NASA/CP—2001-210673

2000 Numerical Propulsion System Simulation Review

June 2001

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2000 Numerical Propulsion System Simulation Review

Proceedings of a conference held at and sponsored by
NASA Glenn Research Center
Cleveland, Ohio
October 4–5, 2000

National Aeronautics and
Space Administration

Glenn Research Center

June 2001

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2000 NUMERICAL PROPULSION SYSTEM SIMULATION REVIEW

John Lytle, Greg Follen, Cynthia Naiman, Joseph Veres, Karl Owen, and Isaac Lopez
National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

SUMMARY

The technologies necessary to enable detailed numerical simulations of complete propulsion systems are being developed at the NASA Glenn Research Center in cooperation with industry, academia, and other government agencies. Large scale, detailed simulations will be of great value to the nation because they eliminate some of the costly testing required to develop and certify advanced propulsion systems. In addition, time and cost savings will be achieved by enabling design details to be evaluated early in the development process before a commitment is made to a specific design. This concept is called the Numerical Propulsion System Simulation (NPSS). NPSS consists of three main elements: (1) engineering models that enable multidisciplinary analysis of large subsystems and systems at various levels of detail, (2) a simulation environment that maximizes designer productivity, and (3) a cost-effective, high-performance computing platform. A fundamental requirement of the concept is that the simulations must be capable of overnight execution on easily accessible computing platforms. This will greatly facilitate the use of large-scale simulations in a design environment. This paper describes the current status of the NPSS with specific emphasis on the progress made over the past year on air-breathing propulsion applications. Major accomplishments include the first formal release of the NPSS object-oriented architecture (NPSS Version 1) and the demonstration of a one-order-of-magnitude reduction in computing cost-to-performance ratio using a cluster of personal computers. The paper also describes the future NPSS milestones, which include the simulation of space transportation propulsion systems in response to increased emphasis on safe, low-cost access to space within NASA's Aerospace Technology Enterprise. In addition, the paper contains a summary of the feedback received from industry partners on the fiscal year 1999 effort and the actions taken over the past year to respond to that feedback. NPSS was supported in fiscal year 2000 by the High Performance Computing and Communications Program.

2000 NPSS Review & Planning Meeting

NASA Glenn Research Center
October 4-5, 2000

Overview Presentation

John Lytle

2000 NPSS Review

Outline

- **Background**
- **1999 Industry Feedback**
- **FY00 Status**
  - **Resource distribution**
  - **Major accomplishments**
- **FY01 Major Milestones**
- **Future Direction**

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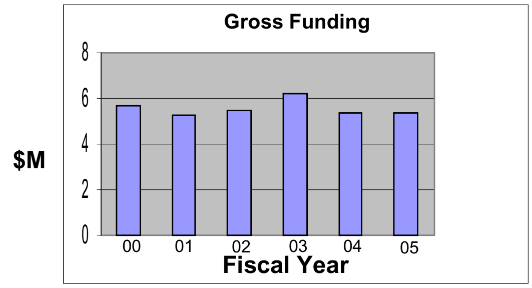
High Performance Computing and Communications (HPCCP)

- The main goal of the HPCCP is to accelerate the development of high-performance computers and networks and the use of these resources in the Federal Government and throughout the American economy.
- The GRC primary role in the HPCCP is through the Computational Aerospace Sciences (CAS) Project. The goal of CAS is to accelerate the availability of high-performance computing hardware and software to the United States aerospace industry for use in their design processes through the solution of *Grand Challenge* problems.
- The goal of the NREN Project is to research, develop and deploy advanced network technologies required by high-performance mission applications that satisfy the needs of the researcher while guiding commercial infrastructure development for the nation.
- The goal of the LTP is to enhance the learning of math, science and engineering in the K-12 educational system through the use of computing and communications technologies and dissemination of information about the NASA missions.

CAS
Computational Aerospace Sciences

NREN
NASA Research and Education Network

LTP
Learning Technologies Project



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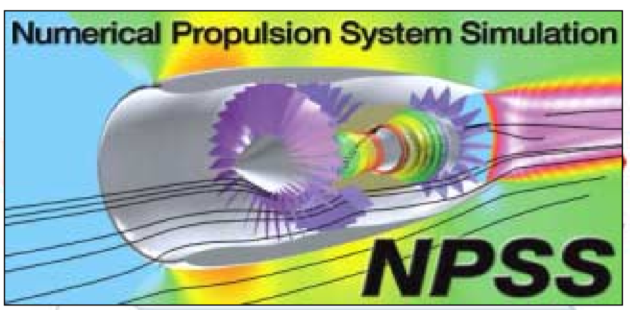
Validated Models

- Fluids
- Heat transfer
- Combustion
- Structures
- Materials
- Controls
- Manufacturing
- Economics



Integrated Interdisciplinary Analysis and Design of Propulsion Systems

High-Performance Computing

- Parallel processing
- Object-oriented architecture
- Expert systems
- Interactive 3-D graphics
- High-speed networks
- Database management systems

Rapid Affordable Computation of

- Performance
- Stability
- Cost
- Life
- Certification requirements

A Numerical Test Cell for Aerospace Propulsion Systems

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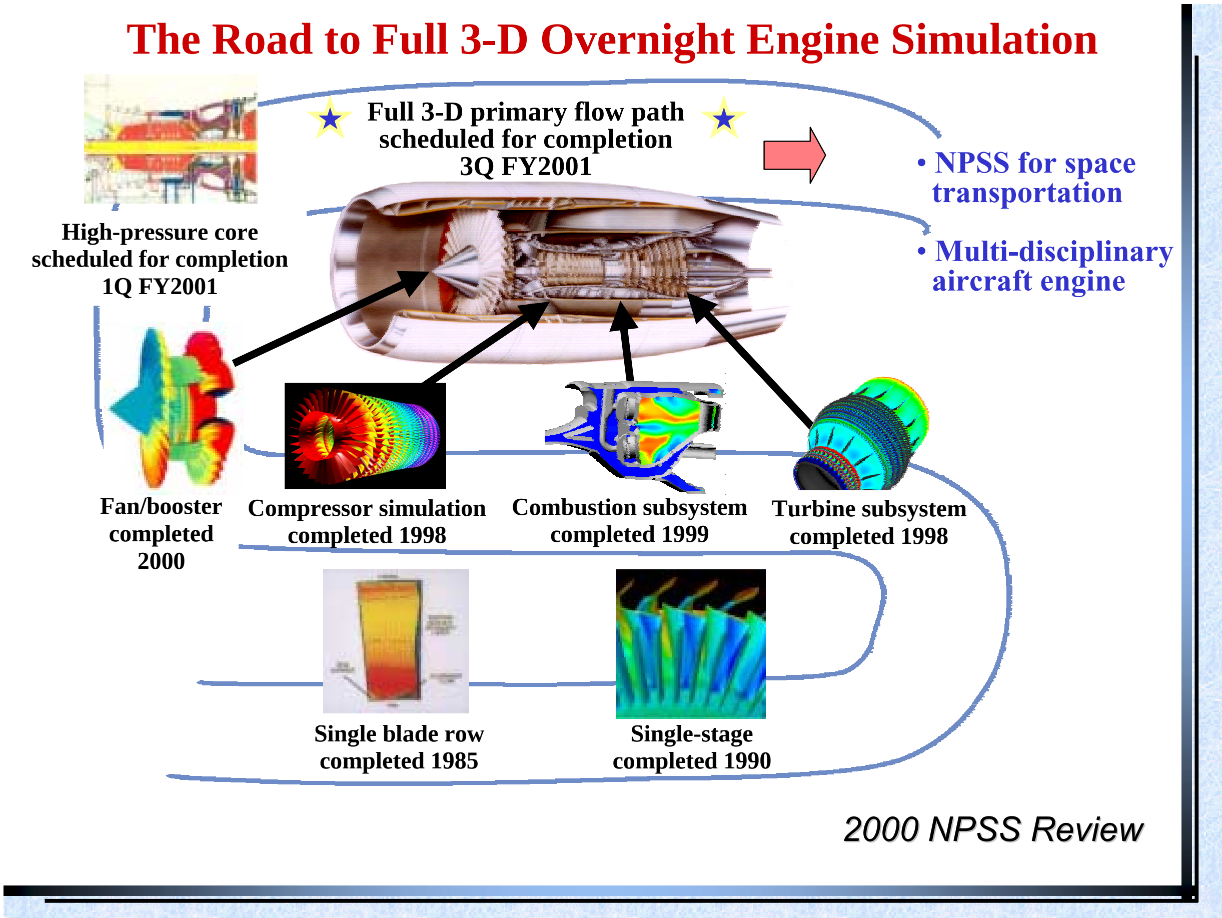
The Road to Full 3-D Overnight Engine Simulation
Full 3-D primary flow path scheduled for completion 3Q FY2001
High-pressure core scheduled for completion 1Q FY2001
• NPSS for space transportation
• Multi-disciplinary aircraft engine
Fan/booster completed 2000
Compressor simulation completed 1998
Combustion subsystem completed 1999
Turbine subsystem completed 1998
Single blade row completed 1985
Single-stage completed 1990
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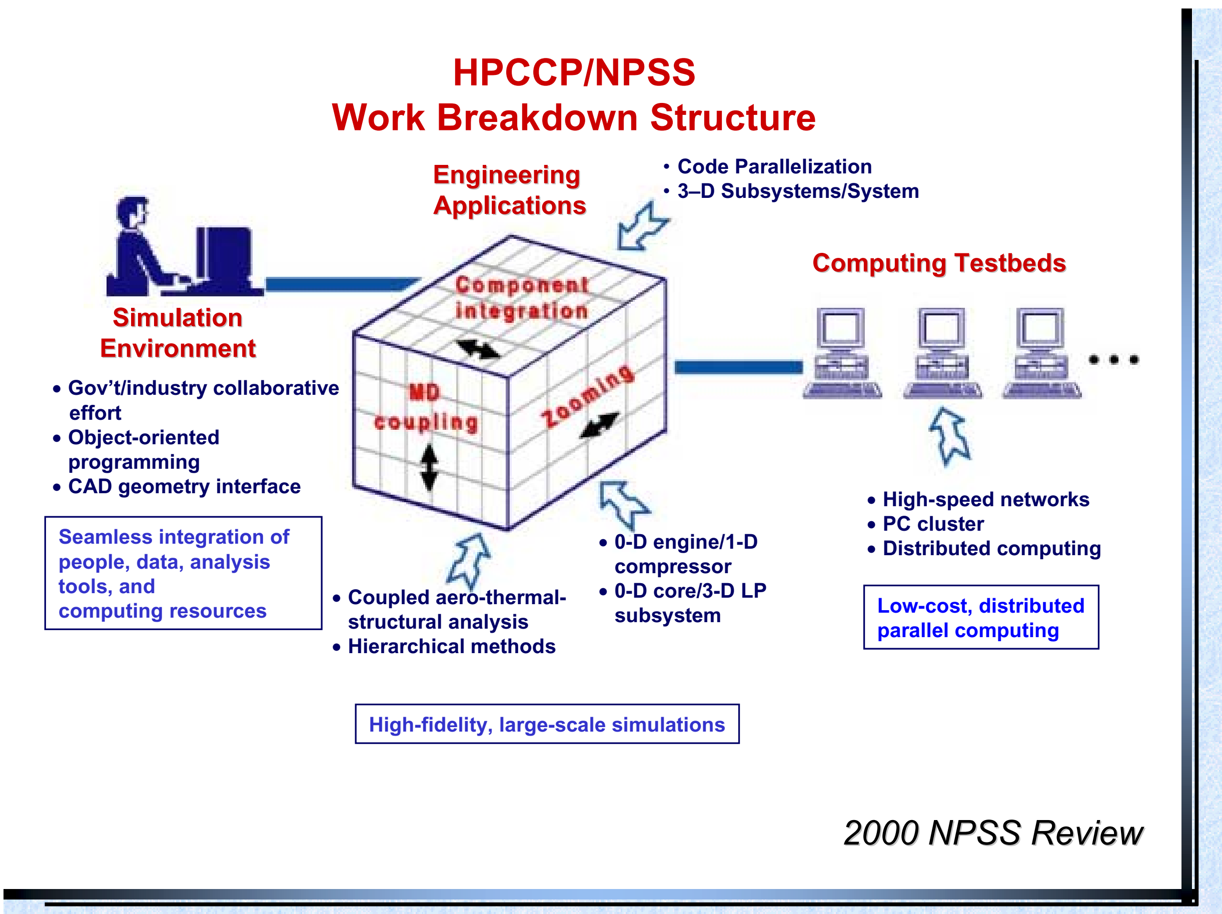
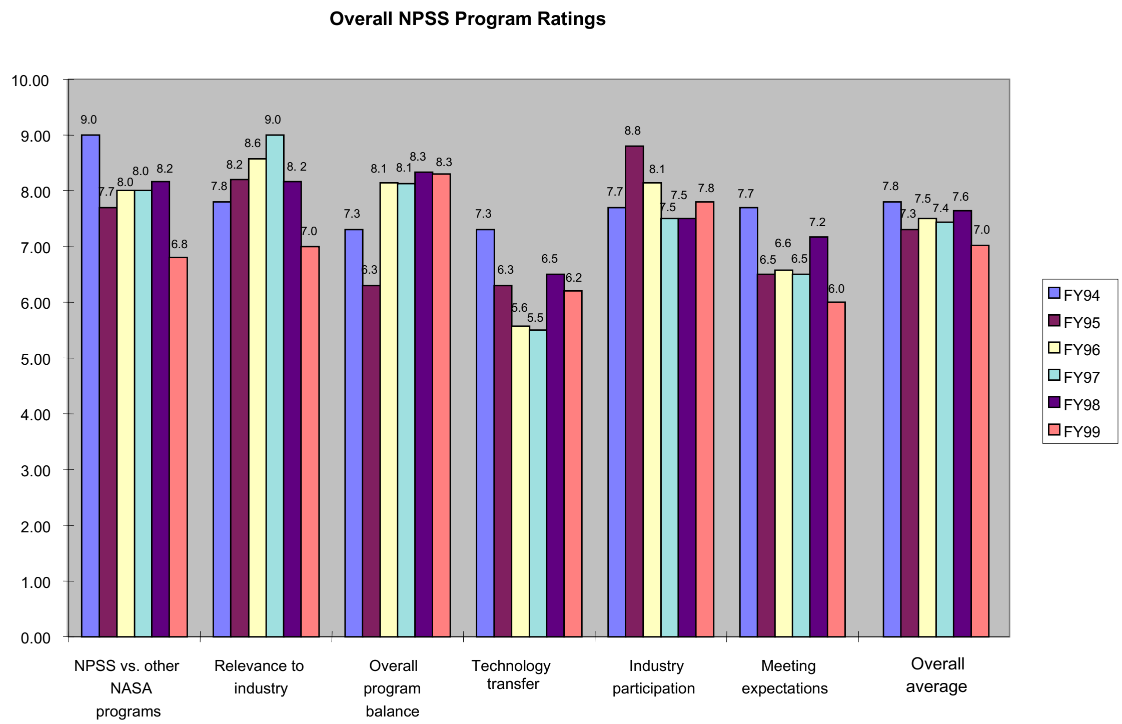

HPCCP/NPSS
Work Breakdown Structure
Engineering Applications
• Code Parallelization
• 3–D Subsystems/System
Computing Testbeds
Simulation Environment
• Gov't/industry collaborative effort
• Object-oriented programming
• CAD geometry interface
Seamless integration of people, data, analysis tools, and computing resources
Component integration
MD coupling
Zooming
• Coupled aero-thermal-structural analysis
• Hierarchical methods
• 0-D engine/1-D compressor
• 0-D core/3-D LP subsystem
• High-speed networks
• PC cluster
• Distributed computing
Low-cost, distributed parallel computing
High-fidelity, large-scale simulations
2000 NPSS Review



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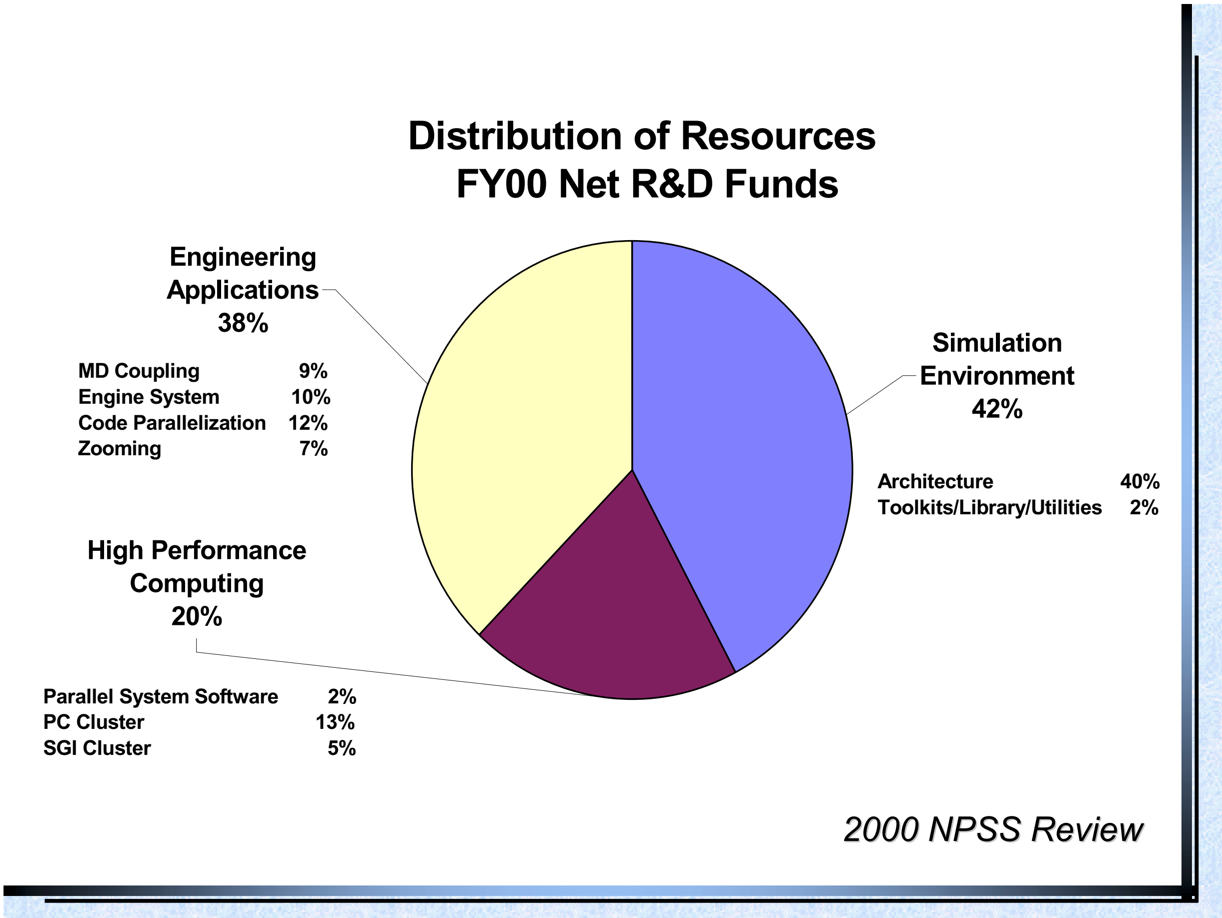
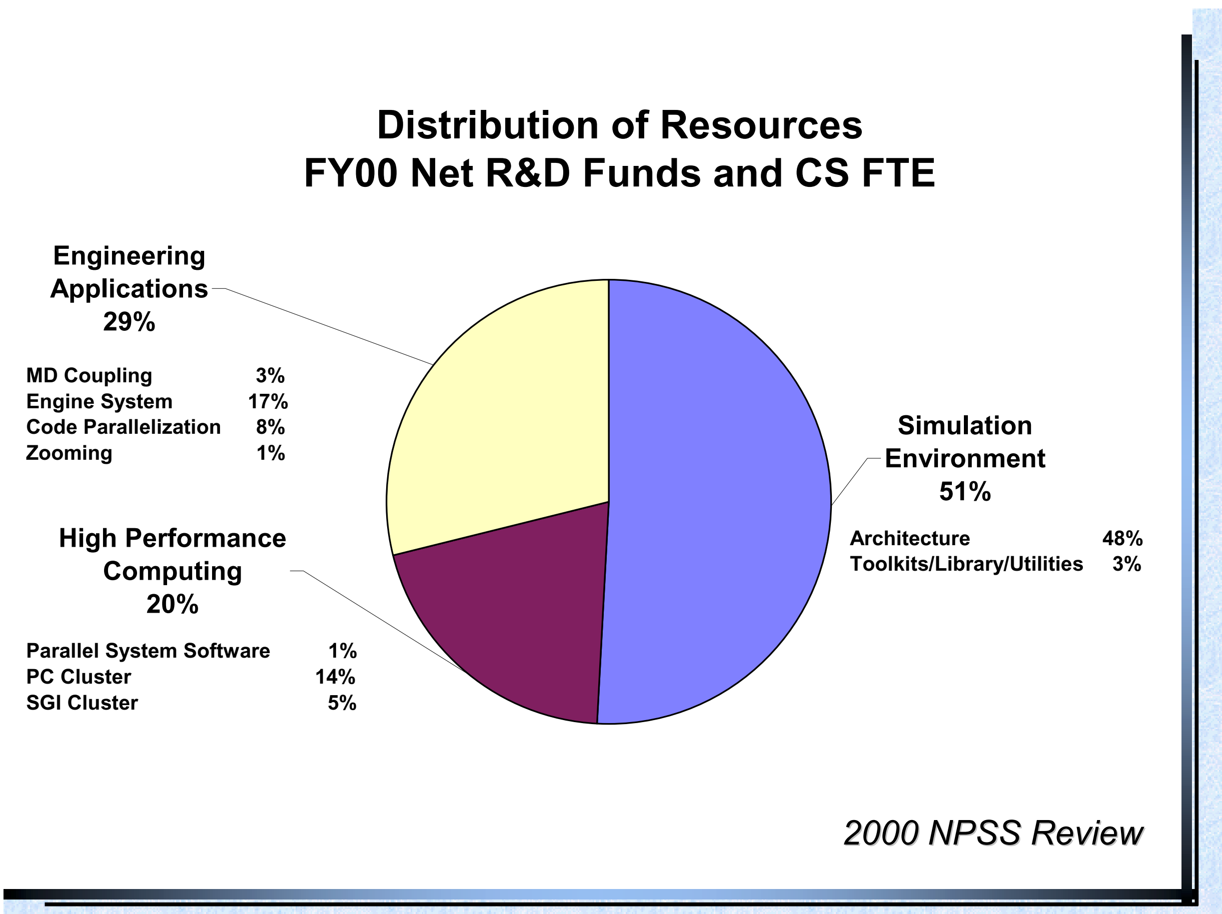
FY99 Executive Committee Report

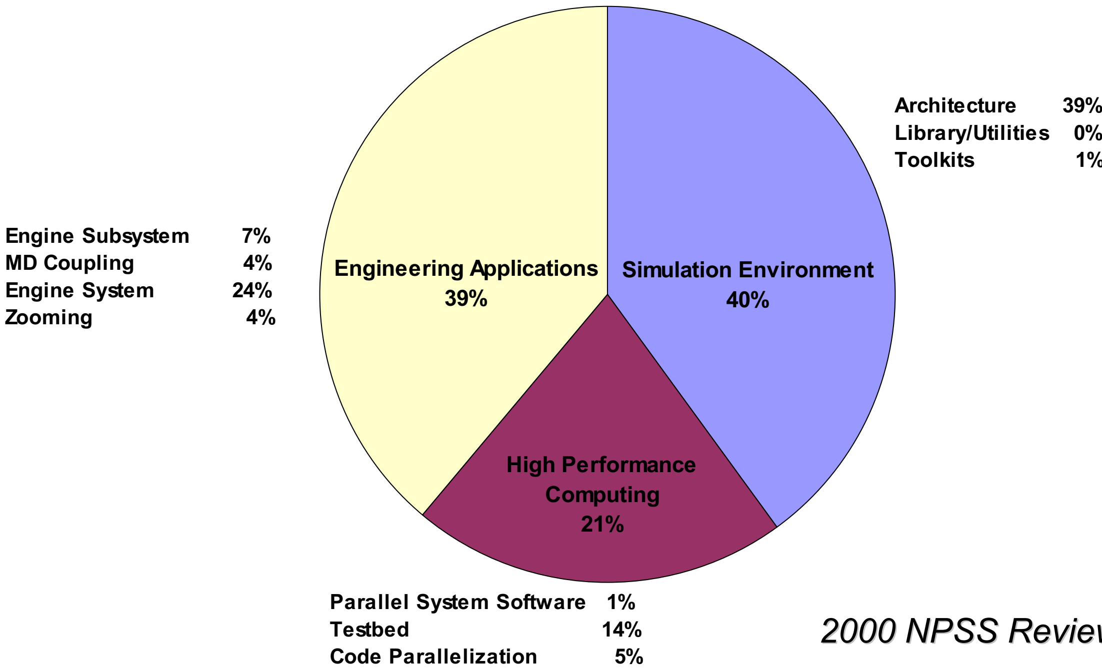
- Phase I, II, & III definitions are out of date or muddled. Restructure and replan to build on the architectural framework, to reflect new focus on integrated CAD analysis capability and high-fidelity/MDO, all tied together with the architecture.
- Concern that Phase 1, including VBS, will not be developed to maturity to enable adoption by industry.
- Unclear on how to integrate access to space objectives. Need to clarify with clear roadmaps and objectives.
- Clearer definition of transition from NPSS to ISE is required.
- International export of industry standard and basic architecture must be separate from items that will have export control issues.
- Must develop specific plan to provide long-term support and maintenance.
- Encourage IHPTET and VAATE usage.

2000 NPSS Review


Distribution of Resources
FY00 Net R&D Funds
Engineering Applications 38%
MD Coupling 9%
Engine System 10%
Code Parallelization 12%
Zooming 7%
Simulation Environment 42%
Architecture 40%
Toolkits/Library/Utilities 2%
High Performance Computing 20%
Parallel System Software 2%
PC Cluster 13%
SGI Cluster 5%
2000 NPSS Review


Distribution of Resources
FY00 Net R&D Funds and CS FTE
Engineering Applications 29%
MD Coupling 3%
Engine System 17%
Code Parallelization 8%
Zooming 1%
Simulation Environment 51%
Architecture 48%
Toolkits/Library/Utilities 3%
High Performance Computing 20%
Parallel System Software 1%
PC Cluster 14%
SGI Cluster 5%
2000 NPSS Review

Distribution of Resources
FY99
Net R&D Funds and CS FTE



2000 NPSS Review

Selected FY00 Highlights

- **Delivered NPSS V 1.0 in March (transient, dynamic linkable libraries, fully interpreted elements, data reduction, distributed objects). V2 requirements completed.**
- **Demonstrated a 547:1 reduction in combustion simulation time and a 400:1+ reduction in turbomachinery simulation time relative to a 1992 baseline.**
- **Initial coupling methodology for 3-D high-pressure core engine simulation completed.**
- **Completed the GE 90 fan/booster subsystem and combustor in preparation for the 3-D primary flowpath engine simulation.**
- **Demonstrated a 9.5:1 improvement in the performance/cost ratio for PC clusters relative to 1999 technology.**
- **NASA/industry team formed and implemented to define requirements and FY01 task for NPSS for space transportation.**
- **NPSS V1 proposed for use in GP 7000 and JSF engine development programs.**

2000 NPSS Review

FY01 Major Milestones

- Release NPSS V2 (real time ORB, CORBA security, limited zooming, dynamic load balancing, initial visual assembly language) (4Q).
- **Demonstrate full 3-D compressor analysis in 3 hours and full 3-D combustor analysis in 2.5 hours (>1000:1 reduction relative to a 1992 baseline)(4Q).**
- **Demonstrate 100:1 reduction in unsteady turbomachinery analysis time relative to 1999 baseline with MSTURBO on the HPCCP parallel testbed (4Q).**
- **Complete 3-D primary flowpath simulation of an advanced aircraft engine (4Q).**
- **Complete 3-D aero/structural/probabilistic analyses. Initiate implementation into the NPSS architecture (4Q).**
- **Initial release of NPSS for space transportation propulsion (4Q)**

2000 NPSS Review

Future Direction

- **Continue to play a strong role in the High Performance Computing and Communications Program.**
- **Increased emphasis on space transportation and aero-space synergy in the near term.**
- **Alignment of long-range goals with Intelligent Synthesis Environment, Intelligent Systems, and Design for Safety.**
- **Initiate new collaborations with DOD and DOE.**
  - **Versatile Affordable Advanced Turbine Engine (DOD)**
  - **Integrated High-Performance Turbine Engine Technology (DOD)**
  - **Accelerated Strategic Computing Initiative (DOE)**
  - **Advanced Turbine Systems and Vision 21 (DOE)**

2000 NPSS Review

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NASA Glenn Research Center
October 4-5, 2000

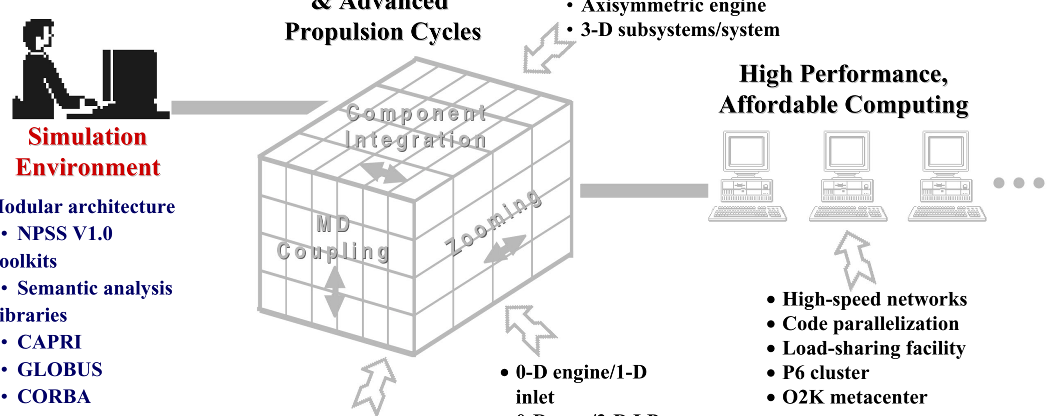
Simulation Environment/ Production Software

Gregory Follen
Cynthia Naiman

Simulation Environment/ Production Software

Engineering Applications & Advanced Propulsion Cycles

- National Cycle Program
- Axisymmetric engine
- 3-D subsystems/system



High Performance, Affordable Computing

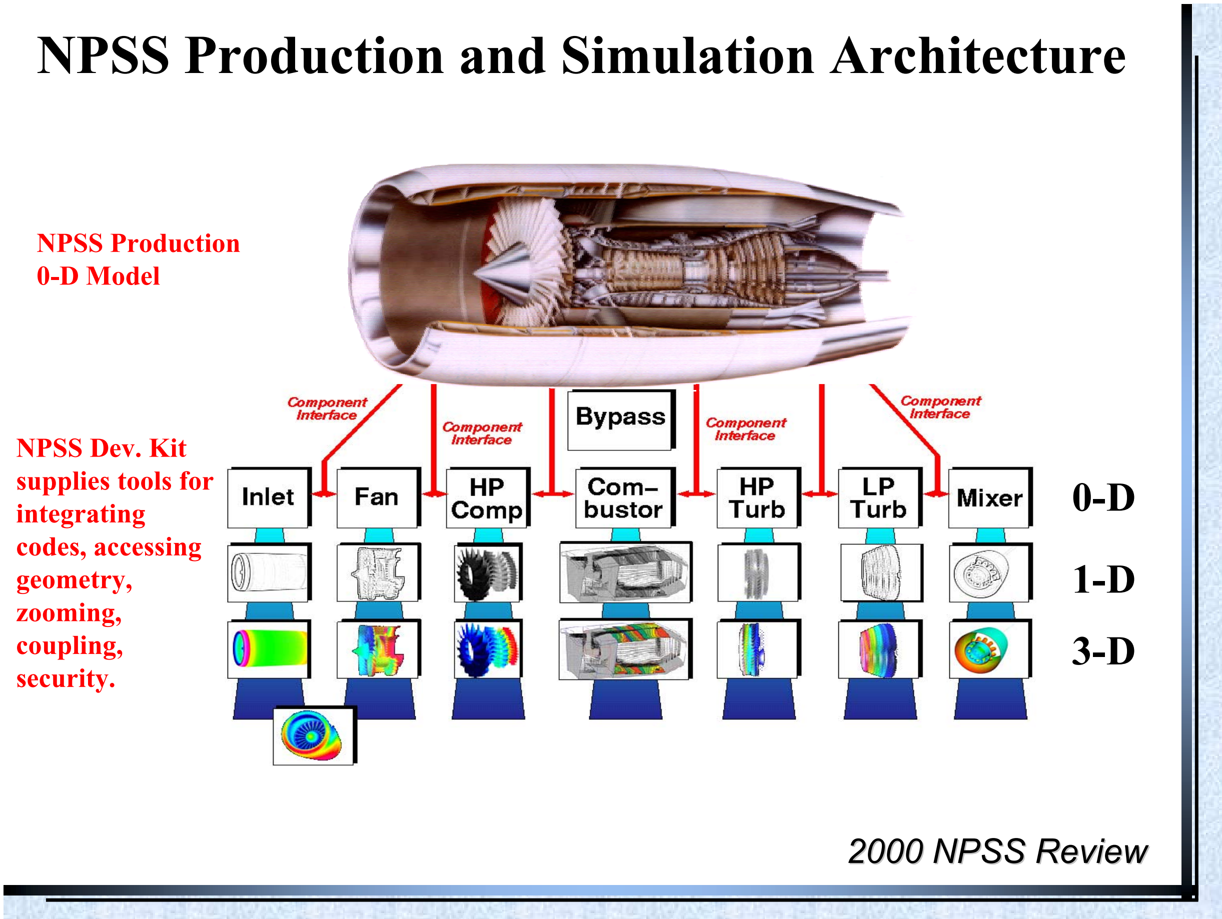
Simulation Environment

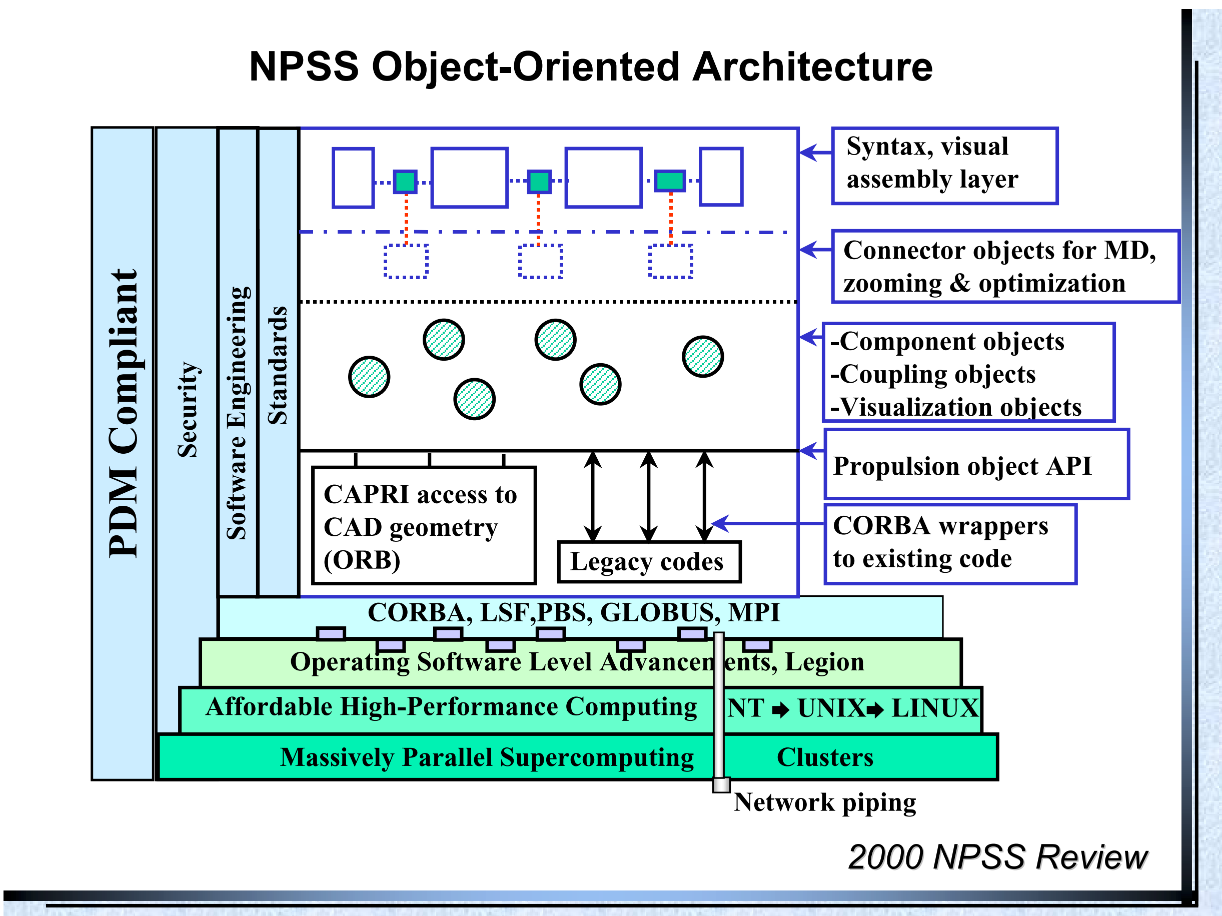
- Modular architecture
  - NPSS V1.0
- Toolkits
  - Semantic analysis
- Libraries
  - CAPRI
  - GLOBUS
  - CORBA

- Coupled aero-thermal-structural (CATS)
- CFD/controls
- Spectrum
- MDICE
- MSAT

- 0-D engine/1-D inlet
- 0-D core/3-D LP subsystem
- 1-D combustor/ 3-D engine

- High-speed networks
- Code parallelization
- Load-sharing facility
- P6 cluster
- O2K metacenter


NPSS Production and Simulation Architecture
NPSS Production
0-D Model
Component Interface
Component Interface
Bypass
Component Interface
Component Interface
NPSS Dev. Kit supplies tools for integrating codes, accessing geometry, zooming, coupling, security.
Inlet
Fan
HP Comp
Com–bustor
HP Turb
LP Turb
Mixer
0-D
1-D
3-D
2000 NPSS Review


NPSS Object-Oriented Architecture
PDM Compliant
Security
Software Engineering
Standards
Syntax, visual assembly layer
Connector objects for MD, zooming & optimization
-Component objects
-Coupling objects
-Visualization objects
Propulsion object API
CAPRI access to CAD geometry (ORB)
Legacy codes
CORBA wrappers to existing code
CORBA, LSF,PBS, GLOBUS, MPI
Operating Software Level Advancements, Legion
Affordable High-Performance Computing
NT ➔ UNIX➔ LINUX
Massively Parallel Supercomputing
Clusters
Network piping
2000 NPSS Review

NPSS Production Topics

- Overview
- Milestones and Deliverables
- FY00 Accomplishments
- NPSS Version 1 Capabilities
- NPSS Version 2 Capabilities
- Current Status
- Schedule

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NPSS Overview

- The Numerical Propulsion System Simulation (NPSS) is emerging as a U.S. industry standard simulation tool for propulsion and airframe companies.
- The modular, flexible, and extensible architecture developed for aeropropulsion simulations can be used for aerospace as well as other applications such as ground-based power systems.
- NPSS provides the functionality of a system simulation tool with increased flexibility for the user, which results in reduction of total development time and cost.
- NPSS has been developed using the object-oriented design with incremental releases.
  - The user's conceptual view of the physical components of the engine model can be mapped directly onto the object class hierarchy.
  - Rapid module creation, duplication, and customization is enabled by the interpretive engineering environment of NPSS.
  - The plug 'n play architecture enables much larger simulations to be performed because of the ease of "plugging" in new or larger modules.
  - This architecture can be extended to support multi-fidelity and multi-discipline simulations in future NPSS versions.
- Teaming with the end user is key to the development of a common modeling tool.

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$50M/Year Estimated Aeronautics Industry Savings If NPSS is Adopted

- Estimate $17M/year for one company - total of $50M/year savings results if NPSS is adopted by aeronautics industry:
    - Common simulation tool to use with partners and customers
    - Early detailed system-level analysis
    - Reduced cost of support, development, time-to-market, and training
    - Increased productivity
        - Improved code portability
        - Cross discipline process integration
        - Easier data query and collation
        - Easier data manipulation/display
        - Modular model sharing (preliminary design, controls, performance)
        - Increased automation
        - Multiple site/platform distributed modeling
        - Documentation automation
    - Increased accuracy of results earlier in the design process
- Benefits only include aeronautics estimated savings.

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Teaming User with Developer is Critical to Success

NASA/Industry Cooperative Effort (NICE-1)

NASA Glenn Research Center at Lewis Field
Honeywell
Rolls-Royce Corporation (RRC)
The Boeing Company
Arnold Engineering Development Center (AEDC)
Wright Patterson Air Force Base (WPAFB)
General Electric Aircraft Engines (GEAE)
Pratt & Whitney (P&W)
Teledyne Ryan Aeronautical
Williams International (WI)

Others who are interested:
U.S. Navy, Lockheed, Aerojet, Rocketdyne, DOE, P&W (power generation), GE (ground-based power), Dryden, Marshall, Langley, Ames

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NPSS Production Milestones and Deliverables

	2000	2001	2002	2003	2004	2005	2006
	V.1		V.2			V.3	
CAPABILITIES	Steady-state, transient, low-fidelity dynamic, reduced order & data reduction, low-fidelity flowpath, geometry design		Full performance envelope 2-D/3-D Euler, mid-fidelity dynamic, mid-fidelity geometry generation			Full engine performance 3-D Navier-Stokes steady-state, transient, high-fidelity geometry generation	
INTEROPERABILITY	Zooming 0-D<->1-D single component, CORBA multi-ORBs, distributed objects		Zooming 0-D<->1-D/2-D, 0-D<->3-D, single components, CORBA security, probabilistic sensitivity analysis			Zooming 3-D<->0-D/1-D/ 2-D, multiple components, multiple disciplines	
PORTABILITY	Sun, SGI, HP	NT, Linux					
RELIABILITY	High-control formal software development process with verification and validation for each incorporation						
RESOURCE MGT	Globus, LSF		Dynamic load balancing, networked clusters				
USABILITY	Script assembly language, dynamic linkable libraries, fully interpreted elements, interactive debug		Visual assembly language				
PERFORMANCE		1000:1 reduction in execution time of 3-D turbo machinery & combustion simulation	Real-time ORB				

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FY00 Accomplishments

- 3/00: Distributed NPSS Version 1.0.0 on schedule, meeting an FY00 NASA Glenn Strategic Implementation Plan milestone.
  - Change requests (CRs) incorporated since the last full version release on August 25, 1998:

    39 requirements + 96 enhancements + 250 defects = 385 total CRs
- 3/00: Conducted software configuration audit: no major findings.
- 3/00: Conducted software acceptance review (SAR).
  - Zero review item discrepancies (RIDs)
  - Received 8 letters of acceptance: Rolls-Royce Corporation, Williams International, GE Aircraft Engine, Pratt & Whitney, Honeywell, Boeing, Arnold Engineering Development Center, Propulsion Systems Analysis Office NASA Glenn.

2000 NPSS Review

FY00 Accomplishments (continued)

- 7/00: Completed requirements definition for Version 2: 153 requirements.
- 7/00: Conducted software requirements review: 0 RIDs.
- 8/00: Distributed NPSS Version 1.1.0 increment.
  - Change requests incorporated since NPSS 1.0.0 full version release on March 30, 2000:

    3 requirements + 14 enhancements + 39 defects = 56 total CRs
- 5/00 & 7/00: Conducted NPSS training at NASA Glenn, P&W, and Williams: over 100 engineers trained to date.
- 7/00: Completed initial draft of NPSS space transportation requirements.
- FY00: Part of ISO 9000 review for high control software.

2000 NPSS Review

FY00 Accomplishments (continued)

- Automated process to track change request progress and generate statistics.
- Improved risk management and metrics collection.
- Interest and use of NPSS expanding: military, ground-based power, space, other NASA centers.
- Received positive partner evaluations: Rolls-Royce Corporation, Williams International, Lockheed, Navy.
- Feedback from partner validation activities continues to increase quality of product: GEAE internal validation, GEAE and P&W Alliance GP7000 validation.
- Number of NPSS models increase: Turbojet, Turbofan, Energy Efficient Engine, High Speed Research, Pulse Detonated Engine, partner & PSAO models, Regenerative Rocket Cycle.

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NPSS Version 1.0.0 Capabilities

NPSS Version 1.0.0 can be used as an aerothermodynamic 0-dimensional cycle simulation tool:

- All model definition through input file(s)
- NIST (National Institute of Standards and Technology)-compliant thermodynamic gas-properties packages: Therm, Janaf, GasTbl
- Sophisticated solver with auto-setup, constraints, discontinuity handling
- Steady-state and transient engine system operation
- Flexible report generation
- Built-in object-oriented programming language for user-definable components and functions
- Support for distributed running of external code(s) via the common object request broker architecture (CORBA)
- Test data reduction and analysis
- Interactive debug capability
- Customer deck generation

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NPSS Version 2.0.0 Capabilities

See NPSS SRS for detailed Version 2 requirements.

- 1-D dynamic engine system operation
- Aircraft installation effects
- Improved thermo architecture and capability
- New components, including combustion, compression, turbine expansion
- Units conversion
- Initial visual-based syntax stand-alone tools (graphical & command)
- Input and output enhancements
- Enhanced NPSS Developer Kit
- Enhanced C++ converter, interactive debugger, and commands
- CORBA Security
- NPSS running in CORBA server mode
- Common geometry interface
- Initial rockets capabilities
- Zooming from low to high fidelity as defined in the NPSS SRS
- New user documentation: Installation Guide and Training Guide

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NPSS Production Current Status

- Completing change requests weekly: requirements, defects, and enhancements.
- Supporting changes needed for partner activities.
- Sub-teams analyzing V2 requirements, prioritizing, estimating effort, assigning, and scheduling work.
- Sub-teams determining which V2 requirements and submitted change requests will be completed by 9/01 with known resources.
- Preparing for upcoming NPSS training sessions.

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NPSS Production Current Status (continued)

- Improving NPSS Developer Kit.
- Prototyping CORBA Security capabilities.
- Prototyping stand-alone tools for visual-based syntax.
- Finishing NT port.
- Analyzing and designing aircraft installation effects.
- Improving user documentation.
- Enhancing C++ converter.
- Working NPSS space requirements definition.

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NPSS Production Schedule

•10/00: Complete NPSS space requirements definition.

•10/00: Provide NPSS rockets training at MSFC and Lockheed.

•00-01: Distribute incremental releases.

•00-01: Provide NPSS training as needed.

•9/01: Conduct software configuration audits for NPSS V2.

•9/01: Conduct software acceptance review for NPSS V2.

•9/01: Distribute NPSS Version 2 for AeroSpace.

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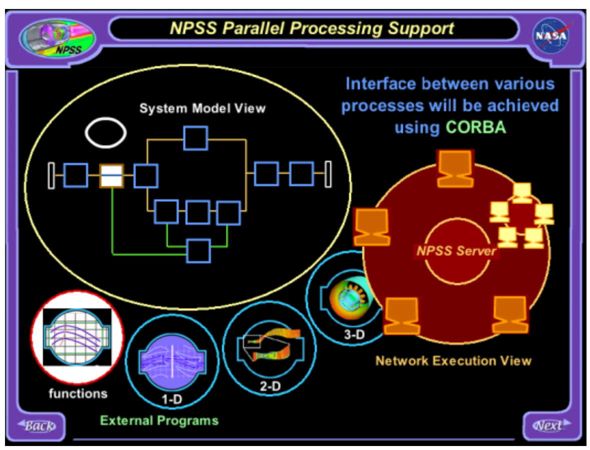
NPSS Development Kit

FY00 Accomplishments

Integrating Codes Through CORBA Wrapping



- **Direct FORTRAN support**
  Allows converting FORTRAN code to a CORBA object without reverting to file I/O & attendant startup/shutdown overheads.
- **Single-precision floating-point variables**
- **'Meta' variables**
  i.e., Shaft, Nmech mapped to multiple boundary conditions.
- **Variable access via functions**
  For parallel codes where the CORBA process doesn't own storage of referenced data.
- **Circumferential averaging**
- **1-D array support**

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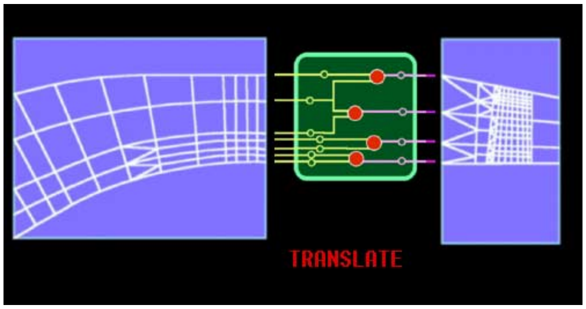
NPSS Development Kit

FY00 Accomplishments



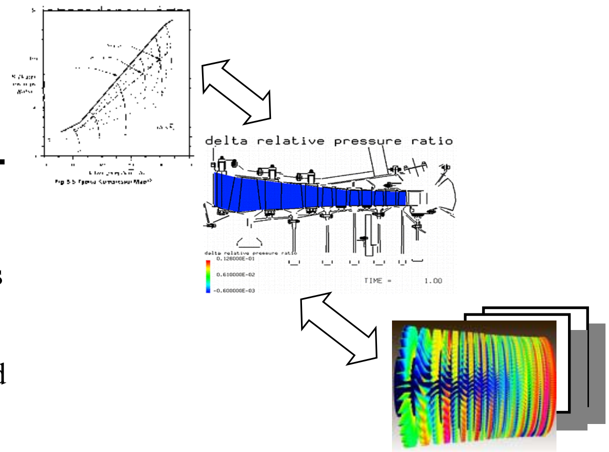
Coupling

- 2-D/3-D/Axi-symmetric mismatched grids, with cell or node centered data
- Interpolation method is internally unstructured, currently the only API uses structured grids
- Rolls-Royce ADPAC-NPSS-ANSYS sensitivity project
    - Will likely require unstructured support. Current interpolator has this, but API and messaging formats need to be defined
    - Likely wrap ANSYS via Java using file I/O
    - ANSYS optimizer loop to be emulated by Java client application
- Examining "best practices in coupling" for recovery into Dev. Kit
    - ASCI project coupling
    - Overflow-ANSYS
    - APNASA-TFLOW

2000 NPSS Review

NPSS Development Kit

FY00 Accomplishments



Zooming

- 'Natural' C++ access to remote variables
- PW 1-D zooming to compressor code
    - GRC 1-D compressor code wrapped with NPSS Dev. Kit
    - NPSS model built
    - What remains is to connect everything up
- PW 3-D/3-D zooming/coupling
    - Demonstration was expected for this meeting
    - ADPAC wrapped in NPSS Dev. Kit
    - PW, NASA code review/examination conducted to appropriate codes to wrap
- 1-D Turbine code wrapped using NPSS Dev. Kit

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NPSS Development Kit

FY00 Accomplishments

CORBA Security

- CORBA Security Workshop summary
  - Defined NPSS security policy
- CORBA Security Quick Start Hands-On Training Summary
  - Hitachi TPBroker SS architecture & administration GUI charts
- Defined NPSS CORBA Security testbed
  - Plans and testbed architecture
  - Purchases and network
  - Relative standards
  - Integration approach
- CORBA Security integration into NPSS schedule-3/01

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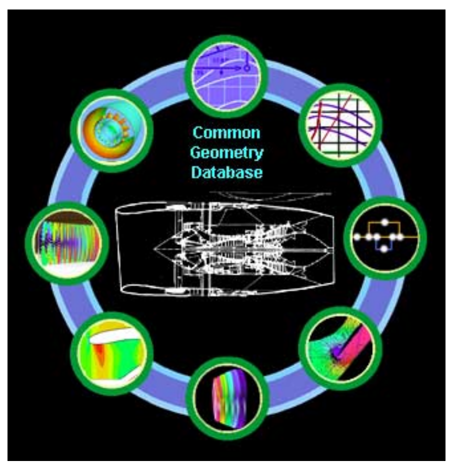
NPSS Development Kit

FY00 Accomplishments



CAD Access & Interoperability Through Common Interface

- MIT grant for CAPRI: added CV port, enhanced IDEAS port
- OMG process
  - Requirements gathering (RFI), **complete**
  - Formal RFP (CAD Services V1.0, **6/00**)
  - Vendors and end users letter of intent (LOI, **9/18/00**)
  - Vendors seek common “ground” for response
  - Develop joint submission, **1/15/01**
  - Submission reviewed and approved as standard
  - Vendor provides commercial support for the standard

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CAPRI FY00:

	UniGraphics	**ProE**	**I-DEAS**	**CATIA V4**	**CV**	**Native - Felisa**
Alpha	**X**					**X**
HP	**X**					**X**
IBM RS6K	**X**			**X**		**X**
SGI	**X**	**X**	**X**	**X**	**X**	**X**
SUN	**X**					**X**
LINUX	**X**					**X**
Windows NT/2000	**X**	**X**			**X**	**X**

CATIA V5 will be examined during this contract, but the best approach for the programming interface is not clear. An AutoCAD geometry reader will not yet be implemented.

A CV (CompterVision’s CADDS V) interface has been written in support of NPSS work with Allison/Rolls Royce and ICEM-CFD.

CAPRI FY01: Geometry Creation

The most significant change for **CAPRI** this year is the addition of Boolean operations on solids. This allows for the specification of fluid passages where the blade is the solid. The blade is simply subtracted from the passage to get the geometry for the CFD calculation. In general very complex shapes can be obtained through a few operations. The current status is as follows:

	Parasolid	ProE	I-DEAS	CATIA V4	CV
Simple Solid Creation	X			X	X
Subtraction	X		X	X	X
Intersection	X			X	X
Union	X			X	X

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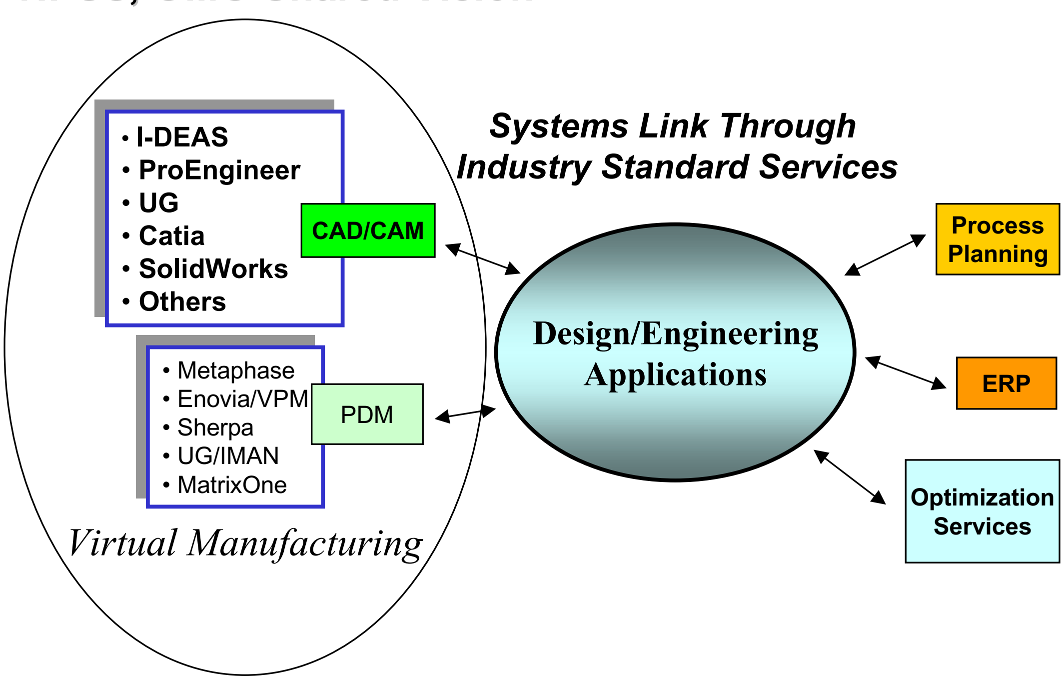
NPSS, OMG Shared Vision



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NPSS Architecture FY01 Milestones

- 1-D zooming fully incorporated into Development Kit.
- 3-D/3-D coupling of aero codes fully incorporated into Development Kit.
- Design of geometry services through CORBA-based CAPRI.
- CORBA Security services fully incorporated into Development Kit.

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NPSS Architecture FY02 Milestones

- 3-D/3-D coupling of ANSYS and ADPAC wrappers incorporated into Development Kit.
- CORBA-based geometry services incorporated into Development Kit.
- CORBA Security services integrated with GLOBUS and incorporated into Development Kit.
- Fast probabilistic integration (FPI) deployed with Development Kit.

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Summary

- •NPSS Version 1 delivered on schedule.
- •NPSS Version 2 requirements have been signed off on.
- •NPSS Version 2 will include space capabilities.
- •NPSS architecture products are merging into NPSS Development Kit and will be releasable through same mechanism as NPSS V.X.

2000 NPSS Review

NPSS CORBA Security Development Status

NASA Glenn Research Center
NPSS Architecture Team Meeting

Tammy M. Blaser

2000 NPSS Review

NPSS CORBA Security Development Status Outline

- CORBA Security Workshop (6/12-14/2000) Summary
  - NPSS Security policy charts
- CORBA Security Quick Start Hands-On Training (6/15-16/2000) Summary
  - Hitachi TPBroker SS architecture & administration GUI charts
- NPSS CORBA Security Testbed
  - Overall plans
  - Progress and purchases
    - Testbed architecture
    - Current workshop (9/21/2000)
    - Current network
  - Relative standards
  - Integration approach
- CORBA Security Integration into NPSS Schedule

2000 NPSS Review

CORBA Security Workshop Summary

- CORBA Security Workshop was taught by Concept Five and assisted by Hitachi, hosted at NASA Glenn, on June 12-14.
- GEAE, P&W, and NASA Glenn attendees.
- Workshop was very successful.
- Day One was a very good CORBA Security and associative security technologies overview.
- By the end of Day Three, the Team had developed an NPSS specific security domain policy.

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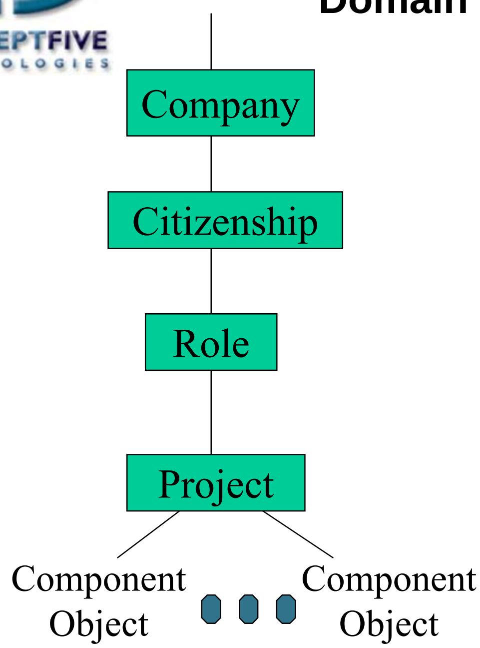
CONCEPTFIVE TECHNOLOGIES

Option 1 for NPSS Domain Hierarchy Domain Access Control Policy



U

Company=GE G

∩

Citizenship=US G

∩

Role=developer G

∩

Project=xyz G

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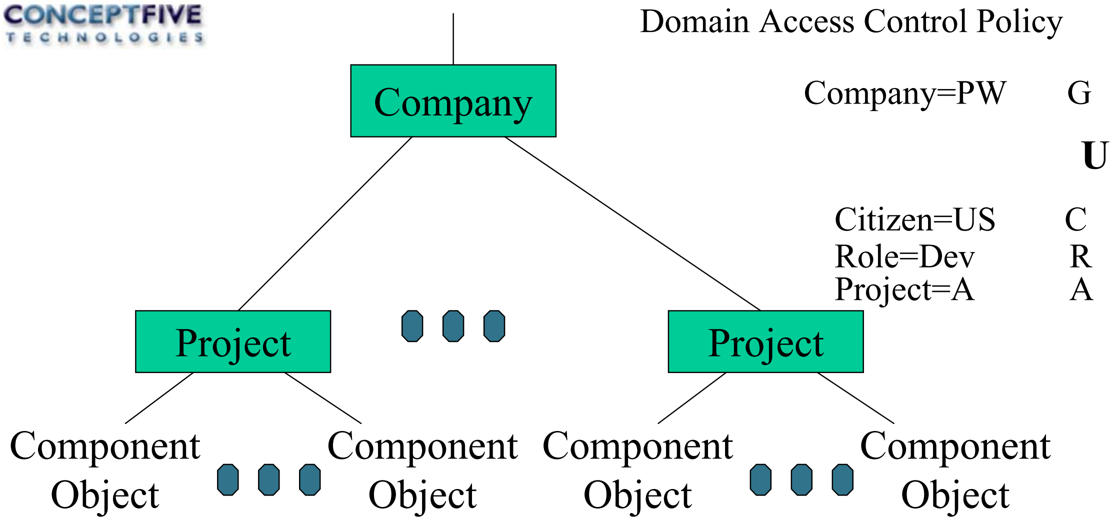
Option 2 for NPSS Domain Hierarchy



Interfaces and Required Rights

Interface	Req. Rights	Admin	Dev/User	User
get_private	GCRP	✓	✓	✗
get_public	P	✓	✓	✓
set_private	GCRP	✓	✓	✗
set_public	P	✓	✓	✓
execute	U	✗	✓	✓
list_private	GCRP	✓	✓	✗
list_public	P	✓	✓	✓

Attributes and Domain Hierarchy

Attributes

ID

Company

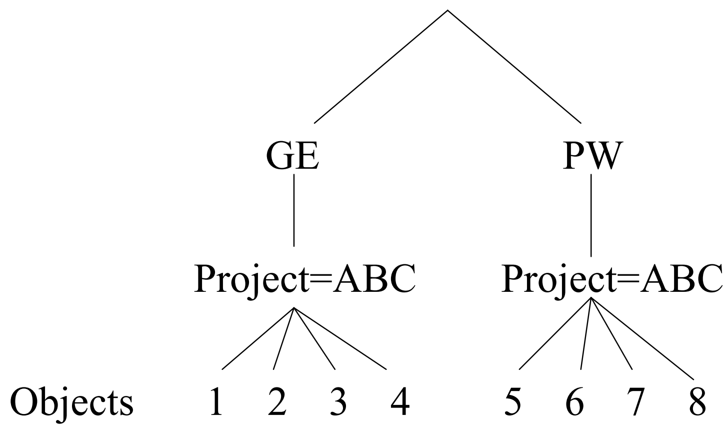
Citizenship

Role

Division

Project

Domain Hierarchy



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Domain Policy

Domain GE		**Domain PW**	
Company=GE	G	Company=PW	G
Domain GE/ABC		**Domain PW/ABC**	
Citizen=US	C	Citizen=US	C
Citizen=Can	C		
Role=User	U	Role=User	U
Role=Dev	R,U	Role=Dev	R,U
Role=Admin	R	Role=Admin	R
Project=ABC	P	Project=ABC	P

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Examples

- User A = PW, US, Dev, ABC
  - In GE/ABC: CRPU - can execute and access public variables in GE.
  - In PW/ABC: GCPRU - can execute and access public and private variables in PW.
- User B = GE, Can, User, ABC
  - In GE/ABC: GCUP - can execute and access public variables in GE.
  - In PW/ABC: UP - can execute and access public variables in GE.

2000 NPSS Review

CORBA Security Quick Start Hands-On Training Summary

- CORBA Security Quick Start Hands-On Training Summary was taught by Hitachi and assisted by Concept Five, hosted at NASA Glenn, on June 15-16.
- P&W and NASA Glenn attendees.
- Hands-On Training was very informative.
- Instructors were very good about answering many ad-hoc questions.

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CORBA Security Quick Start Hands-On Training Summary (continued)

- The three labs consisted of creating
  - A user using the security policy administration GUI.
  - A secure system using the TPBroker Security Service.
  - A secure system exercising delegation using the TPBroker Security Service.

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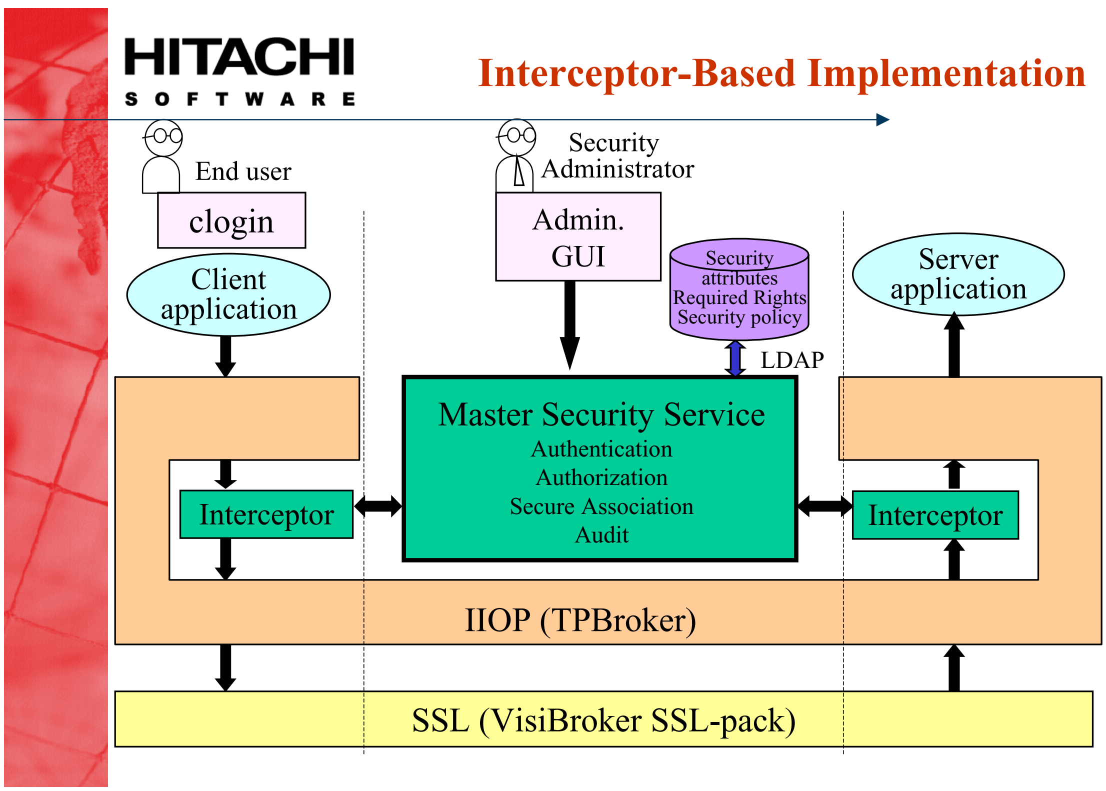

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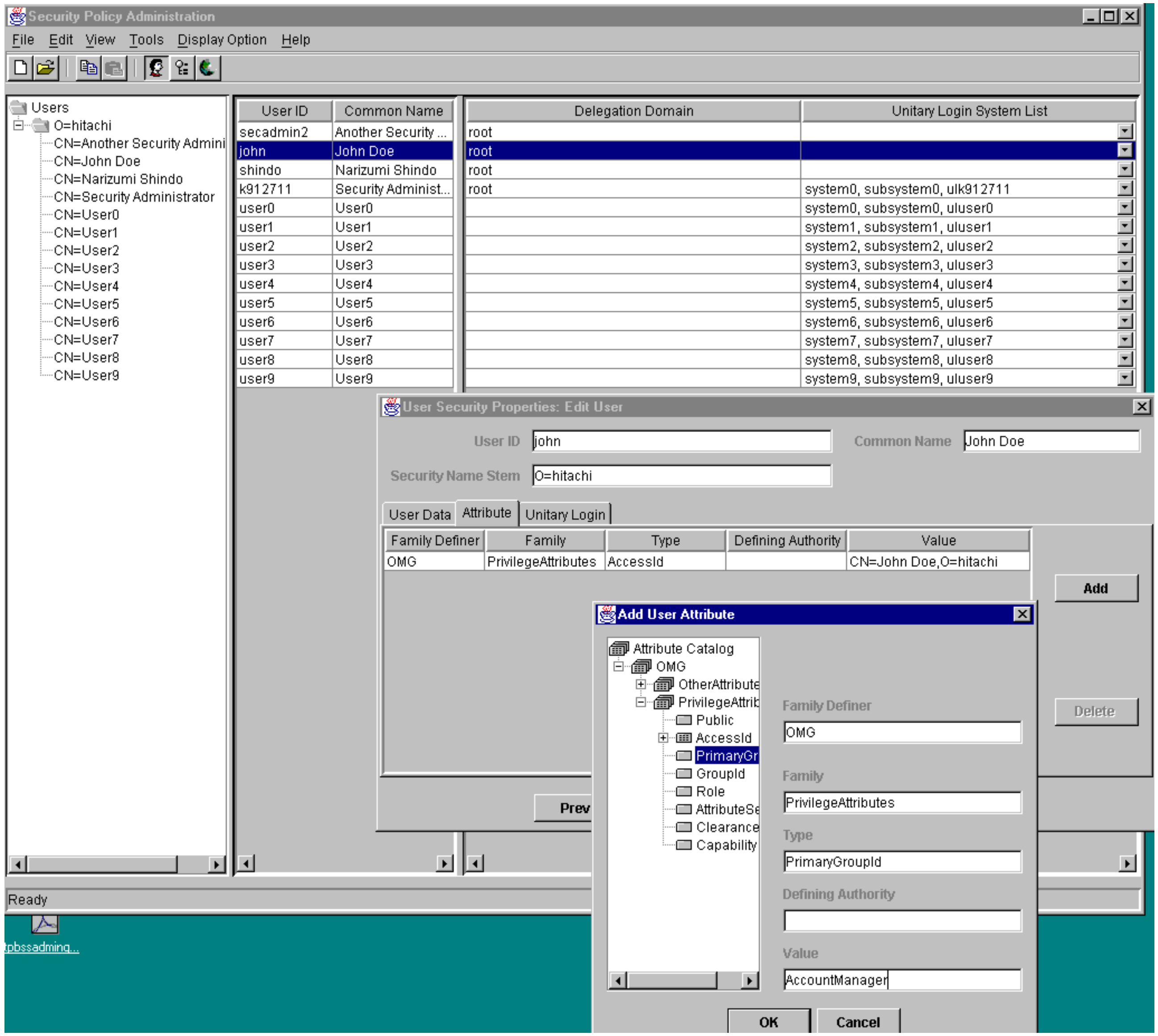
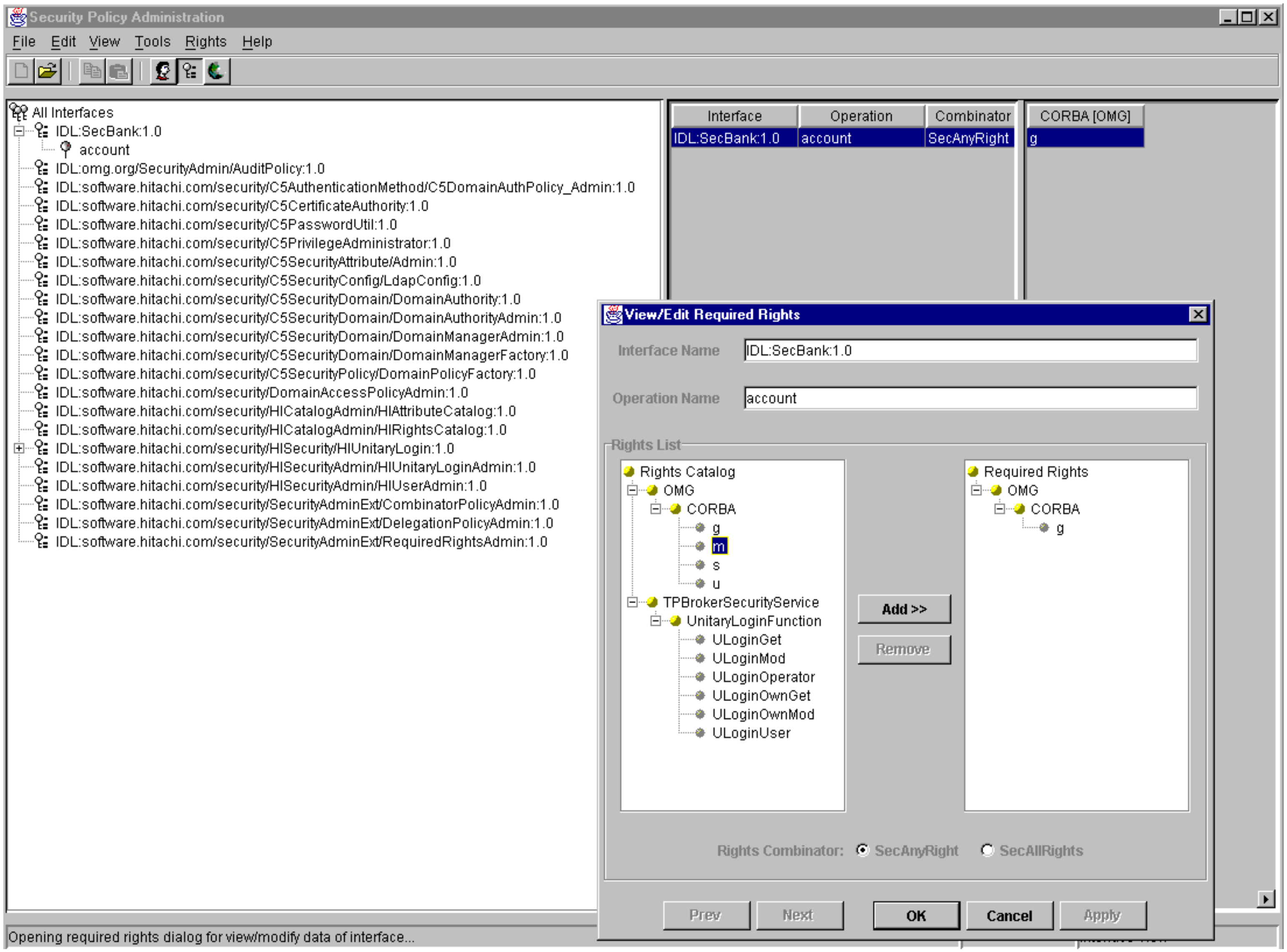
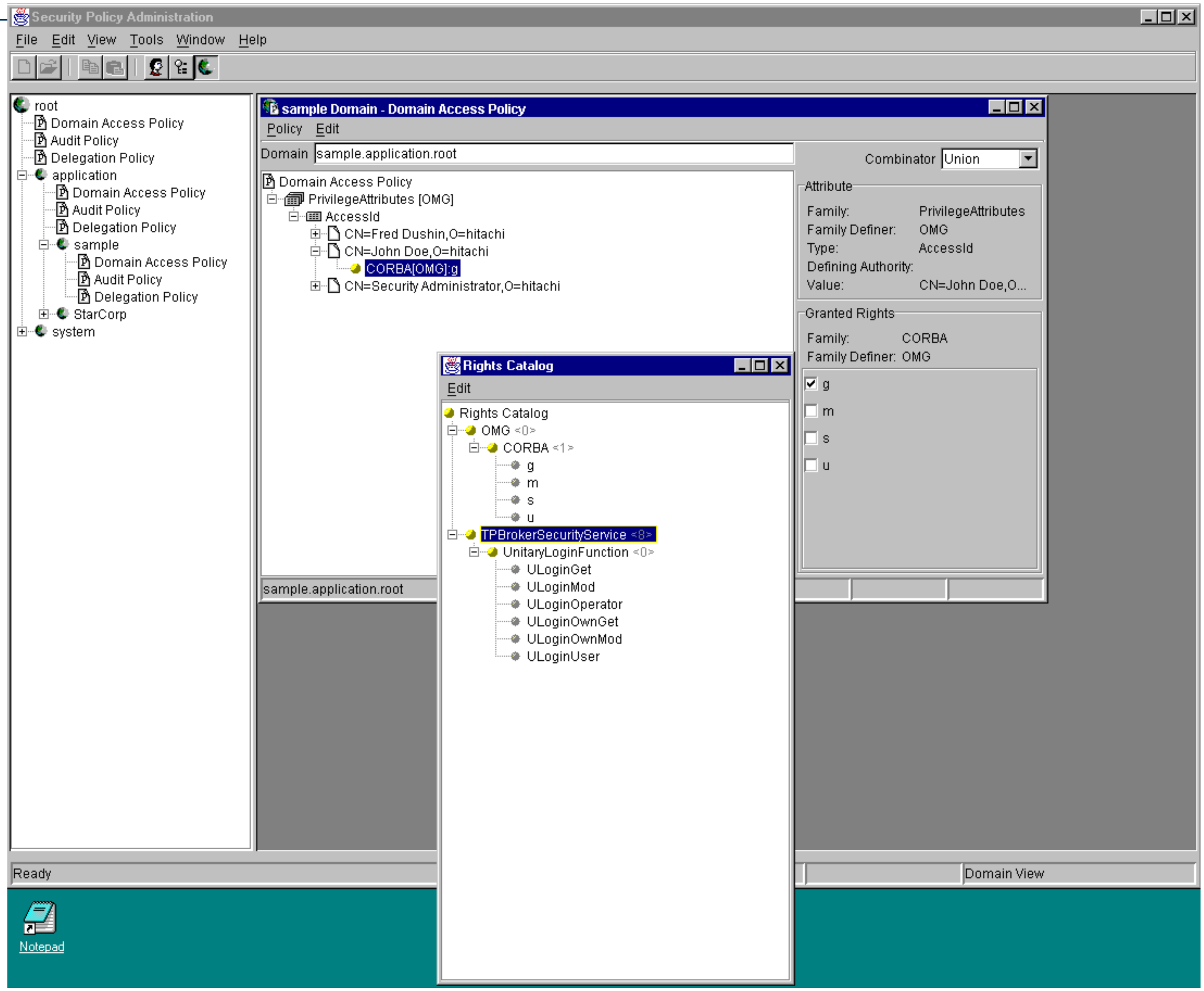
Security Policy Administration (User)



Security Policy Administration (Interface)



Security Policy Administration (Domain Access Policy)



CORBA Security Workshop CORBA Security Quick Start Hands-On Training Overall Summary

- As a result of the CORBA Security training, NASA and partners have developed a very good working relationship with Concept Five and Hitachi.
- Both C5 and Hitachi were very helpful and tailored training to meet NPSS requirements.

2000 NPSS Review

NPSS CORBA Security Testbed Overall Plans

- NPSS CORBA Security Testbed Development
  – Develop a NPSS CORBA Security testbed with Hitachi's TPBroker Security Service (SS) via a dedicated CORBASec network with GEAE and P&W.
- Wrap Codes Development
  – Wrap simulation codes, integrate and retest into the NPSS CORBA Security testbed.

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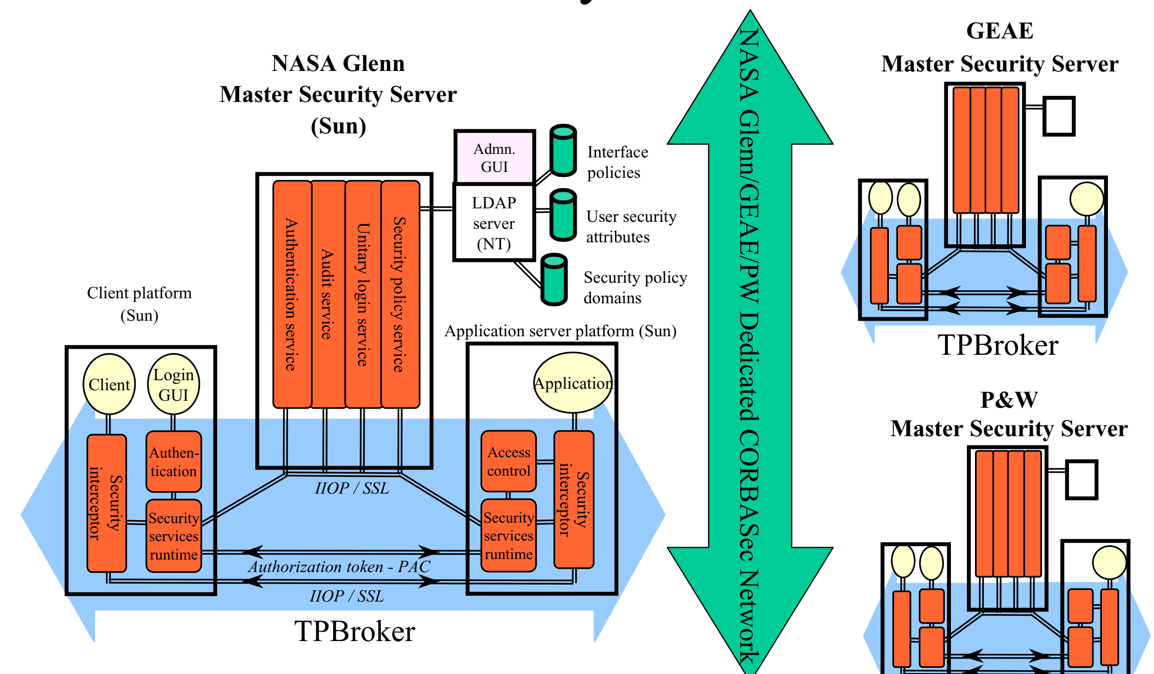
NPSS CORBA Security Testbed Architecture



Hitachi's TPBroker Security Service available now - Iona's OrbixSec in work

2000 NPSS Review

NPSS CORBA Security Testbed Progress and Purchases

- Weekly or as-needed NPSS CORBASec testbed telecons are held with GRC, GEAE and PW.
- NASA Glenn has a purchase request in the procurement system to purchase three Ultra 5 Sun computers.
  - Will ship date 9/28/2000
- At the beginning of the new FY01
  - An existing ACCL PC will be upgraded.
  - Hitachi TPBroker SS & Netscape LDAP s/w will be purchased.
  - NASA Glenn currently making due with borrowed h/w and eval s/w until FY01 start.
- GEAE and PW are also starting to configure their testbeds.

2000 NPSS Review

NPSS CORBA Security Testbed Progress - Current Workshop

- GEAE will host the CORBA Security Technology Day Workshop; Hitachi, GRC and PW attending on 9/21/2000.
  - The workshop will focus on
    - Hitachi's plans to support the portable object adaptor (POA) with ports of the TPBroker Security Service to
      - VisiBroker v.4.x
      - Orbix 2000
    - Hitachi's plans to support Java and C++ for Solaris, Linux, HPUX-11
    - NPSS CORBASec testbed update
    - Update on needed security features
      - SecurID
      - Certificate authentication

2000 NPSS Review

NPSS CORBA Security Testbed Progress - Current Network

- Investigating current NASA, GEAE and PW networks and feasibility to modify them to develop NPSS CORBASec testbed.
  - May be able to extend current NASA Dryden and GEAE encrypted network to NASA Glenn.
  - PW looking into their current networks as well.
- NREN approach was not recommended by NASA Glenn network POCs because of our March 2001 milestone.
- Idea is to use a dedicated network and focus on security software configurations.
  - Will switch back to NASA Glenn and company networks with firewalls in the final integration and test phase.

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NPSS CORBA Security Testbed Relative Standards

- Stay up to date on the following standards and implementations:
  - Common Secure Interoperability level 2 (CSI v.2)
    - Required to interoperate between different secured ORBs: TPBroker, Orbix, Mico, Visibroker.
  - CORBA Component Model (CCM) and Enterprise Java Beans (EJB)
    - Standards coming together, and the future.
  - Domain Membership Management (DMM)
    - DMM and portable object adaptor (POA) integration.
  - Portable Interceptors
    - Plug ’n Play different security products together – replaceability.

2000 NPSS Review

NPSS CORBA Security Testbed Integration Approach

- Wrap codes development
  - Wrap simulation codes, integrate and retest into the NPSS CORBA Security testbed.
  - Interface with CORBA IPG and NPSS Production Teams.
- Integrate with existing legacy simulation’s external security system with *single login* by utilizing the Unitary Login feature (not part of CORBAsec standard, currently)
- Integrate SecurID features
- Integrate Concept Five’s PKI Certificate Login into
  - Existing TPBroker SS s/w login; GUI is ID/password-based.
  - Goal is to smooth the integration of Entrust PKI when fully implemented by all certificate authorities (CA) using CA cross-certification; including NASA Centers, P&W, etc.

2000 NPSS Review

CORBA Security Integration into NPSS Schedule

- GEAE host CORBA Security Technology Day Workshop September 21, 2000.
- Finalize overall testbed network configuration - October 2000.
- Configure NASA Glenn testbed site with new Sun Ultra-5s and TPBroker SS s/w - October 2000.
- Conduct preliminary tests - November 2000 at local sites only.
- Conduct secured CORBA wrapped tests w/all sites - December 2000.
- Add additional security features for legacy systems, SecurID, PKI Certificate Login etc. - January 2000.
- Develop NPSS CORBA Security Development Kit or update existing CCDK based on findings of testbed - February 2001.
- Conduct final tests - February 2001.
- Start NPSS CORBASec Production development & verification planning - March 2001.

2000 NPSS Review

2000 NPSS Review

NASA Glenn Research Center
October 4-5, 1999

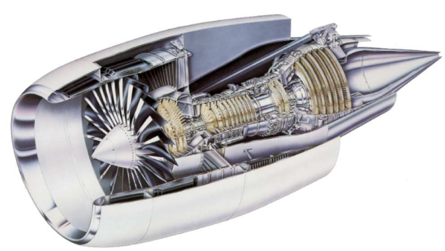
Aircraft Engine Systems

Joseph P. Veres

Detailed Simulation of Aircraft Turbofan Engine

Objective

Develop a detailed flow model of a full turbofan engine that runs on parallel workstation clusters overnight. The model will initially simulate the 3-D flow in the primary flow path including the flow and chemistry in the combustor, and ultimately result in a multidisciplinary model of the engine.



Approach

- The 3-D flow analysis models the GE90 turbofan engine using APNASA (NASA's average-passage flow code).
- Leverage form efforts between NASA and GE in developing the APNASA flow code and workstation clustering technology.
- Contract with GEAE NAS3-98004 Task Order #9
- The National Combustion Code (NCC) will be used to simulate the flow and chemistry in the combustor.
- The APNASA and NCC codes shall be coupled together at NASA Glenn Research Center.

Significance/Metrics

The overnight 3-D simulation capability of the primary flow path in a complete engine will enable significant reduction in the design and development time of gas turbine engines.

Point of Contact

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Detailed Simulation of Aircraft Turbofan Engine

Contributors:

GE Aircraft Engines:

Lyle D. Dailey	Technical Manager, compressor and booster simulations
George Liu	Provided information on GE90 compression system
Bryan Doloresco	Provided 2-D Euler (CAFMIXII) solution for PIP+ compressor
Kevin Kirtley	(GE Corporate Research) Fan simulation with APNASA Version 5

Rolls Royce / Allison

Edward J. Hall	Manager and principal investigator

ASE Technologies:

Paul Vitt	Project Manager
Jason Smith	Performed booster, HPC, and turbine simulations

AP Solutions:

Tim Beach	Provided radial multiblock gridding support (APG)
Mark G. Turner	Consultant on compression and turbine simulations

AYT:

Rob Ryder	Consultant on combustion simulations

NASA Glenn Research Center:

John Adamczyk	APNASA turbomachinery flow code
Nan-Suey Liu	National Combustion Code (NCC)
Jeff Moder	NCC and APNASA code coupling
Le Tran	NCC and APNASA code coupling
John Gallagher	Combustor CAD geometry to grid generator interface
Don VanDrei	Task Manager
Joseph P. Veres	Manager Aircraft Engine Systems

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

	2000	2001	2002	2003	2004	2005	2006
ENGINE COMPONENT	Flow simulation: Fan, LP and HP compressors and turbines, combustor		Combustor simulation with finite-rate chemistry and gaseous fuel		Combustor simulation with finite-rate chemistry and liquid fuel	MD simulation: Fan, LP and HP compressors and turbines, combustor	
ENGINE SUB-SYSTEM	Sequential coupling of core engine components		Feedback coupling of core engine with torque balance			MD simulation of core engine with torque balance	
ENGINE SYSTEM		Feedback coupling of turbofan engine with torque balance, steady-state flow		Feedback coupling of turbofan engine with torque balance, unsteady fan flow		Multi-disciplinary coupling of turbofan engine components with torque balance	
PROPULSION AIRFRAME INTEGRATION			Sequential coupling of external flow code and unsteady turbomachinery flow code		Feedback coupling of external flow code and unsteady turbomachinery flow code	Feedback coupling of external flow and unsteady fan; transient NPSS turbofan engine simulation	

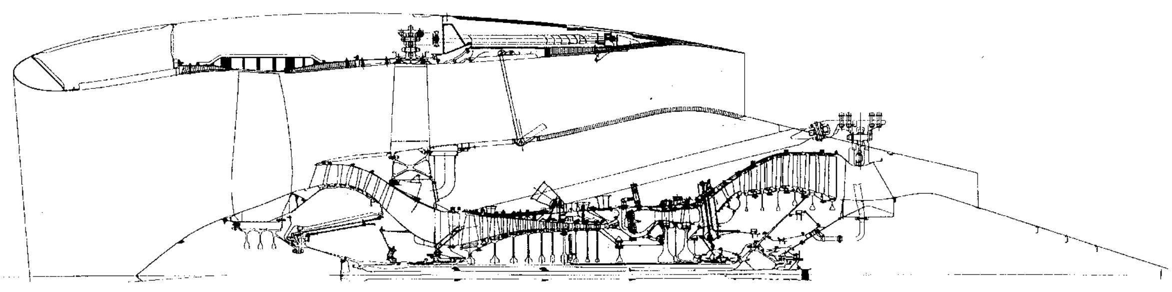
2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Milestones	Performing Organization	Plan Date
FY00		
1. Annular duct simulation with sequential coupling of APNASA and NCC	NASA	4Q00
2. Core engine simulation with sequential coupling of APNASA and NCC	NASA/DYNACS	4Q00
FY01		
3. Annular duct simulation with feedback between APNASA and NCC	NASA/DYNACS	1Q01
4. Core engine simulation with feedback between components and torque balance	NASA/DYNACS	2Q01
5. Full compression system simulation with fan, booster and HP compressor APNASA	APSolutions	2Q01
6. Full engine simulation with sequential coupling of turbomachinery and combustor	NASA/APSolutions	3Q01
7. Combustor simulation with finite rate chemistry and gaseous fuel (NCC Version 1.0)	NASA/AYT	3Q01
8. Engine airframe integration; sequential coupling of OVERFLOW and MSTURBO	NASA/MSU	4Q01
FY02		
9. Full engine simulation with feedback between turbomachinery and combustor	NASA/APSolutions	2Q02
10. Combustor simulation with finite rate chemistry and liquid fuel (NCC Version 1.0)	NASA/AYT	2Q02
11. Unsteady fan simulation modeled with MSTURBO coupled to NPSS V1.0 engine	NASA/MSU	3Q02
FY03		
12. Full engine simulation with feedback between components and torque balance	NASA/APSolutions	2Q03
13. Unsteady fan simulation angle of attack modeled with MSTURBO and OVERFLOW	NASA/MSU	4Q03
FY04		
14. Aircraft external aerodynamics sequentially coupled to unsteady fan and NPSS	NASA/MSU	3Q04

2000 NPSS Review

Detailed Flow Simulation of Aircraft Turbofan Engine



The high-bypass turbofan engine in this simulation effort consists of 49 blade rows

- Fan
- OGV
- 3-stage booster (7 blade rows)
- Fan frame strut
- 10-stage high-pressure compressor (21 blade rows)
- 2-stage high-pressure turbine (4 blade rows)
- Turbine mid-frame strut
- 6-stage low-pressure turbine (12 blade rows)
- Turbine rear frame strut

2000 NPSS Review

Detailed Flow Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

NASA and GEAE Developed APNASA Version 5 Featuring:

- 4-stage Runge-Kutta explicit Navier-Stokes solver
- Local time steps
- Implicit residual smoothing
- Implicit k-ε turbulence model
- Models multi-stage effects by calculating deterministic stresses with generalized closure
- Domain decomposition in axial direction
- Uses MPI message passing
- Radial and tangential multiblock with I-Grid
- Cooling and leakages handled by sources terms and endwall model
- Real gas (linear gamma) model in 3-D

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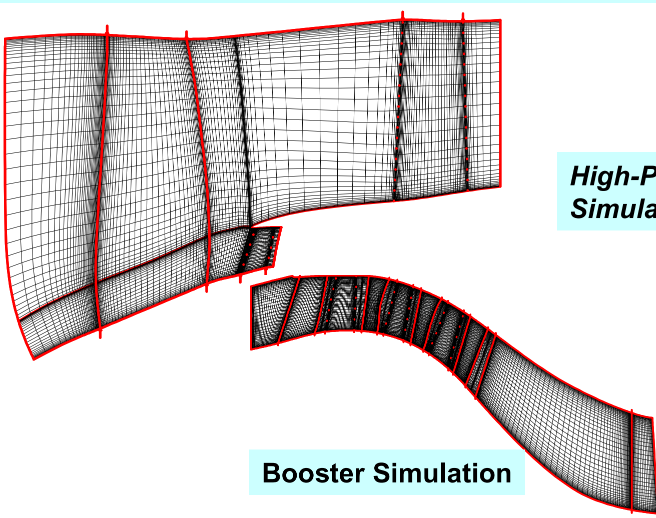
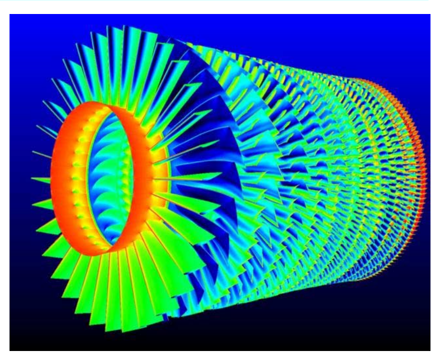
Detailed Flow Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations with APNASA

Simulation of Fan, Bypass Outlet Guide Vane and Booster Stator 1



High-Pressure Compressor (HPC) Simulation: Rig and Engine Conditions



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Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Critical Computing Capability for High-Pressure Compressor Simulations

- All high-pressure compressor (HPC) simulations used NASA NAS Origin 2000.
- In two-hour wall clock period, total of 320, 480, and 880 iterations can be achieved with 84, 104, and 208 processors.
- Typical 15000 iteration case requires about 93, 63, or 34 hours of wall clock time for 84, 104, and 208 processors, respectively.
- Parallel analyses set up with almost equal distribution of processors (i.e., 4, 5 or 10 per blade row).
- Excellent scaling for APNASA flow simulation between 104 and 208 processors.

HPCCP resources allowed many trials to be completed
in a reasonable amount of time even for a large 21 blade row case --
CRITICAL IN DEBUGGING AND DEVELOPMENT

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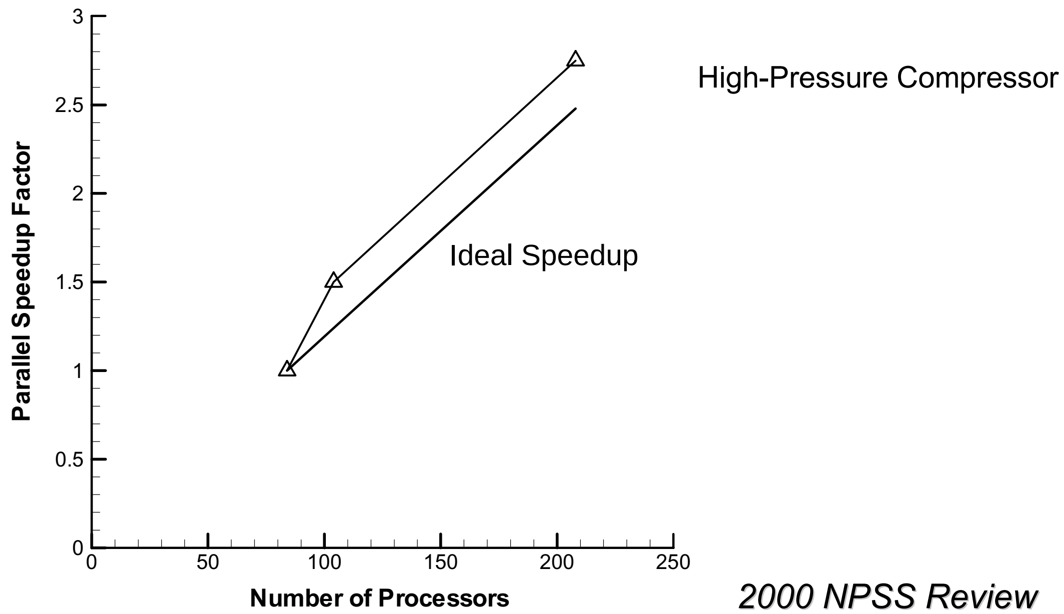
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Performance of APNASA on HPCC NAS Origin 2000 Machines



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Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: HP-LP Turbine Flow Simulation

Aspects of Turbine Simulations

•Transonic aerodynamics

High work HP turbines have strong shock systems.

•Embedded blade row operating conditions

Both upstream and downstream blade rows mutually interact during engine operation.

The average-passage equations actively include the effects of the surrounding blade rows.

•Turbine flight hardware is actively cooled

Airfoils, platforms and casing are cooled by compressor bleed air.

•Hot gas leaks around the tips of rotors through labyrinth seals

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Coupled Flow Simulation of High-Pressure / Low-Pressure Turbines Results in Efficiency Predictions Within 0.8 and 0.5 Percent, and Shock Interaction Loss Predicted Within 0.5 Percent

A computer simulation of the air flow in the GE90 turbofan engine's high- and low-pressure turbines has been created at General Electric Aircraft Engines (GEAE). The 3-D computer simulation was performed using NASA Glenn's average-passage approach named APNASA. This is the first ever flow simulation of an HP and LP turbine, transition duct and exit guide vanes. The simulation was done using 121 processors of a Silicon Graphics Origin cluster with a parallel efficiency of 87% in 15 hours.

Analysis of the simulation has identified excessive turbine aerodynamic interaction losses that can be reduced by 50%. This 50% reduction in turbine interaction losses will result in a $3 million/year savings in fuel costs for a new fleet of aircraft. The parallel efficiency and accurate simulation with APNASA now make it practical for use in the design environment.

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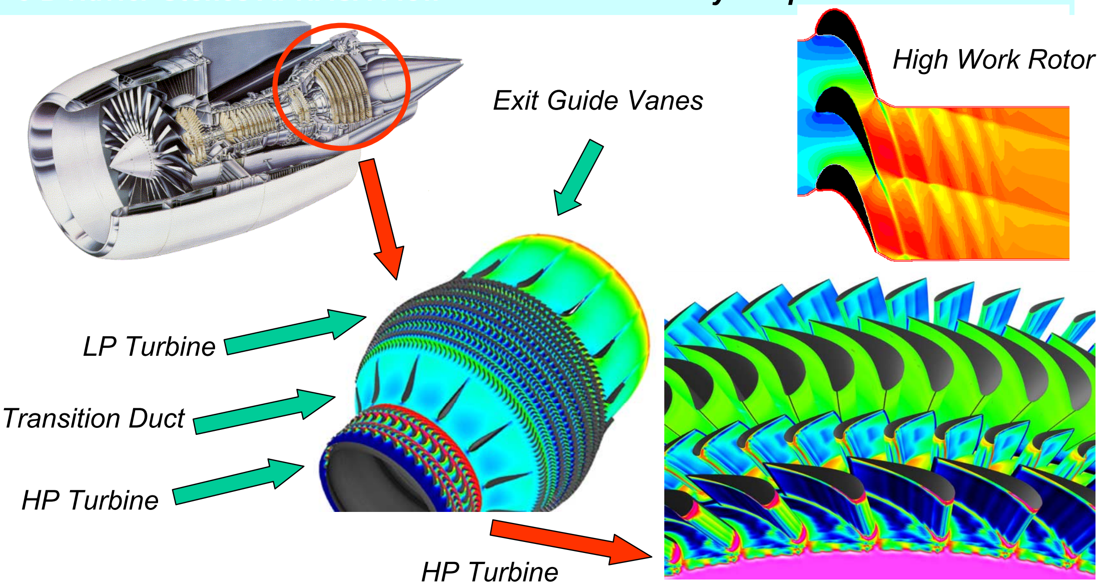
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery

3-D Navier-Stokes APNASA Flow Simulation of Closely Coupled HP-LP Turbines



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Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Processing Requirement for HP-LP Turbine Simulation

- Typical average-passage analysis mesh size for a given blade row
  - 280x45x55 ~ 700,000 grid points
- 10-18 blade rows for a combined HP and LP turbine system
  - 7 to 12.6 million grid points
- Design cycle requirements are 24 to 48 hour turnaround time
- Requires 6,000 to 10,000 iterations for convergence, at 8.x10E-05 seconds/iteration/gridpoint (NAS O2K)
  - Total CPU time will be 930 to 2800 CPU-hours (assuming 100% efficient multiple processor usage).
  - Parallel processing using 40 or more processors is required to meet the design cycle time constraints.

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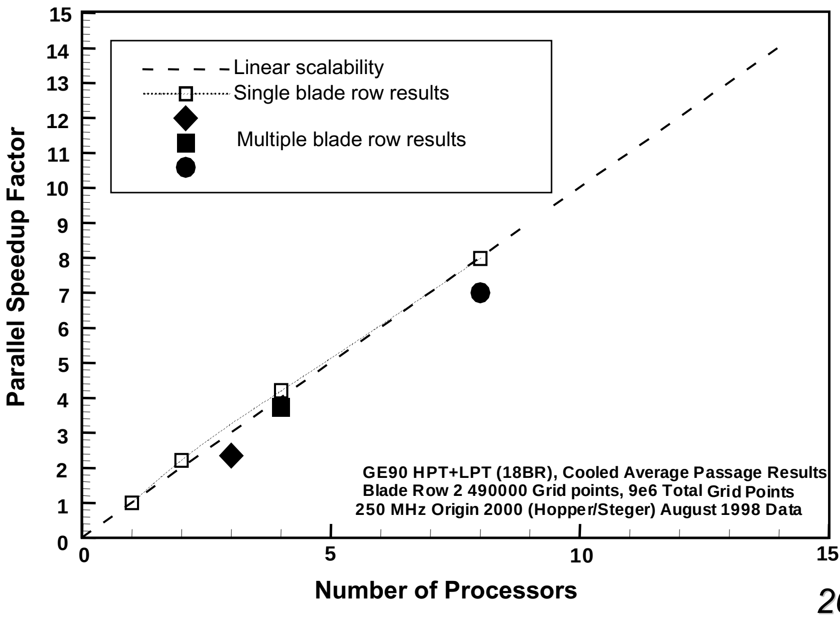
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Performance of APNASA on HPCC NAS Origin 2000 Machines



High-Pressure/
Low-Pressure Turbines

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

GEAE Conclusions: Turbomachinery Simulation

- Full engine simulation program has led to very useful component simulation capability and understanding of component interaction.
- Booster simulations with APNASA notably successful.
- High-pressure-ratio compressor (HPC) still a challenge for Version 5 of APNASA.
- HPCCP resources **extremely** useful for debugging and validating code for high-interest problems at GE.
- Quick demonstrated turn-around time allows APNASA code to be used for analysis in a design environment.

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

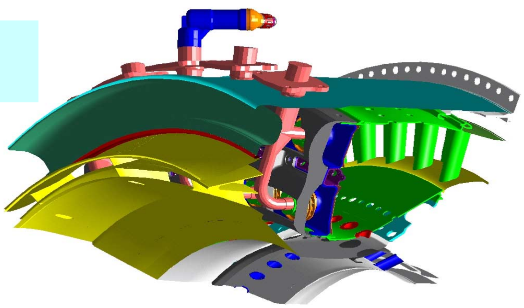
GEAE Recommendations for Future Direction

- Pursue coupled simulation of combustor (NCC or other combustion code) and high-pressure turbine (HPT) with the APNASA turbomachinery flow code.
- Demonstrate successful component simulations (e.g., full compression system) before attempting to simulate full engine.
- Pursue component simulations at off-design conditions.
- Investigate better ways to start simulations and achieve faster *multistage* convergence.
- Pursue large-scale, multistage unsteady simulations to support NPSS activities.

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

National Combustion Code (NCC)



Objective

Develop an integrated system of codes for combustor design and analysis to enable significant reduction in design time and cost.

Approach

- Develop a comprehensive modeling and simulation capability in NCC.
- NCC features a Navier-Stokes flow solver based on an explicit four-stage Runge-Kutta scheme.
- Unstructured meshes.
- Run in parallel on networked workstation clusters.
- The solver can be linked to any CAD system via Patran file system.
- Simulate the turbulent combustion in a modern turbofan engine's combustor - GE90.

Significance/Metrics

- Enable the multidisciplinary analysis of combustors from compressor exit to turbine inlet.
- NCC is a key component of the NPSS.
- Significant reduction in turnaround time enables using NCC in a design environment.

Point of Contact

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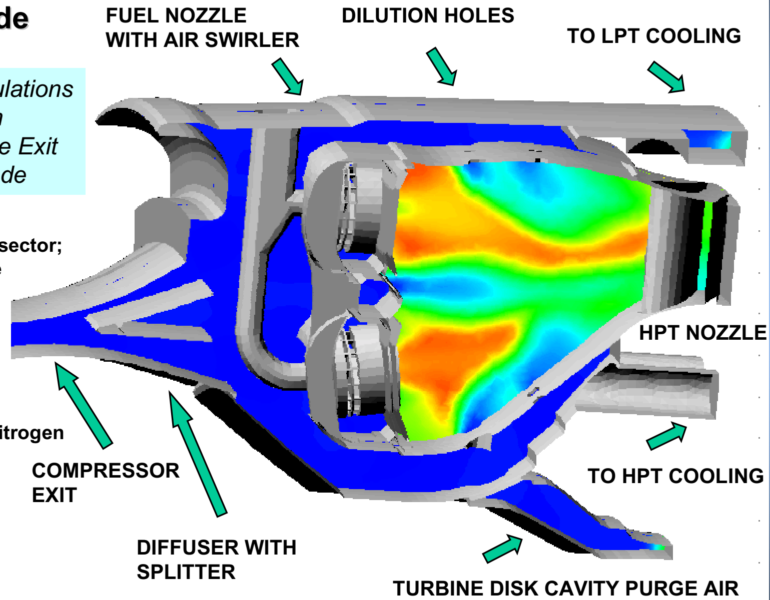
2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

Hot-Flow 3-D Full Combustor Simulations Were Successfully Performed from Compressor Exit to the HPT Nozzle Exit Using the National Combustion Code



Combustor model configuration: 24 degree sector; 1 compressor strut; 4 fuel nozzles; 3 turbine nozzle vanes
Computational domain size: 700,000 tetrahedral elements

3-D aerodynamics, k-e turbulence with wall functions, 4 chemical species fuel oxygen nitrogen and products of combustion
1-step eddy breakup combustion model (fuel + oxygen = products of combustion)

20,000 iterations to convergence consumes 1/2 gigabyte of RAM
- **Single processor Pentium PC 550 MHz: execution time, 22 days**
- **28 processor NAS Origin workstation cluster: execution time, 1 day**

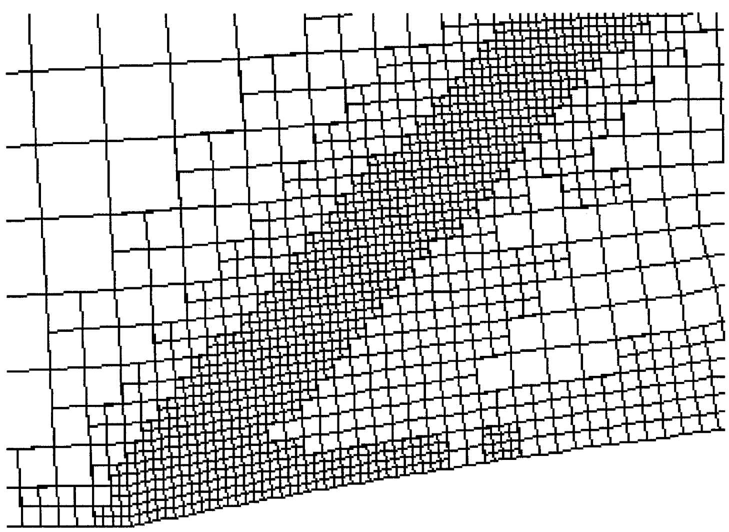
2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

NCC Exploring Mesh Adaptation for Improved Resolution

Four Levels of Adaptation



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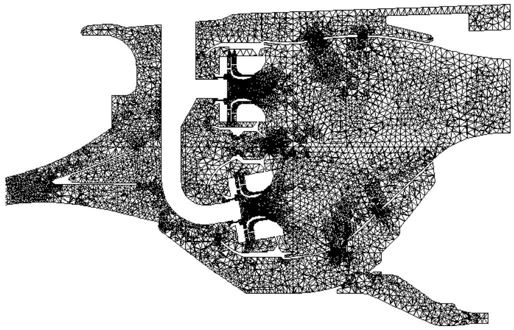
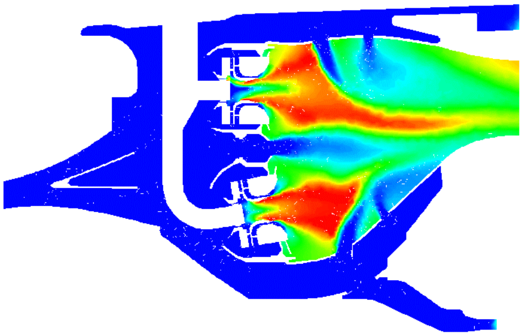
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

Exploring 3-D Mesh Adaptation on Pressure Gradient for Efficient and Better Flow Resolution with Minimal Impact on Execution Time





3 adaptations on pressure gradient, 20,000 iterations on single processor Pentium PC 550 MHz

Mesh Adaptations	Tetrahedral Mesh Size	Execution Time	Accumulative Execution Time
Baseline mesh	700,000	22 days	22 days
First adaptation	1,500,000	1 day	23 days
Second adaptation	2,500,000	1 day	24 days
Third adaptation	3,200,000	1 day	25 days

Total CPU time for 3,200,000 tetrahedral mesh adapted case = 25 days execution time

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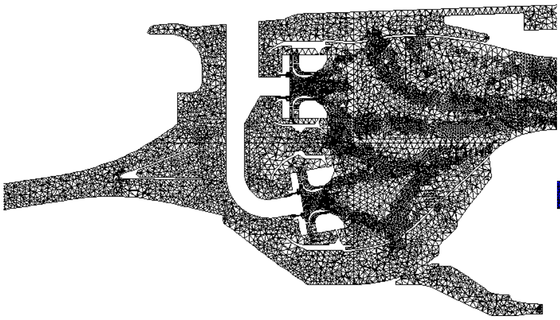
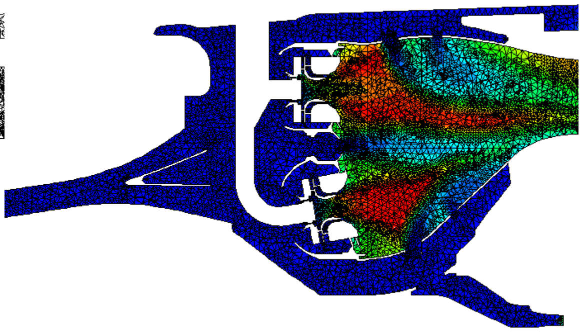
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

1 Level Mesh Adaptation on Pressure, Temperature and Speed Gradients





Base mesh: 720,000 tetrahedral elements
Adapted mesh: 1,760,000 tetrahedral elements

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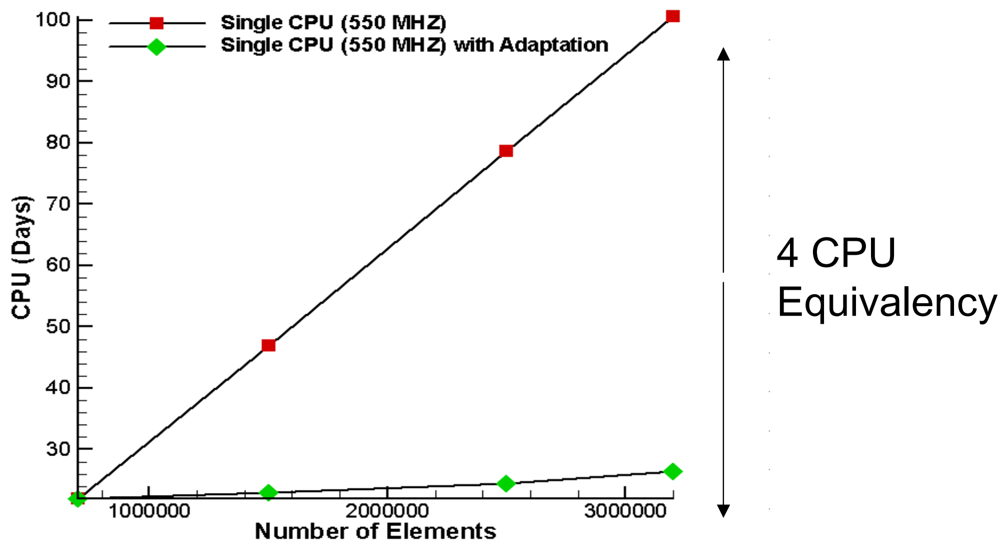
Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

NCC Exploring Mesh Adaptation to Improve Resolution and Reduce Overall Turnaround Time



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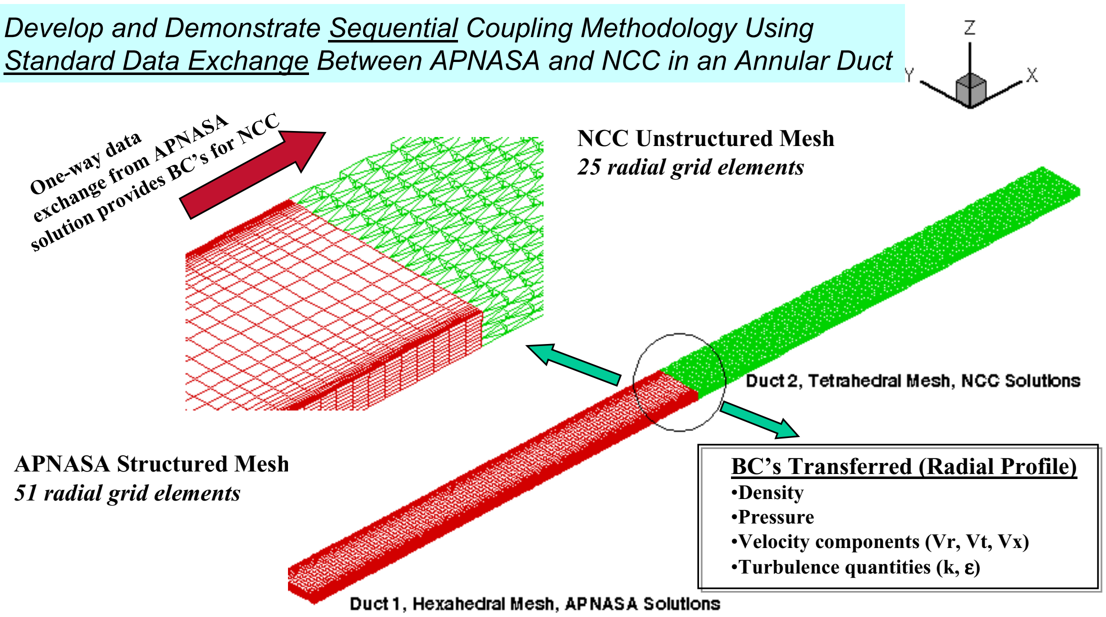
Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Develop and Demonstrate <u>Sequential</u> Coupling Methodology Using <u>Standard Data Exchange</u> Between APNASA and NCC in an Annular Duct



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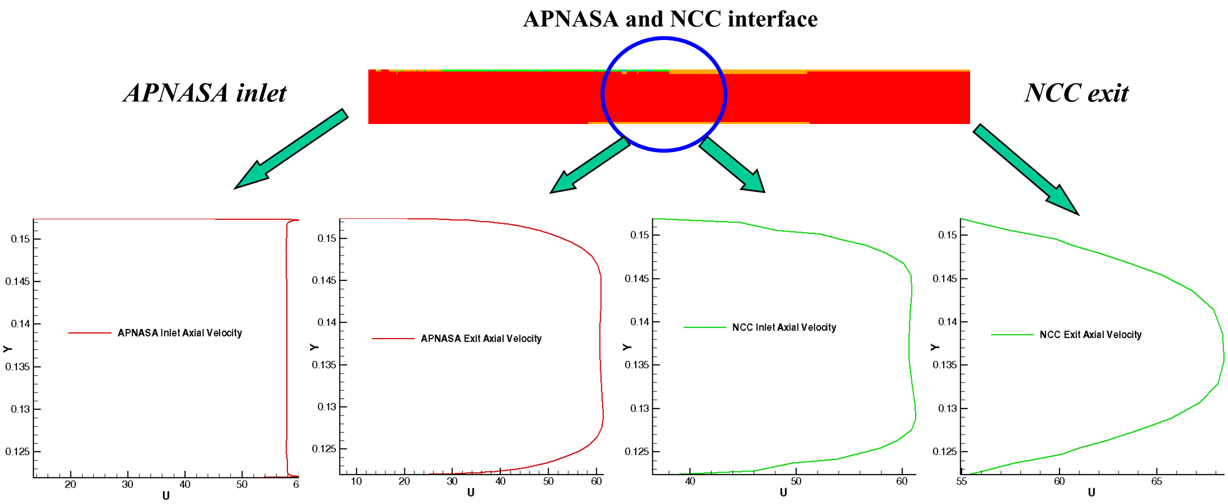
Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Developed and Demonstrated Sequential Coupling Methodology Using Standard Data Exchange Between APNASA and NCC in an Annular Duct



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Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Developed Standard Data Exchange Coupling Methodology

This format will be used by both APNASA and NCC to pass FACE-based flow variables data across the interface plane between APNASA and NCC grids, for annular geometries. This data represents the radial profile (with Nr radial points) of azimuthally averaged data across the interface plane, where the normal to the interface plane is in the axial direction. Note that NCC and APNASA computational grids do not need to match since only radial profiles are being exchanged. This format will also be used for uncoupled test runs to provide inlet and exit BCs, and to compare solutions (between NCC and APNASA) at any desired axial locations.

```
Pref_AP  Tref_AP  Lref_AP  Gasc_AP
Nr
Xhub  Rhub
Xtip  Rtip
span  p  rho  rho_Vx  rho_Vr  rho_Vt  k  ep (point 1)
span  p  rho  rho_Vx  rho_Vr  rho_Vt  k  ep (point 2)
.
span  p  rho  rho_Vx  rho_Vr  rho_Vt  k  ep (point Nr)
```

File Names:
ap_inlet.profile (standard exchange file at inlet, from APNASA)
ap_exit.profile (standard exchange file at exit, from APNASA)
ncc_inlet.profile (standard exchange file at inlet, from NCC)
ncc_exit.profile (standard exchange file at exit, from NCC)

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Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

The velocity components are the cylindrical coordinates components

Vr = radial
Vt = azimuthal
Vx = axial

where (r, t, x) is a LEFT-handed cylindrical coordinate system; that is, (where er, et and ex designates the unit vector in the radial, tangential and axial directions):

et x er = ex (instead of the usual right-handed system of er x et = ex)

(Said another way, theta (azimuthal coordinate) increases in the counterclockwise direction looking in the positive axial direction.)

The variables Xhub,Rhub, Xtip,Rtip, span and all flow variables are non-dimensional.

Pref_AP = reference pressure in units of psi {lbf/(in^2)}

Tref_AP = reference temperature in units of R {Rankine}

Lref_AP = reference length in units of in {inches}

Gasc_AP = gas constant, Rgas, in units of ft^2/s^2/R
(= 1716.48 ft^2/s^2/R for air)

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Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

Below is what NCC does to convert this data to dimensional data in SI units.

Convert to desired units:

Pref = Pref_AP * Pfac
Lref = Lref_AP * Lfac
Tref = Tref_AP * Tfac
Gasc = Gasc_AP * Gfac
Gasc_Tref = Gasc*Tref
= Gasc_AP*Tref_AP * Lfac*Lfac

For SI calculations (NCC), use
Pfac = 6894.72 Pa/psi
Lfac = 1.0ft/12in * 0.3048 m/ft
Tfac = 1./1.8 = 5./9. = 0.55555556
Gfac = Lfac*Lfac/Tfac = 0.16722547

NOTE: Rtip > Rhub should always be true
Xtip = Xhub must currently be true since coding assumes plane normal = x-dir

(For APNASA, Pfac = Tfac = Lfac = Gfac = 1)
Xhub_dim = dimensional Hub axial location
= Xhub * Lref

Rhub_dim = dimensional Hub radius
= Rhub * Lref

Xtip_dim = dimensional tip axial location
= Xtip * Lref

Rtip_dim = dimensional tip radius
= Rtip * Lref

2000 NPSS Review

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

span = percent of radial span between hub and tip, where 0=hub and 1=tip

r = radial location of each data point (dimensional)
= (span * (Rtip - Rhub) + Rhub) * Lref

Xo_dim,Yo_dim,Zo_dim = Cartesian coordinates of r=0
assuming the axial direction (in APNASA) corresponds to the +x direction (in NCC)

Xo_dim = Xhub_dim = Xtip_dim always
Yo_dim = 0 always
Zo_dim = 0 always

Rhoref = reference density
= Pref/(Gasc_Tref)

Vref = reference speed
= sqrt(Gasc_Tref)

Kref = reference turbulent kinetic energy
= Vref*Vref

Epref = reference turbulent specific dissipation
= Vref**3/Lref

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Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

p_dim = dimensional static pressure
= p * Pref

rho_dim = dimensional mass density
= rho * Rhoref

Vx_dim = dimensional axial velocity component
= rho_Vx/rho * Vref

Vr_dim = dimensional radial velocity component
= rho_Vr/rho * Vref

Vt_dim = dimensional azimuthal velocity component (left-handed)
= rho_Vt/rho * Vref

k_dim = dimensional turbulent kinetic energy
= k * Kref

ep_dim = dimensional turbulent specific dissipation
= ep * Epref

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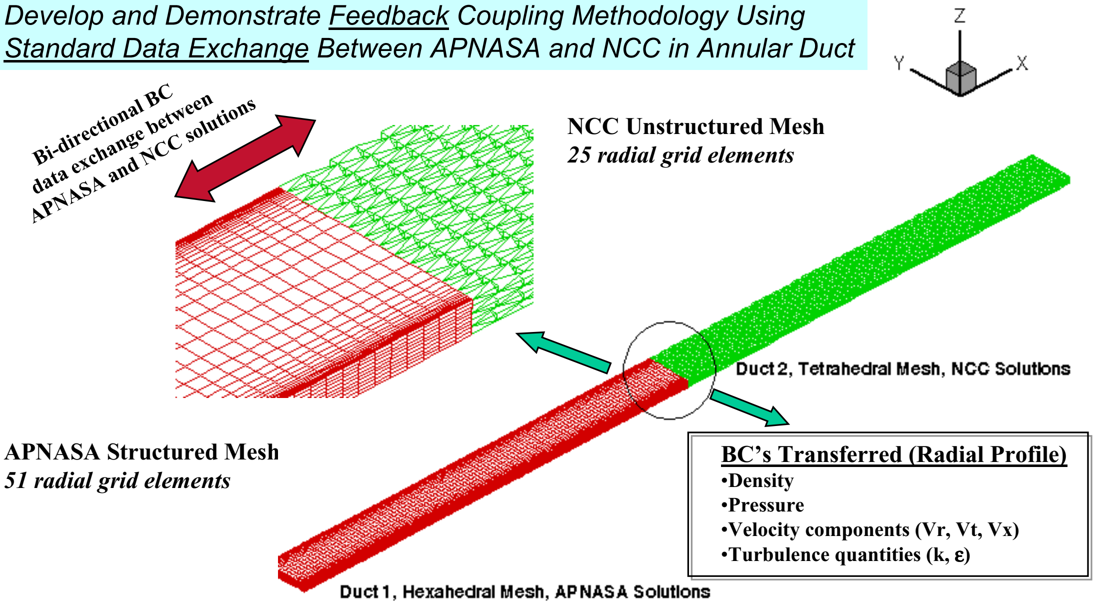
Detailed Simulation of Aircraft Engine

FY01 Plans: Coupling of APNASA and NCC

Develop and Demonstrate Feedback Coupling Methodology Using Standard Data Exchange Between APNASA and NCC in Annular Duct



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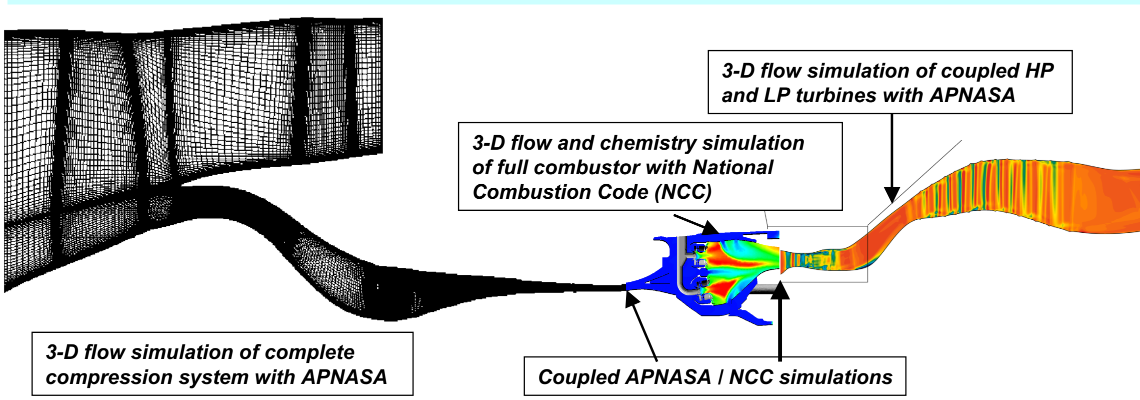
Detailed Simulation of Aircraft Turbofan Engine

FY01 Plans: Coupling of APNASA and NCC

1. *Demonstrate sequential and feedback coupling between APNASA turbomachinery code and NCC.*
2. *NCC combustor simulation with finite rate chemistry.*
3. *Core engine simulation with APNASA and NCC with finite-rate chemistry and torque.*
4. *Full engine model; coupled APNASA turbomachinery simulation to NCC model of combustor.*



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NPSS Multidisciplinary Integration and Analysis

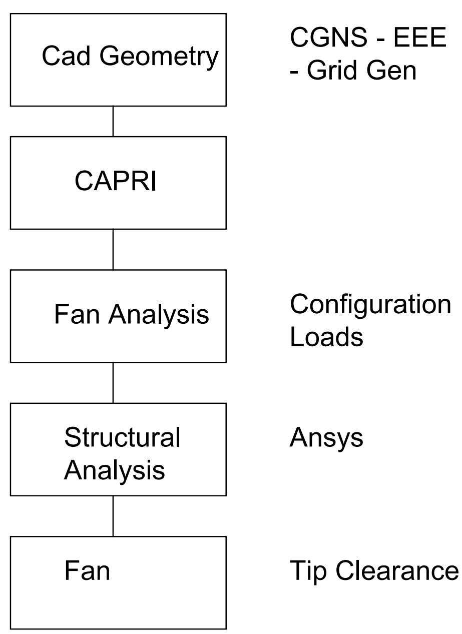
NASA Contract NAS3-98003
Task Order #5

NPSS Review 2000
NASA Glenn Research Center
October 4, 2000

2000 NPSS Review

Initial Task Discussions

- Prototype integration of MD (3-D aero ST2) analysis into NPSS architecture.
- Implement on 1) Linux, 2) NT in IPG environment.
- Define limitation of CGNS standard.
- Define limitations of CAD API when integrating geometry and analysis.
- Explore/define inclusion of probabilistic analysis.



EEE - Energy Efficient Engine
MD - Multidisciplinary

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Multidisciplinary Integration and Analysis

- Objective
  - The objective of this task order is to enhance the NPSS core capabilities by expanding its reach into the high-fidelity multidisciplinary analysis area. The intent is to investigate techniques to integrate structural and aerodynamic flow analyses, and provide benchmark by which performance enhancements to NPSS can be baselined.
- Approach
  - Couple high-fidelity aerodynamic and structural/thermal analysis codes to enable multidisciplinary evaluation of NPSS components.
- Strategy for Success
  - Data processing elements employ standard interface definitions to ensure commonality and modularity.
    - CGNS - CFD General Notation System (CFD standard)
    - CAPRI - CAD data access API (Geometry interface standard)

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Participants in Prototype

- Ed Hall/Joe Rasche - Rolls Royce Corporation (ADPAC, ANSYS)
- Al Magnuson - The ICEM CFD Company (CAPRI, CGNS) interfaces
- Shantaram Pai - NASA Structures Branch (NESSUS/NESTEM)
- Scott Townsend (Executive, CORBA Wrapping)

ADPAC - Advanced Ducted Propfan Analysis Code

NESSUS - Numerical Evaluation Stochastic Structure Under Stress

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Program Technical Elements

- Develop a high-fidelity analysis to calculate the effects on performance of
  - •Variations in tip clearance
  - •Guide vane scheduling
  - •Uncertainty in manufacturing tolerances
  - •Effects of rotational speed on the hot running geometry
- Enable calculation of blade deformations between the ADPAC aero analysis and an ANSYS structural analysis.
- Convert ADPAC to use CAPRI library for geometry analysis.
- Determine whether the CGNS standard can represent ADPAC I/O data.
- Incorporate probabilistic analysis (NESTEM/NESSUS) into ADPAC predictions of performance (link the necessary input/output data required to couple aerodynamic, structural, and probabilistic analysis programs).
- Report performance measurements (speedup and scalability) on the HPCC testbeds. Maintain 80% parallel efficiency.
- Estimate the impact of the new methods on the reduction in engine design or development time relative to a 1997 baseline.

HPCC - High Performance Computing and Communication

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Development Milestones

- Hot to Cold Coordinate Conversion
  - Extract cold manufacturing coordinate database based on desired hot running design shape.
- Cold to Warm Coordinate Conversion
  - Develop automated off-design airfoil shape based on off-design speed and aero loads.
- Incorporate Probabilistic Method
  - Produce statistical variations in airfoil coordinates.
  - Automate CFD performance variation estimates based on statistical airfoil variations.

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Developmental Notes

- Starting with a 3-D fan blade to gain an understanding of the interface issues (data requirements, dependencies, etc.).
- Start ADPAC with a cold geometry and get it up to normal operating conditions, transfer info to Scott so he can examine the I/O.
- ANSYS 5.4 start with a 3-D brick element, ANSYS pressures and temperatures will be passed to NESSUS/NESTEM.
- APNASA is currently integrated with NESSUS/NESTEM.
- Phase 1: Hardwire model together.
- Phase 2: CORBA wrapped components.
- Completed by 10/1/01.

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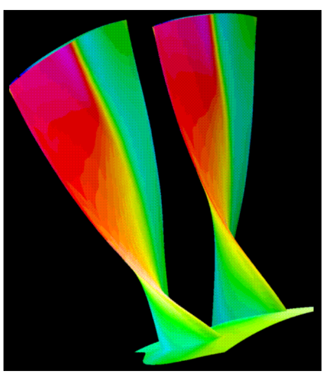
Aero/Structural Coupling



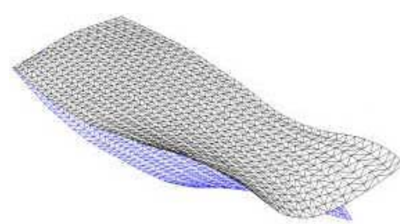
ADPAC CFD Analysis

Input

Geometry, operating conditions

Output

Pressure, temperature



ANSYS Structural Analysis

Input

Geometry, operating conditions, pressure, temperature

Output

Deformations, stress

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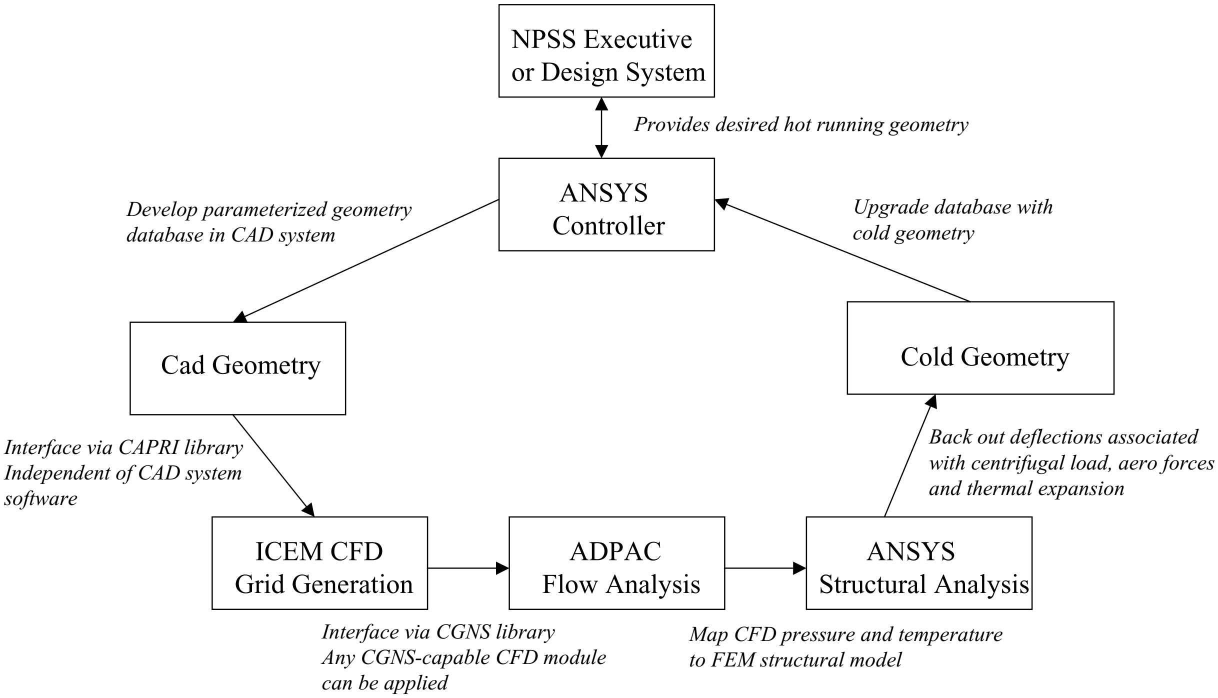
Hot to Cold Conversion



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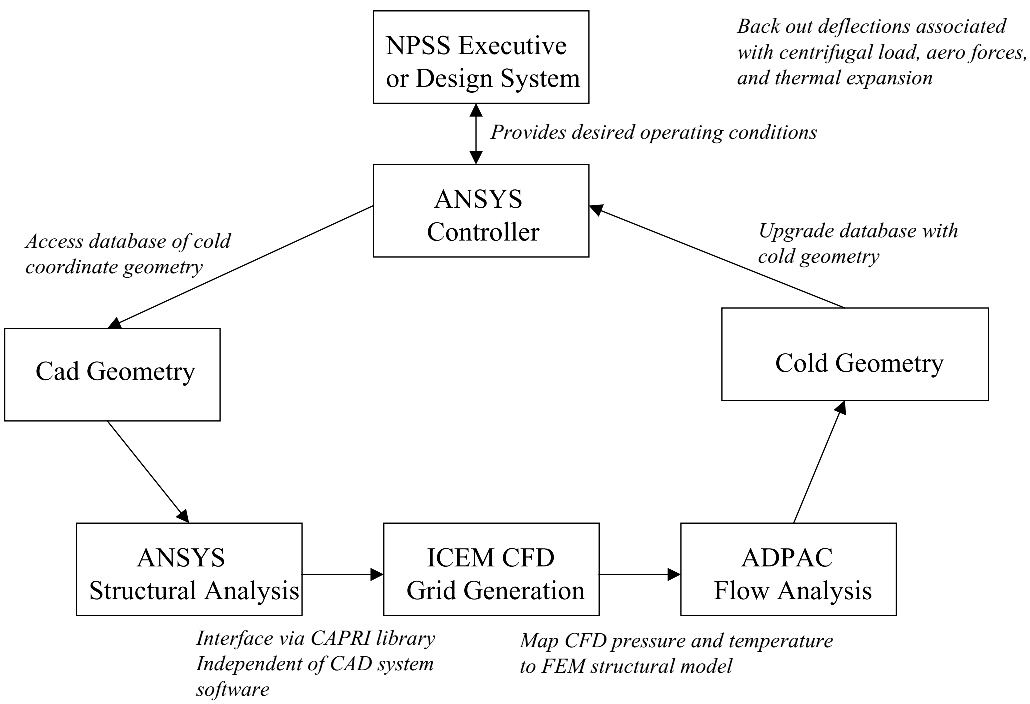
Cold to Lukewarm Conversion



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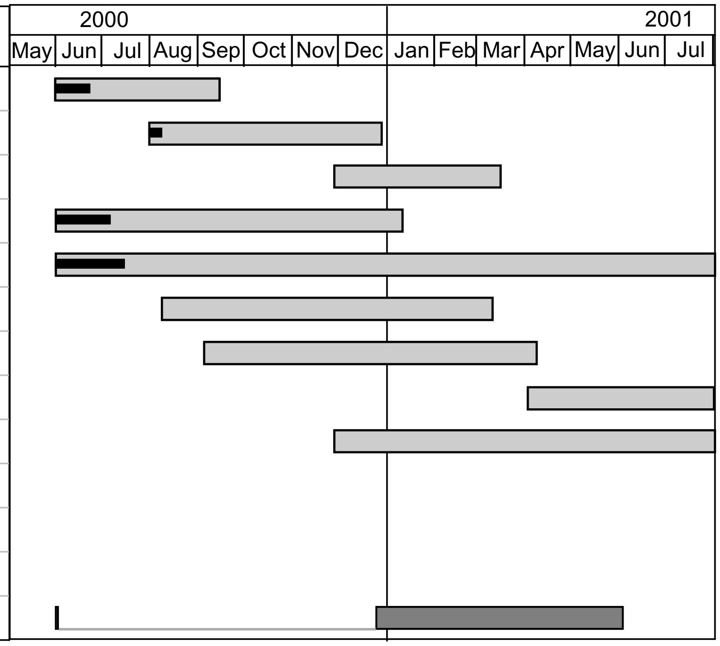
Schedule

ID	Task Name
1	Interface Coding
2	Hot/Cold Deflection Analysis
3	Cold/Warm Deflection Analysis
4	CAPRI CAD Interface
5	ADPAC CGNS Assessment
6	Tip Clearance Effect Analysis
7	NESTEM/NESSUS Integration
8	Probablistic Analysis
9	High Performance Computing Assessment
10	Reporting
11	
12	
13	



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2000 NPSS Review

NASA Glenn Research Center
October 4-5, 2000

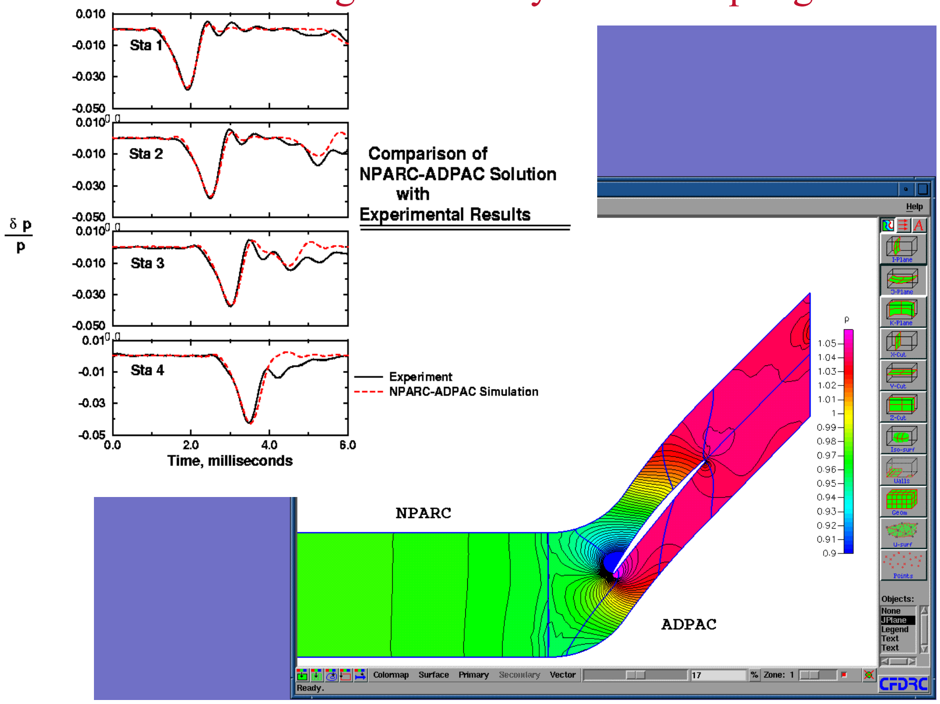
Space Transportation Propulsion Systems

Dr. Meng-Sing Liou
Dr. Mark E. Stewart
Dr. Ambady Suresh
Dr. A. Karl Owen

Outline

- Review of Engine/Inlet Coupling Work
- Background/Organization of Space Transportation Initiative
- Synergy between High Performance Computing and Communications Program (HPCCP) and Advanced Space Transportation Program (ASTP)
- Status of Space Transportation Effort
  - Planned Deliverables FY01-FY06
  - FY00 Accomplishments (HPCCP Funded)
  - FY01 Major Milestones (HPCCP and ASTP)
- Review Current Technical Efforts
  - Review of the Rocket-Based Combined-Cycle (RBCC)
  - Scope of Work
  - RBCC Concept Aerodynamic Analysis - Dr. Stewart
  - RBCC Concept Multidisciplinary Analysis - Dr. Suresh

Engine Inlet Dynamic Coupling



Normalized Static Pressure (Mid-Span)

ADPAC - Advanced Ducted Propfan Analysis Code
NPARC - National Program for Applications Oriented Research in CFD

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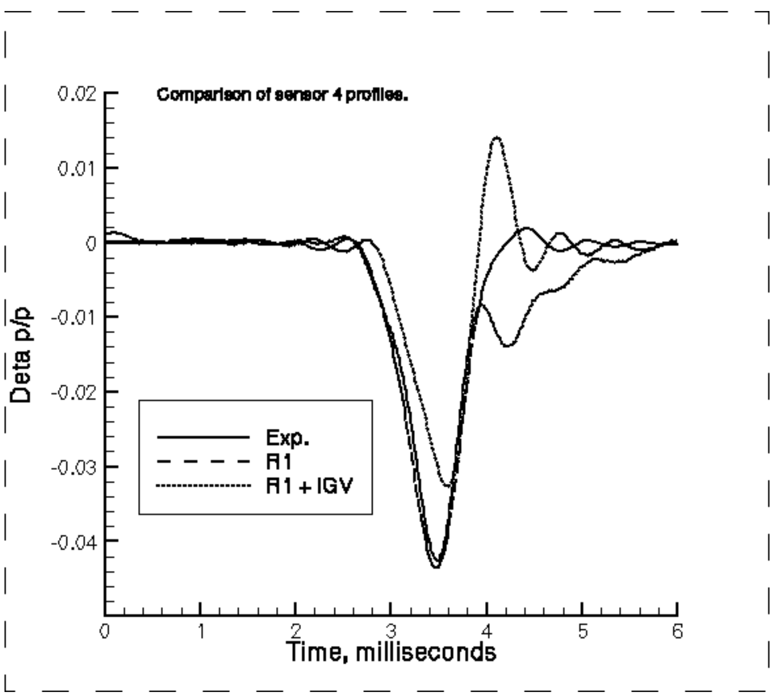
Results



- Additional blade row was modeled.
- Coupled using unsteady mixing plane technique.
- Simulation results not significantly improved.
- Current effort stopped, documented for possible future reopening.

R1 - Rotor 1
IGV - Inlet Guide Vane

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Space Transportation Initiative

2000 NPSS Review

Background

•Growing importance of advanced space transportation propulsion systems and simulations to support development & use of advanced space systems.
•Small space transportation simulation effort begun in FY00.
•Evaluation of advanced technologies by Advanced Space Transportation Program (ASTP) highlights importance of advanced system modeling capabilities.
•Computing and Interdisciplinary Systems Office (CISO) proposes for funding under second- and third-generation reusable launch vehicle projects.
 -Third-generation funds
 -Second-generation zeroed-out in FY01 budget

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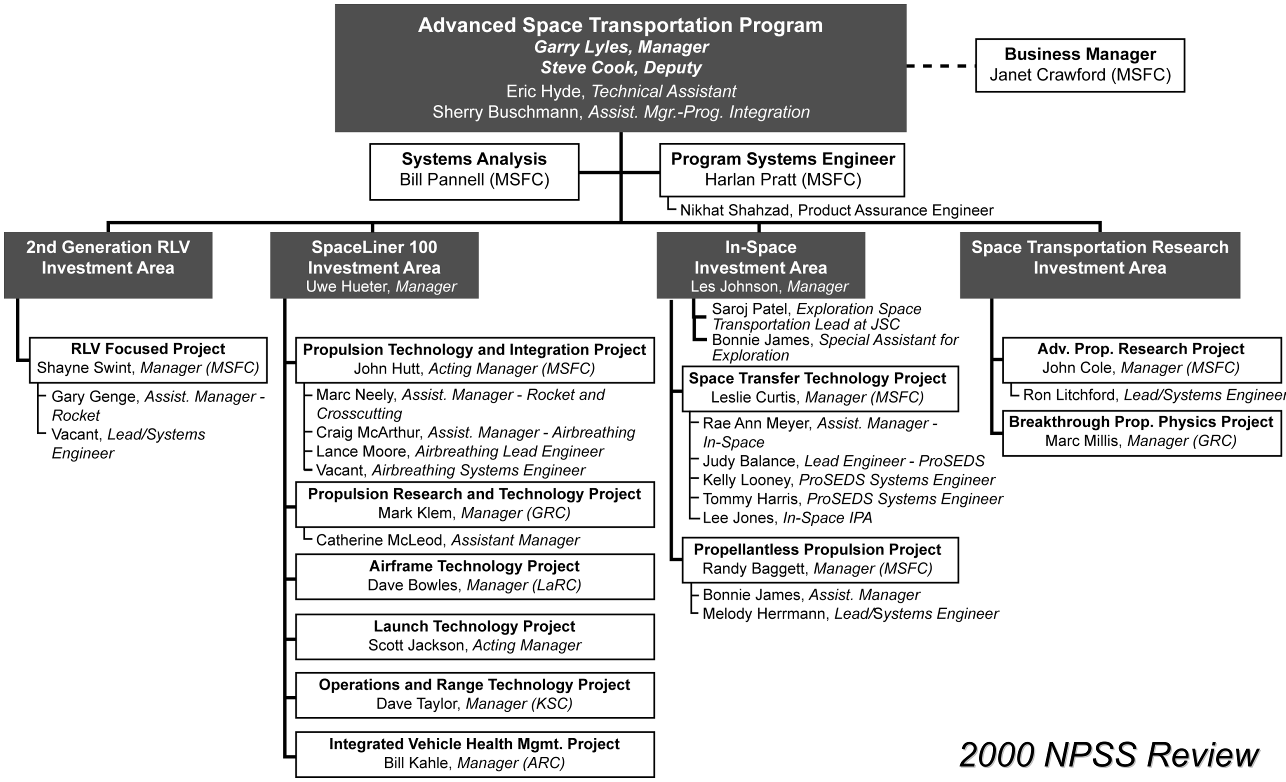
New ASTP Organization



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ASTP Propulsion Story

Second Generation

- **Currently cut out of budget by Congress**
- **Short-term focus – out to FY06**
- **Huge budget – ~$5B – hardware-oriented**
- **Four proposal cycles**
- **Industry-led – hope to team with industry**
- **Proposed under Cycle 2 – rocket sim. development – still under consideration**

Third Generation - SPACELINER100

- **Third-generation Spaceliner**
- **FY01 budget: $445M – foundations – $9.6M**
- **Mature base (foundation) technologies to enable broad range of concepts to meet Gen 3 goals (FY01-06)**
- **Mature rocket engine components to enhance T/W, performance, etc. (FY01-06)**
- **Mature air-breathing components for combined-cycle vehicle thru TRL 6**
- **Fund university studies to identify new concepts (other than rockets or air-breathers) to meet goal 9**

T/W - Thrust to Weight Ratio

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Synergy

- Third-generation reusable launch vehicle funding promised in FY01. Focus on system development:
  - Begin development of rocket engine system simulation
  - Begin development of RBCC system simulation
- HPCCP to focus on high-fidelity and multidisciplinary simulation and prototyping for coupling/zooming/optimization.
- Second-generation reusable launch vehicle funding possible in FY01.
- Future integration.

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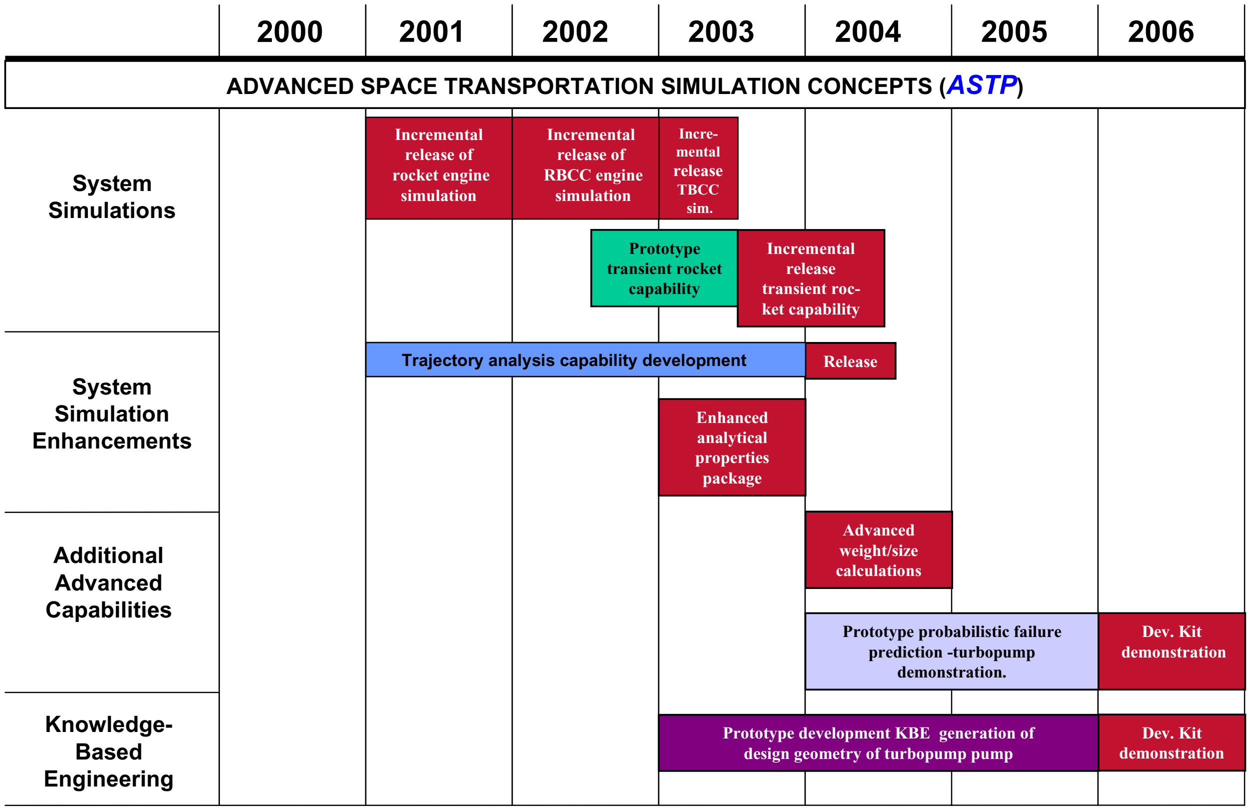
Space Transportation Initiative Major Deliverables

	2000	2001	2002	2003	2004	2005	2006
DEMONSTRATE INTEGRATED TECHNOLOGIES (*HPCCP*)							
RBCC Multi-Disciplinary Coupling	Structural-thermal analysis of GRC RBCC axisymmetric inlet GTX forebody and diverter aerodynamic analysis	Coupled aero-structural-thermal analysis of inlet Forebody simulation for radiation & skin thermal conductivity	Coupled multidisciplinary forebody/inlet demonstration	Dev. Kit tool release			
Pump Multi-Disciplinary Coupling		Uni-directional unsteady aero-structural pump prototype	Bi-directional unsteady aero-structural pump prototype	Bi-directional unsteady aero-structural pump production	Bi-directional unsteady aero-structural pump Dev. Kit tool		
Advanced Grid Generation		Beta release for robust hybrid grid code generator	Release grid code as a stand-alone package for Version 1	Grid generation production demonstration and enhancements			
Zooming					Demonstration of turbopump SS operation zoomed from NPSS rocket sim.	Demonstration of turbopump unsteady operation zoomed from NPSS rocket sim.	Dev. Kit demonstration of turbopump unsteady operation zoomed from NPSS

Space Transportation Initiative Major Deliverables



FY00 Accomplishments and FY01 Milestones

- Accomplishments
  - GRC RBCC concept forebody & boundary layer diverter capability demonstrated.
  - Coupled structural-thermal analysis of GRC RBCC inlet demonstrated.
  - SRS for space transportation incremental release.
  - Acting TFG for space transportation.

- Milestones
  - Coupled aero-structural-thermal analysis of inlet **(HPCCP).**
  - Modify CFD forebody simulation for radiation & skin thermal conductivity **(HPCCP).**
  - Incremental release rocket system simulation **(ASTP).**
  - Formal contractual mechanisms & cooperative agreements in place.
  - Space transportation SRS for Version 2 release.

SRS - Software Requirement Specification
TFG - Technical Focus Group

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Technical Effort: *Glenn Research Center RBCC Concept Support (HPCCP)*

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Motivations for and Scope of Work

Motivations

- **Requirements in support**
  - **Complex geometry**
  - **Physics**
  - **Accuracy**
  - **Efficiency**
  - **Robustness**
  - **Projects**
- **Improved multidisciplinary integration of fluid, thermal and structural analysis codes into current design cycles.**
- **Multidisciplinary analysis well suited to optimization of complete vehicle designs.**

Scope

- **Prototyping of high-fidelity and multidisciplinary coupling of simulations as a prelude to NPSS tool development.**
- **Reduction of analysis time.**
- **Detailed high-fidelity analysis of GRC RBCC concept (GTX).**

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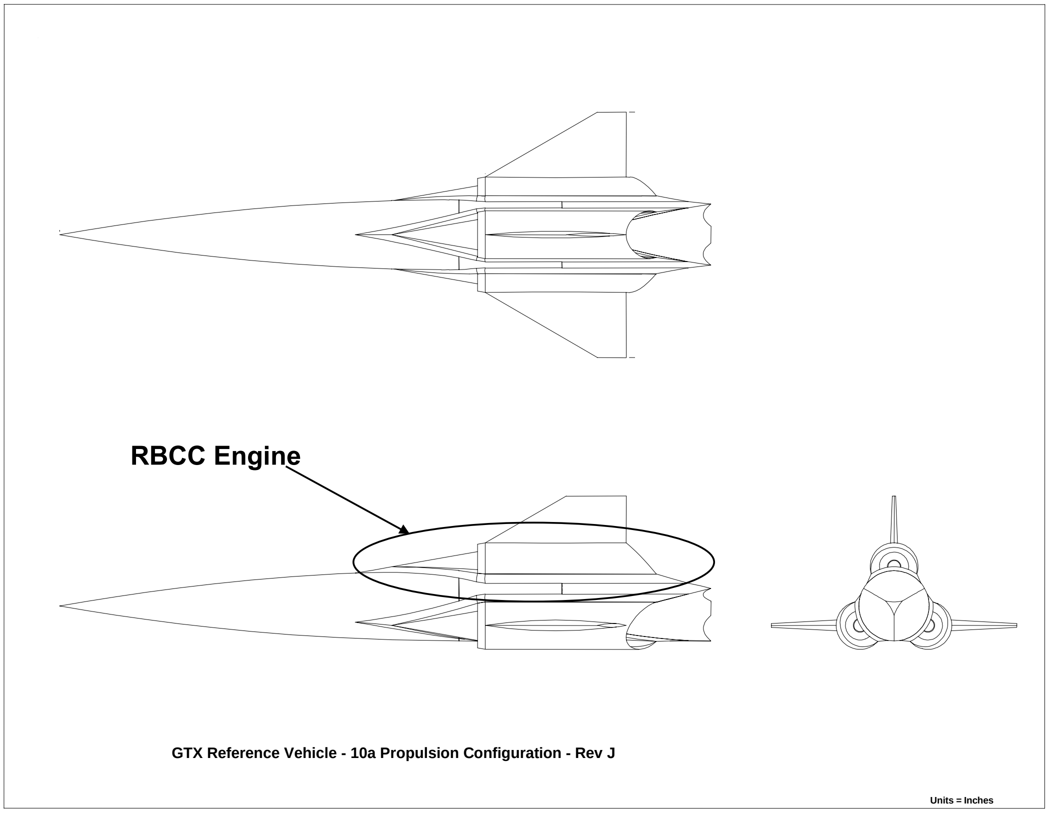
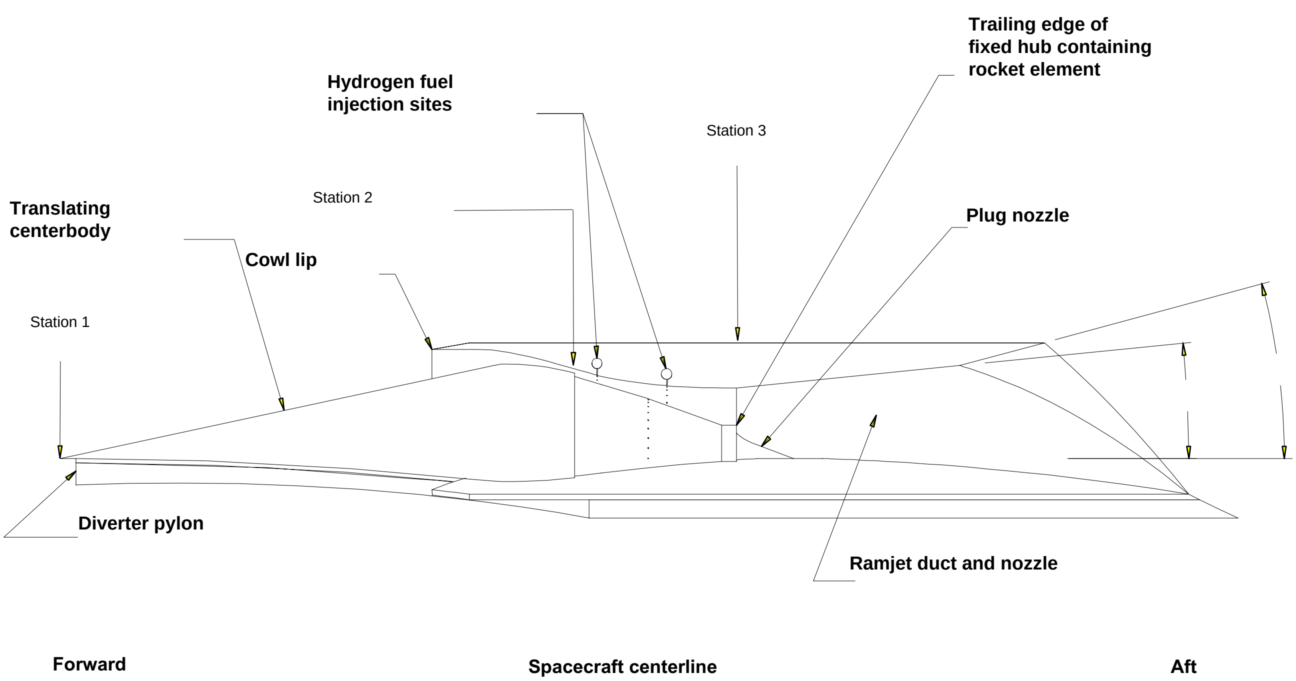


Rocket-Based Combined-Cycle (RBCC)



GRC RBCC 3-D Inlet-Forebody Aerodynamic Analysis

Dr. Mark Stewart

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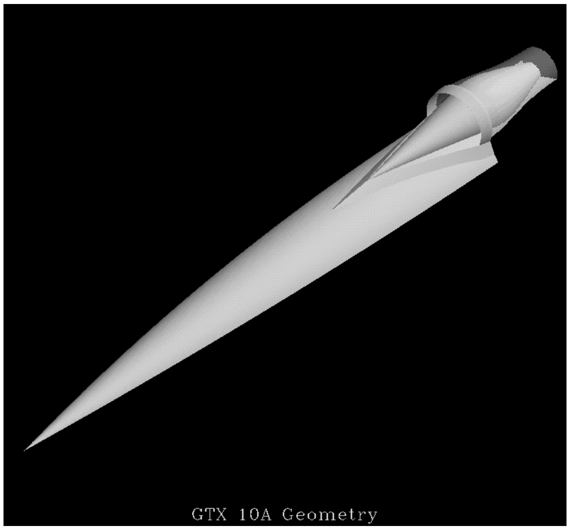
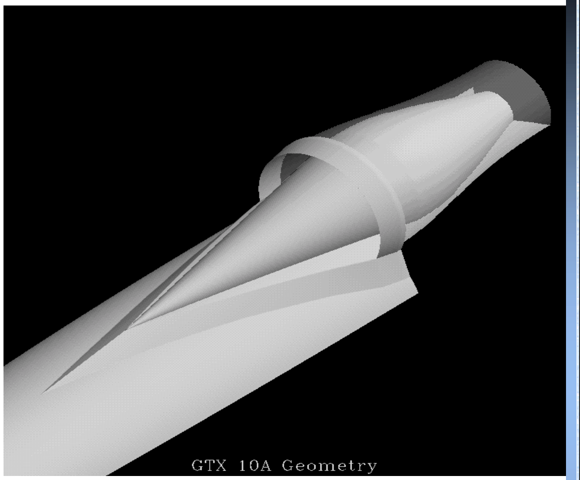
- RBCC, Single-Stage-to-Orbit
- Rocket and Air-Breathing RAM/SCRAM Modes
- Design Questions
  - -Diverter performance
  - -Forebody boundary layer's effect on inlet





•Design point: M=6; altitude=80,000 ft; AOA=4°; Re/ft=1.4×10^5
•Operating range of interest: M=2.5-10.; AOA=0°

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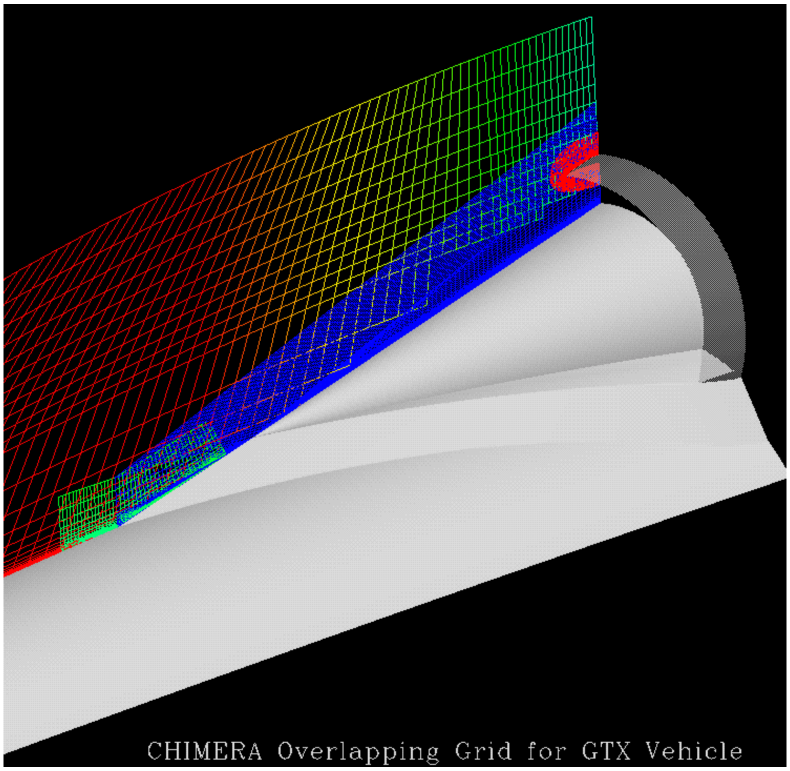

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Validation of CFD Solutions

- Comparison with Theoretical Properties
  - Axisymmetry
  - Y^+ values
- Comparison with Cone Shock Solutions
- Comparison with Rig 3.1 at AOA=0°; M=2.0, 2.5, 3.0, 3.5
  - Forebody boundary layer profiles
  - Forebody static pressure distribution
- Comparison with Independent CFD Solution

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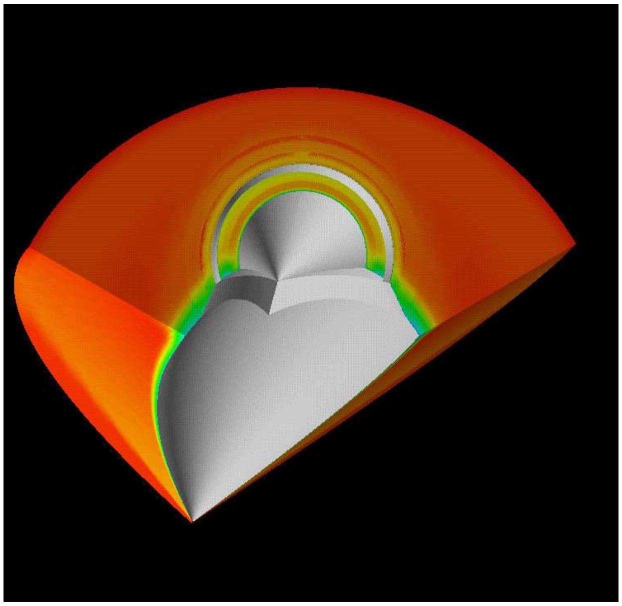
Observations



- Results suggest diverter design changes.
- Results clarify some rig results.

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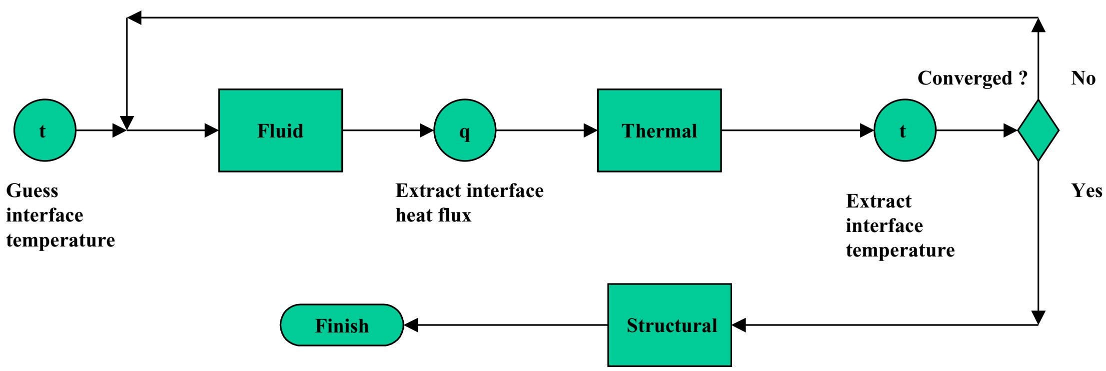
GRC RBCC Concept Multidisciplinary Analysis

Dr. Ambady Suresh

2000 NPSS Review

Multidisciplinary Coupling Procedure



1. Solve fluid (OVERFLOW) problem with a guess interface temperature.
2. Calculate heat flux at interface.
3. Solve thermal (ANSYS) problem with this heat flux loading.
4. Calculate temperature at interface and solve fluid problem again.
5. Once converged, solve structural (ANSYS) problem with pressures and temperatures as loading.

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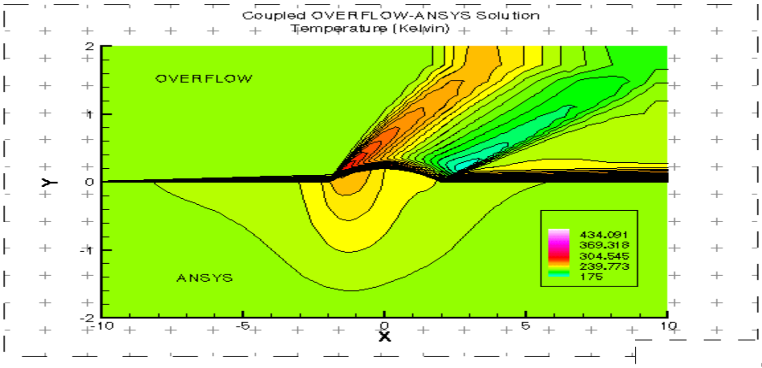
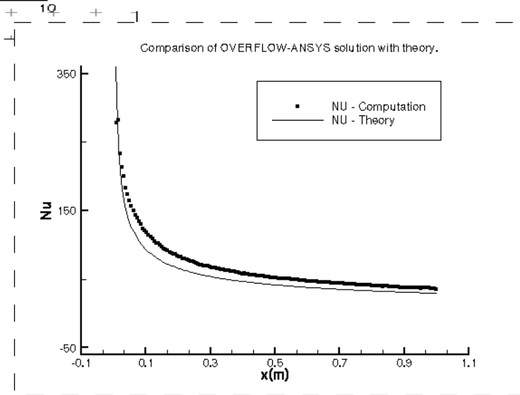
Technique Validations



Supersonic Flow Over a Bump



Conjugate Heat Transfer on a Plate

Nu - Nusselt Number

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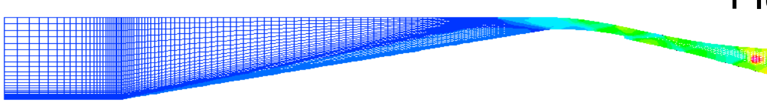
Axisymmetric Multidisciplinary Inlet Results

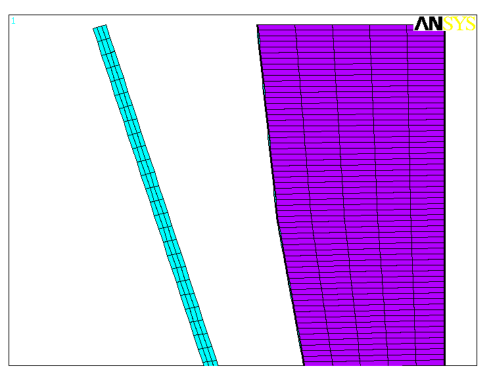


Fluid Grid & Solution

- •Overflow simulation
- •Structured grid

Thermal-Structural Grid

- •Ansys simulation
- •Structured grid



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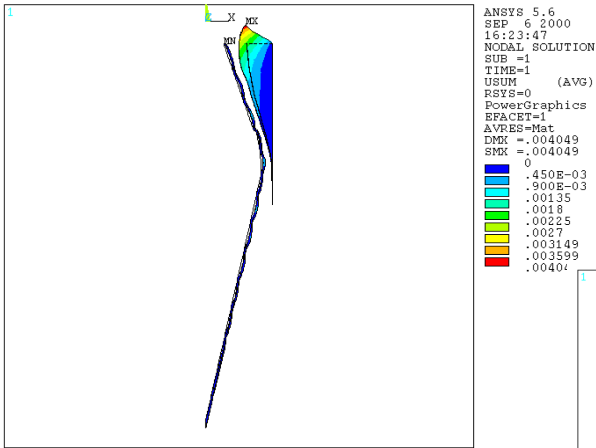
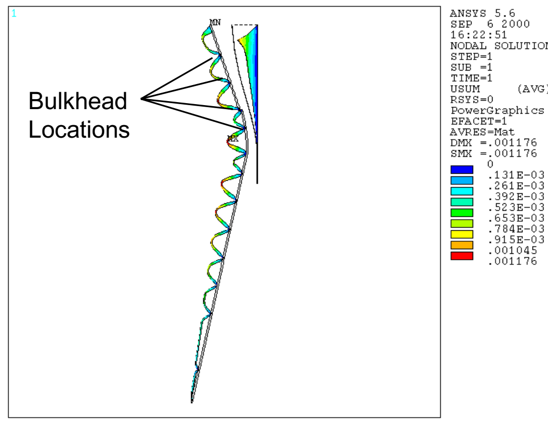
Axisymmetric Structural Results



Thermal-Structural Solution

Structural Solution



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Future Directions

- Couple the fluid and thermal-structural solutions.
- Improve GTX solution by modeling the external flow, better approximations for material properties and more realistic boundary conditions.
- Incorporate the coupling methods into the NPSS-CORBA framework for coupling between codes.

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Current Status and Future Plans

STATUS

- GRC RBCC Project
  - Aerodynamic simulation of forebody-inlet-diverter yielded significant impact on design of diverter.
  - Aero-thermal-structural simulation of inlet provided considerable insight on multidisciplinary simulations - difficulties and techniques.
- Code Enhancement
  - Added $AUSM^+$ flux scheme to the OVERFLOW code and validated, providing an accurate and efficient scheme for calculating flows at all speed regimes (AIAA 2000-4404).

PLANS

- NPSS
  - Incorporate lessons learned and release Dev. Kit coupling tool.
- GRC RBCC Project
  - 120-degree sector simulation.
  - Nose-to-tail conjugate multiphysics simulation.
- Development of an Efficient Grid Generation Methodology -- DRAGON Grid
- Code Enhancement
  - Full finite-rate chemistry.

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2000 NPSS Review

NASA Glenn Research Center
October 4-5, 2000

Testbed Developments and Code Parallelization

Isaac Lopez

Contents

- Milestones
- Accomplishments
- Running R4 fan application on the PII cluster
  - Comparison to other platform
- National Combustor Code speedup

Testbed Developments and Code Parallelization

	2000	2001	2002	2003	2004	2005
Code Parallelization		Achieve a 2.5-hour turnaround of a full compressor simulation using APNASA Achieve a three-hour turnaround of a full combustor simulation (1.3 million elements) Demonstrate a 100:1 reduction in turnaround time (relative to 1999) of the new parallel MSTURBO code (unsteady)	Demonstrate highly-parallel, distributed algorithms for aerospace propulsion applications		Demonstrate compressor code application using new highly-parallel, distributed algorithms	Demonstrate combustor code application using new highly-parallel, distributed algorithms
Testbed	Demonstrated a cost/performance ratio of 9.4 in favor of the commodity-based cluster (PII, 64 CPUs)		Demonstrate distributed engine simulation on NASA distributed testbeds (PIII, 128 CPUs; SGI Origin 2K)	Demonstrate 99% availability on distributed computing systems (P?, 128 CPUs; SGI Origin 2K)	Demonstrate propulsion application running in 4th generation of commodity-based cluster (P 64 bit?, 512 CPUs?)	

Accomplishments

- Demonstrated 9.4X cost/performance ratio on Pentium II cluster as compared to SGI Origin 2000.
- Demonstrated an application running over a WAN (GRC and LaRC) using LSF Multicluster software. LSF Multicluster is a tool similar to the functionality of Globus but only between sites using LSF.
- Demonstrated an AvSP application running on NASA IPG.
- Upgraded the Pentium II cluster to Pentium III. Added an additional 64 processors to the cluster.

WAN - Wide Area Network
LSF - Load Sharing Facility
AvSP - Aviation Safety Program
IPG - Information Power Grid

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Accomplishments

- Achieve a 6-hour turnaround time with NCC on a large-scale, fully reacting combustor simulation.
- A prototype of the parallel version of the MS TURBO code was released to NASA GRC for evaluation.
- Lattice Boltzmann model codes have been parallelized and tested on NASA Linux cluster. Close to 100% scalability has been achieved.

NCC - National Combustion Code

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Accomplishments

- Achieved an overnight turnaround (10.7 hours) of a full compressor simulation when using APNASA. This represents a 560:1 reduction in a full compressor simulation turnaround relative to a 1992 baseline.
- A paper concerning the parallel performance of the 3-D CE/SE codes was prepared and presented at the 1st Intl. Conference on CFD during July 10-14, 2000 in Kyoto, Japan. The 3-D code was run on from 1 to 256 processors.

CE/SE - Computational Element/Solution Element

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Pentium II Cluster "Aeroshark"

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Pentium II Cluster

- Hardware
  - 74 Pentium II 400MHz CPUs
  - 4 Pentium Pro 200 MHz
  - 18 GB RAM; 65 GB swap
  - 45 GB permanent user storage; 192 GB temporary storage
  - Gigabit ethernet & Fast ethernet
  - Debian Linux 2.2 Beta

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Pentium II Cluster

Computing Nodes

Hardware

- 2 Pentium II (Deschutes) 400MHz CPUs
- 512 MB RAM
- 2048 MB swap
- 8GB local disk
- Fast Ethernet
- Debian Linux 2.2 Beta

Software

- Portland Group Compilers V3.0
  - C, C++, F77, F90, HPF
- MPICH
- PVM3
- LSF
- Globus

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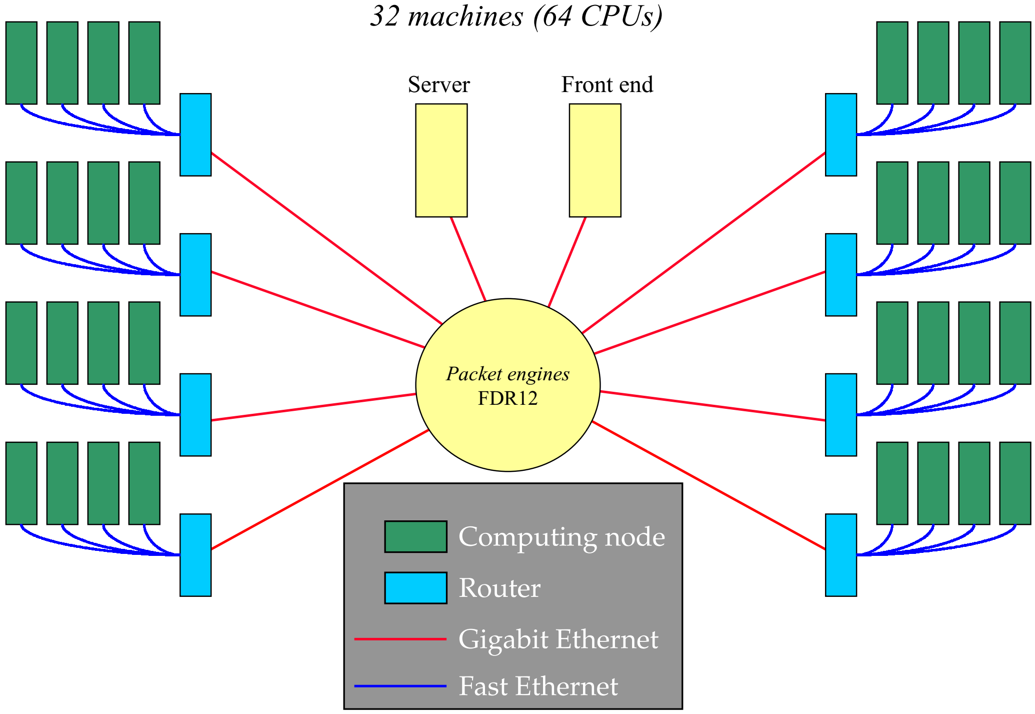
Pentium II Cluster Network Architecture

32 machines (64 CPUs)



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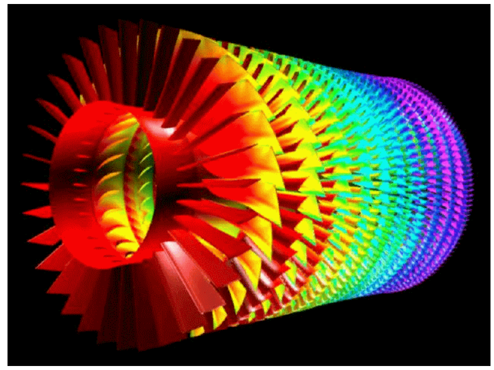
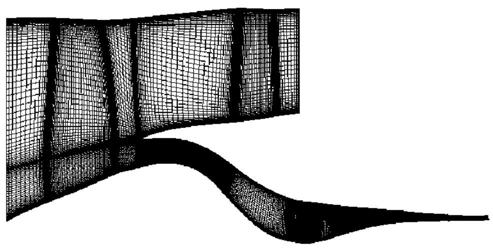
APNASA

APNASA is a computer code being developed by a government / industry team for the design and analysis of turbomachinery systems. The code is based on the average-passage model developed by John Adamczyk at the NASA Glenn Research Center.



Objective

- To develop a turbomachinery simulation capability that will provide a detailed analysis during the design process of gas turbine engines.



Significance

- The APNASA code can be used to evaluate new turbomachinery design concepts.
- When integrated into a design system, the code can quickly provide a high-fidelity analysis of a turbomachinery component prior to fabrication. This will result in a reduction in the number of test rigs and lower development costs.
- Either APNASA or the methodology on which it is based has been incorporated into the design systems of six gas turbine manufacturers.

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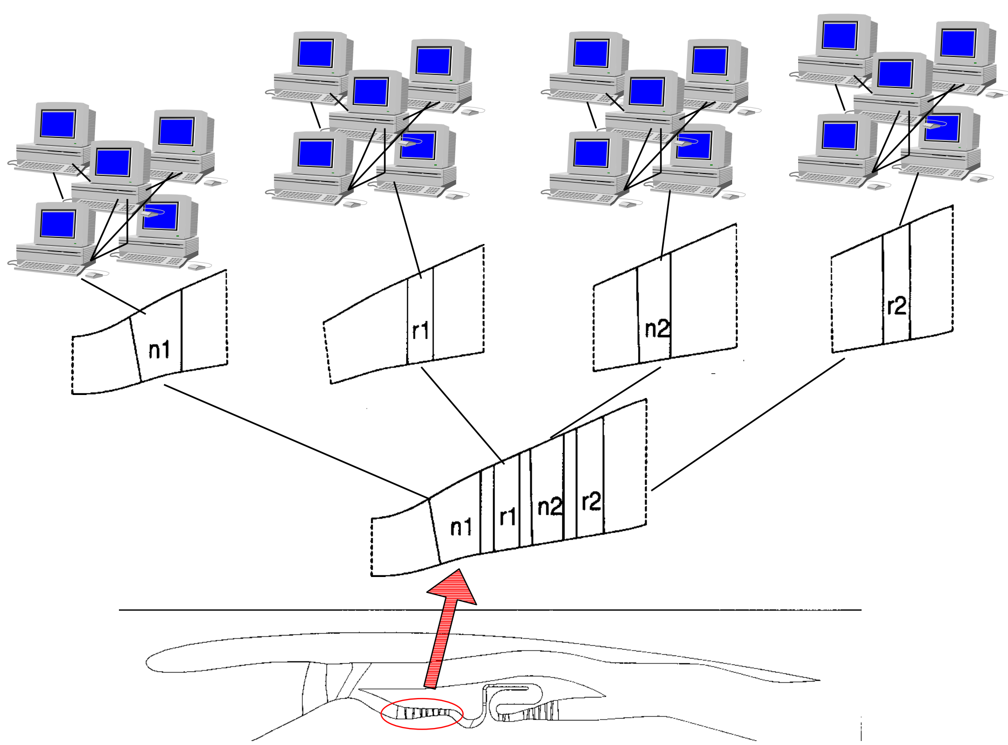
Two Levels of Parallel Capability in APNASA Average-Passage Code



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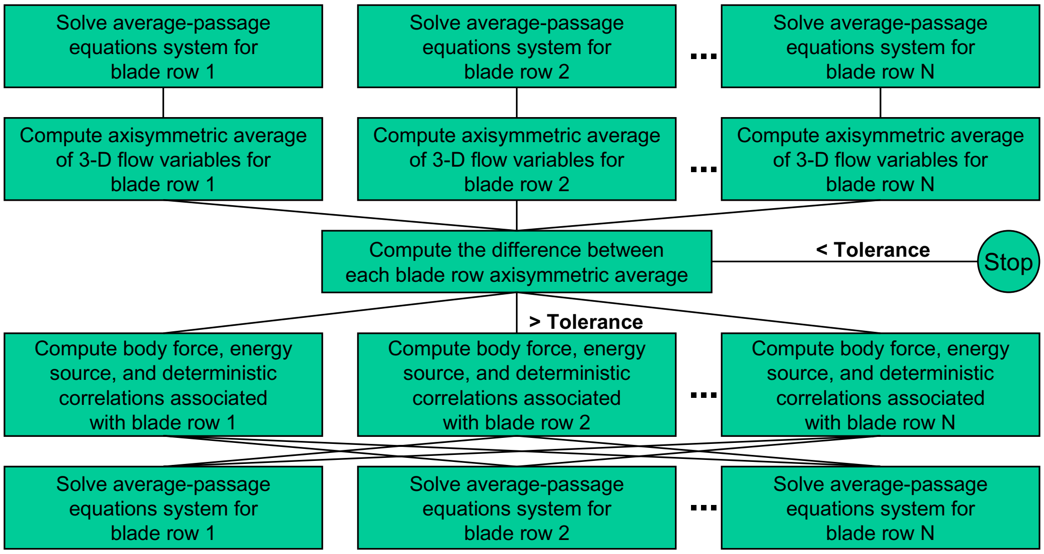
APNASA
Solution Algorithm for the Average-Passage Model



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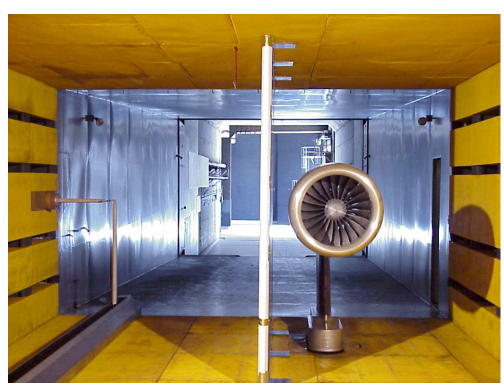
Fan Noise Prediction

- Goal: Use CFD-Based Flow Field Predictions as Input to Fan Noise Prediction Codes
- Testbed: NASA-GE Scale Model Fan



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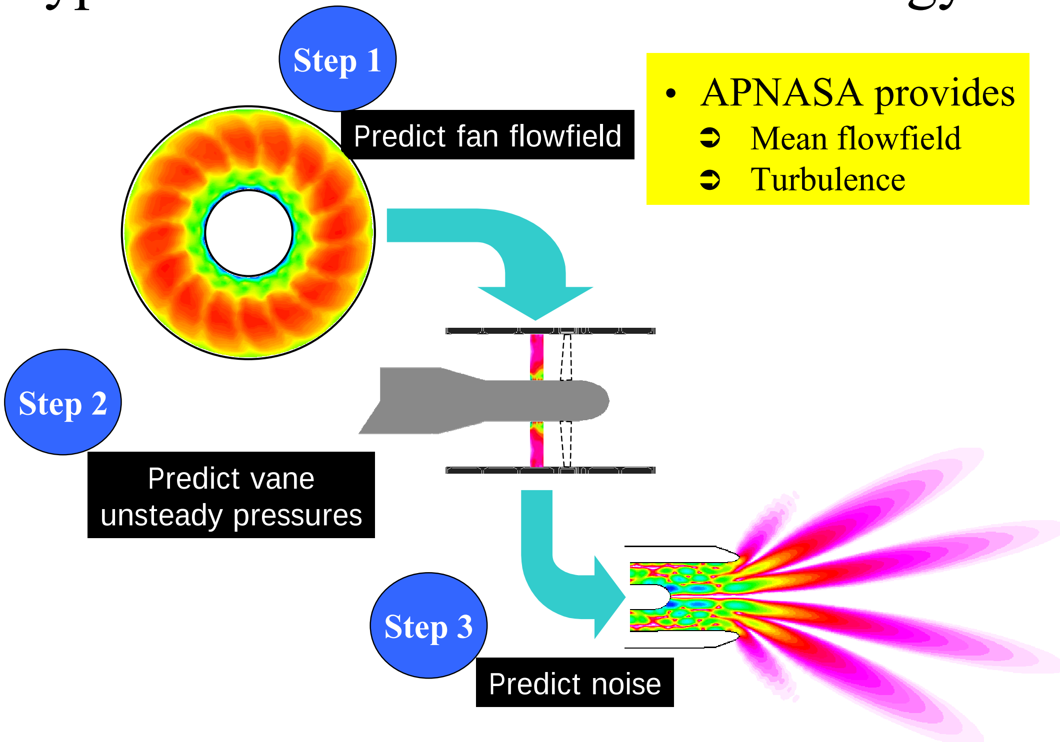
Typical Noise Prediction Methodology

- APNASA provides
  - Mean flowfield
  - Turbulence



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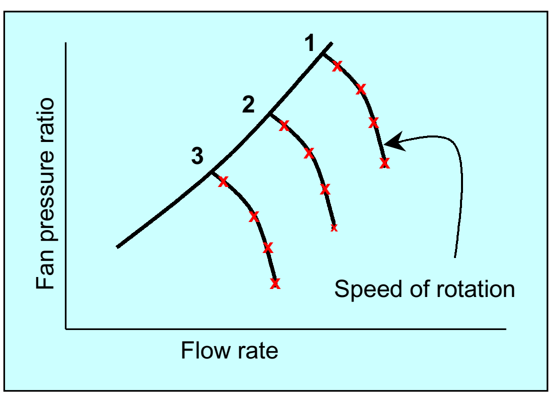
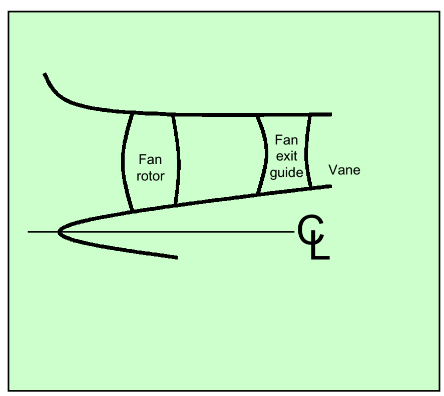
Simulation of High-Speed Fan in Support of Aeroacoustic Analysis





Time average flow field of 3 configurations, each configuration simulated at 4 throttle condition along speed line corresponding to 1)takeoff, 2) cutback, and 3) approach.

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Average-Passage Simulation of the R4 Single-Stage Fan

- Geometry
  - 3 different rotors
    - 61.7% (cutback speed)
    - 87.5% (approach speed)
    - 100% (takeoff speed)
  - 3 different stators
    - Baseline
    - Reduced noise
    - Reduce vane count
  - Each with an axisymmetric mesh measuring 407x51 and a 3-D mesh measuring 407x51x51

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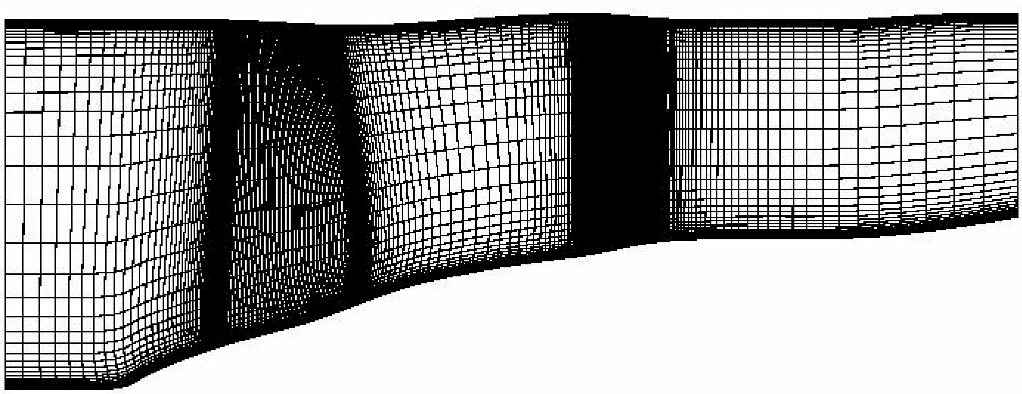
R4 Single-Stage Fan

Rotor (100% Speed) + Vane (Baseline)



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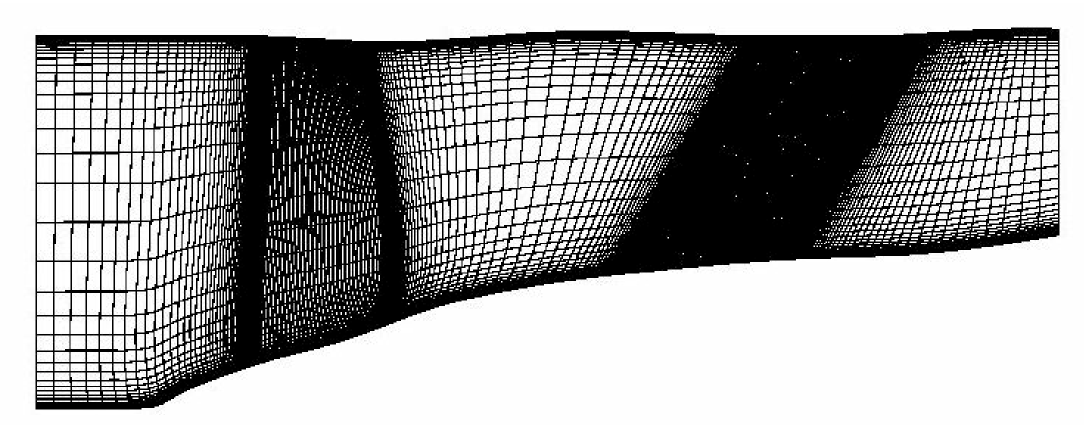
R4 Single-Stage Fan

Rotor (100% Speed) + Vane (Reduce Noise)



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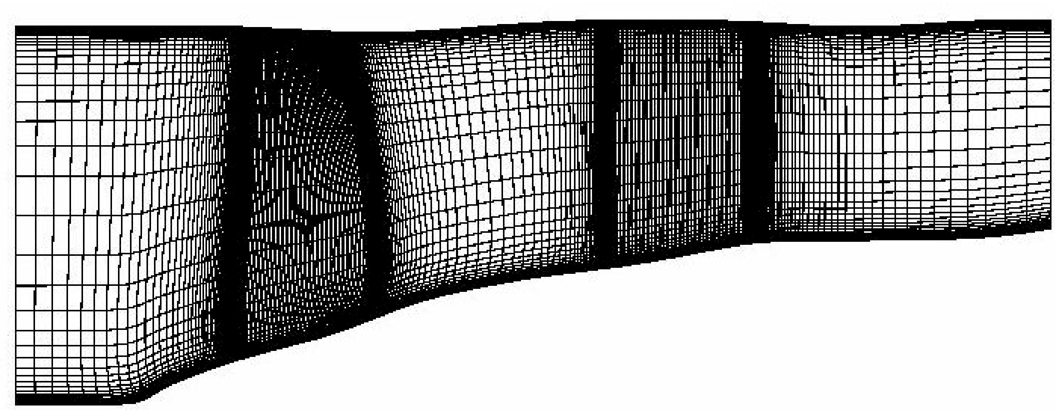
R4 Single-Stage Fan

Rotor (100% Speed) + Vane (Reduce Count)



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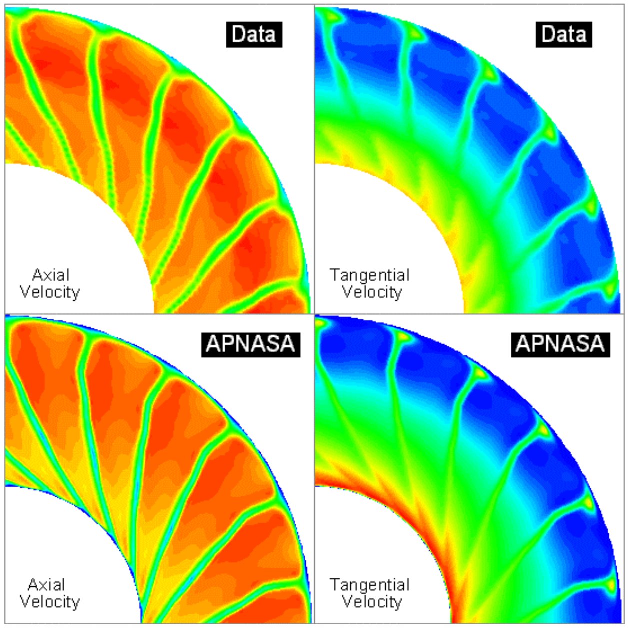
APNASA Flowfield Predictions

Comparisons of Measured and Predicted Fan Flow Fields
Distirbutions of Mean Velocity Components Downstream of the Fan



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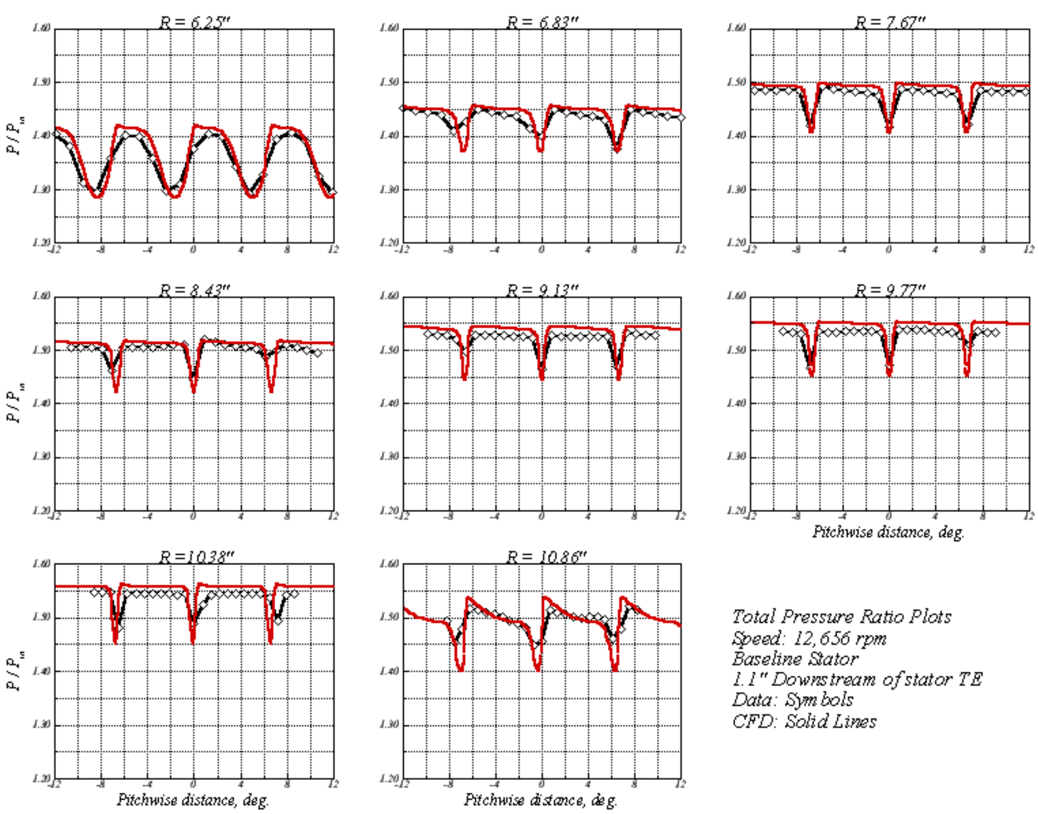
APNASA Flowfield Predictions



Average-Passage Simulation of the R4 Single-Stage Fan (continued)

- CPU Requirements
  (per blade row running both blade rows simultaneously)
  - 130 seconds per iteration
  - 360 CPU hours for a 100 “flip” run (100x50 iterations x 2 blade rows)
  - 180 wall clock hours for a 100 “flip” run (100x50 iterations)

- Memory Requirements
  - ~250 MB per blade row
  - 500 MB total running both blade rows simultaneously (2x250)

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Performance

- For the single-stage fan case (with a mesh size of 407 x 51 x 51 for each blade row), a single"flip" takes approximately 6500 seconds of wall-clock time on the aeroshark cluster.
- This compares to 2750 seconds of wall-clock time to run the same case on an SGI Origin 2000 system composed of 250 MHz R10000 MIPS processors.
- This equates to roughly a factor of 2.36.

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Cost / Performance Ratio

- Cost
  - SGI Origin 2000, 250 MHz R10000, 24 CPUs
    - $468K
  - Aeroshark, 24 CPUs
    - $21K
- Cost Ratio
  - 22.3
- Cost / Performance Ratio
  - 9.4X

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Conclusion

- Clearly the use of the commodity-based cluster has a tremendous potential to provide a computing platform on which detailed aeropropulsion simulations can be executed in a time compatible with the engine design cycle.
- The cost/performance ratio shown by the cluster was impressive considering the cost differential between commodity-based clusters and traditional UNIX workstation clusters.
- As a result of this work the aeroshark cluster will be upgraded to address all the performance issues.

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Future Work

- Upgrade Cluster
  - Larger number of CPUs
  - Improve interprocessor communication

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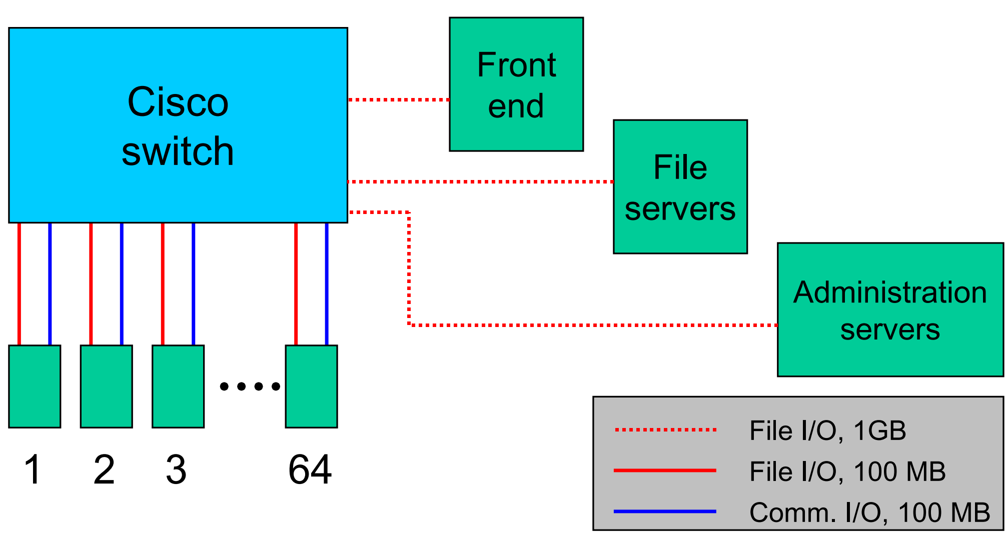
New Pentium III Cluster Network Architecture

64 machines (128 CPUs)



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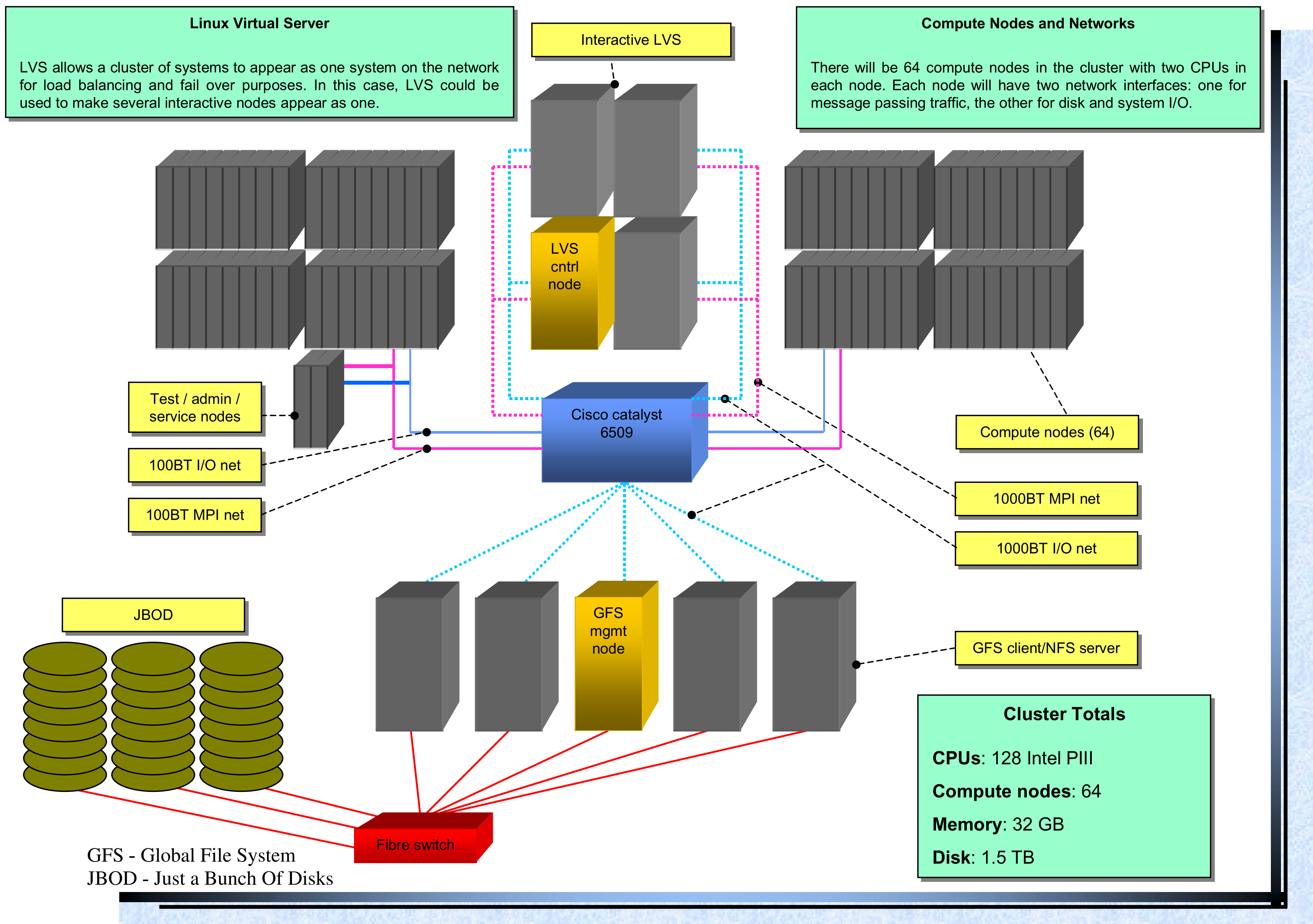

Linux Virtual Server
LVS allows a cluster of systems to appear as one system on the network for load balancing and fail over purposes. In this case, LVS could be used to make several interactive nodes appear as one.
Interactive LVS
Compute Nodes and Networks
There will be 64 compute nodes in the cluster with two CPUs in each node. Each node will have two network interfaces: one for message passing traffic, the other for disk and system I/O.
LVS cntrl node
Test / admin / service nodes
100BT I/O net
100BT MPI net
Cisco catalyst 6509
Compute nodes (64)
1000BT MPI net
1000BT I/O net
JBOD
GFS mgmt node
GFS client/NFS server
Cluster Totals
CPUs: 128 Intel PIII
Compute nodes: 64
Memory: 32 GB
Disk: 1.5 TB
Fibre switch
GFS - Global File System
JBOD - Just a Bunch Of Disks

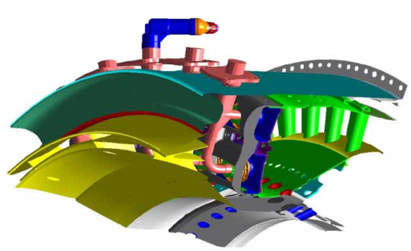
National Combustion Code: Parallel Performance

Theresa Babrauckas

2000 NPSS Review

National Combustion Code (NCC)

- Code Description
  - Integrated system of codes for the design & analysis of combustion systems
  - Advanced features to meet designers' requirements for model accuracy and turn-around time
  - Industry/government development team
  - Primary flow solver is CORSAIR-CCD
- Fundamental Features at Inception
  - Unstructured mesh
  - Parallel processing



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NCC Performance Improvement Effort

- Achieve a 15-hour turnaround time with NCC on a large-scale, fully reacting combustor simulation by September 1998.
- The current goal is to achieve a 3-hour turnaround of a full combustor simulation (1.3 million elements) using CORSAIR-CCD by September 2001. This will represent a 1000:1 reduction in turnaround time relative to 1992.

2000 NPSS Review

Benchmark Test Cases

- Lean direct-injection / multiple Venturi swirler (LDI-MVS) combustor
  - ~444,000 computational elements
  - Finite-rate chemistry (12 species, 10 steps)
  - All turbulence, species and enthalpy equations turned on
  - Estimated converge at 10K iterations
- The benchmark geometry to satisfy the NPSS milestones should be in the range of 1.3 million elements.
- A second LDI-MVS test case is also available with ~971,000 elements.

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Benchmark Hardware Platforms

Hardware Platform

- IBM SP-2
  - 144 RS6000/590s
- SGI Origin 2000
  - 64 & 256 250 MHz, R1000 processors

2000 NPSS Review

Baseline Performance

- Test case
  - LDI-MVS combustor (444K elements)
  - Finite-rate chemistry (12 species, 10 steps)
  - Platform: IBM SP-2
- Performance
  - 64 processors
  - 61.4 secs/iteration
- Estimated convergence in 10,000 iterations for 171 hours.
- Estimated convergence for a 1.3 million element combustor is 512 hours.

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Significant Performance Improvements

- Algorithm modifications
- Code streamlining
- Deadlock elimination
- Hardware upgrades
- IDLM kinetics module
- SGI FORTRAN I/O library
- Domain decomposition strategy

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Algorithm Modifications

- CORSAIR-CCD uses a four-stage Runge-Kutta algorithm.
  - The convective, viscous and artificial dissipation terms were originally computed at each stage.
- The algorithm was modified:
  - The convective terms continue to be computed at each stage.
  - The viscous and artificial dissipation terms are computed at first stage and held constant for the remaining stages.
- This modification eliminated substantial computation and cut the required message passing in half.

2000 NPSS Review

Performance Following Algorithm Modifications

- Test case
  - LDI-MVS combustor (444K elements)
  - Finite-rate chemistry (12 species, 10 steps)
  - Platform: IBM SP-2
- Performance
  - 84 processors
  - 28.5 secs/iteration
- Estimated convergence in 10,000 iterations or 79 hours.
- Estimated convergence for a 1.3 million element combustor is 238 hours.

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Performance Profiling Results: Code Streamlining

54% of time spent in two chemistry routines

- 40.1% chdiff (calculates viscosity and thermal conductivity of the gas mixture)
- 13.8% chprop (solves for gas-phase temperature and update gas-phase specific heat)
- 4.7% derivatives (calculate the 1st order derivatives)
- 4.4% chmsol (solves the linear systems of equation)
- 4.1% residual_smoothing
- 2.0% chmscc (calculates the coefficient matrix and B vector)

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Code Streamlining (continued)

- Streamlined finite-rate chemistry operations
  - Replaced “a**0.25” with “sqrt(sqrt(a))”.
  - Eliminated unnecessary indexing of temporary variables.
  - Relocated some operations to an initialization routine.
  - Several divisions operations were replaced by their multiplicative inverse.

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Performance Following Code Streamlining

- Test case
  - LDI-MVS combustor (444K elements)
  - Finite-rate chemistry (12 species, 10 steps)
  - Platform: IBM SP-2
- Performance
  - 84 processors
  - 14.8 secs/iteration
- Estimated convergence in 10,000 iterations or 41 hours.
- Estimated convergence for a 1.3 million element combustor is 123 hours.

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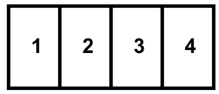
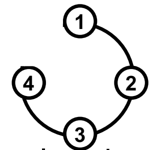
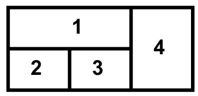
Deadlock Elimination

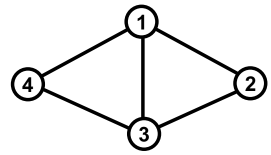
- The existing communication scheme was sufficient with a simple process topology.





- Deadlock was encountered when the process topology became more complex.





- A new communication scheme was developed to handle any arbitrary configuration of processes.
- This modification allowed increasing the number of processors used from 84 to 96.

2000 NPSS Review

Performance Following Deadlock Elimination

- Test case
  - LDI-MVS combustor (444K elements)
  - Finite-rate chemistry (12 species, 10 steps)
  - Platform: IBM SP-2
- Performance
  - 96 processors
  - 13.0 secs/iteration
- Estimated convergence in 10,000 iterations or 36 hours.
- Estimated convergence for a 1.3 million element combustor is 108 hours.

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Hardware Upgrade

- IBM SP-2
  - 96 processors
  - 13.0 secs/iteration
  - Speedup = ~80.4
  - Efficiency = ~84%
- SGI Origin 2000
  - 32 processors
  - 10.1 secs/iteration
  - Speedup = 26.3
  - Efficiency = 82%

- A 1.3 x improvement in performance was realized by switching to the SGI Origin.
- Estimated convergence for a 1.3 million element combustor is 84 hours.

2000 NPSS Review

Hardware Upgrade

- IBM SP-2
  - 32 processors
  - 34.4 secs/iteration
  - Speedup = ~30.4
  - Efficiency = ~95%
- SGI Origin 2000
  - 32 processors
  - 10.1 secs/iteration
  - Speedup = 26.3
  - Efficiency = 82%

- A 3.4 x improvement in performance was realized when comparing 32 processor results on the SGI Origin.

2000 NPSS Review

ILDM Kinetics Module

- Intrinsic low-dimensional manifold (ILDM)
- Replaced the existing finite-rate chemistry module
  - Solve two scalar equations rather than 12 equations for species.
  - Species are obtained from the ILDM tables.
  - Properties such as density, viscosity, temperature can be obtained from ILDM tables.
  - Computation and message passing cost are reduced considerably.

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Performance with the ILDM Kinetics Module

- Test case
  - LDI-MVS combustor (444K elements)
  - ILDM Kinetics Module
  - Platform: SGI Origin 2000
- Performance
  - 32 processors
  - 2.1 secs/iteration
- Estimated convergence in 10,000 iterations or 6 hours.
- Estimated convergence for a 1.3 million element combustor is 18 hours.

2000 NPSS Review

SGI FORTRAN I/O Library

- Scaling improved by switching to SGI f90 compiler.
  - Performance did not change when using <= 32 processors.
  - Performance improved when using > 32 processors.
  - Initialization time decreased dramatically.

- The SGI f90 I/O library handled multiple processes accessing the same file much more efficiently than the SGI f77 I/O library.
  - Each process was printing a residual to the standard output.

2000 NPSS Review

Domain Decomposition Strategy

- METIS* grid partitioning tool (Univ. of Minnesota) was used to provide an alternative domain decomposition strategy for NCC.
  - The interface between processes is minimized.
  - Each process communicates with more of its neighbors, but the size of each message is much smaller.
- Code scalability is greatly improved on the Origin 2000, allowing an increase in the number of processors being used efficiently.

* Metis is a Greek word meaning ‘wisdom.’

2000 NPSS Review

Performance with the METIS Grid Partitioning Tool

- Test case
  - LDI-MVS combustor (444K elements)
  - ILDM kinetics module
  - Platform: SGI Origin 2000
- Performance
  - 96 processors
  - 0.69 secs/iteration
- Estimated convergence in 10,000 iterations or 1.9 hours.
- Estimated convergence for a 1.3 million element combustor is 5.8 hours.

2000 NPSS Review

Performance with the METIS Grid Partitioning Tool

- Test case
  - LDI-MVS combustor (971K elements)
  - ILDM kinetics module
  - Platform: SGI Origin 2000
- Performance
  - 96 processors
  - 1.37 secs/iteration
- Estimated convergence in 10,000 iterations or 3.8 hours.
- Estimated convergence for a 1.3 million element combustor is 5.1 hours.

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National Combustor Code (NCC) Performance Timeline

- The current goal is to achieve a three-hour turnaround of a full combustor simulation (1.3 million elements) using CORSAIR-CCD by September 2001. This will represent a 1000:1 reduction in turnaround time relative to 1992.
- 1992: Estimated time to solution was 3,072 hours.
- 1995: Time to solution was 500 hours.
- 1999: Time to solution was 9 hours.
- 2000: Time to solution is 6 hours.
- Currently at 512:1 turnaround time.

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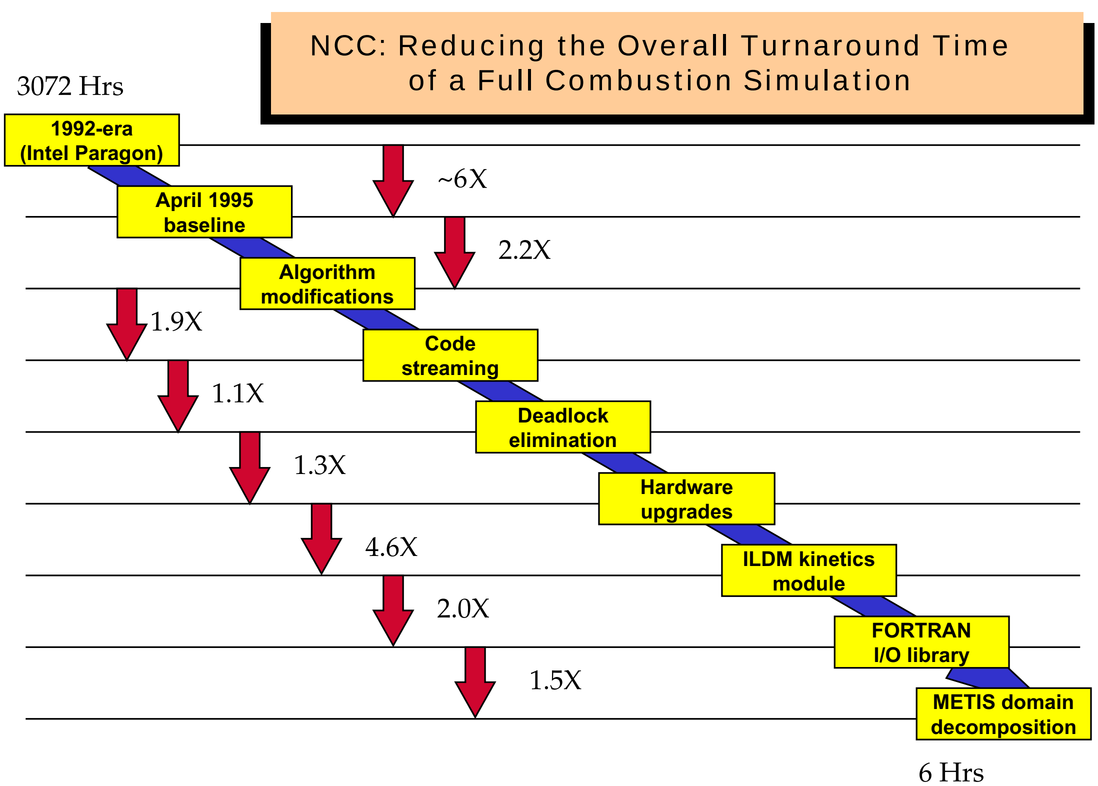

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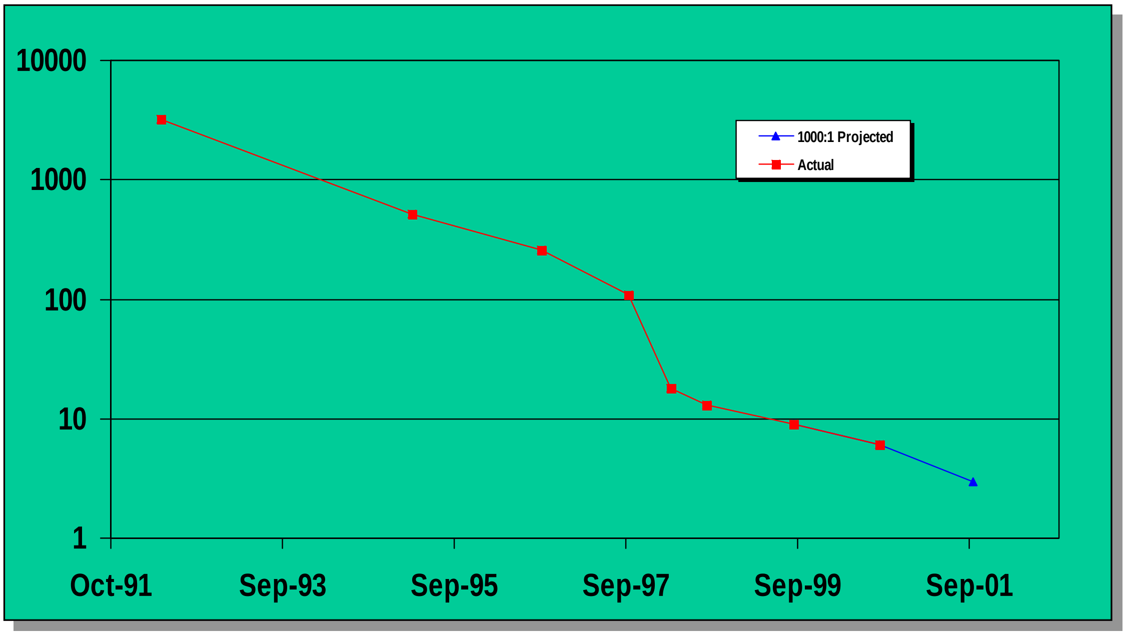
NCC: Estimated Reduced Turnaround Time



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Future Work Planned

- Investigate mixing message passing with shared memory programming to enable using additional processors more efficiently.
  - Continue to use MPI for existing domain-level, coarse-grained parallelism.
  - Investigate using OpenMP for loop-level parallelism.

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13. ABSTRACT *(Maximum 200 words)*

The technologies necessary to enable detailed numerical simulations of complete propulsion systems are being developed at the NASA Glenn Research Center in cooperation with industry, academia and other government agencies. Large scale, detailed simulations will be of great value to the nation because they eliminate some of the costly testing required to develop and certify advanced propulsion systems. In addition, time and cost savings will be achieved by enabling design details to be evaluated early in the development process before a commitment is made to a specific design. This concept is called the Numerical Propulsion System Simulation (NPSS). NPSS consists of three main elements: (1) engineering models that enable multidisciplinary analysis of large subsystems and systems at various levels of detail, (2) a simulation environment that maximizes designer productivity, and (3) a cost-effective, high-performance computing platform. A fundamental requirement of the concept is that the simulations must be capable of overnight execution on easily accessible computing platforms. This will greatly facilitate the use of large-scale simulations in a design environment. This paper describes the current status of the NPSS with specific emphasis on the progress made over the past year on air breathing propulsion applications. Major accomplishments include the first formal release of the NPSS object-oriented architecture (NPSS Version 1) and the demonstration of a one order of magnitude reduction in computing cost-to-performance ratio using a cluster of personal computers. The paper also describes the future NPSS milestones, which include the simulation of space transportation propulsion systems in response to increased emphasis on safe, low cost access to space within NASA's Aerospace Technology Enterprise. In addition, the paper contains a summary of the feedback received from industry partners on the fiscal year 1999 effort and the actions taken over the past year to respond to that feedback. NPSS was supported in fiscal year 2000 by the High Performance Computing and Communications Program.

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