.**
- **Scalability**
  - **Very good since they were handled by Globus.**
- **Reliability**
  - **Very good since they were handled by Globus.**

CORBA and GLOBUS



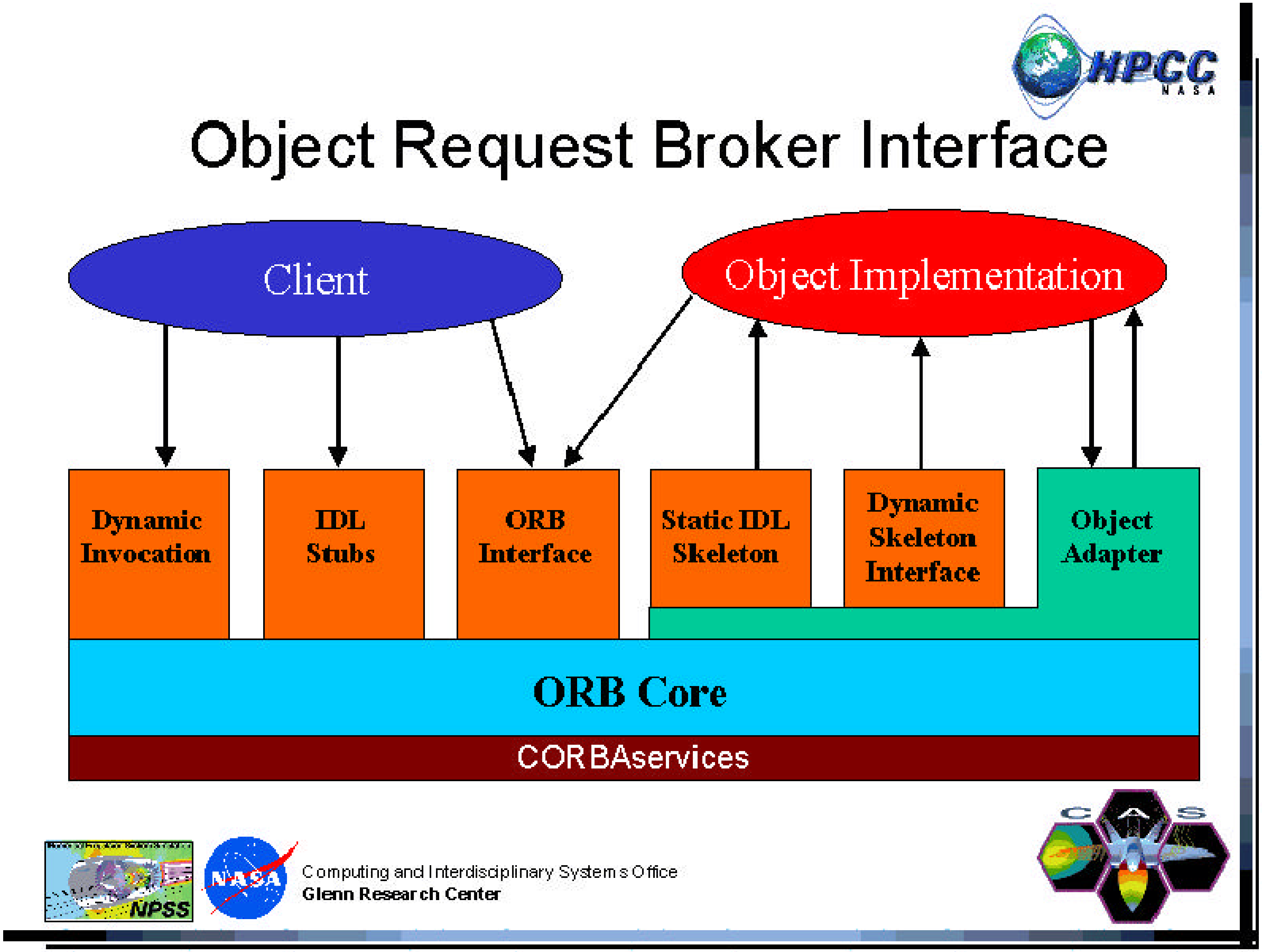
Multi-component Application
Multi-Fidelity Engine Model

- **Time to port**
  - **After initial learning curve, time to port is minimal**
- **Execution time**
  - **Similar to any batch queueing system**
- **Scalability**
  - **Very scalable for jobs that do not require intense messaging**
- **Reliability**
  - **Similar to any current batch queuing system--LSF, PBS, etc.**



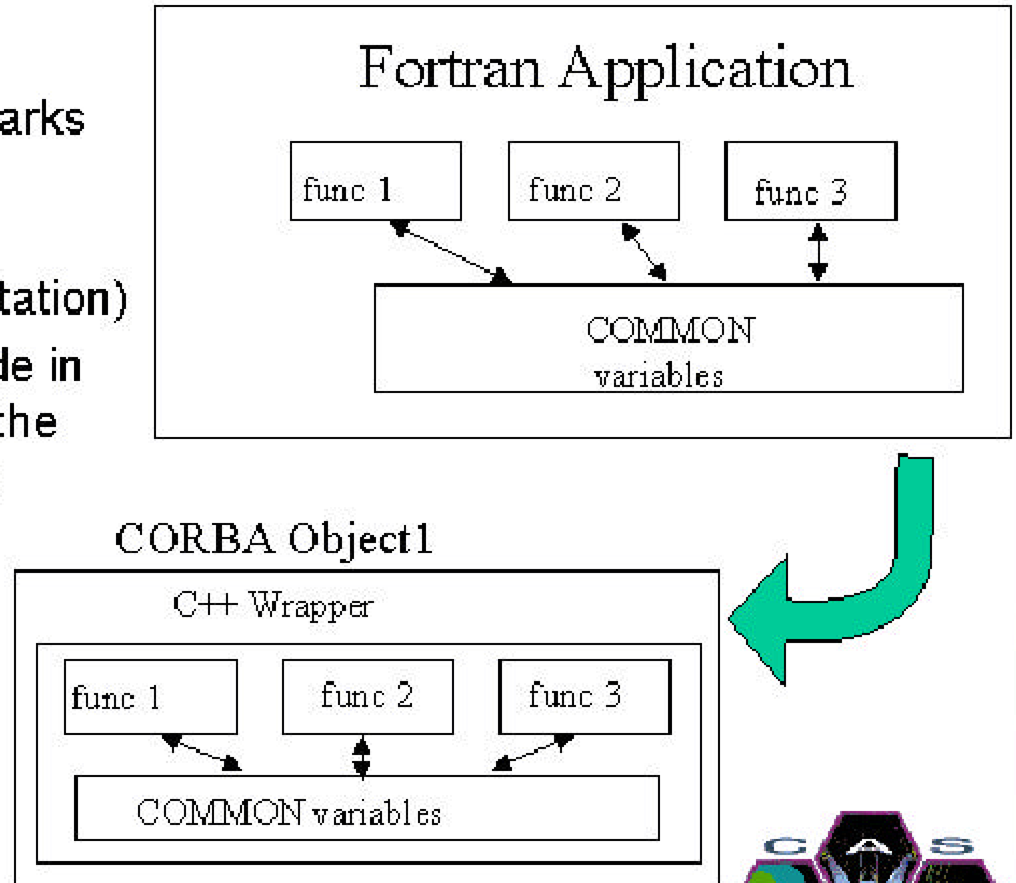
CFD-based shaft power balance:
20 processors, 5 RPM adjustments, 14 hours

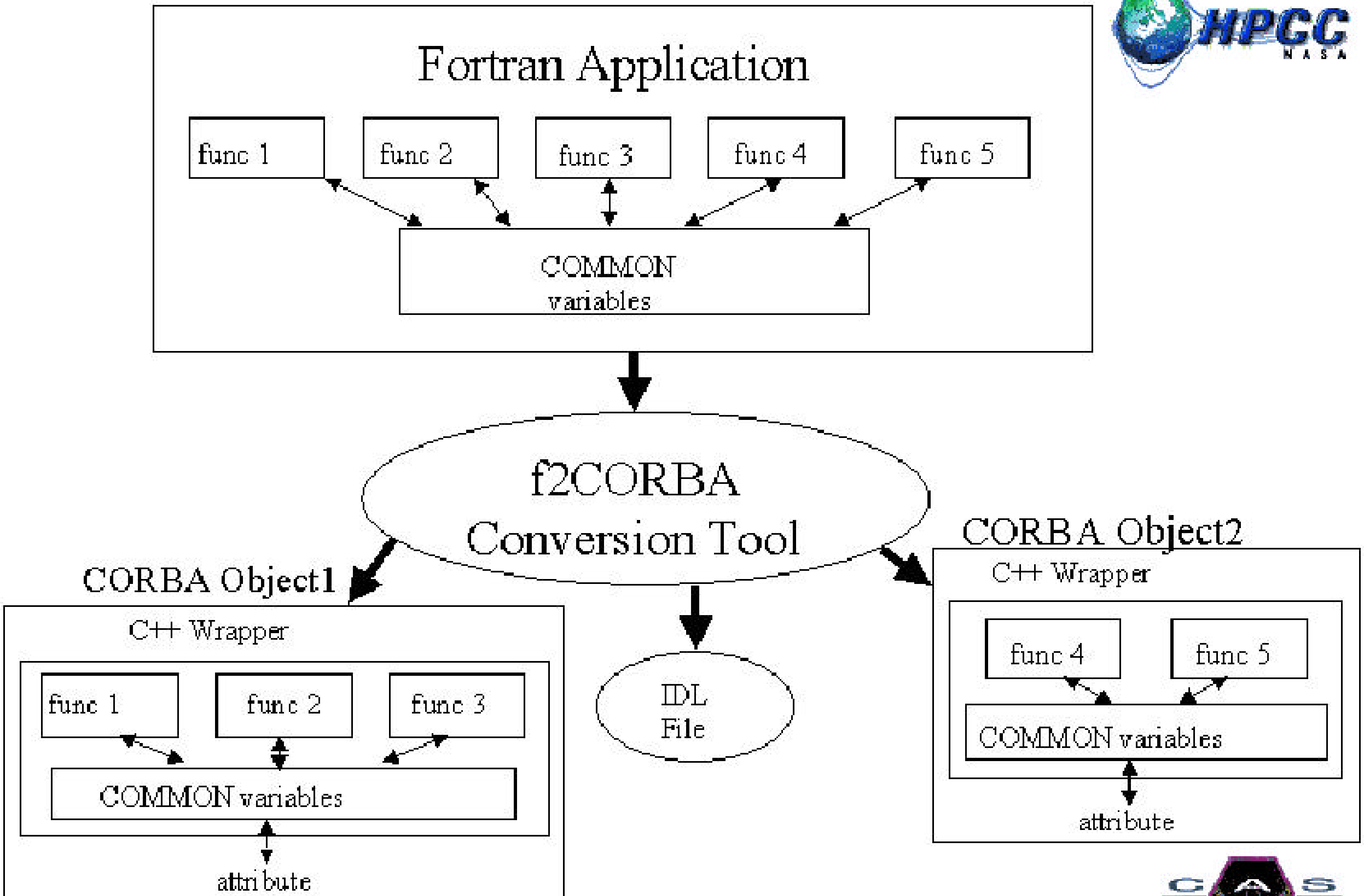
Developing CORBA-Based Distributed Scientific Applications from Legacy Fortran Programs

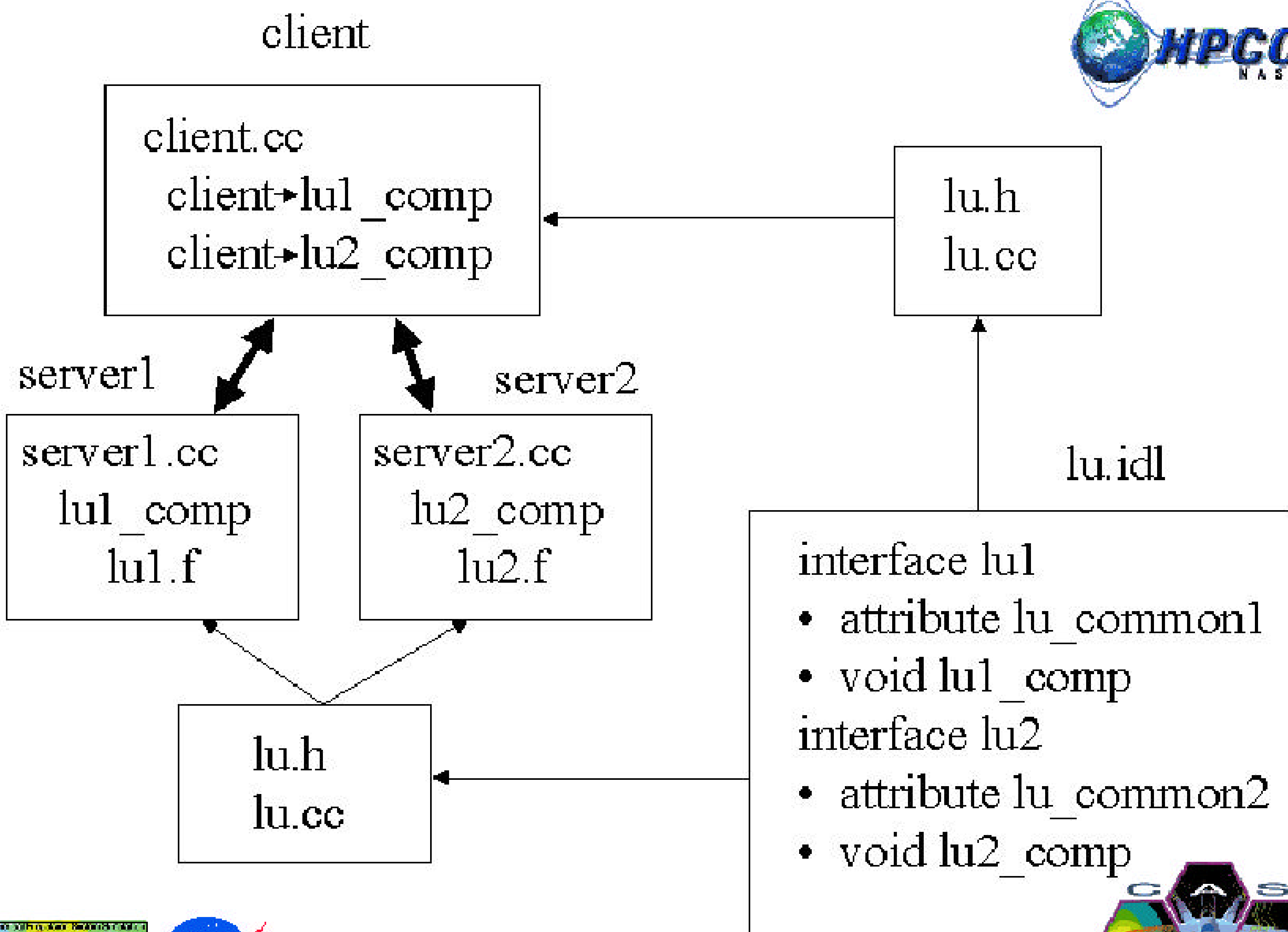


Test Case

- LU: NAS Parallel Benchmarks (NPB) Serial Version
- Wrapped LU in one C++ object(interface implementation)
- Objectified LU Fortran code in the server is activated by the client through IDL-defined interface




Fortran Application
func 1
func 2
func 3
func 4
func 5
COMMON
variables
f2CORBA
Conversion Tool
CORBA Object1
C++ Wrapper
func 1
func 2
func 3
COMMON variables
attribute
IDL
File
CORBA Object2
C++ Wrapper
func 4
func 5
COMMON variables
attribute


client
client.cc
client→lu1_comp
client→lu2_comp
lu.h
lu.cc
server1
server2
server1.cc
lu1_comp
lu1.f
server2.cc
lu2_comp
lu2.f
lu.idl
interface lu1
• attribute lu_common1
• void lu1_comp
interface lu2
• attribute lu_common2
• void lu2_comp
lu.h
lu.cc

Performance measurements

Benchmark LU (3D NS)	Traditional		1 client – 2 servers			
	Comp	Total	Binding	Comp.	Comm.	Total
Sun Ultra	2.99	3.05	0.046	2.99	0.33	3.37
PC Linux	1.51	1.58	0.019	1.51	0.19	1.72

Benchmark BT (*Beam-Warming*)	Traditional		1 client – 2 servers			
	Comp	Total	Binding	Comp.	Comm.	Total
Sun Ultra	6.99	7.25	0.047	6.99	2.12	9.16
PC Linux	4.16	4.35	0.019	4.16	1.38	5.73

CAS 3.3: Interoperability and Portability
Systems, Services and Environments

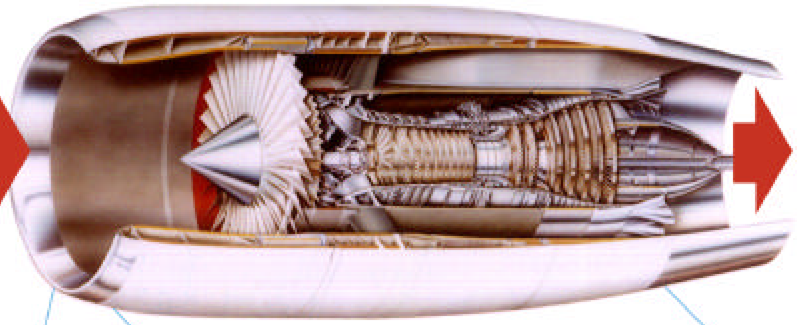
PCA 3	Develop component technologies for interoperability and portability	9/03
HPCCP 3.3	Interoperable and portable systems, services and environments	9/03

- **Implementation Plan**
  - Continue NPSS development
  - Demonstrate NPSS zooming, CAD interface, incorporation of new tools
  - Provide automated gridding capability
  - Develop and evaluate high-performance language extensions
  - Enhance resource management and scheduling systems
- **Current Status**
  - NPSS development status
  - NPSS CAD interface
  - NPSS zooming

Numerical Propulsion System Simulation (NPSS)

Validated Models

- Fluid Mechanics
- Heat Transfer
- Combustion
- Structural Mechanics
- Materials
- Controls
- Manufacturing
- Economics



Rapid Affordable Computation of:

- Performance
- Stability
- Cost
- Life
- Certification Req.

NPSS

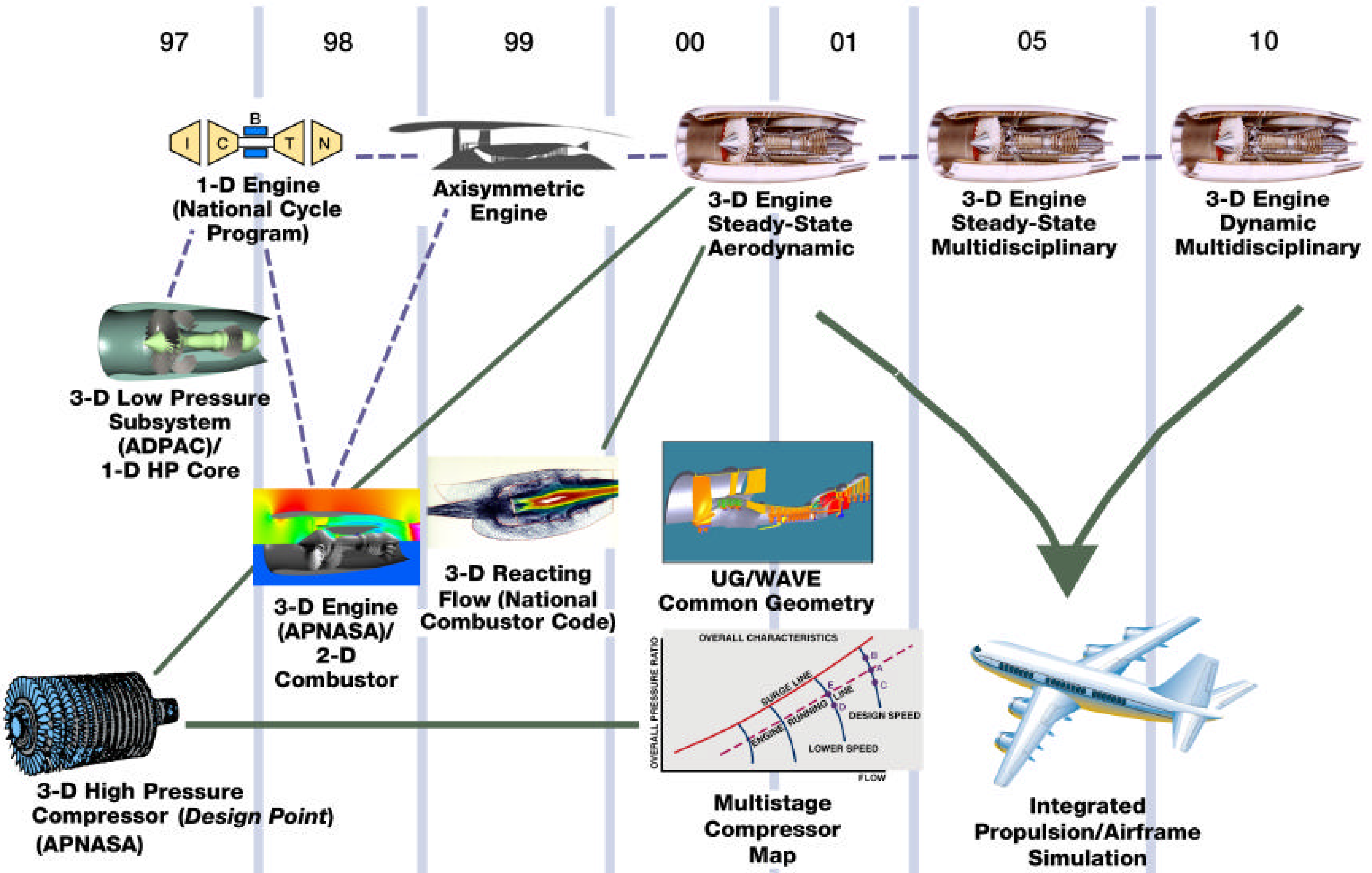
Integrated Interdisciplinary Analysis and Design of Propulsion Systems

High Performance Computing

- Parallel Processing
- Expert Systems
- Interactive 3-D Graphics
- Networks
- Database Management Systems
- Automated Video Displays

A Numerical Test Cell for Aerospace Propulsion Systems

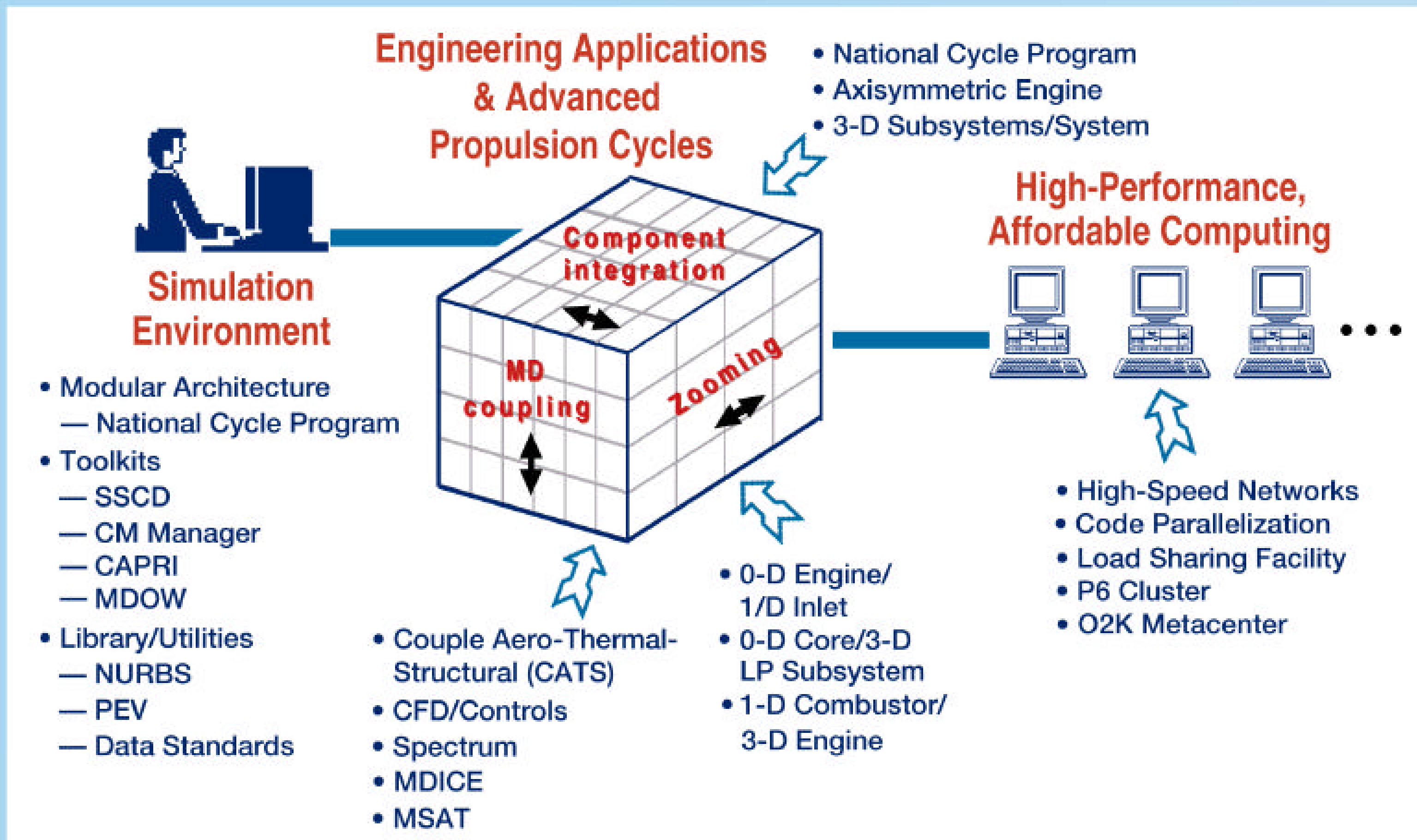
Roadmap for NPSS Overnight Simulations



CD-98-77415

NPSS

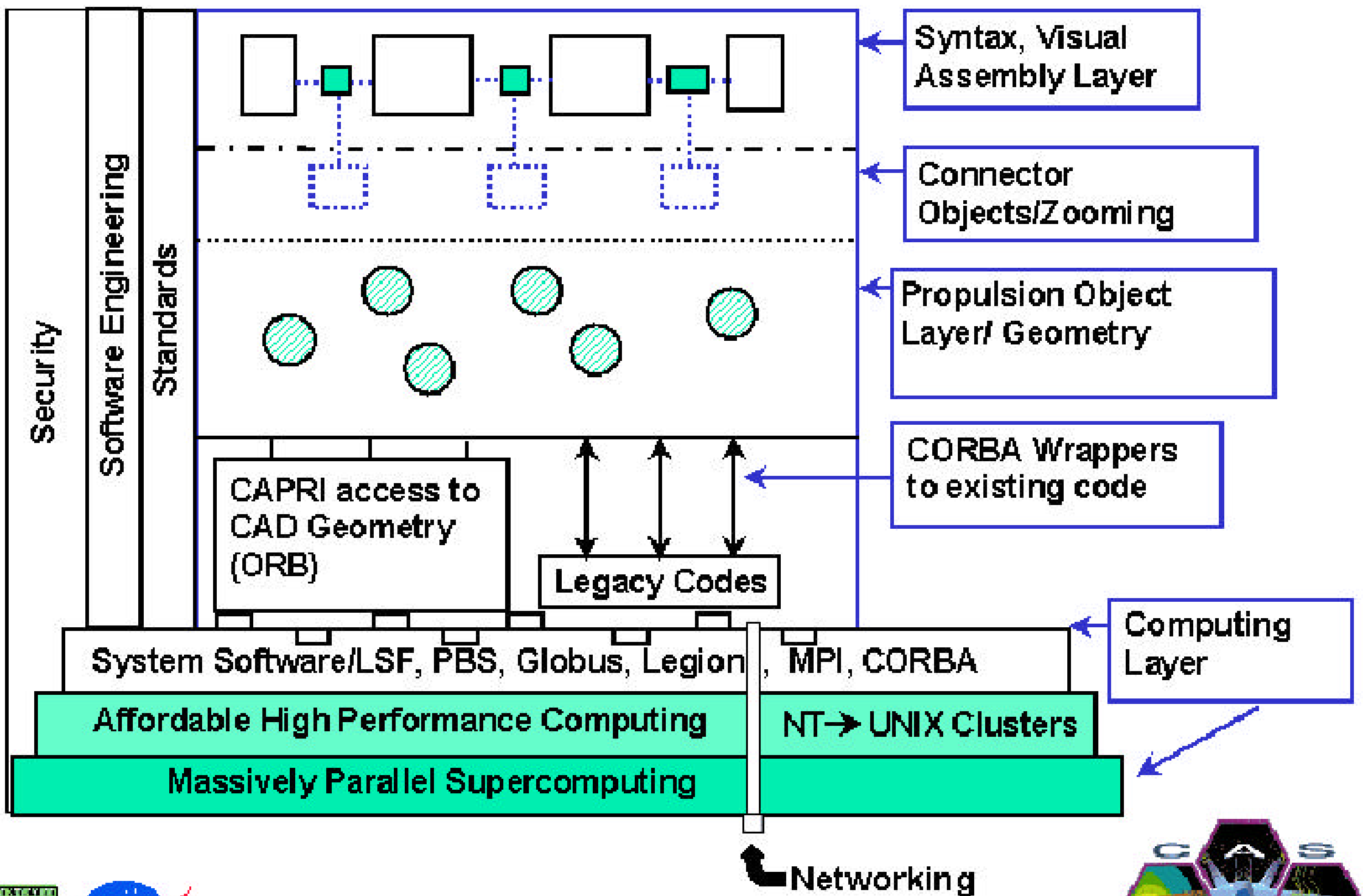
Work Breakdown Structure



Computing and Interdisciplinary Systems Office
Glenn Research Center

CD-97-73749-2

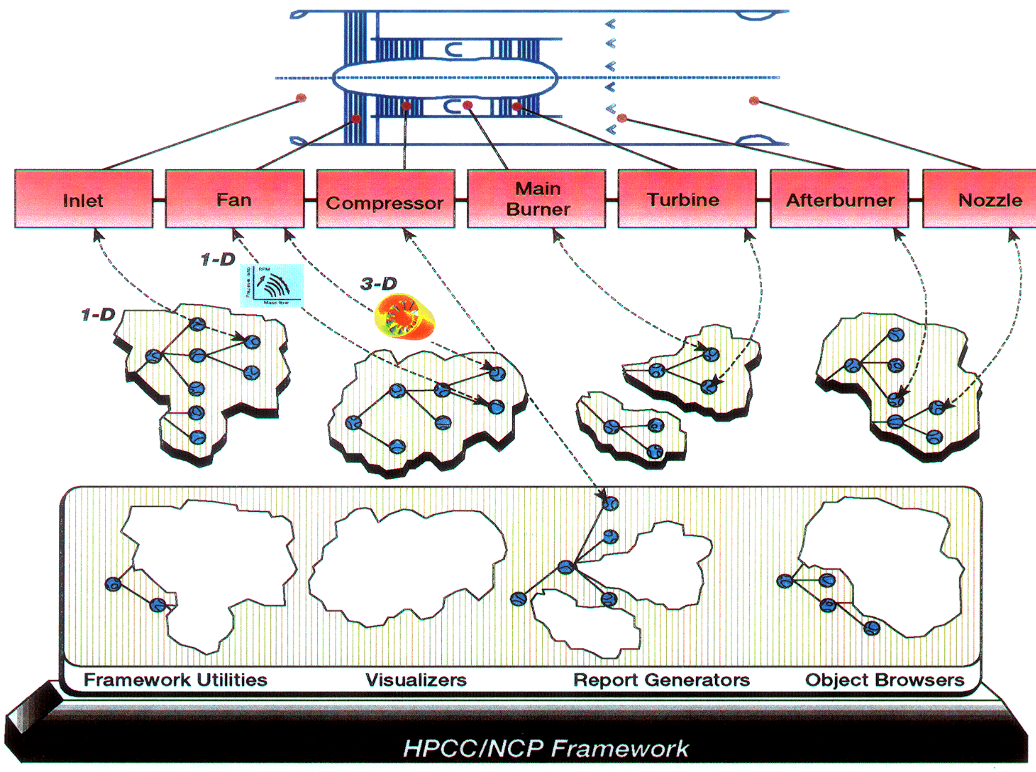
NPSS Object Oriented OPEN Architecture



Near Term Release Schedule

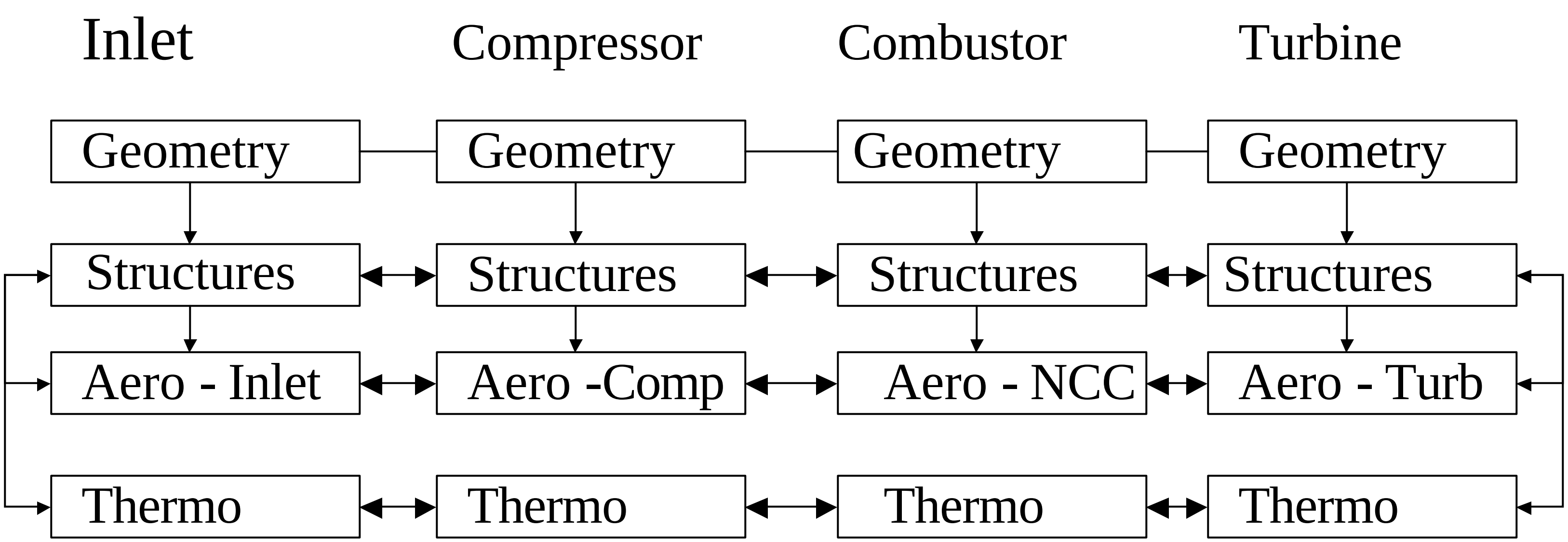
	'99	'00	'01	'02
• **Provide a Framework supporting Distributive and Collaborative Computing to Reduce Design and Analysis time for Aerospace Propulsion Systems.**				
• **NPSS Versions (Steady State and Transient, Engineering Components)**	**NPSS V1.0** • Initial Customer Deck • Dynamic Link Library	**NPSS V1.0** •Zooming from 1D/2D to 0D •RL10 Demo •Fully interpretive elements	**NPSS V2.0** •Zooming from 3D to 0D •Initial MD Probabilistic •1D dynamics	**NPSS V3.0** •MD architecture •Probabilistic, sensitivity analysis
	• Distributed Objects • Demonstration on HPCC computing resources	• PC Implementation • Demo Distributed Simulation	• Deploy Distributed Simulation on Heterogeneous Computers	

NPSS System Requirements

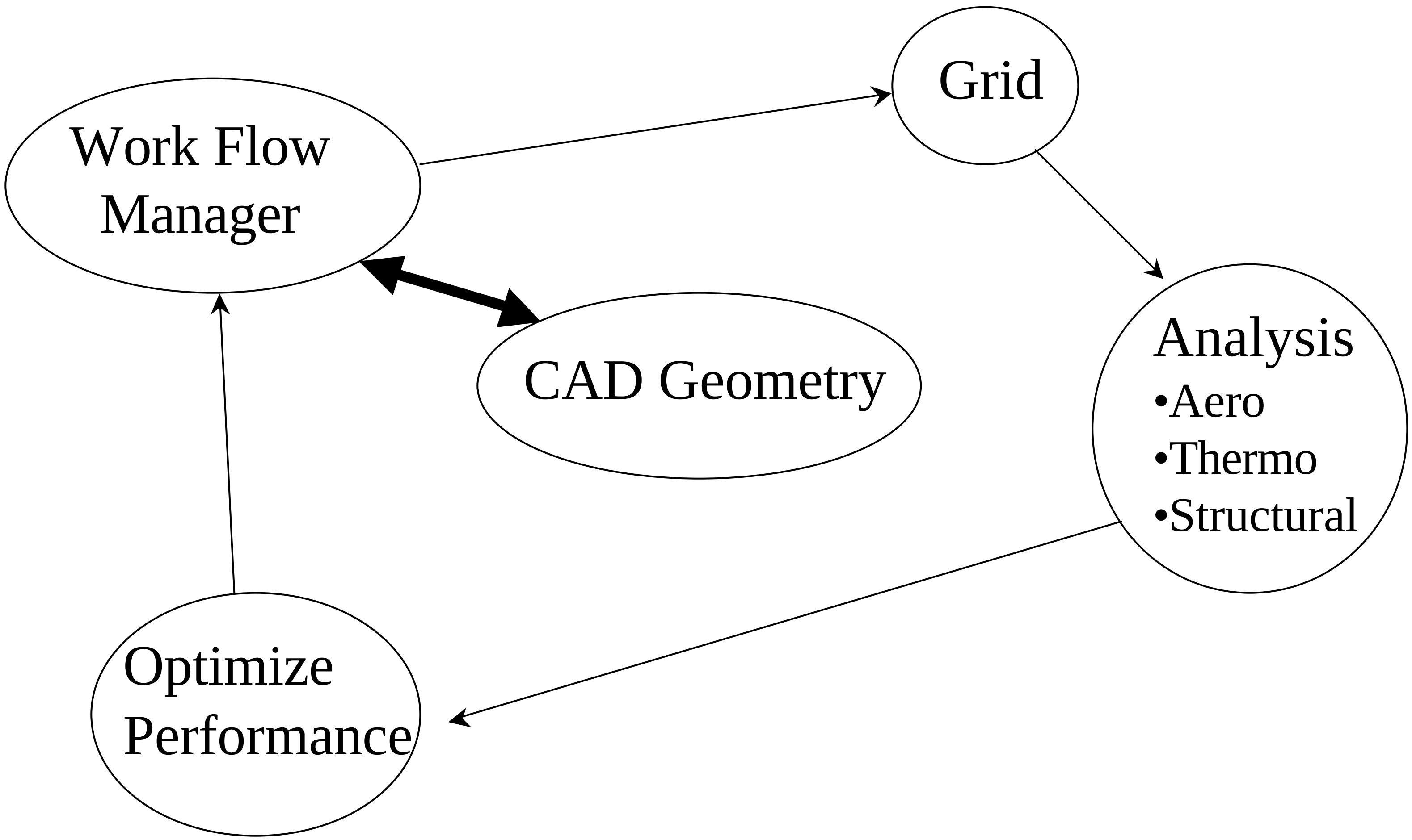


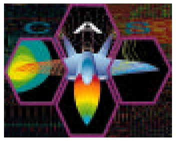
No Small Feat

- What if this system had to be built for each CAD system?
- What if this system had to be built for each CFD code?



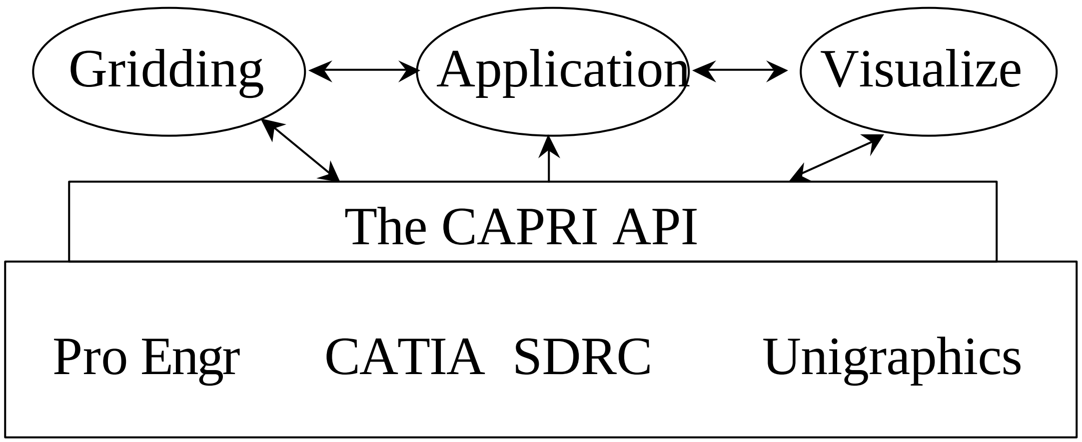
Center of the Universe





CAPRI

- **CAPRI: Computational Analysis PRogramming Interface**
  - A vendor neutral API that provides geometry information from the CAD representation to geometry-dependent applications (e.g. grid generators, CFD, structures codes)
  - Uses solids based CAD system geometry kernel
  - Supports high level (engineering) queries into the CAD model
  - Support for “boundary” to “boundary” interpolation (for example, CGNS)
  - API available at: http://www.grc.nasa.gov/WWW/capri
  - Commercialization being explored
- **CAPRI is the software layer between the CAD System and various applications:**
  - Single address space
  - Multi-language (C and Fortran)



CORBA Capri Approach

CORBA Capri Approach

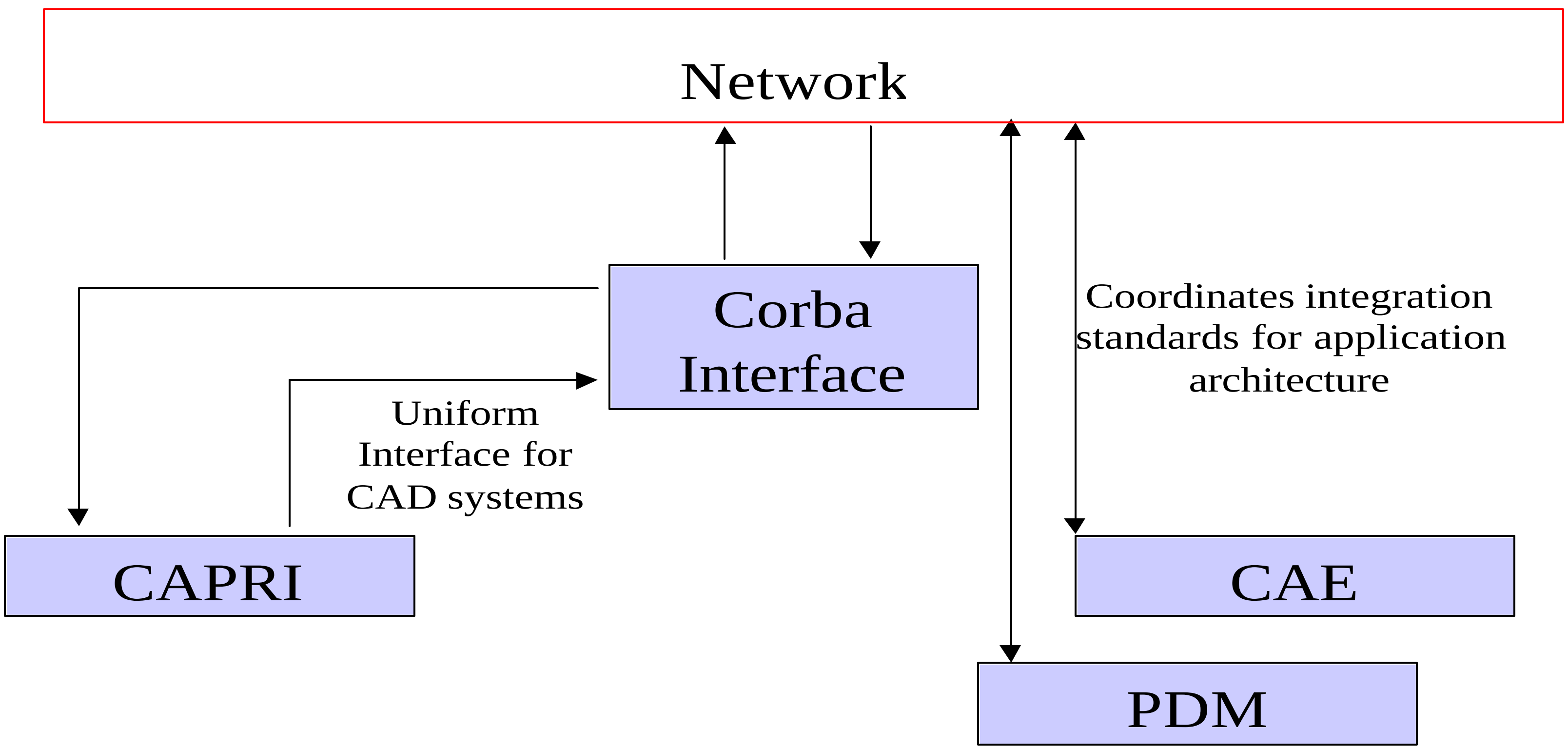
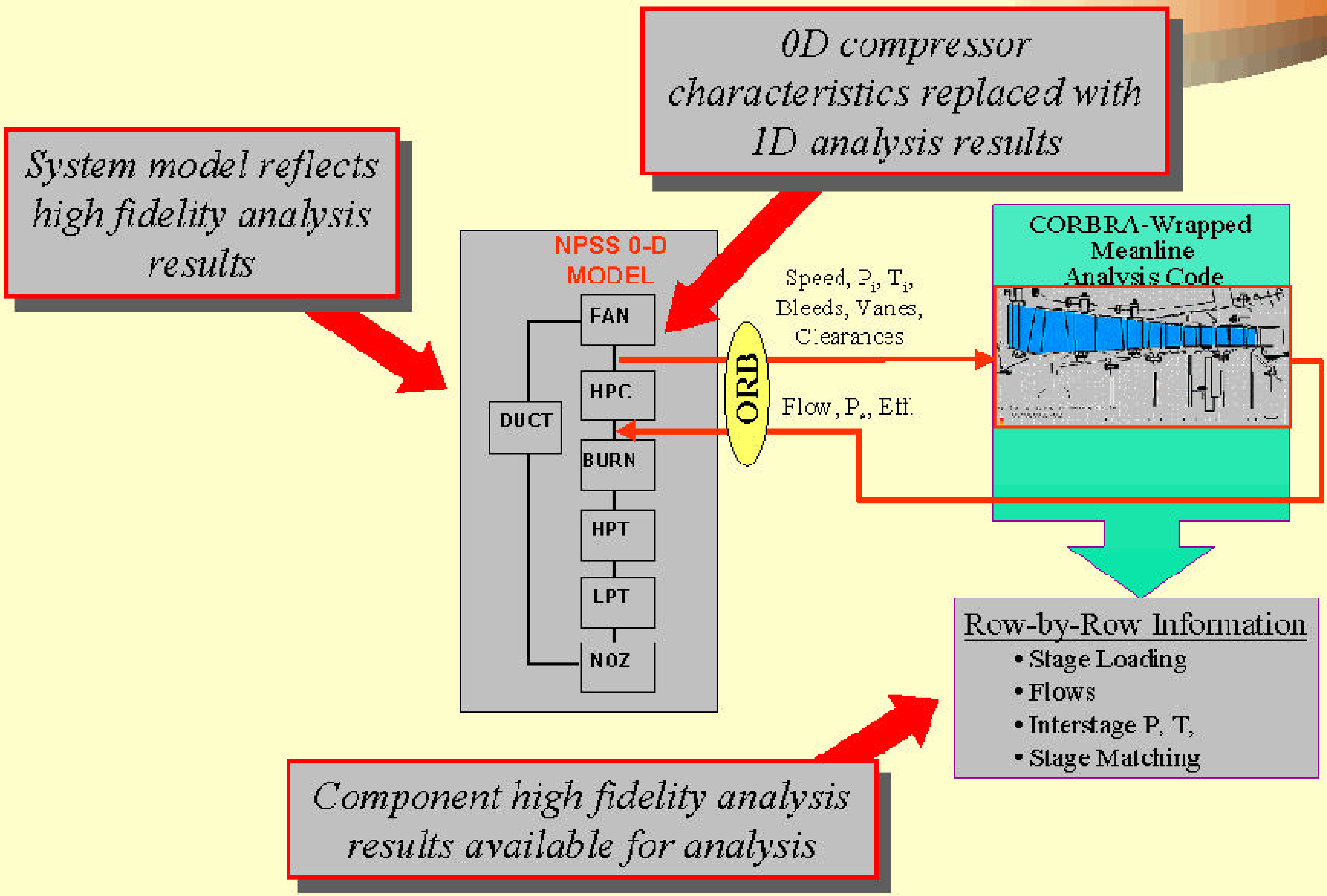
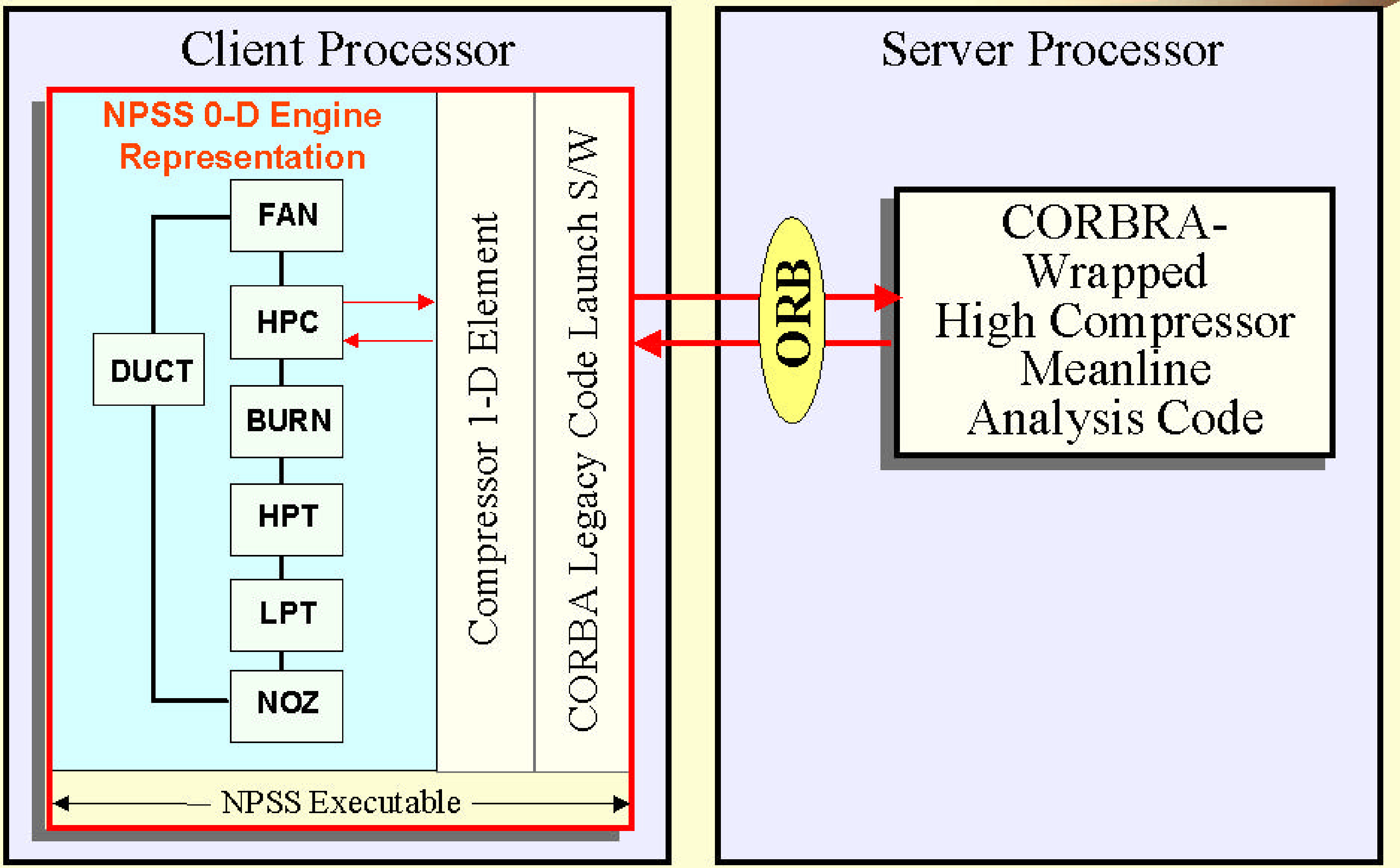


Figure 1. A network diagram illustrating the linking of CAPRI to design software.

NPSS Zooming to 1D High Compressor



NPSS Zooming to 1D High Compressor



CAS 4.3

PCA 4	Develop component technologies for usability	9/04
HPCCP 4.3	Develop tools to improve usability of aerospace simulation capabilities	03/04

- **Implementation Plan**
  - Demonstrate visual based interface assembly of engine simulation
  - Demonstrate CORBA interface for executing applications with security capability
  - Demonstrate adaptive coupling for object-based multidisciplinary application
  - Develop automated gridding with error assessment and grid refinement
  - Assess advanced optimization methods
- **Current Status**
  - NPSS visual based assembly

Visual Assembly
Script Based Syntax

- **NPSS command line based**
  - npss [-v] [-debug] [-I *dirname*] [-corba] [-i] [-log] file1 file2

- **C++ syntax** for element creation, sequence, viewing, CORBA

```
Model BWB {
Element FlightConditions AMB0 {. . .}
Element Inlet Inlet {. . .}

linkPorts ("FlightConditions.Outlet", "INLET.F1_I", "FL0");
```

- **Programming constructs**, declare new variables, comments, If-then-else, do while's, arithmetic functions: *, /, +, -, exponentiation, logicals, >, <, =,....

Visual Assembly

Visual Based Syntax Process Tasks

- Customer Feedback 3/1/99
  - Review NCP Version 1 Usability Feedback
  - Create User Surveys
  - Visit Customer Sites for User Studies
  - Distribute and complete surveys
- Analysis 7/2/99
  - Study the software requirements previously specified for the VBS
  - User Profiles, Current and anticipated task analyses
  - Use Case Scenarios, Usability goals
  - Software and hardware compatibility requirements
- Design In Progress
  - Storyboards, VBS-NPSS API Definition
  - Low-Fi Prototype, Documentation Online

Visual Based Syntax Analysis Tasks

Basic analysis tasks that should be supported by the VBS are:

1. Model Creation/Modification
2. Steady-State Performance Analysis (Design/Off-Design)
3. Data Reduction Analysis
4. Transient Analysis
5. Customer Deck Generation/Maintenance/Execution
6. Control Design Support (State-Variable Model)
7. Phase II, III requirements

All of these basic tasks have some functions in common, which are:

8. Case Management, plotting, interactive debug

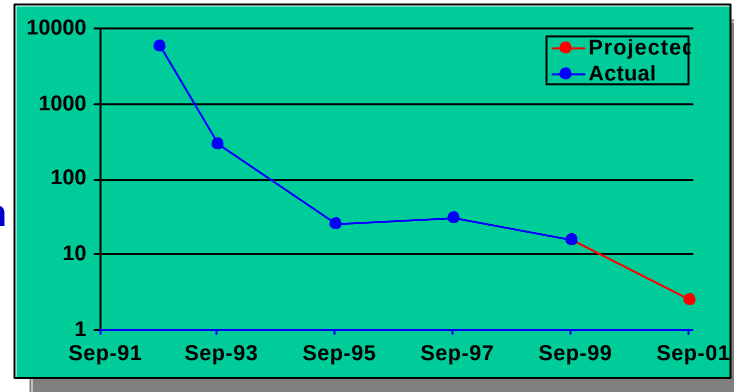
CAS 5.3

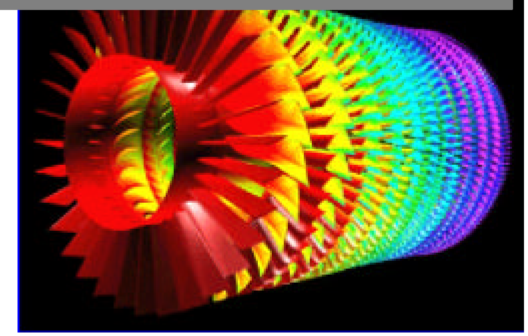
PCA 5	Demonstrate integrated HPCC technologies	9/02
HPCCP 5.3	Demonstrate improvement in time-to-solution for aerospace applications	12/01

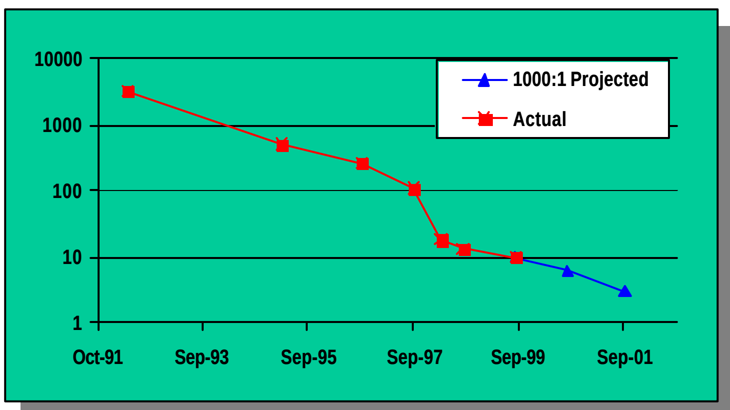
- **Implementation Plan**
  - Apply CAS technologies to Space Transportation (ascent, descent), stability and controls, propulsion
- **Current Status**
  - Continue separate and coupled compressor and combustor simulations
  - Apply optimization framework to Space Transportation
  - Begin support of Space Transportation ascent and descent analyses

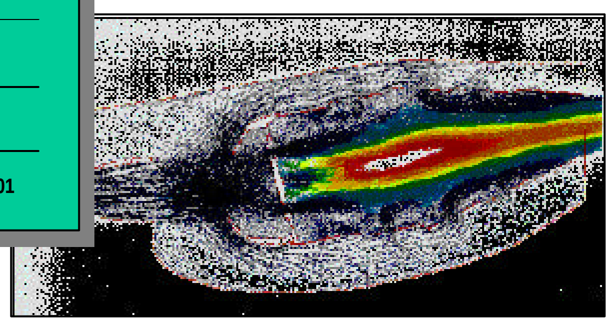
Compressor and Combustor Simulations

- **Compressor and cumbustor simulations on track for 1000X improvements**
  - **Average-Passage Code (APNASA) demonstrates 400:1 reduction in time to solution. Overnight turnaround (15 hours) has been achieved for a full compressor simulation when using APNASA. (9/99)**
  - **Full combustor simulation demonstrates 307:1 reduction relative to 1992 baseline. It was previously reported (2Q99) that the full combustor simulation achieved a 200:1 reduction in time to solution. Additional improvements have since resulted in a 307:1 reduction. (9/99)**









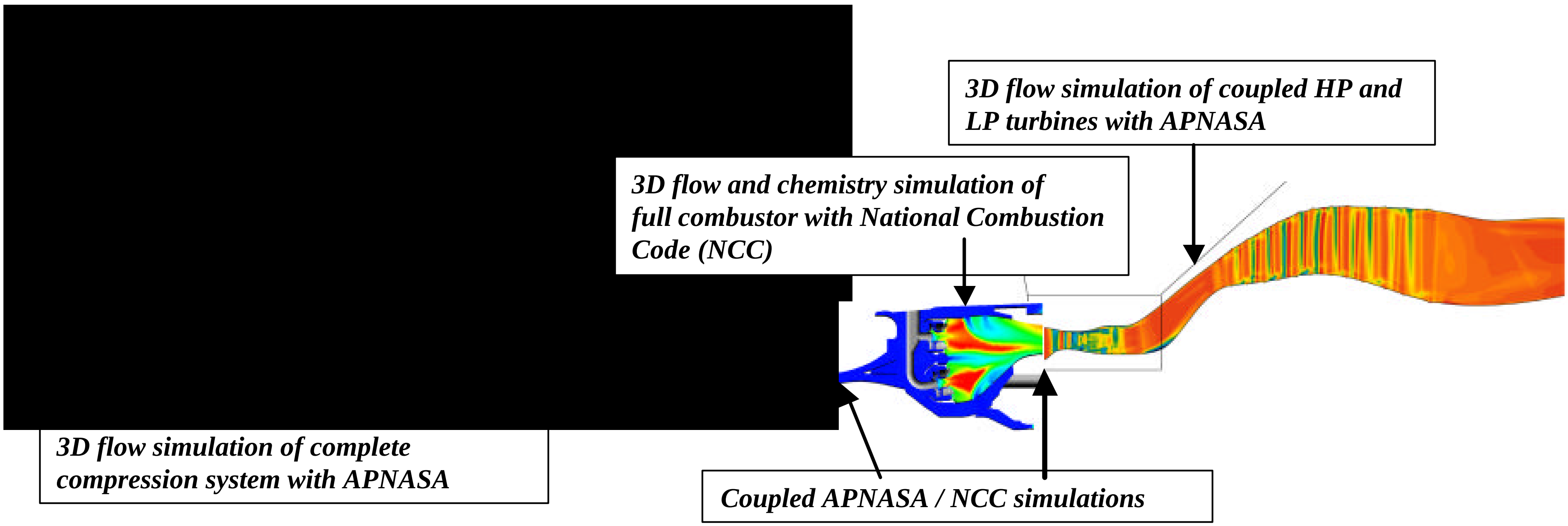
Detailed Flow Simulation of Modern Turbofan Engine

Status:

•Cooled high pressure turbine and low pressure turbine have been modeled as a coupled subsystem

•Full combustor from compressor exit to turbine inlet has been simulated

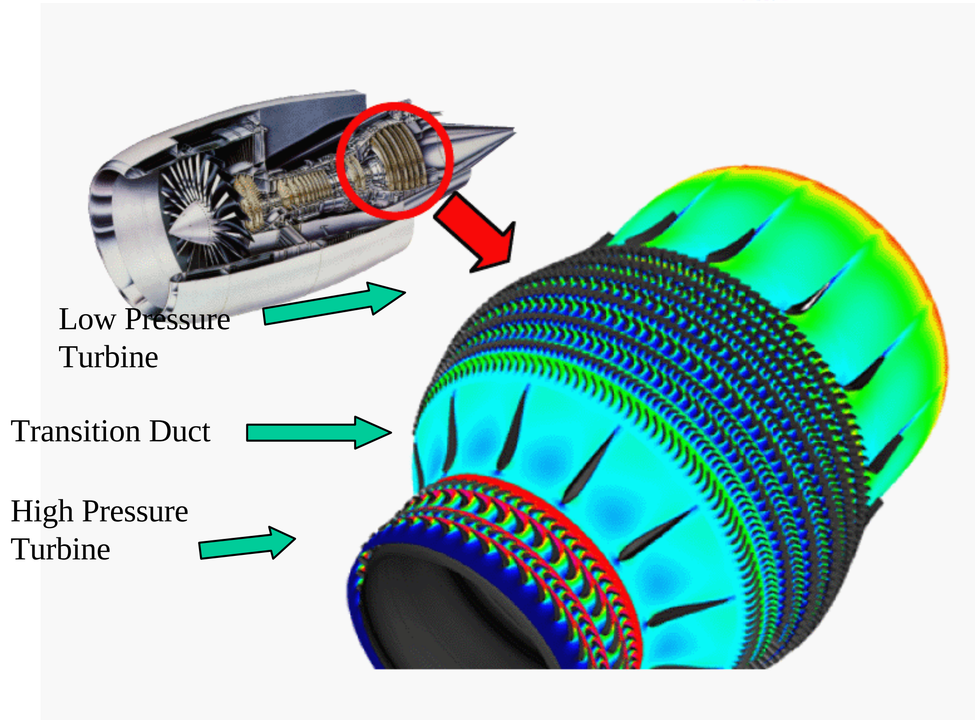
•Individual compression system components have been simulated



Coupled Flow Simulation of High Pressure-Low Pressure Turbines Results in Significant Fuel Savings

Objective:
Create a high-fidelity computer simulation of the flow through a full modern high bypass ratio turbofan engine.

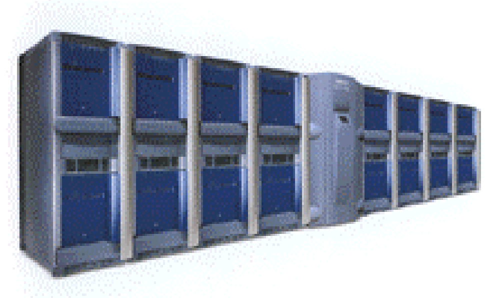
Approach:
Using a modular approach to the full engine simulation goal, a flow simulation of the tightly coupled high pressure and low pressure turbines has been completed. The computer simulation was performed using NASA's 3-D average passage approach (APNASA). The simulation was done using 121 processors of a Silicon Graphics Origin cluster with a parallel efficiency of 87% in 15 hours.



Significance:
The accurate and rapid simulation of a large turbine subsystem enabled designers to reduce turbine interaction losses in dual-spool engines by 50%. This will result in a $3 million/year savings in fuel costs for a typical fleet of commercial aircraft.

Point of Contact: **Joseph P. Veres**
(216)433-2436

HSCT Design and MDO Framework Background



1992 NASA LaRC decisions:

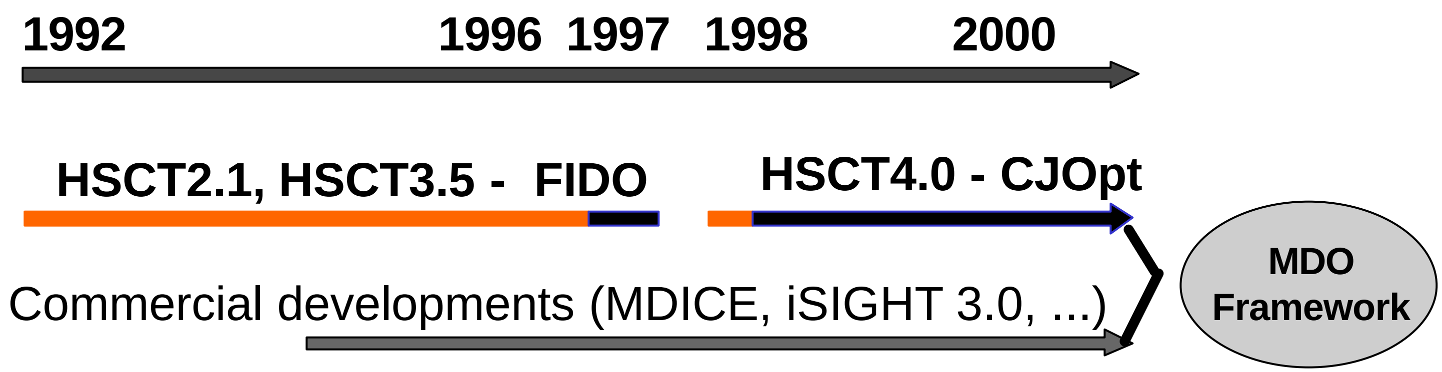
- Began research in Multidisciplinary Design Optimization (MDO) with high-fidelity analysis codes
  - Exploit High Performance Computing and Communication (HPCC) as Grand Challenge application focus
- Selected High Speed Civil Transport (HSCT) as focus application
  - Exploit synergy with the High Speed Research (HSR) program

By 1999:

- Evolved into the HSCT4.0 application
  - Research endeavor in both MDO and HPCC
  - Unique combination of disciplinary breadth and depth in MDO research

POC: Joe Rehder
757-864-4481
j.j.rehder@larc.nasa.gov

Framework History



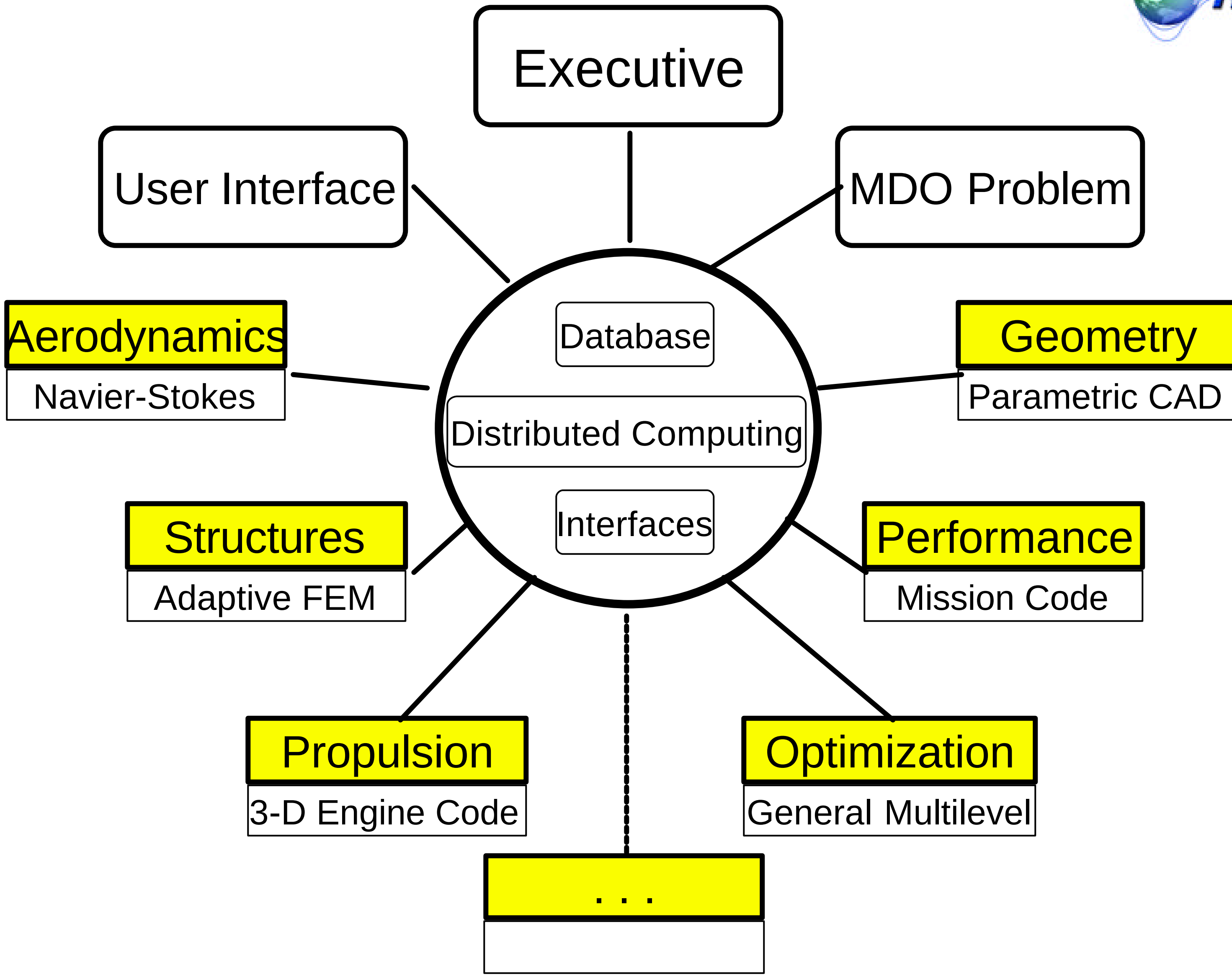
(orange bar) % effort devoted to framework related issues

(dark bar) % effort available for application

FIDO : **F**ramework for **I**nterdisciplinary **D**esign **O**ptimization

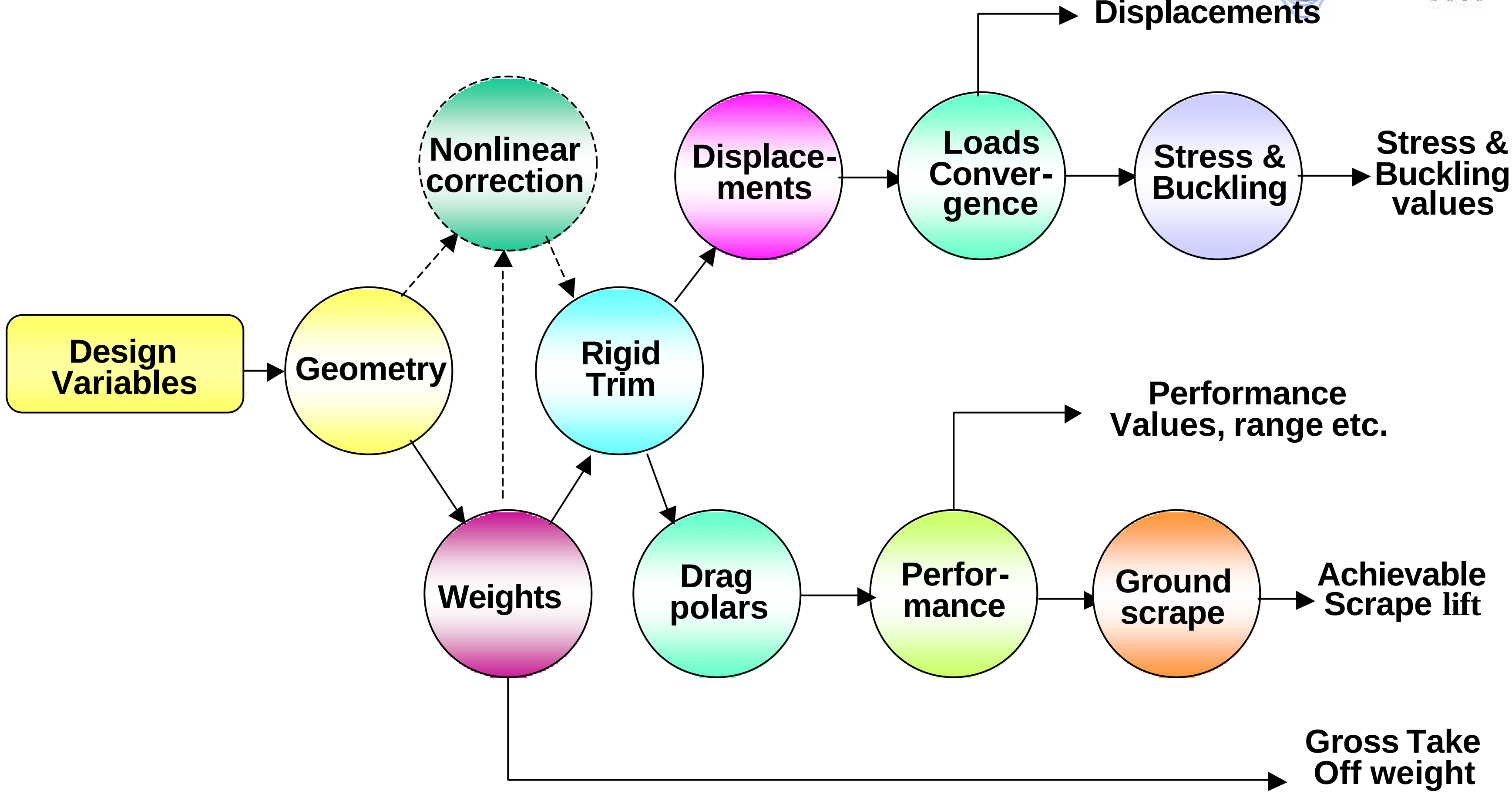
CJOpt: **C**ORBA - **J**ava **Opt**imization

HPCCP HSCT Application Goal

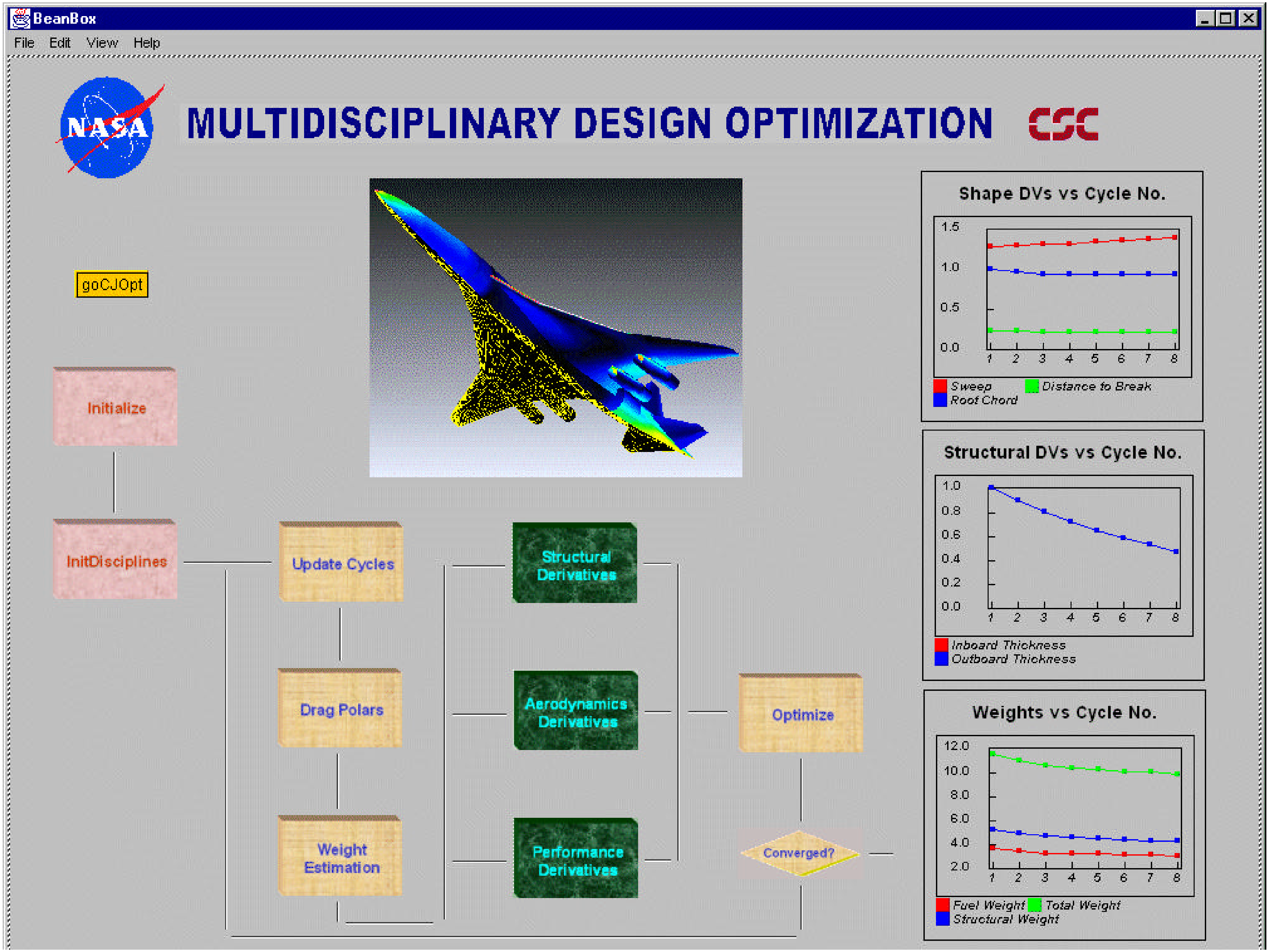


Analysis

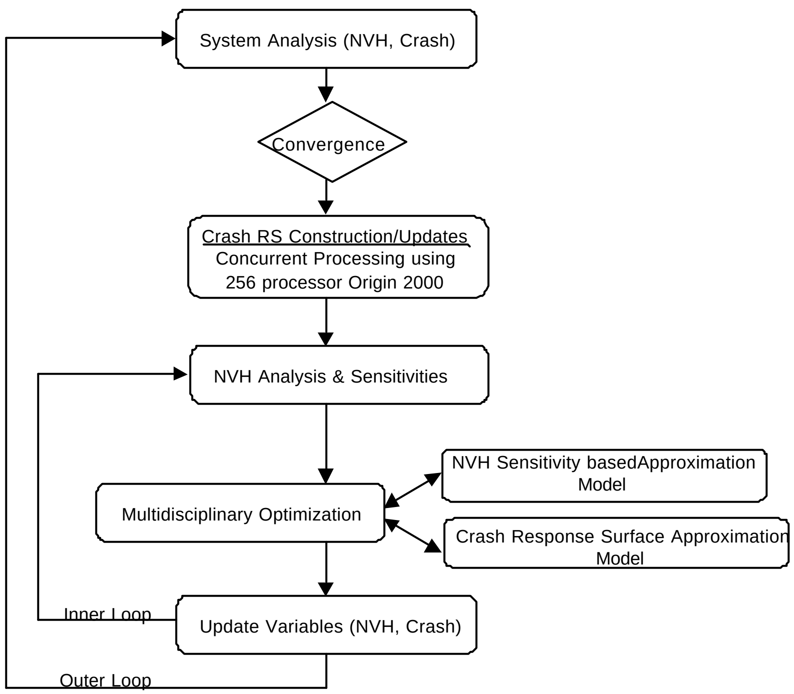
HSCT4.0 Analysis

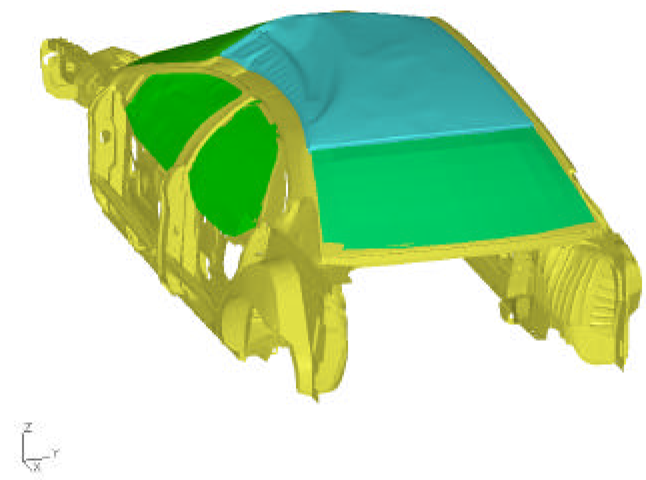


Integrated with CJOpt environment


BeanBox
File Edit View Help
NASA
MULTIDISCIPLINARY DESIGN OPTIMIZATION
CSC
goCJOpt
Initialize
InitDisciplines
Update Cycles
Drag Polars
Weight Estimation
Structural Derivatives
Aerodynamics Derivatives
Performance Derivatives
Optimize
Converged?
Shape DVs vs Cycle No.
Sweep
Distance to Break
Root Chord
Structural DVs vs Cycle No.
Inboard Thickness
Outboard Thickness
Weights vs Cycle No.
Fuel Weight
Total Weight
Structural Weight

CAS Technologies Enable Multi-disciplinary Design Optimization (MDO) Demo





Removed initial design violations while reducing weight by 15 kg.

Used 256-processor Origin 2000 at ARC to reduce otherwise intractable MDO problem from 257 days of non-stop execution (if done on a single processor) to 1day through code parallelization and concurrent analyses.

Used iSIGHT framework to enable interoperability of two high-fidelity analysis codes: MSC NASTRAN for static response NVH response and RADIOSS for crash response.

Demonstrated application of advanced MDO methods including sensitivity based approximations, response surfaces, and numerical search strategies to real vehicle design problem: MDO of vehicle under constraints of two disciplines (vibration, noise, and harshness (NVH) and crash) with 40 design parameters and over 390K dof.

Prepared technologies for future application to aerospace vehicles.

<ins>*POCs:*</ins> **Kodiyalam**, *Engineous;* **Yang**,*FORD Research;* **Sobieski**, *NASA LaRC*

CAS 6.3

PCA 6	Demonstrate significant engineering, scientific, and educational impacts from integrated HPCC technologies	9/05
HPCCP 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	9/05

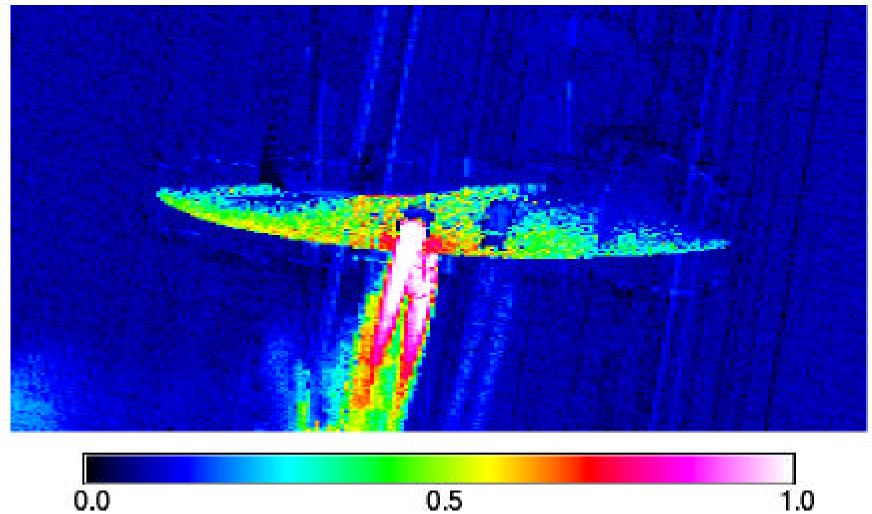
- **Implementation Plan**
  - **Apply CAS technologies to National Air Space (TBD), Space Transportation (ascent, descent, propulsion; analysis, design, optimization), powered lift, UEET (propulsion), Aviation Safety (propulsion/engine models)**
  - **Evaluation of new analysis methods (e.g., CIR)**
- **Current Status**
  - **Baseline for CIR computation determined**

Computational Infrared Radiation Computation

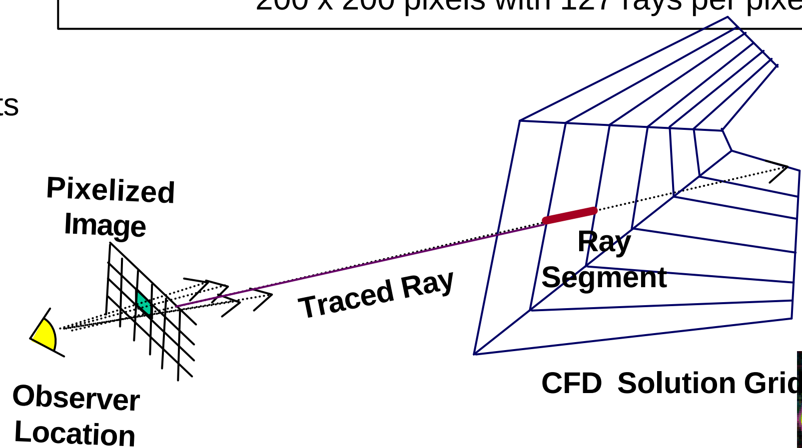
Generated Baseline CIR (Computational Infrared Radiation) Computation for the Harrier Aircraft in Ground Effect

- **Objectives:**
  - Allow alternative method for validating complex aerodynamic predictions
  - Greatly reduce the complexity and cost of verifying aerothermodynamic models
  - Provide better understanding of innovative vehicles
- **Approach:**
  - Incorporate new accelerative algorithms and parallel processing into CIR code
- **Accomplishment:**
  - The Monte Carlo Ray Trace program (CIRCE) was ported to SGI Origin 2000 (02K) computers
  - Applied to the baseline test case:

    A Harrier aircraft, flying in ground effect. The Harrier grid has 18 blocks and 2,833,700 points in half space
- **Significance:**
  - Initial work indicates feasibility



CIR calculation showing radiative energy from a Harrier jet operating in ground effect. The normalized scale runs from minimum to maximum radiant energy. The case is a run with 200 x 200 pixels with 127 rays per pixel.



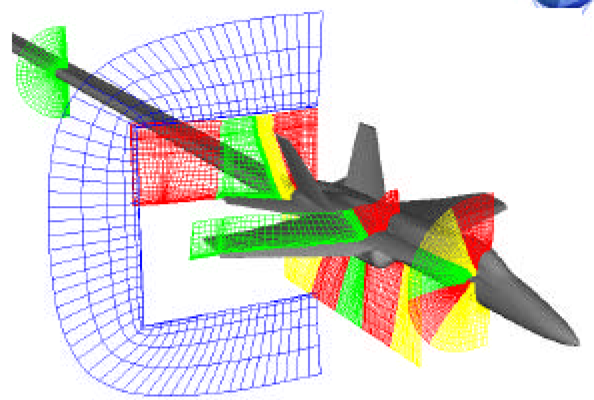
CAS 7.4

PCA 7	Establish sustainable and wide-spread customer use of HPCC Program technologies	9/06
HPCCP 7.4	Establish sustained use of CAS tools and techniques towards meeting Aerospace Technology Enterprise goals and objectives	9/06

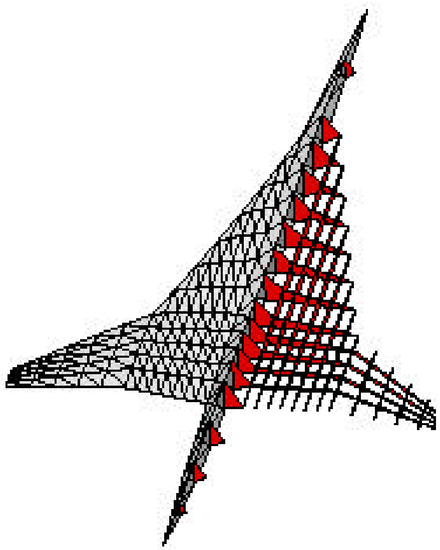
- **Implementation Plan**
  - Determine infusion of CAS technology
  - Support graduate and post-doctoral high-performance research
- **Current Status**
  - Began CAS Technology inventory/survey task 4/00
  - CAS Workshops Aug. 1998, Feb. 2000
  - NPSS Industry Reviews and Training
  - Support in place for 18 graduate students
  - Awards and recognition

Fourth HPCC/CAS Workshop August 25-27, 1998

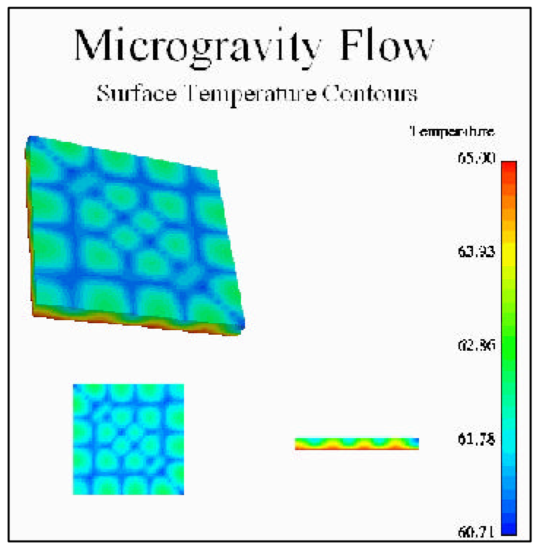
- Approximately 45 technical papers, approx. 12 from ESS
- Over 100 attendees from government, industry and academia
- Panel discussions sessions: “The Future of High Performance Computing and its Role in Aircraft Development” and “Keys to Building Frameworks/environments for Design and Engineering”
- Presentation by James Bailey, “Isaac Inside: The Cultural Filters on Truly New Computing.”



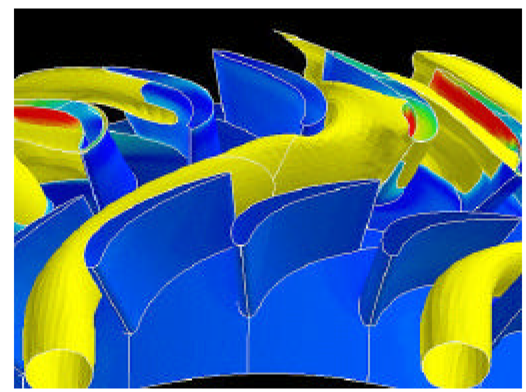
“Performance and Applications of ENSAERO-MPI on Scalable Computers,” Farhangnia et al.



“High-Fidelity Aeroelastic Analysis and Aerodynamic Optimization of a Supersonic Transport,” Giunta



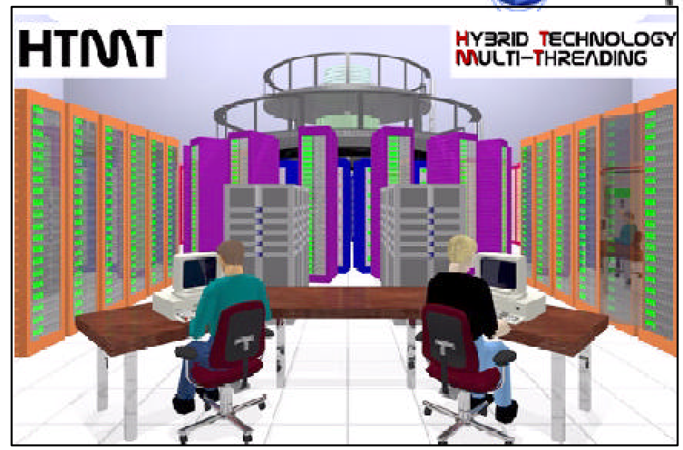
“Parallel Finite Element Computation of 3D Coupled Viscous Flow and Transport Processes,” Carey



“Parallel Visualization Co-Processing of Overnight CFD Propulsion Applications,” Edwards

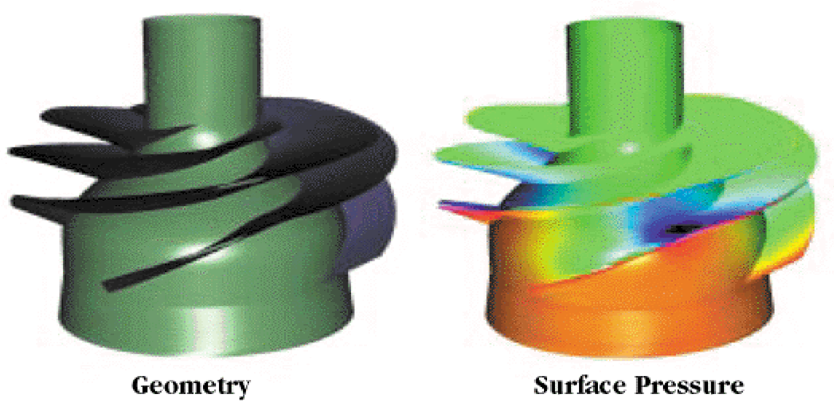
Fifth HPCC/CAS Workshop, Feb. 15-17, 2000

- 47 technical presentations over 2 1/2 days
- 170 attendees (government, industry, academia)
- Panel discussion on how researchers will tackle aeroscience challenges in the 21st Century with new and "neoclassical" approaches to scalable algorithms, applications, and computing machinery
- Welcome Reception at Computer Museum History Center at ARC
- Guy Kawasaki's special presentation on "Rules for Revolutionaries"
- Proceedings available on CD from awaller@mail.arc.nasa.gov



"HTMT-class Latency Tolerant Parallel Architecture for Petaflops Scale Computation"
Thomas Sterling and Larry Bergman (JPL)

REUSABLE LAUNCH VEHICLE (RLV) RURBOPUMP INDUCER
Rotational Speed: 7850 RPM
Mass Flow: 9093 GPM
Re: 7.99e+7

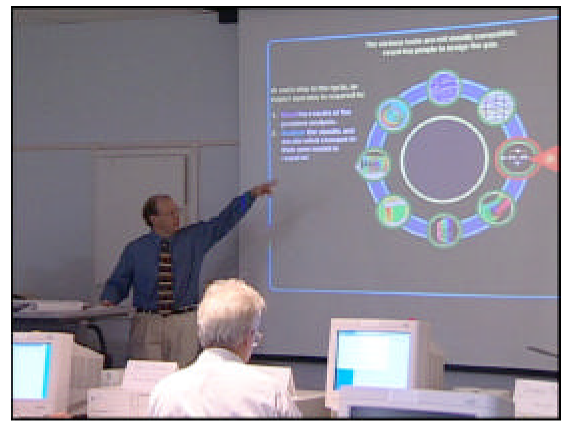


"Towards Flange-To-Flange Turbopump Simulations for Liquid Rocket Engines"
Cetin Kiris and Robert Williams
(ARC/MSFC)

Panel Discussion: Preparing for the Twenty-first Century:
Scalable Algorithms and Applications f
Aerospace Science and Engineering

NPSS Industry Review and Training

- **NPSS Industry Review and Training Held October 1998**
  - **Held NPSS Annual Industry Review October 21-22, 1998.**
  - **20 team members from industry attended.**
  - **The meeting addressed many topics: lessons learned on Version 1, NCP Version 2 requirements, usability, zooming, user documentation, and NCP deployment.**
- **NPSS Industry Review and Training Held October 1999**
  - **Held NPSS Annual Industry Review October 6-7, 1999.**
  - **Over forty people attended representing thirteen different organizations from government, academia, and industry.**
  - **Industry interest in and support for NPSS remains high, and suggestions for future work emphasized the need to quickly extend the architecture to include high fidelity multi-disciplinary analysis tools.**
  - **In conjunction with the review, the NPSS team provided two two-day training sessions on using NPSS**
    - modeling air breathing jet engines
    - modeling rocket engines
- **Approximately 100 people have received NPSS training**



BRHR Support FY98, FY99, FY00

Title	PI	No. of Grad Students	No. of Post Doc and Faculty	Papers and Reports
Prophesy: A hierarchical tool for modeling and analyzing parallel, scientific applications	Taylor, Valerie Northwestern Univ.	1	1 (faculty)	2 (Conf. Paper)
Compiler Technology for Effective Parallelization of NASA Codes	Mellor-Crummey Rice Univ.	2	4 (3 PD, 1 faculty)	
Integrating Legacy Applications Within a Middleware Environment	Fatoohi, Rod San Jose State Univ.	2	1 (faculty)	
Desgin space exploration for MDO on a teraflop computer	Grossman, B. VPI	1	1 (faculty)	4 (Conf. Paper)
Design space exploration for MDO on a teraflop computer	Haftka, Raphael Univ. of Florida	1	1 (faculty)	2 (Conf. Paper)
Data compression for storage and transmission	Lee, D. NRC at Ames		1 (full time PD)	3 (Conf. Paper)
Efficient parallel algorithm for Inviscid and viscous flow simulation	Hafex/Chattot UC Davis	2	3 (1 PD, 2 faculty)	
Parallel hybrid-grid method for IDS application	Delanaye, Michel NRC at Ames		1 (full time PD)	2 (Conf. Paper)
Development of an Innovative Algorithm for Aero-Structure Interaction Using LB Method	Mei, Renwei U. of Florida			
Evolution in Denentralized Emergent Computation Algorithm to Structural Analysis and Design	Hajela, Prabhat Rensselaer Poly. Inst.			
Novel Scalable algorithms for Aerospace Design Optimization on MP Computers	Chattas, Omar Carnegie Mellon Univ.			
Achieving Application Performance on the Information Power Grid	Su, Alan UC San Diego	1		

Computational Aerospace Sciences (CAS) Project

TECHNICAL STATUS: ARC BASIC RESEARCH AND HUMAN RESOURCES

BR3.AM1 : Support Graduate and Post-Doctoral HPC Research
Data management technology using supercompact multiwavelets

Objective:
To development data management tools which are essential for the analysis, representation and manipulation of digital data, signals from experiments, images and data for virtual flight simulation.

Approach:
Develop appropriate wavelets suitable for field simulation data and implement computational multiresolution tools (using the newly-developed supercompact multi-wavelets) for 3-D numerical simulation data.

Accomplishments:
A prototype 3-D truncation compression code has been developed and demonstrated using CFD data.

Significance:
The current algorithm with 3Dprovides efficient CFD data compression. Truncation even with high accuracy (e.g. 1x10-6 error) may allow significant compression ratio (around 50:1), thus reducing storage and transmission requirements.

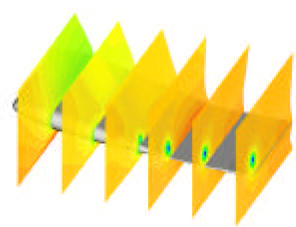
Status/Plans:
The method is being tested for data compression on various forms of data sets (simulation and experiments).

Point of Contact:
Dohyung Lee, Ames, dohyung@nas.nasa.gov

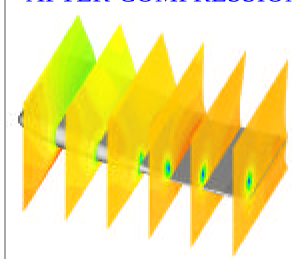
Wing Tip Vortex Validation

NACA0012, Wing Aspect Ratio=0.75,
Re=4.6x106, α=10°, 2.5M Grid (115x189x115)

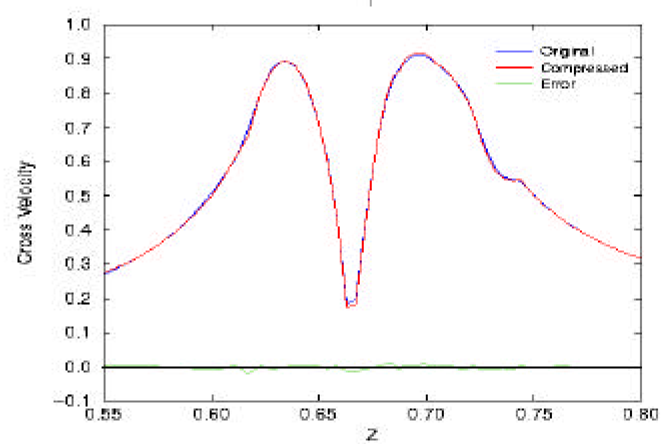
BEFORE COMPRESSION



RECONSTRUCTED
AFTER COMPRESSION



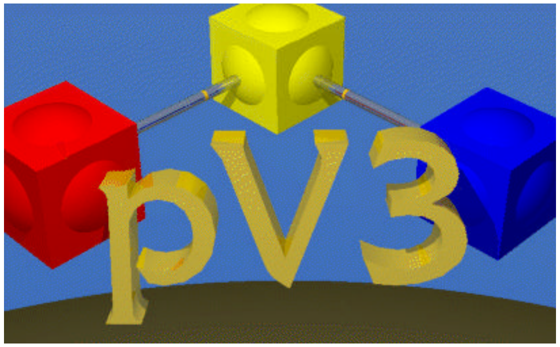
x / c = 1.5



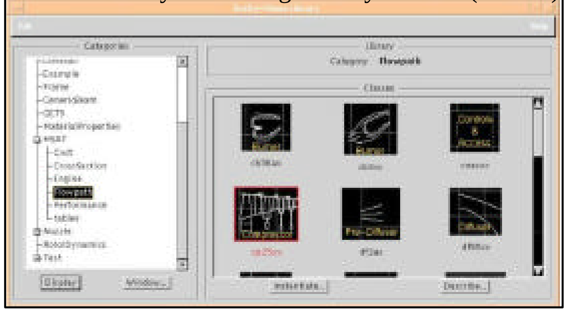
Comparison of velocity before and after compression

Space Act Awards for GRC Software

- **Two Space Act Board Awards were made in the second quarter of FY 99 for software developed under CAS.**
  - **The first award was for the pV3 parallel visualization product. The software enables the user to interactively view results from complex simulations executing over parallel, distributed processors. Mr. Greg Follen and Dr. Robert Haimes coproduced the software. The tool is used at NASA, in the aircraft engine industry and in academia for visualizing 3-D turbomachinery flows. Negotiations with potential vendors are underway for commercialization of the software.**
  - **The second award was for the Mechanical System Analysis Tool (MSAT). MSAT is an object-oriented framework for linking preliminary design tools and doing early structural analysis and weight estimations. The tool was used by the NASA/HSR Team to perform trade studies on the mixer/ejector nozzle. Dr. Charles Lawrence, Dr. Mark Kolb, HuaHua Lee and Jack Madelone coproduced the software.**



Mechanical System Design/Analysis Tool (MSAT)



CAS Budget Plans

CAS Budget	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Totals
Ames Research Center	**9,918**	**11,707**	**12,657**	**13,190**	**14,700**	**12,700**	**6,600**	**81,472**
Applications	2,455	2,669	2,527	2,500	2,499	2,588	1,346	16,583
Computing Testbeds	2,699	3,737	3,411	3,917	5,607	3,408	1,773	24,551
Systems Software	3,125	3,565	4,887	4,835	4,706	4,874	2,535	28,527
BRHR	568	734	821	813	792	820	427	4,976
Project Management	1,071	1,001	1,011	1,125	1,097	1,010	520	6,835
Langley Research Cntr.	**4,180**	**4,275**	**4,258**	**4,812**	**4,200**	**4,200**	**2,200**	**28,125**
Applications	2,318	2,349	2,517	2,821	2,533	2,533	1,325	16,397
Computing Testbeds	300	297	300	294	241	241	132	1,806
Systems Software	721	773	719	823	724	724	378	4,861
BRHR	480	535	480	529	482	482	251	3,240
Project Management	360	320	242	346	220	220	114	1,821
Glenn Research Center	**5,668**	**5,268**	**5,485**	**6,198**	**5,400**	**5,400**	**2,700**	**36,119**
Applications	1,677	1,355	1,657	2,266	1,660	1,753	876	11,243
Computing Testbeds	222	224	222	222	223	226	113	1,451
Systems Software	3,037	2,839	2,854	2,979	2,764	2,729	1,365	18,566
BRHR	140	141	140	140	140	142	71	914
Project Management	592	709	612	591	613	550	275	3,944
CAS Totals	**19,766**	**21,250**	**22,400**	**24,200**	**24,300**	**22,300**	**11,500**	**145,716**

CAS Staffing Plans

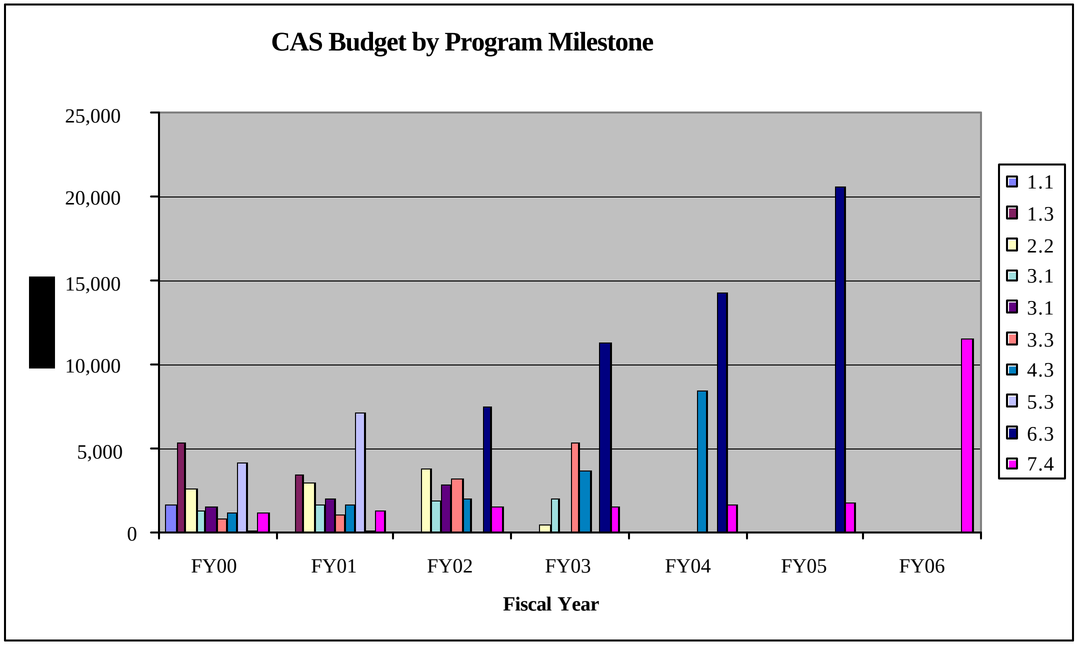
Civil Servant Workforce	FY00	FY01	FY02	FY03	FY04	FY05	FY06	Totals
Ames Research Center	**24.0**	**25.0**	**25.0**	**25.0**	**25.0**	**25.0**	**12.5**	**161.5**
Applications	15.5	16.5	16.5	16.5	16.5	16.5	8.3	106.3
Computing Testbeds	2.0	2.0	2.0	2.0	2.0	2.0	1.0	13.0
Systems Software	4.0	4.0	4.0	4.0	4.0	4.0	2.0	26.0
BRHR	1.0	1.0	1.0	1.0	1.0	1.0	0.5	6.5
Project Management	1.5	1.5	1.5	1.5	1.5	1.5	0.8	9.8
Langley Research Cntr.	**17.0**	**13.0**	**14.0**	**16.0**	**16.0**	**16.0**	**8.0**	**100.0**
Applications	11.0	8.5	8.5	10.5	10.5	10.5	5.3	64.8
Computing Testbeds	0.5	0.5	0.5	0.5	0.5	0.5	0.3	3.3
Systems Software	2.0	1.0	2.0	2.0	2.0	2.0	1.0	12.0
BRHR	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5
Project Management	3.0	3.0	3.0	3.0	3.0	3.0	1.5	19.5
Glenn Research Center	**51.0**	**54.0**	**54.0**	**54.0**	**54.0**	**54.0**	**27.0**	**348.0**
Applications	16.5	16.5	16.5	16.5	16.5	16.5	8.3	107.3
Computing Testbeds	3.5	3.5	3.5	3.5	3.5	3.5	1.8	22.8
Systems Software	28.0	31.0	31.0	31.0	31.0	31.0	15.5	198.5
BRHR	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Project Management	3.0	3.0	3.0	3.0	3.0	3.0	1.5	19.5
CAS Totals	**92.0**	**92.0**	**93.0**	**95.0**	**95.0**	**95.0**	**47.5**	**609.5**

Mapping between milestones and WBS elements

	PCA1	PCA2	PCA3	PCA4	PCA5	PCA6	PCA7
ATA	C1.3.6 C1.3.7 C1.3.8 C1.3.9 C1.3.10 C1.3.12 C1.3.13 C1.3.14		C3.3.3	C4.3.4	C5.3.1-C5.3.7	C6.3.2-C6.3.9 C6.3.11	
CT	C1.1.1 C1.1.2 C1.2.3	C2.2.1 C2.2.2 C2.2.3 C2.3.2	C3.1.5				
SSW	C1.3.1 C1.3.2 C1.3.3 C1.3.4 C1.3.5 C1.3.10	C2.2.4 C2.2.5 C2.2.6 C2.2.7 C2.3.1	C3.1.1-C3.1.5 C3.3.1-C3.3.2 C3.3.4-C3.3.6	C4.3.1 C4.3.2 C4.3.3		C6.3.10	
BRHR	C1.3.1 C1.3.11 C1.3.12 C1.3.13		C3.1.3	C4.3.5			C7.4.3
Proj. Mgt.						C6.3.1	C7.4.1 C7.4.2

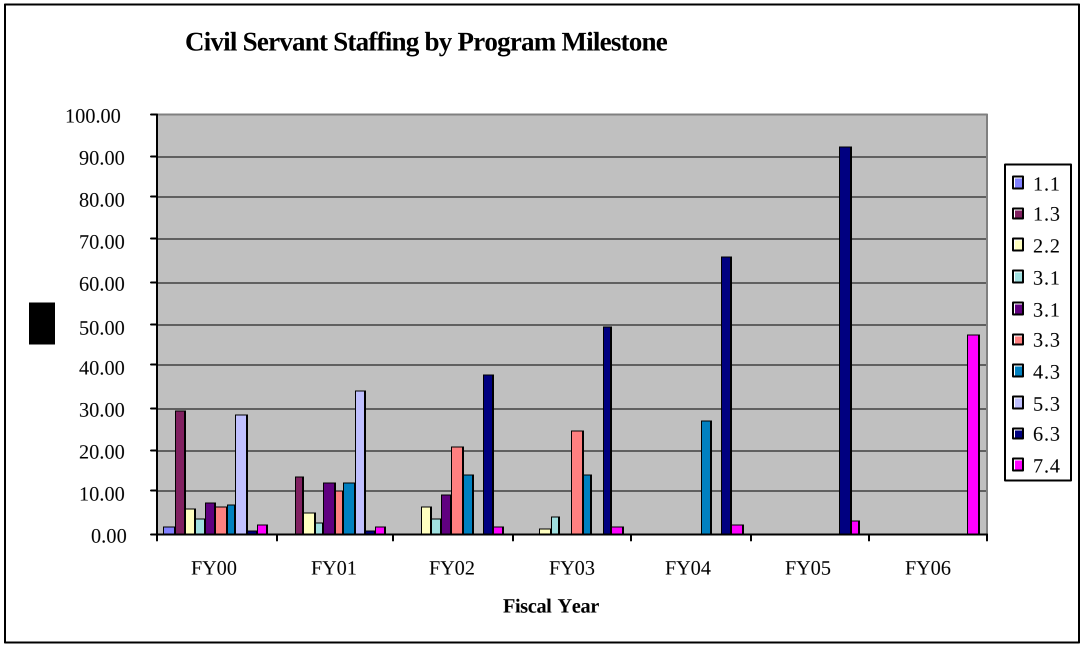
Milestones in red appear in more than one WBS element.

CAS Budget Plans by Program Milestone



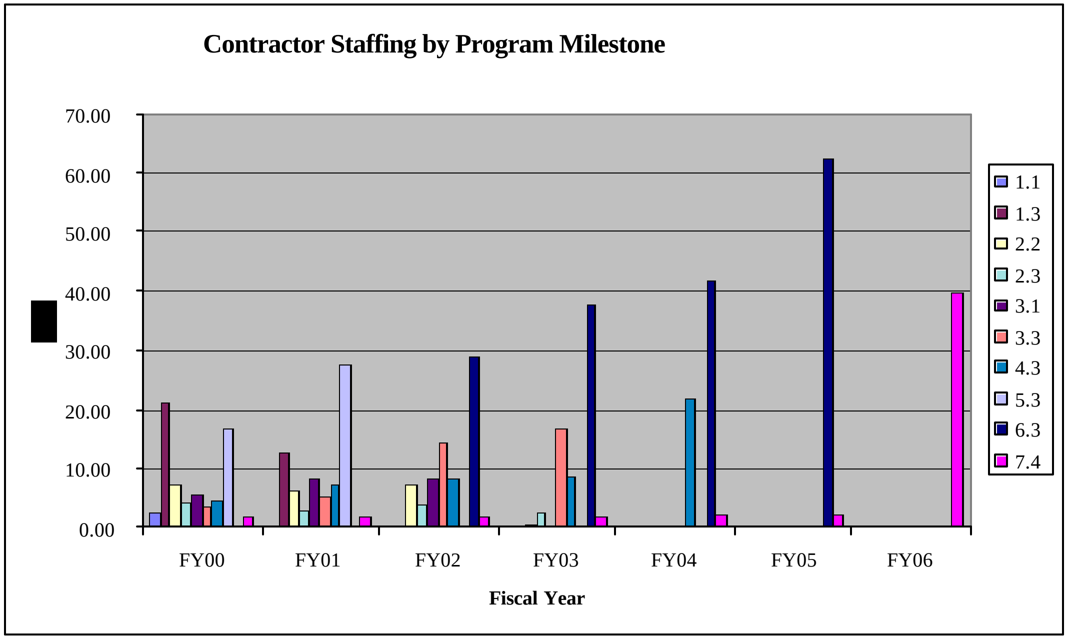
CAS Budget								
Project Element	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**Totals**
H1.1	1,611	0	0	0	0	0	0	1,611
H1.3	5,285	3,425	0	0	0	0	0	8,710
H2.2	2,537	2,922	3,728	412	0	0	0	9,599
H 2.3	1,398	1,650	1,889	1,997	0	0	0	6,933
H3.1	1,494	2,051	2,749	0	0	0	0	6,293
H3.3	810	1,055	3,207	5,286	0	0	0	10,357
H4.3	1,182	1,624	1,961	3,611	8,416	0	0	16,793
H5.3	4,136	7,021	0	0	0	0	0	11,156
H6.3	101	102	7,457	11,429	14,296	20,538	0	53,921
H7.4	1,213	1,402	1,411	1,465	1,589	1,762	11,500	20,342
TOTAL	**19,766**	**21,250**	**22,400**	**24,200**	**24,300**	**22,300**	**11,500**	**145,716**

CAS Civil Servant Staffing Plans by Program Milestone



CAS Civil Servant Staffing								
Project Element	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**Totals**
H1.1	1.8	0.0	0.0	0.0	0.0	0.0	0.0	1.8
H1.3	29.5	13.5	0.0	0.0	0.0	0.0	0.0	42.9
H2.2	5.8	4.8	6.5	1.3	0.0	0.0	0.0	18.4
H 2.3	3.9	2.9	3.8	4.1	0.0	0.0	0.0	14.6
H3.1	7.2	12.5	8.9	0.0	0.0	0.0	0.0	28.6
H3.3	6.4	10.1	20.8	24.8	0.0	0.0	0.0	62.1
H4.3	6.8	12.1	13.7	13.9	26.8	0.0	0.0	73.2
H5.3	28.2	34.3	0.0	0.0	0.0	0.0	0.0	62.5
H6.3	0.4	0.4	37.8	49.4	65.9	91.9	0.0	245.7
H7.4	2.0	1.6	1.6	1.6	2.4	3.1	47.5	59.8
TOTAL	**92.0**	**92.0**	**93.0**	**95.0**	**95.0**	**95.0**	**47.5**	**609.5**

CAS Contractor Staffing Plans by Program Milestone



CAS Contractor Staffing								
Project Element	**FY00**	**FY01**	**FY02**	**FY03**	**FY04**	**FY05**	**FY06**	**Totals**
H1.1	2.6	0.0	0.0	0.0	0.0	0.0	0.0	2.6
H1.3	20.9	12.6	0.0	0.0	0.0	0.0	0.0	33.5
H2.2	7.2	6.3	7.1	0.2	0.0	0.0	0.0	20.8
H 2.3	4.0	3.1	3.7	2.6	0.0	0.0	0.0	13.4
H3.1	5.6	8.3	8.1	0.0	0.0	0.0	0.0	21.9
H3.3	3.5	5.2	14.2	16.7	0.0	0.0	0.0	39.6
H4.3	4.6	7.2	8.2	8.7	21.6	0.0	0.0	50.3
H5.3	17.0	27.9	0.0	0.0	0.0	0.0	0.0	44.8
H6.3	0.1	0.1	28.9	37.9	41.8	62.7	0.0	171.5
H7.4	1.9	1.9	1.9	1.9	2.1	2.3	39.5	51.5
TOTAL	**67.3**	**72.5**	**72.0**	**68.0**	**65.5**	**65.0**	**39.5**	**449.8**