NASA/TM—2002-211197

2001 Numerical Propulsion System Simulation Review

John Lytle, Gregory Follen, Cynthia Naiman,
Joseph Veres, Karl Owen, and Isaac Lopez
Glenn Research Center, Cleveland, Ohio

March 2002

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Cleveland, Ohio, November 7–8, 2001

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Glenn Research Center

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National Aeronautics and Space Administration
Glenn Research Center
Cleveland, Ohio

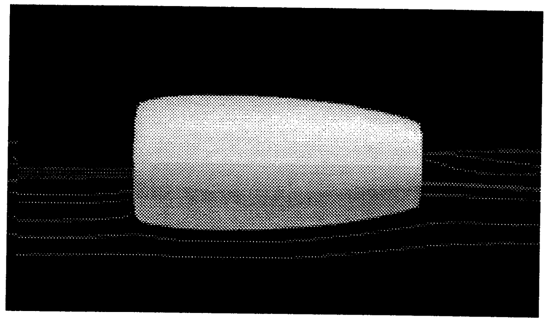
SUMMARY

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 2000 effort and the actions taken over the past year to respond to that feedback. NPSS was supported in fiscal year 2001 by the High Performance Computing and Communications Program.

The Numerical Propulsion System Simulation Overview

Annual Review and Planning Meeting

November 7–8, 2001



Dr. John K. Lytle

2001 NPSS Review

Outline

- Introduction
- Strategic Plan
- 2000 Executive Committee Report
- 2001 Major Accomplishments
- 2002 Milestones
- Issues
- Summary

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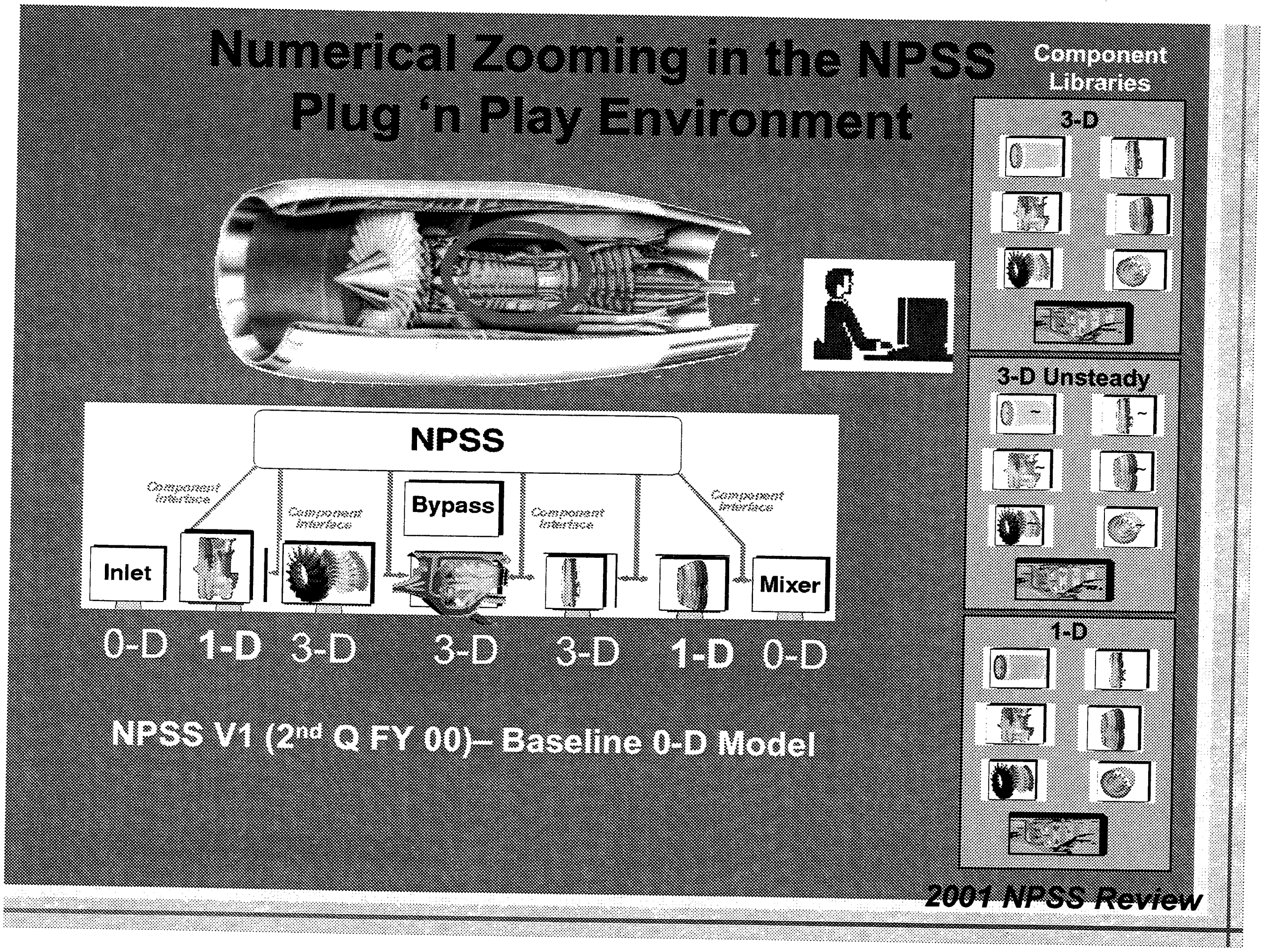
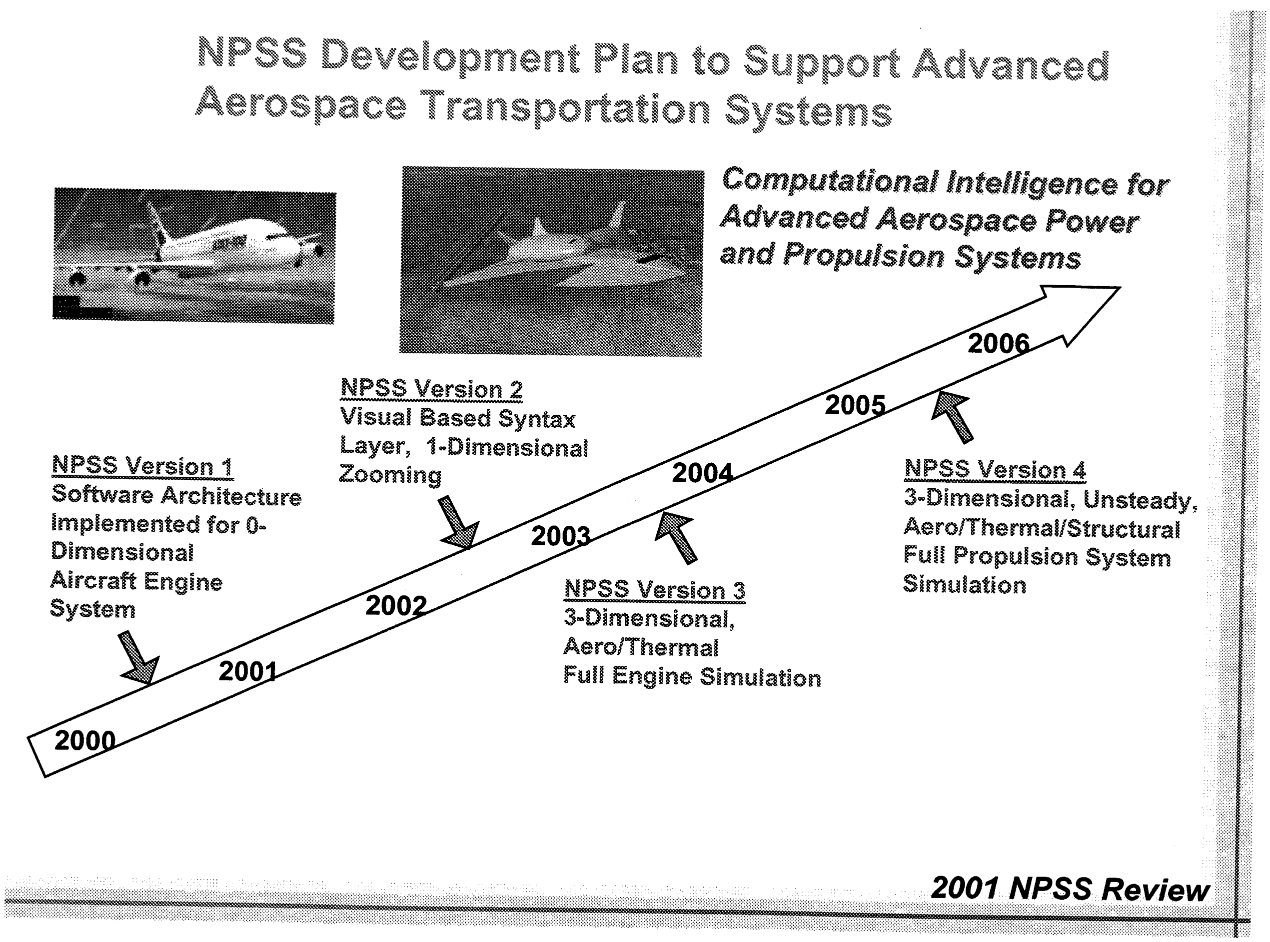
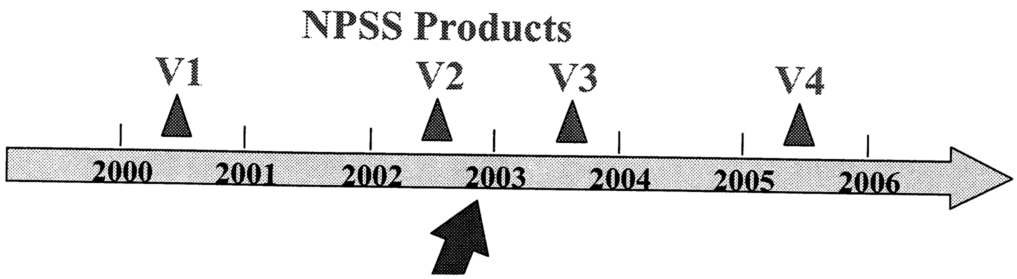

Numerical Zooming in the NPSS Plug 'n Play Environment
Component Libraries
3-D
3-D Unsteady
1-D
NPSS
Component Interface
Component Interface
Bypass
Component Interface
Component Interface
Inlet
Mixer
0-D 1-D 3-D 3-D 3-D 1-D 0-D
NPSS V1 (2nd Q FY 00)– Baseline 0-D Model
2001 NPSS Review

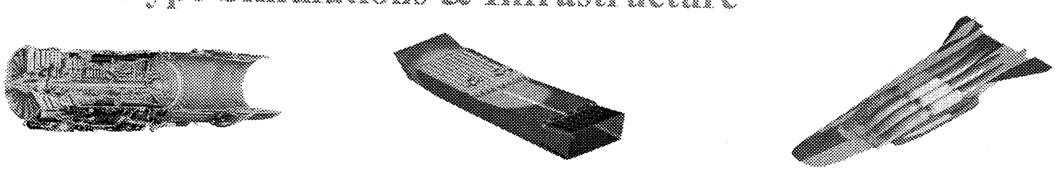

NPSS Development Plan to Support Advanced Aerospace Transportation Systems
Computational Intelligence for Advanced Aerospace Power and Propulsion Systems
NPSS Version 1
Software Architecture implemented for 0-Dimensional Aircraft Engine System
NPSS Version 2
Visual Based Syntax Layer, 1-Dimensional Zooming
NPSS Version 3
3-Dimensional, Aero/Thermal Full Engine Simulation
NPSS Version 4
3-Dimensional, Unsteady, Aero/Thermal/Structural Full Propulsion System Simulation
2000
2001
2002
2003
2004
2005
2006
2001 NPSS Review

Development Strategy



Developers Kit: Tools for Integrating Legacy Code into the NPSS Environment

3-D Prototype Simulations & Infrastructure



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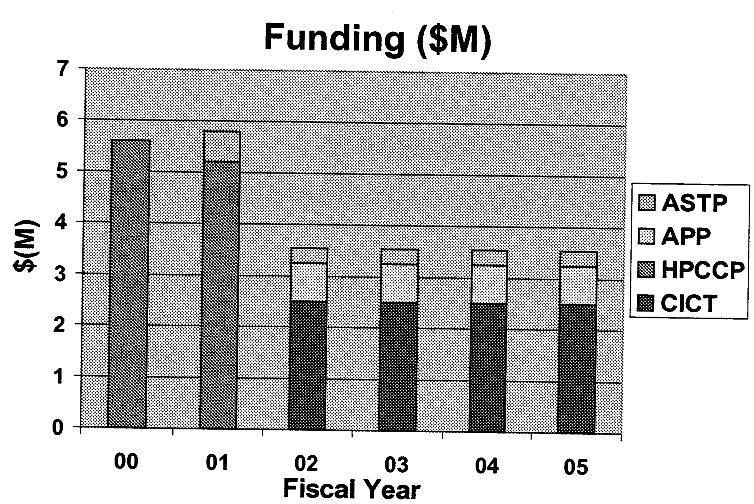
Programmatic Support



HPCCP - High Performance Computing and Communications
APP - Aerospace Power and Propulsion ASTP - Advanced Space Transportation Program
CICT - Computing, Information, and Communications Technology

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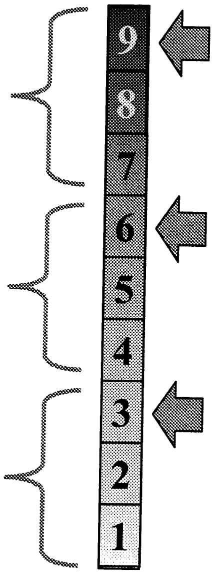
Funding and Technology Readiness Level

Fund Sources

Technology Readiness Levels



End User Programs

Actual system "flight proven" through successful mission operations

NASA/End User Cost Sharing

- Development Partners
- Non-aerospace Industry
- Other Gov't and Universities

System/subsystem model or prototype demonstrated in a relevant environment

NASA Programs

- Computing, Information, and Communications Technologies
- Aerospace Power and Propulsion

Analytical and experimental critical function and/or characteristic proof-of-concept

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FY 00 Executive Committee Report

- Completing Version 2 on time including Space Propulsion operational cycle model.
- Redefine Phase III Team membership.
- Lack of NT release is holding back adoption of NPSS by several companies.
- Architecture does not yet handle parametric geometry. Develop as a parametric API. Define a specification which will drive scientific/engineering analysis through geometric and non-geometric parameters.
- CFD demonstrations need to focus on developing generic capabilities within the NPSS architecture. Launching NASA and commercial codes will validate the 3-D objects.
- Require a cohesive strategic plan for space propulsion with customer input.

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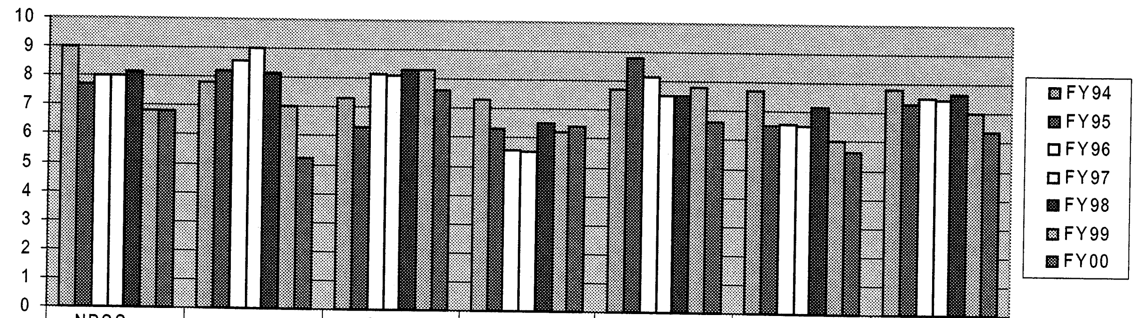
OVERALL NPSS PROGRAM RATINGS



	NPSS vs Other NASA Programs	Relevance to Industry	Overall Program Balance	Technology Transfer	Industry Participation	Meeting Expectations	Overall Average
FY94	9	7.8	7.3	7.3	7.7	7.7	7.8
FY95	7.7	8.2	6.3	6.3	8.8	6.5	7.3
FY96	8	8.57	8.14	5.57	8.14	6.57	7.5
FY97	8	9	8.13	5.5	7.5	6.5	7.44
FY98	8.17	8.17	8.33	6.5	7.5	7.17	7.64
FY99	6.8	7	8.3	6.2	7.8	6	7.02
FY00	6.8	5.2	7.6	6.4	6.6	5.6	6.37

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Selected FY01 Highlights

- Demonstrated full 3-D compressor analysis in 2.5 hours and full 3-D combustor analysis in 1.9 hours (>1000:1 reduction relative to a 1992 baseline).
- Demonstrated a 100:1 reduction in unsteady turbomachinery analysis time relative to a 1999 baseline with MSTURBO on the HPCCP parallel testbed.
- Demonstrated in excess of 10X reduction in cost/performance ratio for high performance computing platforms.
- Completed the first successful application of the lattice Boltzmann method to transonic airfoil cascade flow.
- Completed NPSS models of the flow path and feed system for an advanced space transportation propulsion system.
- NPSS V1 won the NASA 2001 Turning Goals into Reality Awards for Engineering Innovation and co-winner of the Software of the Year Award. Selected by industry for use on the GP 7000 and the Joint Strike Fighter engine development programs.

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FY02 Major Milestones

- Release NPSS V2 (real time ORB, CORBA security, 1-D zooming and limited 3-D zooming, initial visual-based assembly layer).
- Complete demonstration of 3-D aero/thermal full aircraft engine simulation and lessons learned for incorporation into the NPSS environment.
- Complete 3-D aero/structural/thermal simulation of an advanced space transportation turbopump and primary flow path.
- Create first CORBA-based Information Power Grid Job Brokers to identify available, distributed computing resources.
- Demonstrate new parallel algorithms for aerospace propulsion applications that use in excess 500 processors at over 90% efficiency.

2001 NPSS Review

Future Direction

- Near term work will focus on completing Version 2 and the Developers Kit to bring in high-fidelity, multi-disciplinary analysis tools.
- NASA supported technology readiness level (TRL) will be limited to ~4. Look for cost sharing partners to take products to TRL 6.
- Redefine the long range vision for advanced simulations to enable smarter, more adaptive tools that work collaboratively and to provide seamless access to ground-, air-, and space-based distributed resources.
- Establish stronger partnerships with related Programs
  - DOE Accelerated Strategic Computing Initiative
  - DOD Versatile Affordable Advanced Turbine Engine Program
  - NASA Advanced Space Transportation Program
  - NASA Ultra-Efficient Engine Technology Program
- Identify and cultivate commercialization opportunities for NPSS V1.

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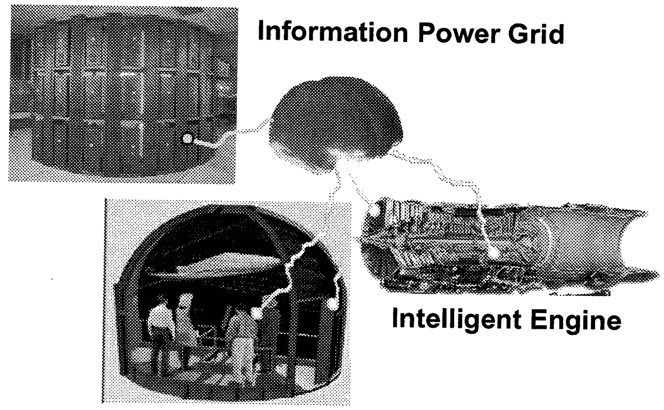
What is Computational Intelligence for Aerospace Power and Propulsion?

- Revolutionary Engineering Environment
  - Multi-fidelity, multi-disciplinary plug 'n play design
  - Integration of people, data, tools and computing platforms throughout the life cycle
  - Measurement data processing
  - Continuous knowledge capture
  - Immersive visualization
  - Quantifiable risk assessment
- Intelligent Engine
  - Imbedded, wireless sensors
  - Distributed controls
  - Data extraction and synthesis
  - Knowledge management architecture
- Autonomous Decision Making in Design, Test and Operation



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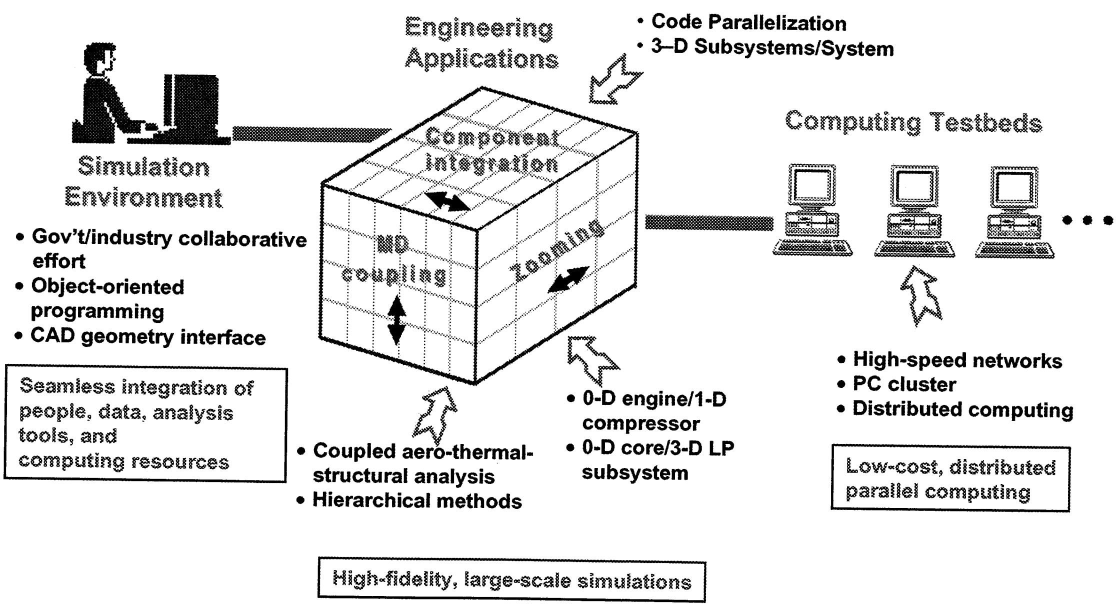
NPSS - Major Elements



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Simulation Environment/ Production Software

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Cynthia Naiman
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216–433–5238

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Presentation Outline

- Vision and Objective
- General Description
- Schedule
- Milestones
- FY01 Accomplishments
- FY02 Plans
- Conclusion

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Vision and Objective

- NPSS Vision
- Create a "Numerical Test Cell" enabling complete aerospace propulsion simulations overnight on cost-effective platforms
- NPSS Product Objective
- Provide a common tool and extensible framework to enable rapid, high-confidence, cost efficient design of aerospace systems

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General Description

- Common Tool
  - First application: traditional aerothermodynamic 0-D cycle analysis simulation tool
  - Full system simulation tool throughout product life-cycle
  - Simulation tool with extension capabilities from framework

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General Description Continued

- **Extensible Framework**
  - Provides unprecedented levels of interoperability among critical resources used in design, development, & operation of aerospace propulsion systems
  - Enables multi-fidelity analysis
  - Enables multi-discipline simulation
  - Preserves proprietary and legacy codes
  - Facilitates addition of customized codes
  - Facilitates distributed collaborative engineering
  - Increases modeling flexibility

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General Description Continued

- **Various Models**
  - Advanced Rocket Concept
  - Regenerative Rocket Cycle
  - Rocket-Based Combined Cycle
  - Turbine-Based Combined Cycle
  - Ground-Based Power
  - Physiological Benchmark
  - Pulse Detonation Engine
  - Air Breathing Jet Engines
  - High Speed Research
  - Turbojet
  - Turbofan
  - GE-90 Core
  - Energy Efficient Engine
  - First Order Lag
  - Second Order Lag
  - Integrated Systems Test of an Airbreathing Rocket

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Numerical Propulsion System Simulation Roadmap

	'00 CY	'01	'02	'03	'04	'05	'06
	V.1		V.2	V.3		V.4	
CAPABILITIES	Steady-State, Transient, Low fidelity Dynamic, Reduced order & data reduction, Low Fidelity Flowpath, Geometry Design		Mid Fidelity Dynamic, Mid Fidelity Geometry Access CAD Systems	Full Performance Envelope 2D/3D Euler, Mid Fidelity Dynamic, Mid Fidelity Geometry Access across CAD systems		Full Engine Performance 3D Navier-Stokes Steady State, Unsteady, Transient, High Fidelity Geometry generation	
INTEROPERABILITY	Zooming 0D<->1D Single component, CORBA multi-ORBs, Distributed Objects		Zooming 0D<->1D/2D, 0D<-3D, Single components, CORBA Security	CORBA Security with SecurID, Probabilistic sensitivity analysis		Zooming 3D<->0D/1D/2D, Multiple components. Couple Multiple disciplines: structures, thermal	
PORTABILITY	Sun, SGI, HP	NT, Linux				Miniaturization of hardware	
RELIABILITY	High-Control Formal Software Development Process with Verification and Validation for each incorporation						
RESOURCE MGT	Globus, LSF		Information Power Grid aware load balancing, networked clusters	Information Power Grid Dynamic load balancing		Distributed gathering of simulation data for monitoring, convergence, visualization	
USABILITY	Script assembly language, Dynamic linkable libraries, Fully interpreted elements, interactive debug		Visual assembly language	Web Based Visual assembly language tools		Web Aware Visual assembly language tools	
PERFORMANCE		1000:1 reduction in execution time of 3D Turbo Machinery & Combustion simulation	24:1 reduction in 0D-1D zooming	Real-time ORB 100:1 reduction in 3D-3D coupling simulation			

Milestones

- **NASA Glenn Strategic Implementation Plan Milestones**
  - NPSS Space Transportation Simulation (September 2001)
  - NPSS Version 2 Release (March 2002)

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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)

Additional Parties:
U.S. Navy, Lockheed, Aerojet, Rocketdyne, DOE, P&W (power generation, fuel cells), GE (ground-based power), Dryden, Marshall, Langley,and Ames

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FY01 Accomplishments

- **Current & Potential Use of NPSS V1.X**
  - Engine Alliance (General Electric Aircraft Engines and Pratt & Whitney partnership)
  - General Electric Aircraft Engines
  - Pratt & Whitney
  - Joint Strike Fighter (JSF) Program
  - Williams-International
  - Georgia Institute of Technology and Modern Technologies Corporation in support of Ultra-Efficient Engine Technology (UEET)
  - NASA GRC Propulsion Systems Analysis Office
  - Arnold Engineering Development Center of Department of Defense

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FY01 Accomplishments Continued

- **NPSS V1.X Training**
  - NPSS Space Training at Marshall (11/00)
  - NPSS Aero Training at Georgia Tech (1/01)
  - NPSS Aero Training at P&W (2/01)
  - NPSS Aero Training at Glenn (5/01)
  - NPSS Space Training at Glenn (5/01)
    Attendees: Rocketdyne, Lockheed, P&W, Aerojet, and Glenn
  - NPSS Dev Kit Training at Glenn (6/01)
    Attendees: Boeing, GEAE, P&W, Ames, and Glenn

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FY01 Accomplishments Continued

- Completed Prototype Visual Based Syntax (VBS) stand-alone tools & received user feedback (November 2000)
- Space Transportation Sub-Team Started (January 2001)
  Participants: Marshall, Rocketdyne, Aerojet, Lockheed, P&W, and Glenn
- Zooming Sub-Team Started (January 2001)
- Conducted Usability Testing on VBS Alpha Version (June 2001)
  Participants: GEAE, Lockheed, Boeing, Honeywell, and Glenn
- Provided VBS Alpha for Trial Period (September 2001)

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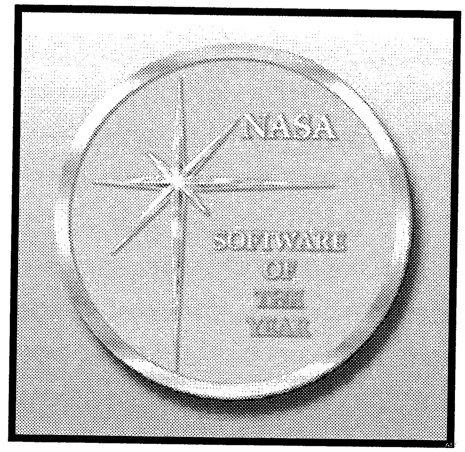
Award Winning Numerical Propulsion System Simulation Version 1

NPSS Version 1 Wins NASA Office of Aerospace Technology 2001 Turning Goals Into Reality Award for Goal 3 Pioneering Technology Innovation

NPSS Version 1 Wins 2001 NASA Software of the Year Award



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NPSS Production Status

- NT Port Remains High Priority
- Supporting Changes Needed for Partner Use
- Supporting Space Transportation
- Completing Change Requests Weekly
- Working on V2 requirements
- Improving Documentation

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NPSS Version 2 Capabilities

- Space transportation components & capability
- Enhanced NPSS Development Kit
  - Zooming & Coupling
  - CORBA Security
  - Common geometry interface
- NPSS running in CORBA server mode
- Initial VBS capability (graphical & command)
- 1-D dynamic engine system operation
- Aircraft installation effects
- Improved thermo architecture and capability, updated JANAF
- New components, including combustion, compression, turbine expansion, ambient, control toolbox
- Enhanced customer deck, C++ converter, autodoc, solver, interactive debugger, commands, message handler
- Improved documentation

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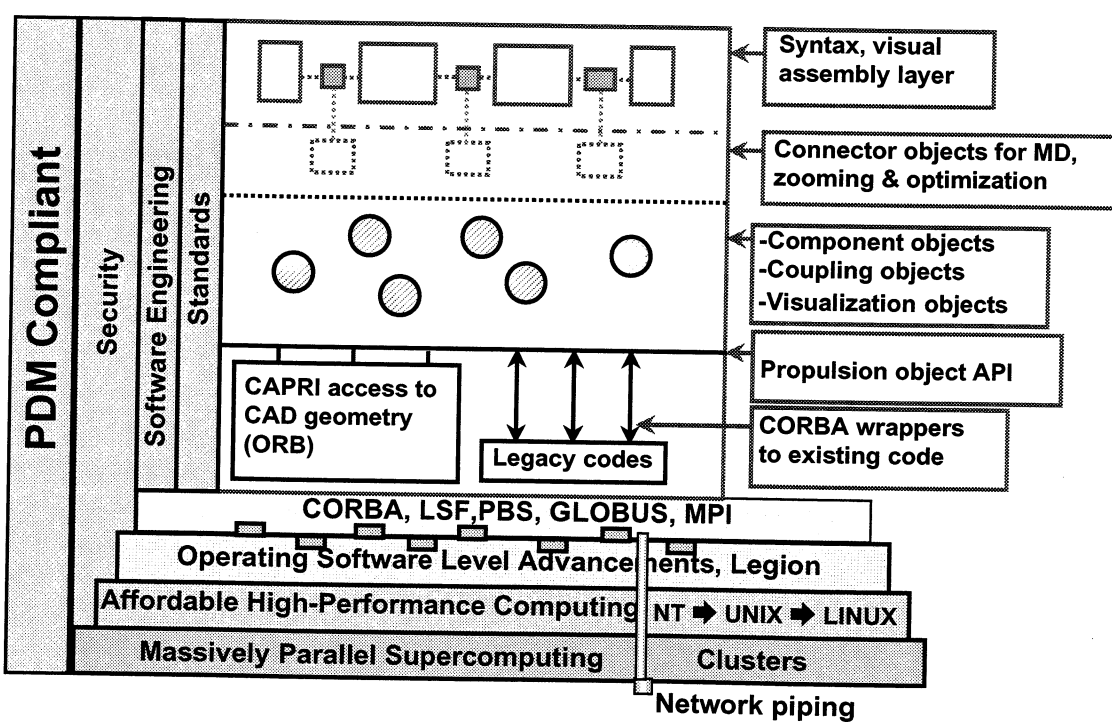
NPSS Object-Oriented Architecture



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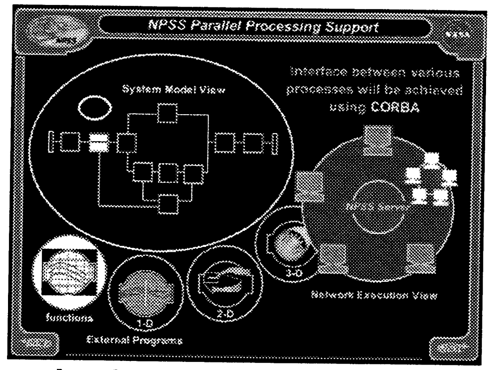
NPSS Development Kit FY01 Accomplishments

Integrating Codes Through CORBA Wrapping



- **CCDK now part of production CORBA release**
- **Ported to VisiBroker 4.0 and Sparcworks 6.1**
- **File transfer support**

  Allows specifying inputs and retrieving outputs via files rather than multiple set/get calls
- **Improved NameService support**

  Use of NamingContexts avoids collisions between users.
- **Improved interpolator**

  Handles more geometries, FileInterp tool provides file based access
- **Additional documentation**

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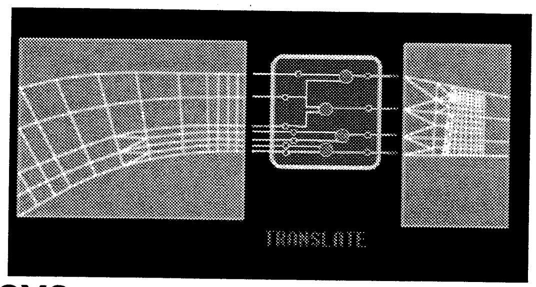
NPSS Development Kit FY01 Accomplishments

Coupling



- **Rolls-Royce ADPAC-NPSS-ANSYS sensitivity project**
  - **Rolls-Royce technique based on ANSYS macros, Perl script, and FORTRAN support programs**
  - **NPSS CORBA technique utilizes Java form of CCDK, refactors macros and support programs to be more generic in form of data communicated between tools**

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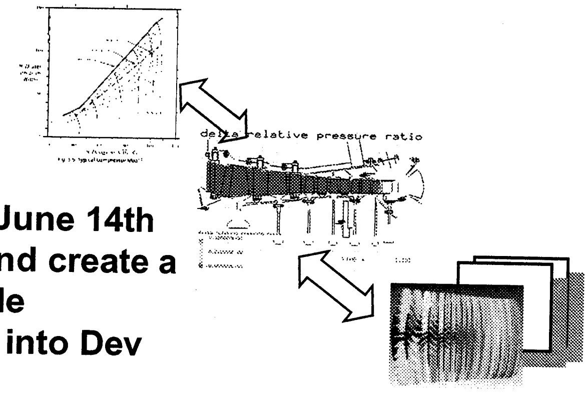
NPSS Development Kit FY01 Accomplishments



Zooming

- Training class was held at GRC on June 14th that showed how to CORBA wrap and create a DLM of CSPAN, 1D compressor code
- Remote variable access assembled into Dev Kit
- CSPAN 1-D zooming compressor code, DLM'ed and CORBA Wrapped
- PUMPA 1D Pump code DLM'ed and CORBA Wrapped
- 1-D Turbine code wrapped using NPSS Dev Kit
- Next Training class is scheduled for December 5-6 and will include how to CORBA wrap, create a DLM and add CORBA security using CSPAN and its variables

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NPSS Development Kit FY01 Accomplishments

CORBA Security

- **September 2000 -** NPSS ORB switched from Iona's Orbix v2.3 a Basic Object Adaptor (BOA) ORB implementation to Borland's VisiBroker v4.x a Portable Object Adaptor (POA) ORB implementation
- **December 2000 -** Purchased CORBASec s/w: TPBroker Security Service (TPBSS v3.4) from Hitachi
  - TPBSS supports the TPBroker ORB, a hardened version of VisiBroker v3.x BOA based
- **January 2001 -** Received TPBSS v3.4 on schedule and installed CORBASec s/w in the NPSS CORBASec Test Bed
  - GEAE NPSS partner also purchased and receives TPBSS v3.4
  - PW NPSS partner receives TPBSS v3.4 evaluation copy
- **March 2001 -** Presented NPSS CORBASec Test Bed at the Object Management Group (OMG) Distributed Object Computing Security Workshop (DOCsec) 2001
  - Presentation was converted into a NASA Glenn technical paper, entitled "Using CORBASec to Secure Distributed Aerospace Propulsion Simulations" as TM-2001-210937
    - Visit ftp://ftp-letrs.lerc.nasa.gov/LeTRS/reports/2001/TM-2001-210937.pdf
- **June 2001 -** Presented NPSS CORBASec training plans at NASA Glenn's Zooming training "Using NPSS to Zoom to Higher Fidelity Codes"
- **July 2001 -** NASA and GEAE upgrade NPSS CORBASec Test Bed to Hitachi Security Service (HSS v4.0)

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NPSS Development Kit FY01 Accomplishments

CORBA Security

- Collaborative/Multiple Domain First Phase Users:
  - NASA Glenn Research Center
  - Company 1
  - Company 2
- Multiple commercial ORBs (VisiBroker 4.x, Orbix 2000), supporting CORBASec ORB Interoperability, will be implemented in the final phases.
- Exercising use of the SSL for on wire encryption (3DES) with CORBASec
- Multiple Authentication techniques implemented and planned
- NPSS Simulation developers use a CORBASec enhanced NPSS API Development Kit to enable and deploy CORBASec
- Configured with multiple Firewalls

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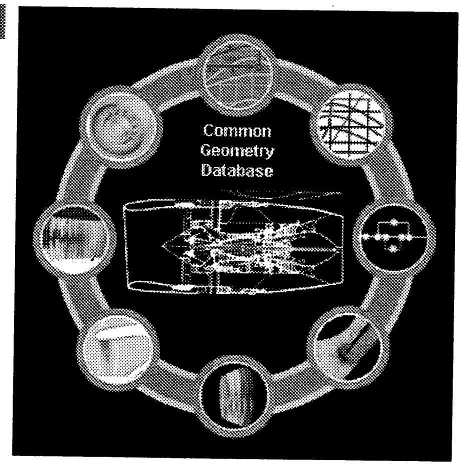
NPSS Development Kit FY01 Accomplishments



CAD Access & Interoperability Through Common Interface

- MIT grant for CAPRI:
  - New surface tessellator built, ability to create and modify geometry
- OMG process
  - CAD Services standard approved by OMG architecture board on 7/13/01. A finalization Task Force is resolving the final implementation details and is scheduled to complete efforts by 2/15/02
  - Unigraphics, TranscenData and OpenCascade plan commercial implementation of the CAD Services standard
  - A new RFP is being proposed to establish a common interface for KBE systems

2001 NPSS Review

CAPRI FY01: API

	Parasolid	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	X

CATIA V5 is under examination, but it is not clear what is the best approach for the programming interface. An AutoCAD geometry reader has not yet been implemented.
A CV (CompterVision's CADDS V) interface has been written in support of NPSS work with Allison/Rolls Royce and ICEM-CFD.

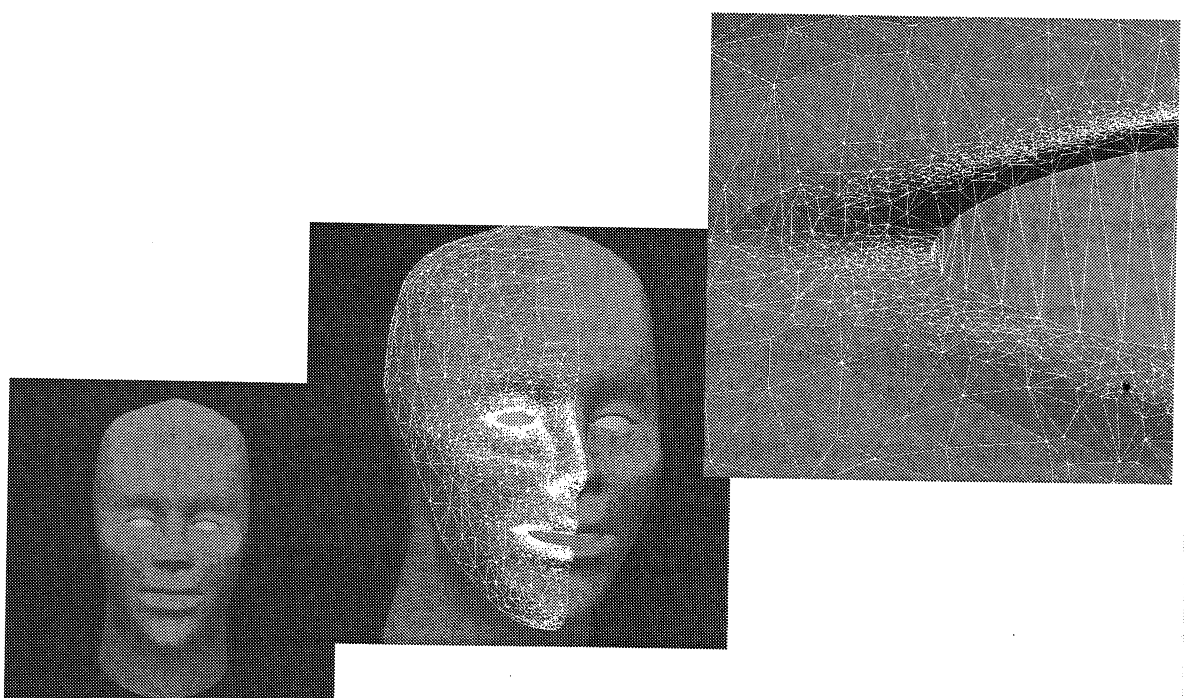
CAPRI FY01: Geometry Creation

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:

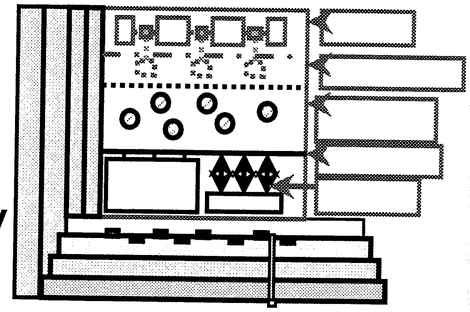
	Parasolid	ProE	I-DEAS	CATIA V4	CV
Simple Solid Creation	X		X	X	X
Subtraction	X	X	X	X	X
Intersection	X	X	X	X	X
Union	X	X	X	X	X

The CV port currently has a problem writing the resultant part(s) out. There is also a problem with CATIA is separating the new part(s) from the original model file.

CAPRI's New Tessellation Ability Can Even Tessellate the Author



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
- Not Done: Design of geometry services through CORBA-based CAPRI
- Not Done: CORBA Security services fully incorporated into Development Kit

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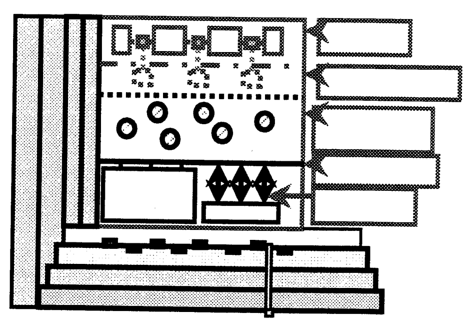
NPSS Architecture FY02 Milestones



- 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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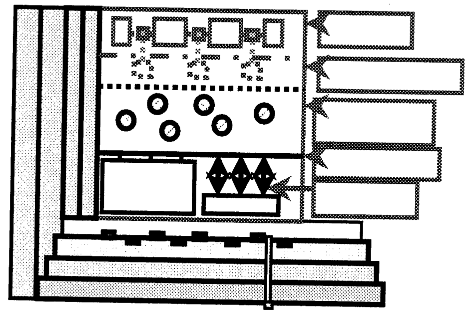
NPSS Architecture FY02 Metrics



Status	without Dev Kit	w/Dev Kit	Reduction
Done	2 days to connect 0D,1D	2 hours	8 to 1
Done	10 days to connect 0D,3D	4 hours	20 to 1
9/02	5 days to connect 0D,1D,3D	1 hour	40 to 1
9/03	5 days to connect 3D,3D	.5 hour	160 to 1
9/04	5 days to connect 3D MD codes	.5 hour	160 to 1

Assumes an eight hour day

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FY02 Plans

- NPSS On-Site (December 2001)
- NPSS Dev Kit Training (December 2001)
- Software Configuration Audit (March 2002)
- Software Acceptance Review (March 2002)
- Distribute NPSS V2 Full Release (March 2002)
- NPSS V3 Requirements Definition (April 2002)
- Begin Design/Analysis/Implementation of V3

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Conclusion

Thanks to our collaborative team for such a successful 2001!

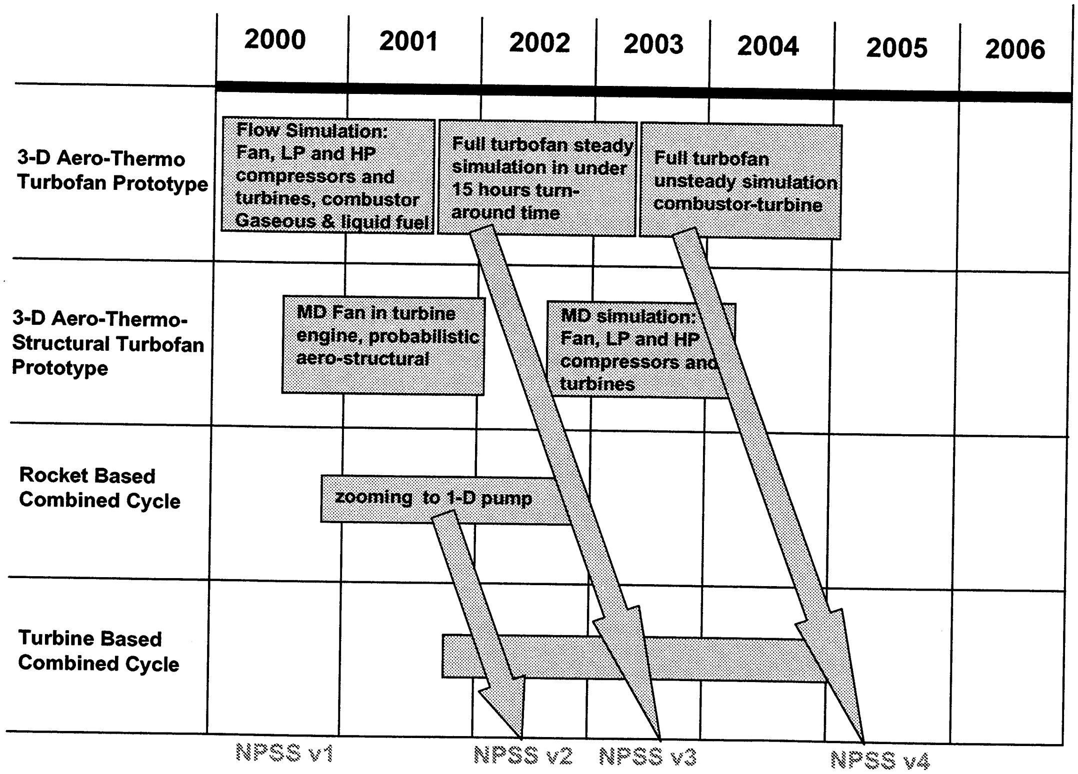
2001 NPSS Review

Aircraft Propulsion Simulations

Joseph P. Veres

2001 NPSS Review

High Fidelity Simulation of Aerospace Engines



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High Fidelity Simulation of Aerospace Engines

NPSS Phase 3

Objective

The purpose of NPSS Phase 3 is to do prototype high fidelity aerospace engine simulations with NASA software in order to develop standard techniques of communicating boundary condition data between the high fidelity simulation codes. The simulation codes include aerodynamic, thermal and structural disciplines. Develop techniques of zooming data between high and low fidelity simulation codes. The results of the developed zooming and code coupling techniques will be incorporated into the NPSS developers toolkit.

Approach

- Demonstrate code coupling and zooming between CFD simulations of aerospace engines. From these demonstrations coordinate the effort for the development of a standard NPSS developers toolkit
- Identify representatives from aerospace industry to be on the Phase 3 Team
- Hold on-site meetings of the Phase 3 Team at NASA Glenn Research Center

Status

- Latest Phase 3 on-site meeting was held 3-22-01. Next meeting to be in FY02.
- A document titled "Code Coupling Lessons Learned and Issues" has been drafted based on experiences gained from the Full Turbofan Simulation project

2001 NPSS Review

Aircraft Propulsion

Presentation Outline

- Status of Full Turbofan Engine Simulation
- Compression System Simulation
- Combustor Simulation
- Turbine Simulation
- Summary and Future Directions

2001 NPSS Review

Aircraft Propulsion

Presentation Outline

- *Status of Turbofan Engine Simulation*
- **Compression System Simulation**
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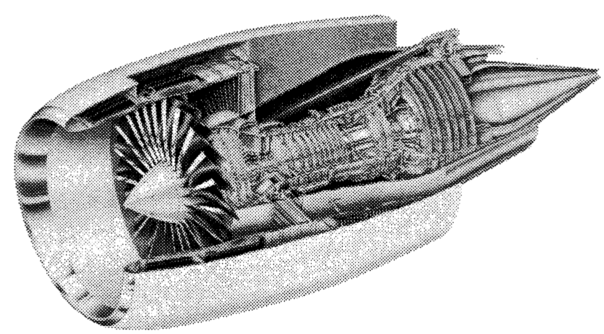
2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Objective:
Complete turbofan engine simulation using advanced 3-D Navier-Stokes flow and chemistry codes, APNASA, and the National Combustion Code (NCC)



Shown:
The GE90 high-bypass ratio turbofan engine.

Accomplishment:
Successful simulation of a 3-dimensional flow in the primary flowpath of the GE90 high bypass ratio turbofan engine. The simulation of the compressor components and cooled high pressure and low pressure turbines were performed using the APNASA turbomachinery flow code. The combustor flow and chemistry were simulated using the NCC. The core engine simulation matches the engine thermodynamic cycle system model at the sea-level takeoff condition.

Point of Contact:
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U.S.A.

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E-mail: Joseph.Veres@grc.nasa.gov

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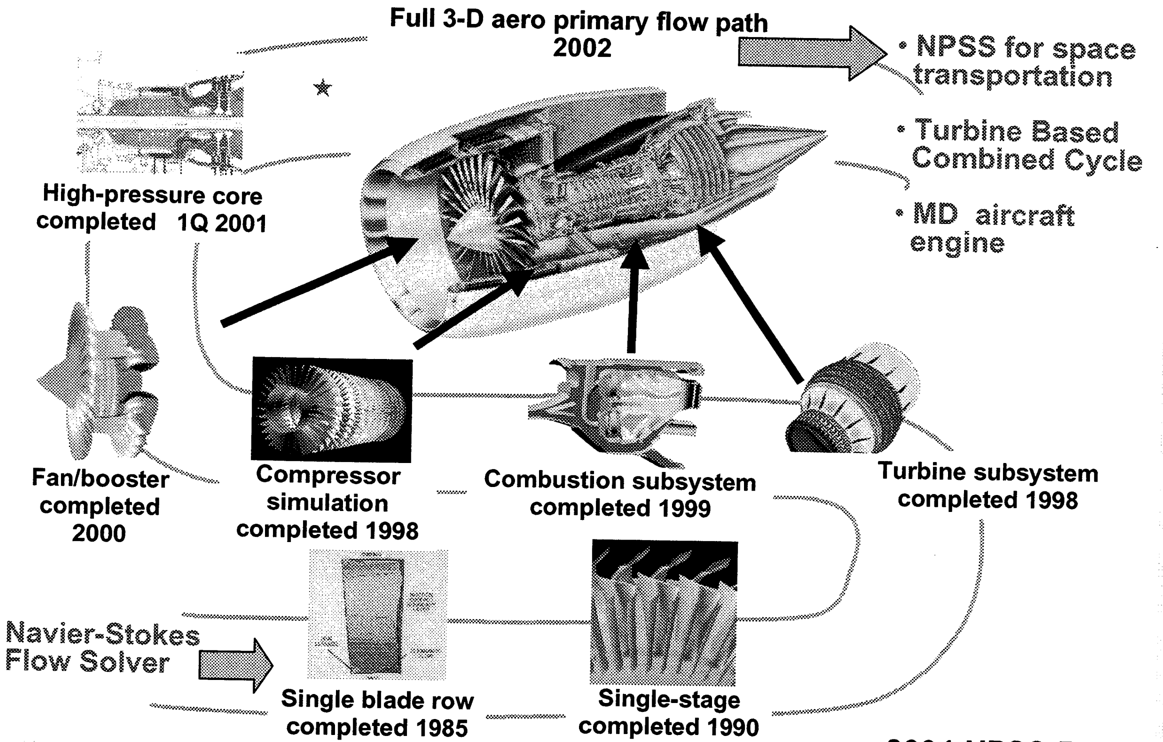
The Road to Full 3-D NPSS Engine Simulation



2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Contributors

AP Solutions:

Mark G. Turner	Compression and turbine simulations with APNASA
Rob Ryder	Combustion simulations with National Combustion Code
Mark Celestina	High pressure compressor with APNASA
Le Tran	Combustor solution animations

NASA Glenn Research Center:

John Adamczyk	APNASA turbomachinery flow code
Nan-Suey Liu	National Combustion Code (NCC)
Jeff Moder	NCC and APNASA Code Coupling
John Gallagher	CAD geometry
Joseph P. Veres	Project Manager Aircraft Engine Systems

2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Status

- Simulation of the core engine with APNASA and NCC using sequential coupling (completed)
- Compression system simulation of fan, booster and high pressure compressor with APNASA version 5. Full compression system simulation not completed, delayed to FY02
- Combustor simulation of full combustor with the National Combustion Code (NCC) with finite rate chemistry and gaseous and liquid spray fuel injection (completed)
- High and low pressure turbines simulated with APNASA v.5 (completed)

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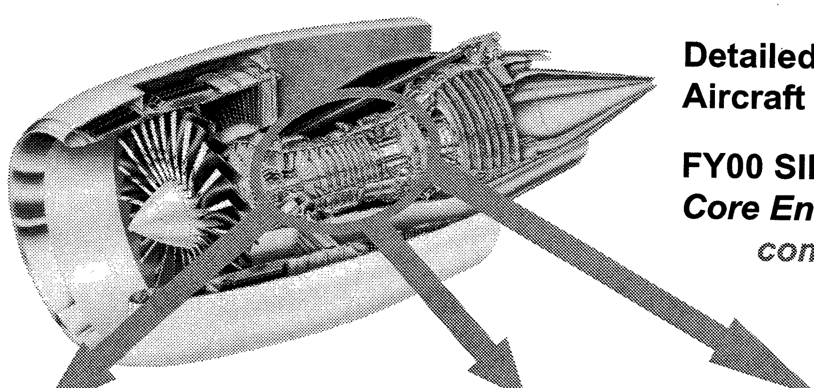


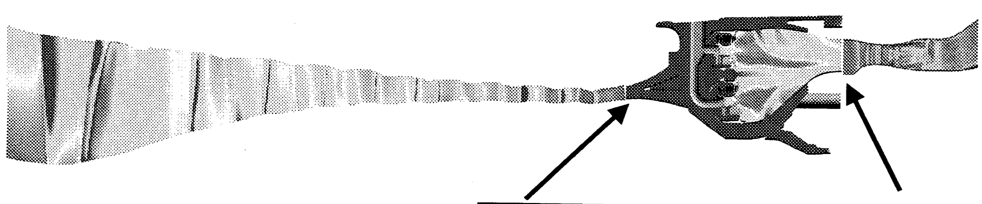
Detailed Simulation of Aircraft Turbofan

FY00 SIP Milestone:
Core Engine Simulation
completed

3D flow simulation of HP compressor with APNASA

3D flow and chemistry simulation of combustor with NCC

3D flow simulation of HP turbine with APNASA



Coupled APNASA / NCC simulations

Computational simulation of the flow through the core engine components in a modern turbofan engine; the high pressure compressor, combustor and the cooled high pressure turbine.

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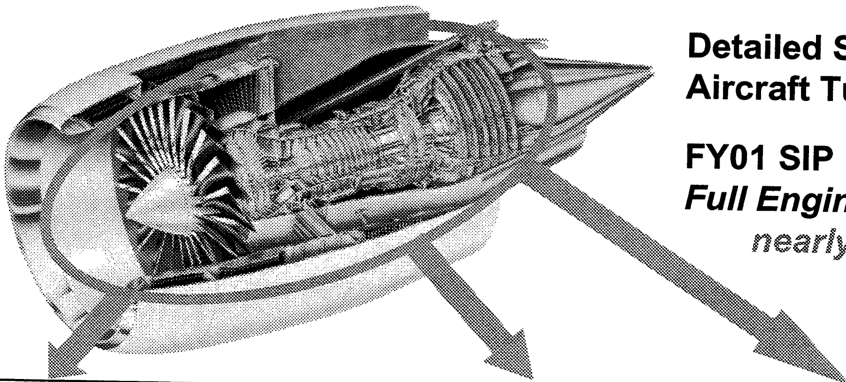
Detailed Simulation of Aircraft Turbofan

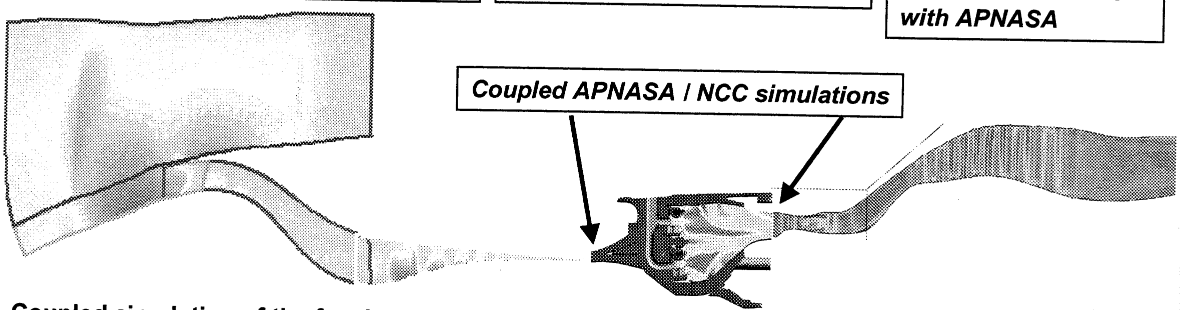
FY01 SIP Milestone:
Full Engine Simulation
nearly completed



3D APNASA flow simulations of fan, low and high pressure compressors

3D NCC flow and chemistry simulation of combustor

3D flow simulation of HP and LP turbines with APNASA



Coupled simulation of the fan, low pressure and high pressure compressors have been delayed to FY02

2001 NPSS Review

Aircraft Propulsion

Presentation Outline

- **Status of Full Turbofan Engine Simulation**
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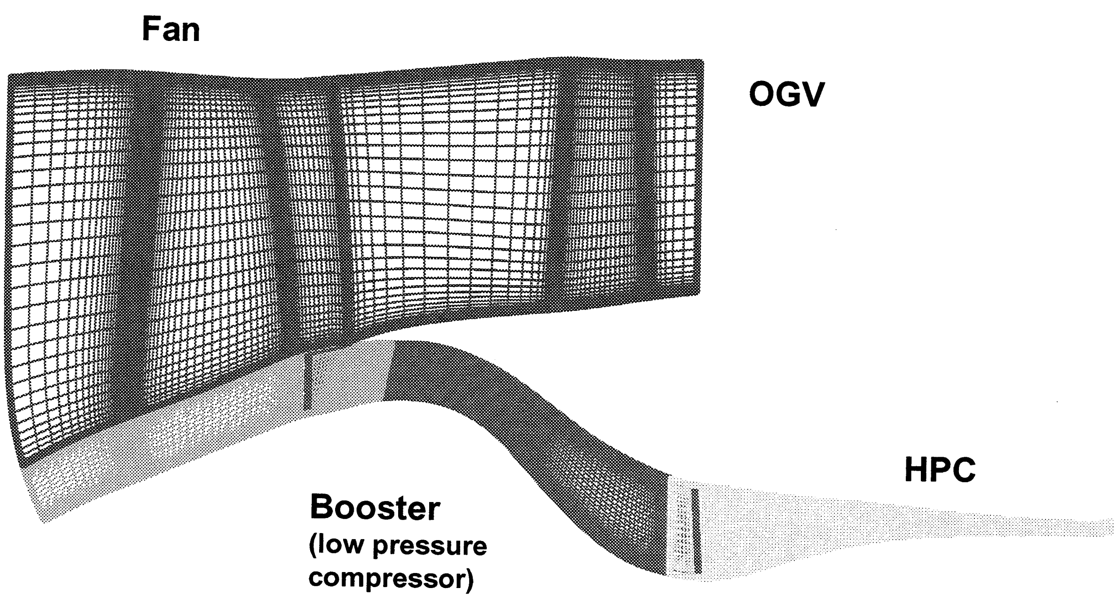
Detailed Simulation of Aircraft Turbofan Engine

Grid for Full Compressor Simulation



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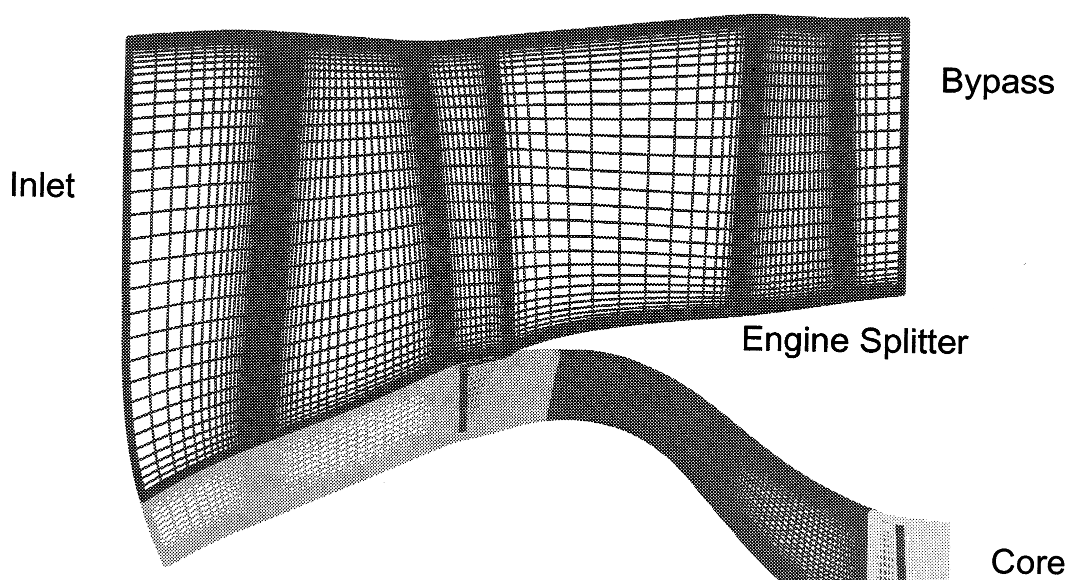
Detailed Simulation of Aircraft Turbofan Engine

Grid for Fan, Outlet Guide Vane and Booster



Fan, OGV and Booster Stator 1 uses two blocks

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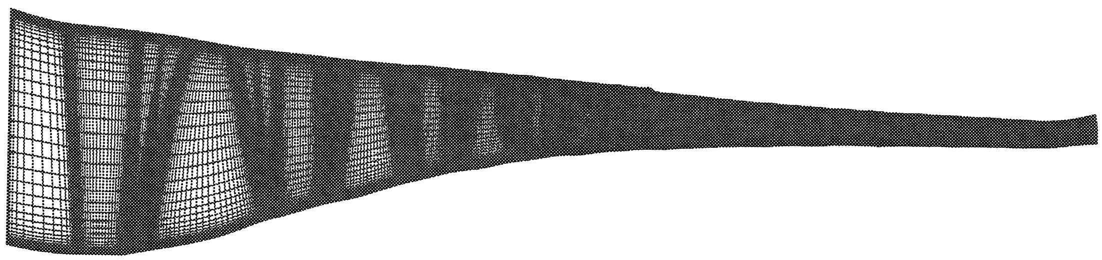
Detailed Simulation of Aircraft Turbofan Engine

Grid for 21 Blade Row High Pressure Compressor



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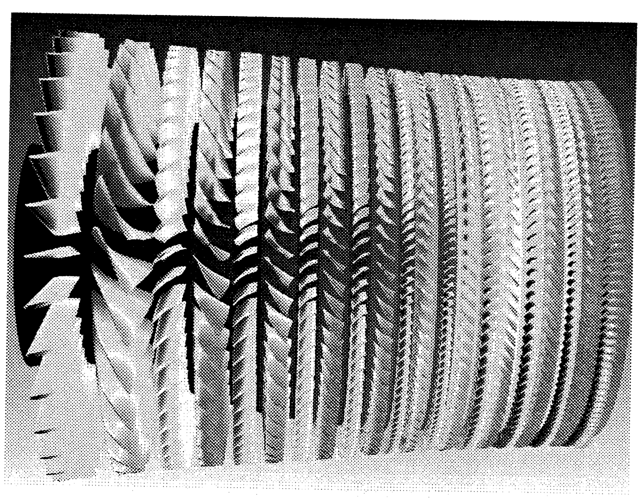
Detailed Simulation of Aircraft Turbofan Engine

High Pressure Compressor Simulation With APNASA Flow Code



3-D simulation was successfully performed for the 21 blade row high pressure compressor at the engine cycle condition using the APNASA flow code.

OVERNIGHT PARALLEL EXECUTION

ROTOR TIP CLEARANCE FLOW

COMPRESSOR BLEED AIR

BLADE FILLETS AT ROTOR HUB

STATOR BUTTON GEOMETRY

STATOR LEAKAGE FLOW

INFLOW LEAKAGE BOUNDARY CONDITIONS

OUTFLOW LEAKAGE BOUNDARY CONDITIONS

To match thermodynamic cycle model of HPC, APNASA was run by adjusting inlet total pressure to match exit corrected mass flow. The corrected and physical shaft rotational speeds were held constant at cycle values.

2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Computer timing for the high pressure compressor (HPC) converged APNASA simulation on the SGI Origin 3000 computer at Ames Research Center (Chapman):

Wall Clock Time:	2 hour 30 minutes 50 seconds
CPU Time:	1242 CPU hours or 52 CPU days

The converged solution took 10,000 iterations. This is 200 flips of 50 iterations per flip of the 21 blade row GE90 compressor.

A total of 504 processors (400 MHz) were used, with 16-27 processors per blade row depending on the grid size. The size of the 3D grid is 9.9 million grid nodes.

This translates to less than 45 seconds per flip (the wait time between flips has been reduced by adding 1 dedicated processor for the script). The flipping process is an exchange of information with adjacent blade rows. The load balancing is not yet optimized to the fullest extent. One of the current limitations to reducing the time to solution is that the CPU a job gets cannot be controlled by the user. Therefore the relative location of processors (and its memory) will vary from blade row to blade row. It will also vary if the job was resubmitted.

Further reductions to these timings would be possible if the topology of the processors for each blade row could be specified.

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Aircraft Propulsion

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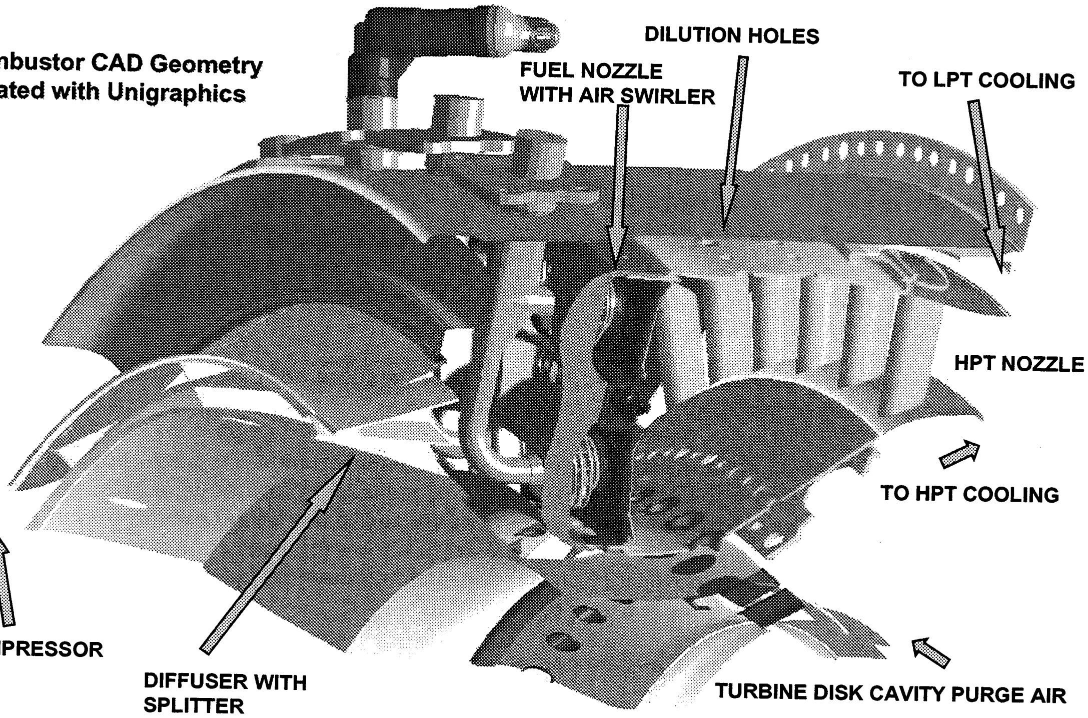
Detailed Simulation of Aircraft Turbofan Engine



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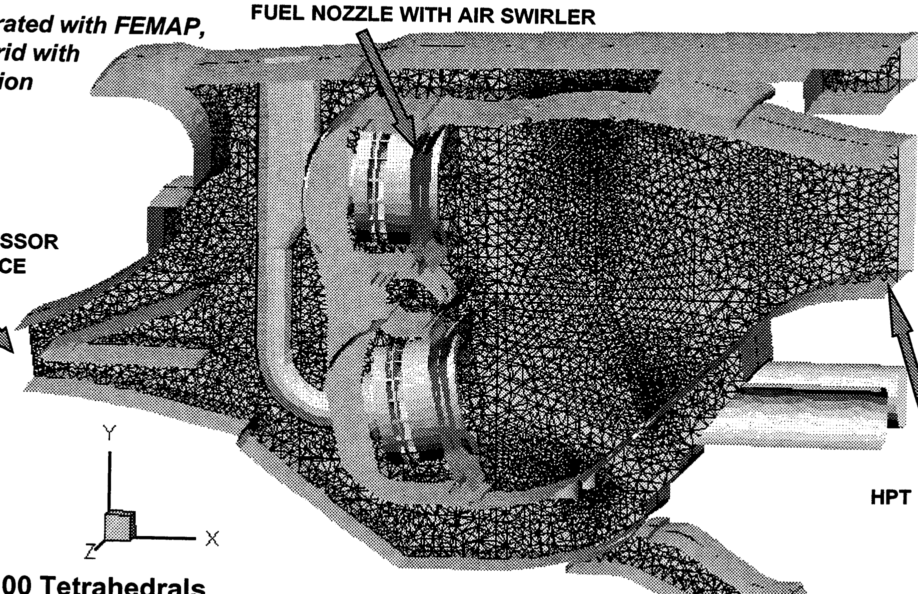
Detailed Simulation of Aircraft Turbofan Engine

Combustor Grid with Adaptation



1,100,000 Tetrahedrals
24° Periodic Sector

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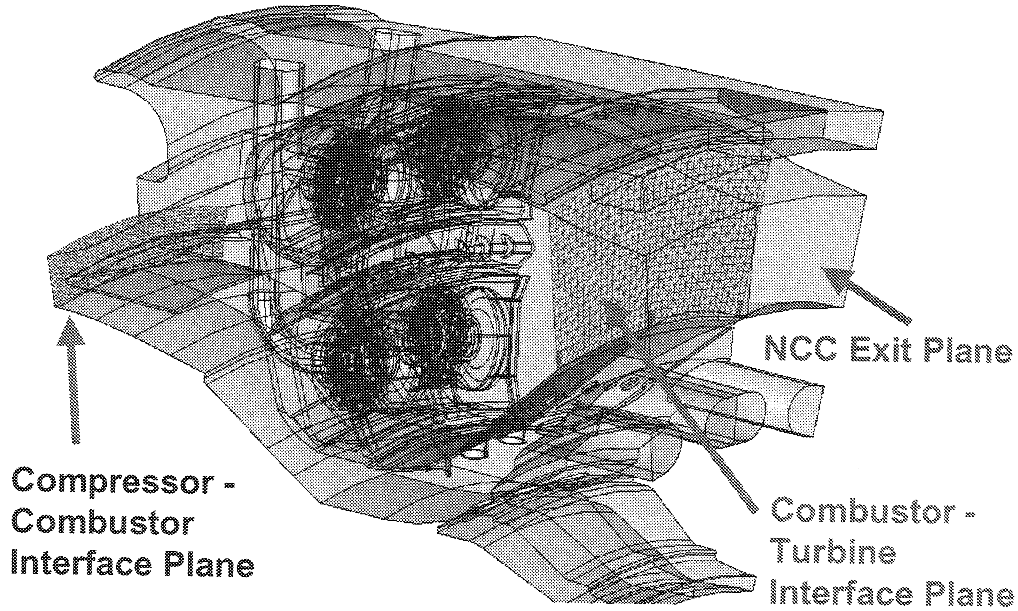
Detailed Simulation of Aircraft Turbofan Engine

Combustor Data Interface Planes



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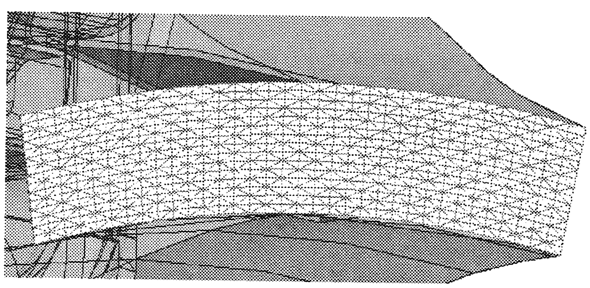
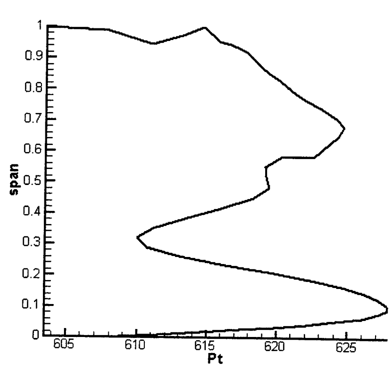
Detailed Simulation of Aircraft Turbofan Engine

Combustor - Compressor Interface



The compressor inflow plane is gridded with a structured polar mesh. This eliminates interpolation error from a structured mesh to an unstructured mesh. This also increases the accuracy of the circumferential mass-averaging methodology. This mesh is then split into triangles and used as the surface mesh for the volumetric tetrahedral mesh.



The compressor circumferential mass-averaged profile from APNASA was imposed onto the NCC inflow mesh boundary by:

1) Holding the profile shape and interpolating onto the NCC inflow mesh
2) Running NCC one iteration
3) Calculate the inlet mass flow
4) Scale the (u,v) profile to match APNASA mass flow (the two computational meshes are mismatched)

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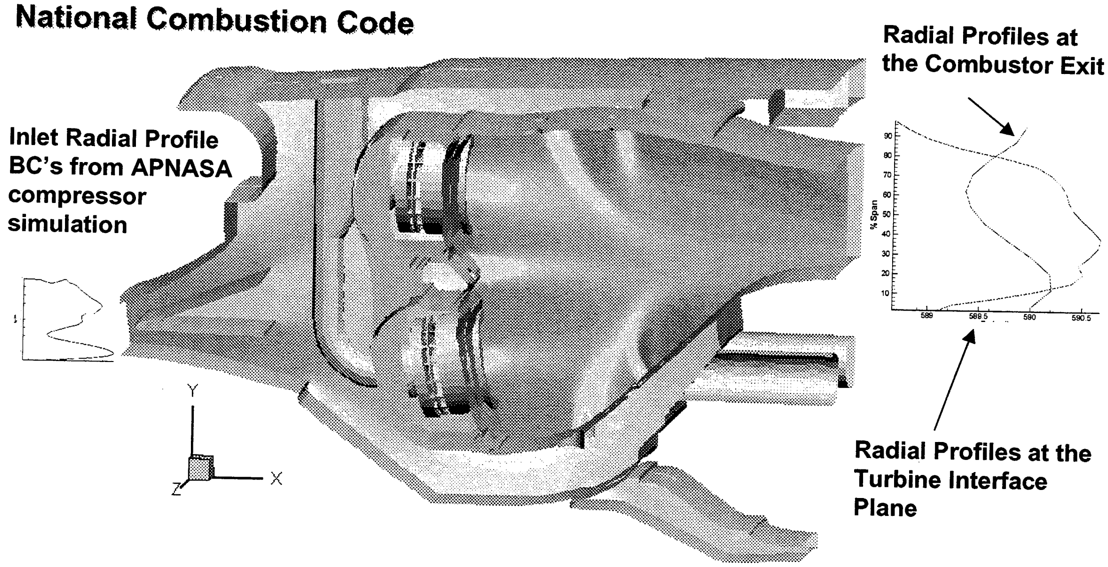
Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Pressure

National Combustion Code



Aerodynamic mass averaged profiles were exchanged at the combustor - turbine interface plane

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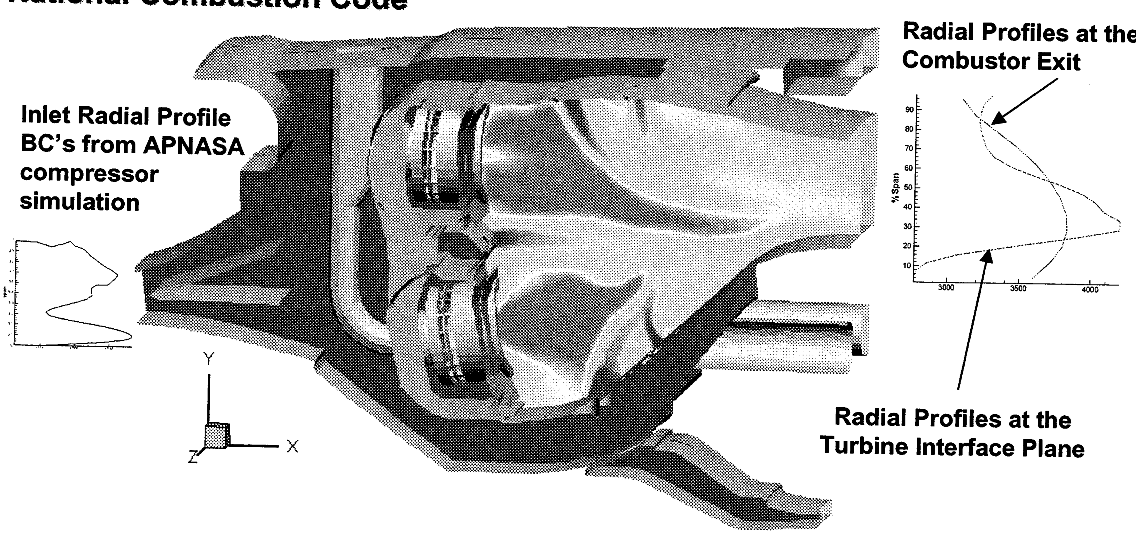
Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Temperature

National Combustion Code



Energy related mass averaged profiles were exchanged at the combustor exit plane due to dilution activity at the interface plane

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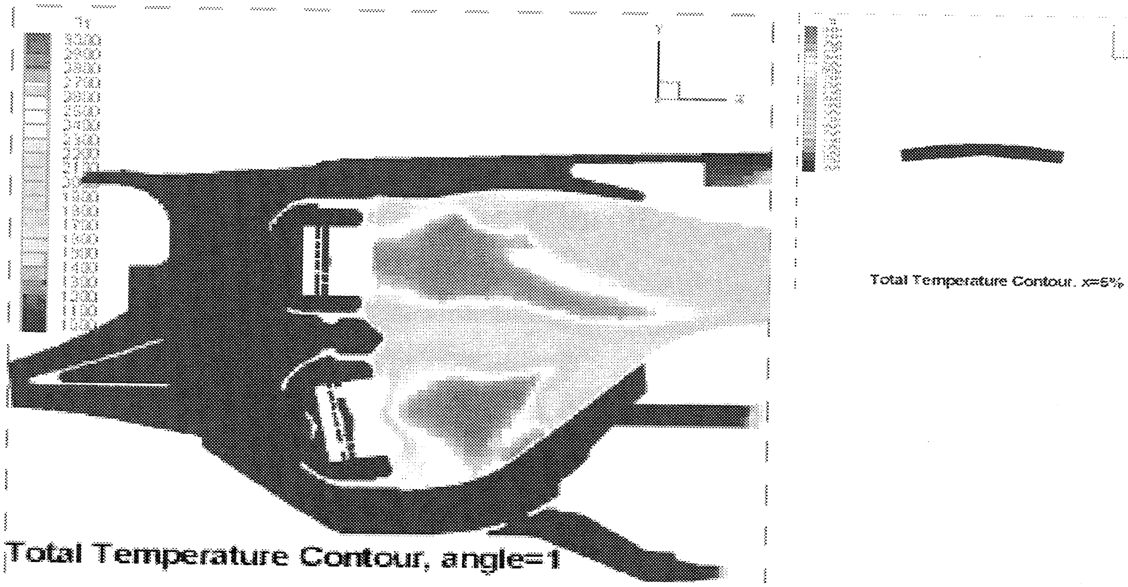
Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Temperature Animation



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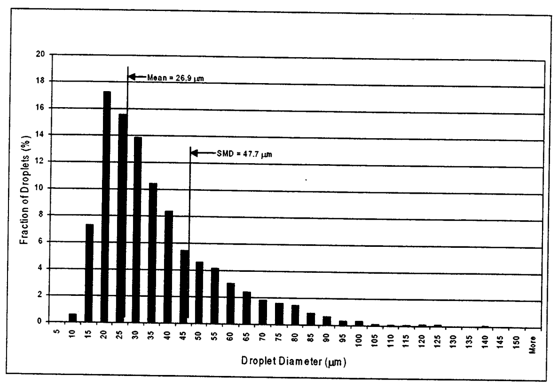
Liquid Spray Droplet Fuel Injection for Increased Fidelity of Combustor Simulations

- Gaseous fuel injection sites are replaced with liquid spray droplet fuel injection streams, using Jet-A fuel, with discrete liquid spray droplet jets issuing from those sites. Coupling of the spray droplets with the local aerodynamic field results in realistic spreading of the spray, with subsequent evaporation and combustion.
- The computational results are generated using a modeled distribution of the droplet diameters, based on data obtained from a turbine combustor experiment. The data were modeled using the Rosin-Rammler droplet size distribution, with a mean diameter of 26.9 microns, and an SMD (Sauter mean diameter) of 47.7 microns, with mass distribution as shown in the figure.



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Liquid Spray Droplet Fuel Injection for Increased Fidelity of Combustor Simulations

Temperature Field

Simulation using Jet-A Spray Droplets

Black Spheres Represent Liquid Spray Droplets

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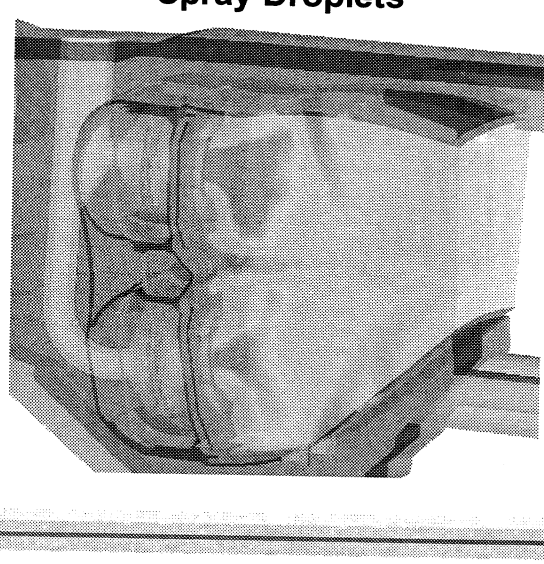
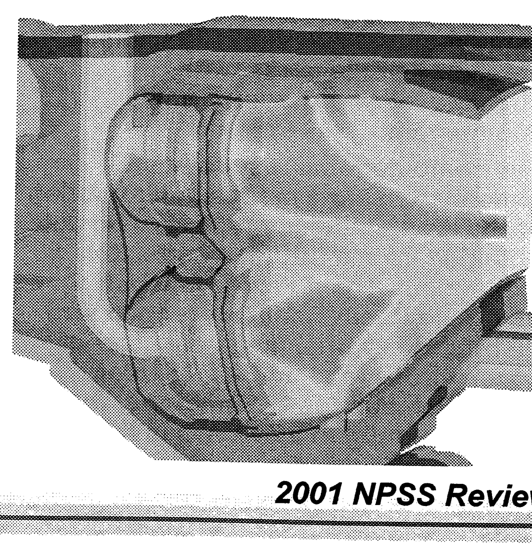
Liquid Spray Droplet Fuel Injection for Increased Fidelity of Combustor Simulations

Temperature Field

Simulation using Jet-A Spray Droplets



Simulation using Jet-A Gaseous Fuel



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Liquid Spray Droplet Fuel Injection for Increased Fidelity of Combustor Simulations

- Stronger and more pronounced central recirculation zones were observed in the spray droplet simulation when compared to the gaseous simulation result. For gaseous fuel simulations, it is necessary to increase the density and injection velocity of the fuel to match overall stoichiometry. This leads to increased flow momentum through the fuel nozzles. For the liquid fuel spray droplet simulations, exact physical properties of the fuel are used without approximations, so that realistic boundary conditions can be applied. This leads to much improved aerodynamics and combustion simulations of the primary zone and the entire combustor.

- The flame structures between the two simulations are different, and result from the different physical processes at work for the two fuel types. The liquid fuel droplet trajectories, evaporation and fuel/air mixing processes are fundamentally different than those for the gaseous fuel case. This has a significant effect on the resulting primary zone flow and flame patterns, in the stabilization of the flame, and in the interaction of the dilution hole jets with the combustion processes inside the combustor.

2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Computer Timings for Combustor Simulations

Computer timing for the combustor for a converged National Combustion Code (NCC) simulation of the GE90 combustor on the parallel computer at Ames Research Center (Turing; Origin 2000 workstation):

Wall Clock Time:	36.5 hours
CPU Time:	558 CPU hours

The combustor simulation converged in 42,000 iterations.

A total of 16 processors were used.

Size of the 3D grid is 364,000 elements for a 12 degree 2 fuel nozzle case.

Wall clock time will be significantly reduced in FY02 by running simulations with the latest version of NCC (version 1.0.7) and Increasing the number of processors.

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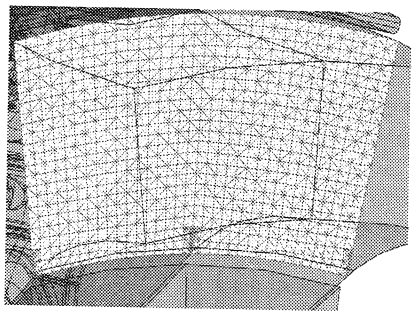
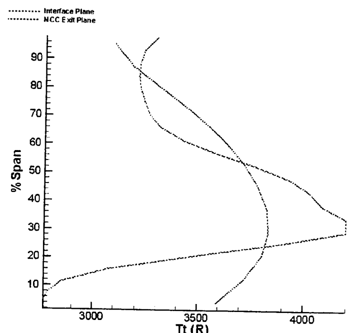
Detailed Simulation of Aircraft Turbofan Engine

Combustor - Turbine Interface



Grid the turbine interface plane with a structured polar mesh. This eliminates interpolation error from a structured mesh to an unstructured mesh. This also increases the accuracy of the circumferential mass-averaging methodology. This mesh is then split into triangles and used as the surface mesh for the volumetric tetrahedral mesh. A similar process was employed for the NCC combustor exit plane.



APNASA total pressure (Pt) was interpolated onto the NCC exit plane mesh, while the NCC solution was circumferentially mass-averaged at the turbine interface plane and supplied to the APNASA turbine calculation. Since the interface plane was just downstream of the last set of dilution holes and chemical reactions were still taking place, total enthalpy (Ht) was averaged at the NCC exit plane and passed to the APNASA calculation.

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Aircraft Propulsion

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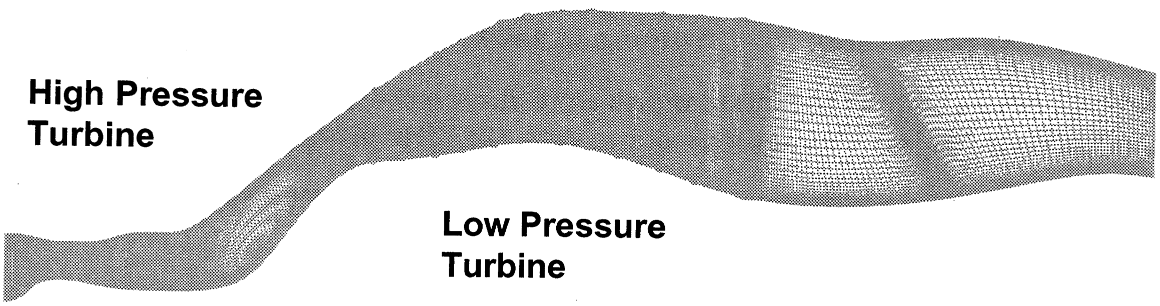
Detailed Simulation of Aircraft Turbofan Engine

Turbine Simulation with APNASA Turbomachinery Flow Code

Grid for Turbine



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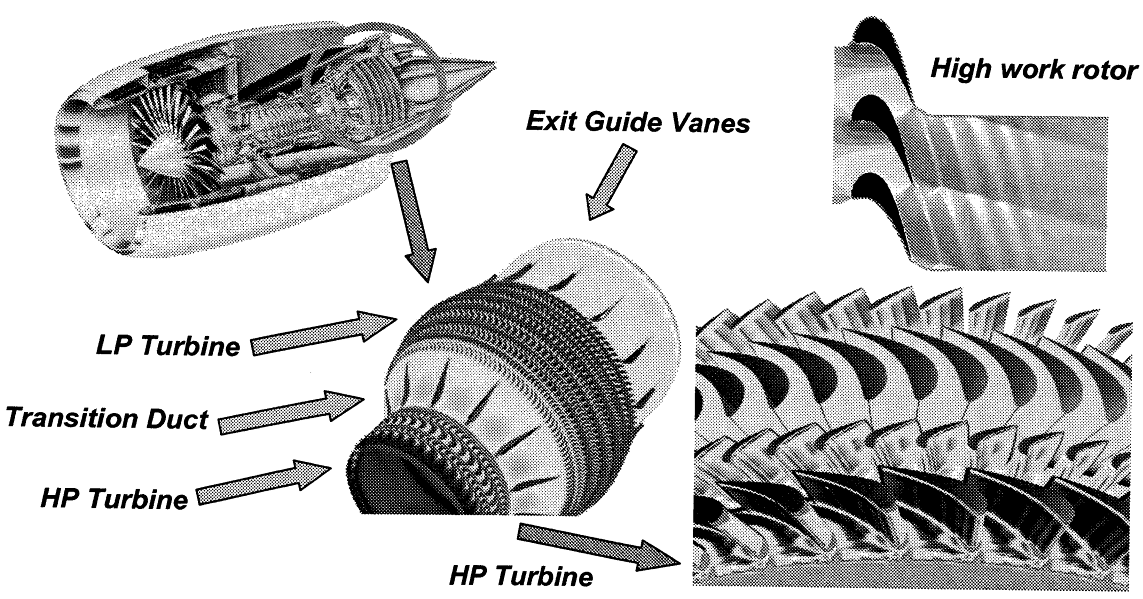
Detailed Simulation of Aircraft Turbofan Engine

Turbine Simulation with APNASA Turbomachinery Flow Code



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Detailed Simulation of Aircraft Turbofan Engine

Computer Timings for Turbine Simulations

The coupled high and low pressure turbine simulations with the APNASA turbomachinery flow code were presented at the IGTI Turbo Expo in Indianapolis in June, 1999 under the title:

"Multistage Simulations of the GE90 Turbine," ASME Paper 99-GT-98.

The computer timings for the turbine simulations for the Hopper / Steger computer at AMES Research Center, which is a 128 node machine with 250 MHz processors, was 15 hours in 1999.

(Note that the compressor simulations were run on the Chapman computer, which is a 512 node machine with 400 MHz processors).

If the turbine simulations were run on Chapman, the expected speed up factor is then 512*400 / (128*250) = 6.4.

The APNASA turbine simulation can now be done on Chapman with 504 processors in **2** hours **16** minutes.

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Detailed Simulation of Aircraft Turbofan Engine

Combustor - Turbine Interface

The following slide shows the combustor - turbine interface plane which has been chosen as the BC exchange location for the following reason:

At this plane, there is no flow recirculation in the combustor solution and almost all the combustion has taken place. However, there is a strong variation in the blade-to-blade plane due to the potential effects of the thick turbine nozzle. This is shown as a flow angle variation of +/-25 degrees and the static pressure variation blade to blade which is much larger than any radial variation.

A method has been created to transfer the boundary conditions from this plane to the inlet plane of the turbine, so the average quantities of interest can be matched at the interface plane between NCC and APNASA (Ht, Pt, rCu and mass flow).

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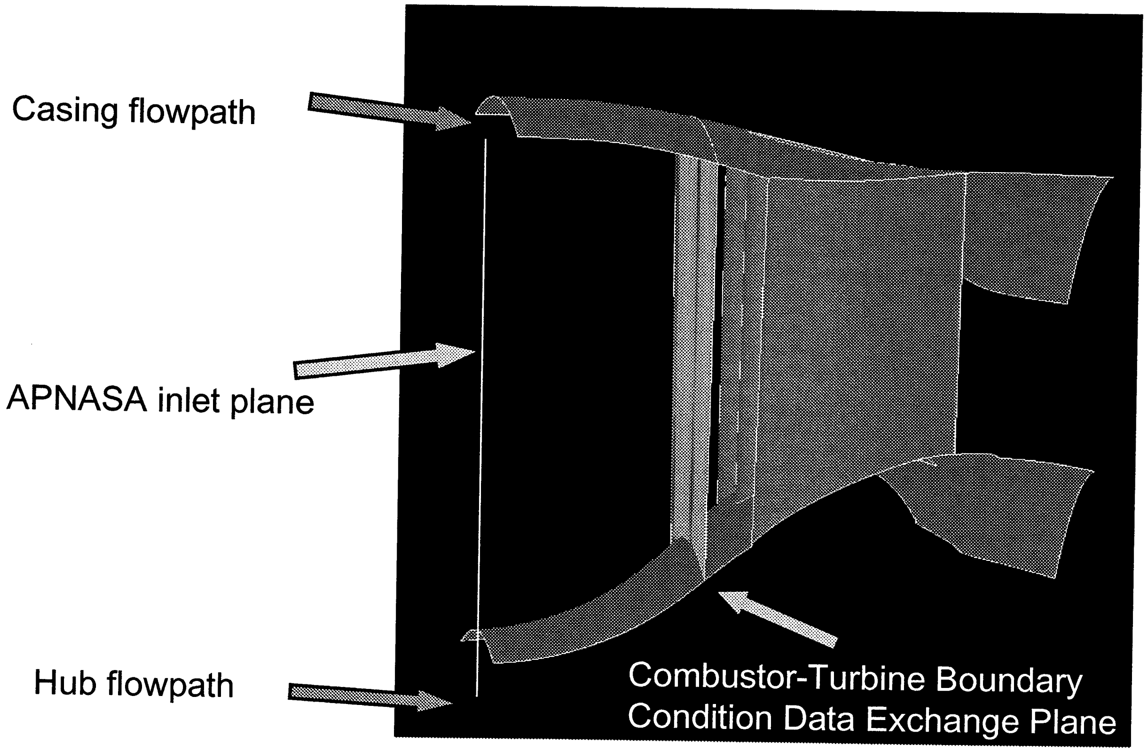
Combustor - Turbine Interface



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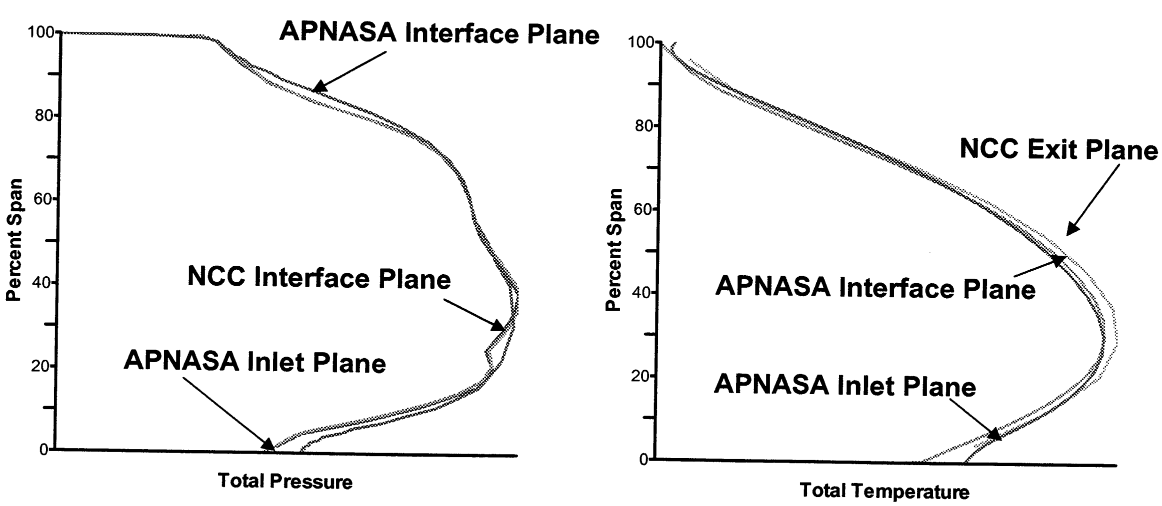
Detailed Simulation of Aircraft Turbofan Engine

NCC-Turbine Coupling
Radial Profile Comparisons



Total Pressure from NCC Interface Plane, Total Temperature from NCC Exit, and 1D level set to match thermodynamic cycle.

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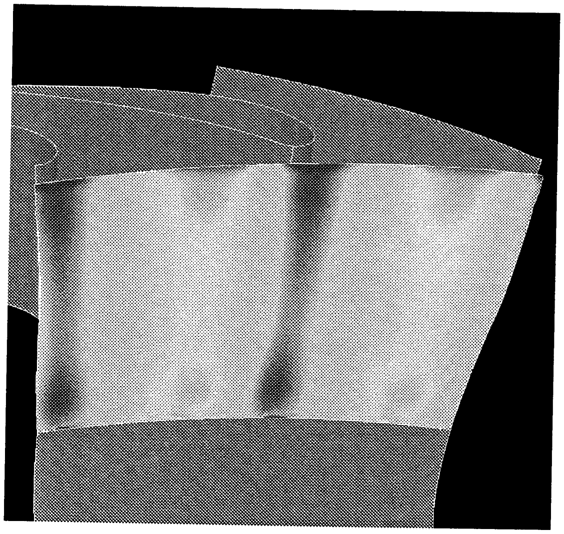
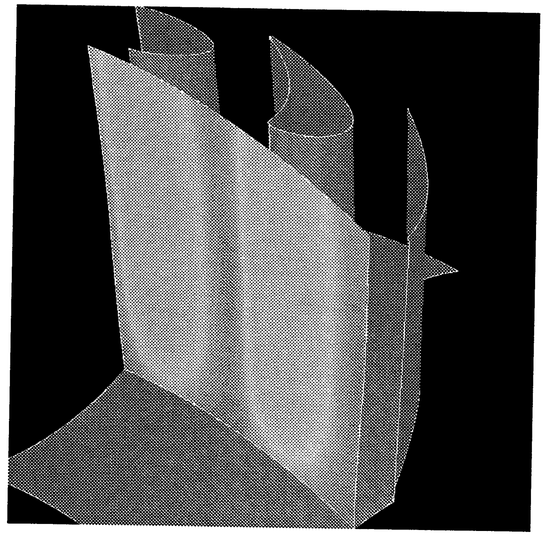
Combustor - Turbine Interface

Combustor-Turbine BC Data Interface Plane



Absolute flow angle in blade-to-blade plane. Blue is –25°, red is 25°.



Static Pressure

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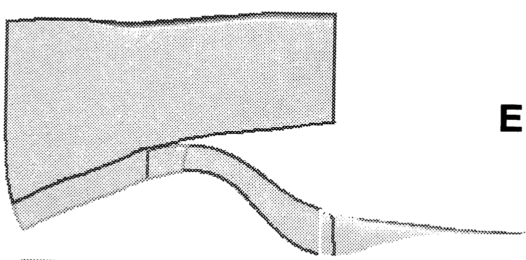
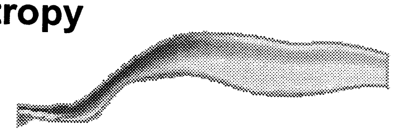
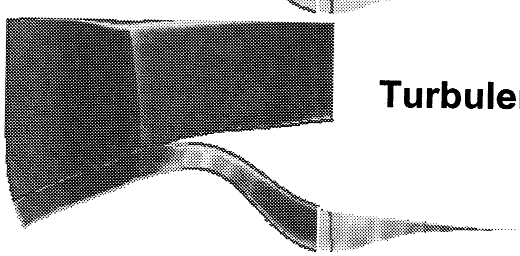
Detailed Simulation of Aircraft Turbofan Engine

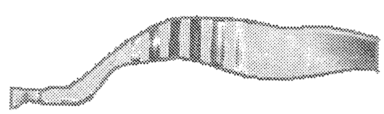


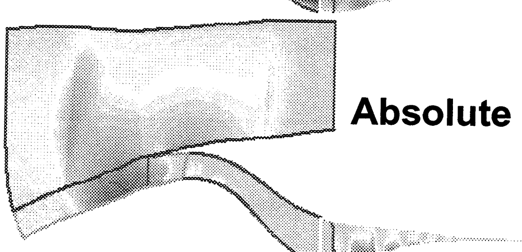
Entropy



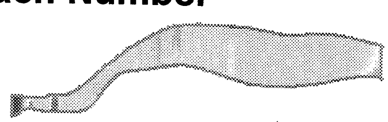


Turbulence Intensity





Absolute Mach Number



2001 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

Comparison of CFD to Cycle

Location in Core Engine	Parameter	Difference % CFD - Cycle / Cycle
HP Compressor Exit / Combustor Inlet	Mass Flow	- 1.1
	Total Pressure	+ 2.1
	Total Temperature	- 1.1
	Compressor Pressure Ratio	0.0
	Compressor Horsepower	- 3.1
Combustor Exit / HP Turbine Inlet	Mass Flow	- 2.0
	Total Pressure	0.0
	Total Temperature	+ 1.6
	Combustor Pressure Ratio	+ 1.9
	Combustor Temperature Rise	+ 1.6
HP Turbine Exit	Mass Flow	- 1.0
	Total Pressure	+ 0.50
	Total Temperature	- 1.7
	HP Turbine Pressure Ratio	+ 0.20
	Turbine Horsepower	- 0.80

2001 NPSS Review

Aircraft Propulsion

Presentation Outline

- Status of Full Turbofan Engine Simulation
- Compression System Simulation
- Combustor Simulation
- Turbine Simulation
- *Summary and Future Directions*

2001 NPSS Review

Aircraft Propulsion
Detailed Simulation of Aircraft Turbofan Engine
Summary

- First complete 3-D aerodynamic simulation of core engine ever reported (completed)
- Successfully simulation of 3-D flow in all components of the turbofan engine (completed)
- Simulation of compressor and turbines with APNASA flow code (completed)
- Combustor flow and chemistry simulated with the National Combustion Code with gaseous & liquid spray models (completed)
- Radial profile boundary conditions transferred to downstream components; compressor to combustor to turbine (completed)
- Simulations were performed on parallel computers at NASA Ames Research Center for fast execution

2001 NPSS Review

Aircraft Propulsion
Detailed Simulation of Aircraft Turbofan Engine

Computer timings for the high pressure compressor, combustor and the coupled HPT and LPT

Component/ Subsystem	Simulation Code	Computer	CPU Processor Speed	Number of Processors	Grid	Iterations Elements	Wall Clock Time
High pressure Compressor	APNASA (version 5)	SGI Origin 3000 (Chapman)	400 MHz	504	9,900,000	10,000	2.5 hrs (2001)
Combustor	National Combustion Code (NCC v.0.9.3)	SGI Origin 2000 (Turing)	195 MHz	16	364,000	42,000	36.5 hrs(2001)
High and low pressure turbines	*APNASA (version 5)*	*SGI Origin 2000 (Hopper / Steger)*	*250 MHz*	*121*	*8,700,000*	*10,000*	*15 hrs (1999)*
High and low pressure turbines	APNASA (version 5)	SGI Origin 3000 (Chapman)	400 MHz	504	8,700,000	10,000	2.3 hrs (2001)

2001 NPSS Review

Aircraft Propulsion
Detailed Simulation of Aircraft Turbofan Engine

Plans for 2002

- Simulation of full compression system with APNASA v.5
- NASA Glenn Research Center Strategic Implementation Plan milestone for FY02:

  Full turbofan engine simulation in under 15 hours of turnaround time
- Combustor simulation with finite rate chemistry and liquid fuel spray
- Hold meetings with NPSS Phase 3 Team to discuss methods developed to couple high fidelity codes such as APNASA, NCC with NPSS. Incorporate standardized code coupling methods into the NPSS developers kit
- Unsteady turbine simulation coupled to combustor simulation with National Combustion Code, to model hot streaks through turbine

2001 NPSS Review

Space Transportation Simulations

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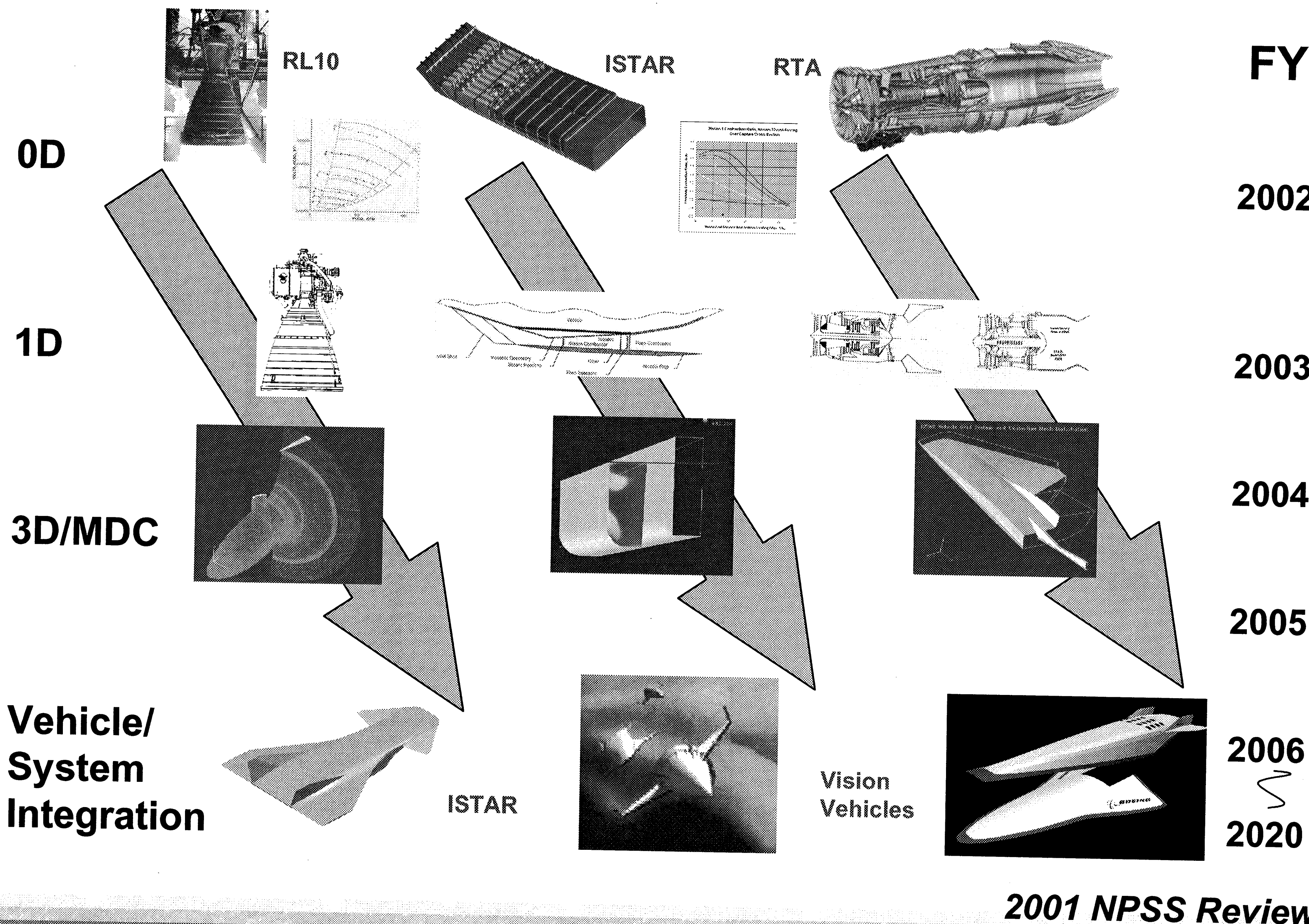
2001 NPSS Review

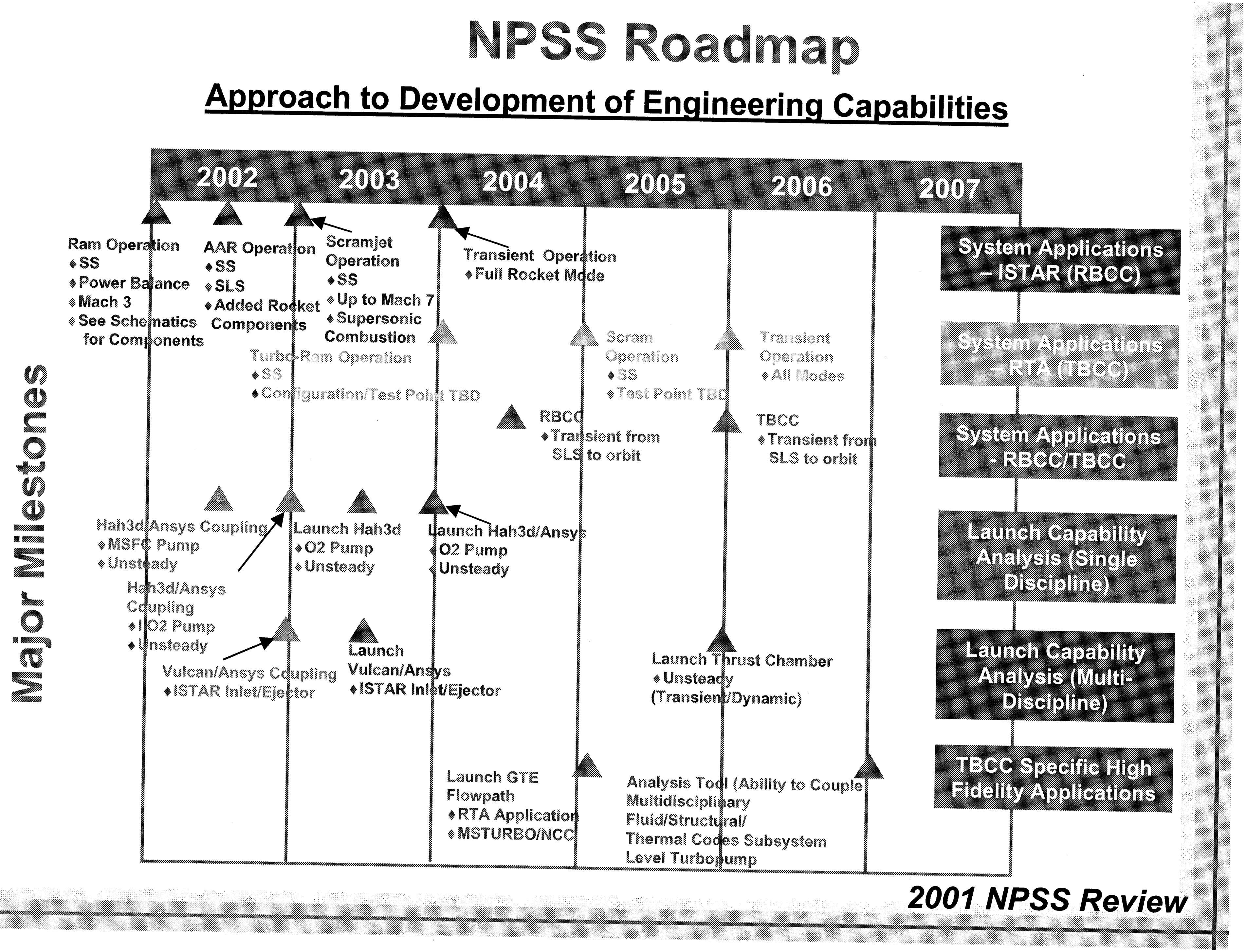
Space Transportation
Presentation Outline

- Program Status
- System Level Simulation Modeling
- Multidisciplinary Coupling Demonstrations
- Summary & Future Directions

2001 NPSS Review

NPSS Vision for Space Access Propulsion




NPSS Roadmap
Approach to Development of Engineering Capabilities
2002
2003
2004
2005
2006
2007
Major Milestones
Ram Operation
♦SS
♦Power Balance
♦Mach 3
♦See Schematics for Components
AAR Operation
♦SS
♦SLS
♦Added Rocket Components
Scramjet Operation
♦SS
♦Up to Mach 7
♦Supersonic Combustion
Transient Operation
♦Full Rocket Mode
Turbo-Ram Operation
♦SS
♦Configuration/Test Point TBD
Scram Operation
♦SS
♦Test Point TBD
Transient Operation
♦All Modes
RBCC
♦Transient from SLS to orbit
TBCC
♦Transient from SLS to orbit
Hah3d/Ansys Coupling
♦MSFC Pump
♦Unsteady
Launch Hah3d
♦O2 Pump
♦Unsteady
Launch Hah3d/Ansys
♦O2 Pump
♦Unsteady
Hah3d/Ansys Coupling
♦LO2 Pump
♦Unsteady
Vulcan/Ansys Coupling
♦ISTAR Inlet/Ejector
Launch Vulcan/Ansys
♦ISTAR Inlet/Ejector
Launch Thrust Chamber
♦Unsteady (Transient/Dynamic)
Launch GTE Flowpath
♦RTA Application
♦MSTURBO/NCC
Analysis Tool (Ability to Couple Multidisciplinary Fluid/Structural/Thermal Codes Subsystem Level Turbopump
System Applications – ISTAR (RBCC)
System Applications – RTA (TBCC)
System Applications - RBCC/TBCC
Launch Capability Analysis (Single Discipline)
Launch Capability Analysis (Multi-Discipline)
TBCC Specific High Fidelity Applications
2001 NPSS Review

NPSS Space Transportation

Objective

The purpose of NPSS for Space Transportation is to expand the NPSS capabilities to support the space access propulsion community and the NASA access to space effort (Advanced Space Transportation Program).

FY01 Milestones

- Develop and release an RBCC capable NPSS simulation capability
- Develop and release a rocket capable NPSS simulation capability (Strategic Implementation Plan – SIP milestone)

FY02 Milestones

- Expand RBCC capability to include to additional operational modes
- Engineering demonstration of MDC for turbopump application (SIP milestone)
- Engineering demonstration of MDC for RBCC application (SIP milestone)

2001 NPSS Review

Status

- Three Industry Partners Under Contract
  - Future Contractual Funding under RASER
  - Use Case Demonstration Being Developed
  - Space Act Agreement in Process
- Funding Sources
  - Advanced Space Transportation Program
  - Computing, Information, and Communications Technology Program
- Software Requirements Specifications Document for Space Transportation Accepted.
- Incremental Release of NPSS for RBCC (ISTAR Configuration)
- Multidisciplinary Coupling Engineering Demonstrations Underway
  - Unsteady Pump Simulation
  - ISTAR Propulsion System Simulation
- Contract Modifications for Use Case Execution

2001 NPSS Review

Space Transportation
Presentation Outline

- Programmatic Status
- *System Level Simulation Modeling*
  - Rocket Engine Simulation Development
  - RBCC Engine Simulation Development
- Multidisciplinary Coupling Demonstrations
- Summary & Future Directions

2001 NPSS Review

System Simulation Accomplishments
(as of October 1, 2001)

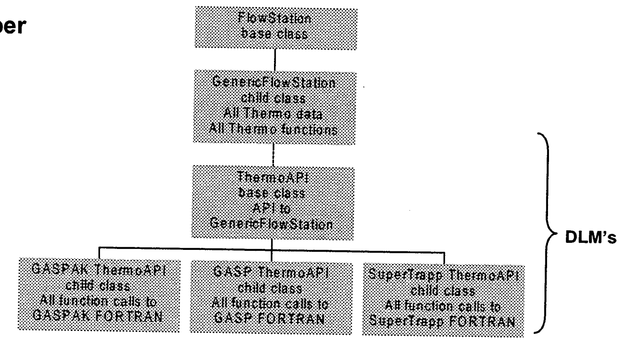
- GASPAK Thermodynamic Capabilities Added to NPSSv1
- System Demonstrated Capability of Matching Rocket Model (ROCETS)
- ISTAR Ramjet Operation (Mach=3.0): AirFlow Path and Feed System Coupled Model Matched to ROCETS/MERPAC
- Upgraded JANNAF Thermodynamics Properties Tables Incorporated into NPSSv1 for Use in Advanced Space Access Propulsion Systems – Honeywell Implements CEA Solver
- Zoom to 1D Pump Code (Pumpa) for Rocket Application

2001 NPSS Review

"Plug-n-Play Thermo"

- Defined Design Requirements
  - GenericFlowStation Child Class Created
  - ThermoAPI base Class Created
  - Wrappers for GASPAK, GASP & SuperTrapp written
    - Additional property packages require unique API / wrappers

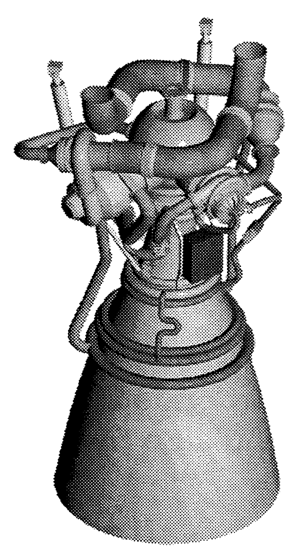
- GFS object contains pointer to the wrapper of choice
- Thermo API creates ThermoSpecial objects (variables unique to specific property packages)
- Specific Thermo API contains all calls to FORTRAN routine



2001 NPSS Review

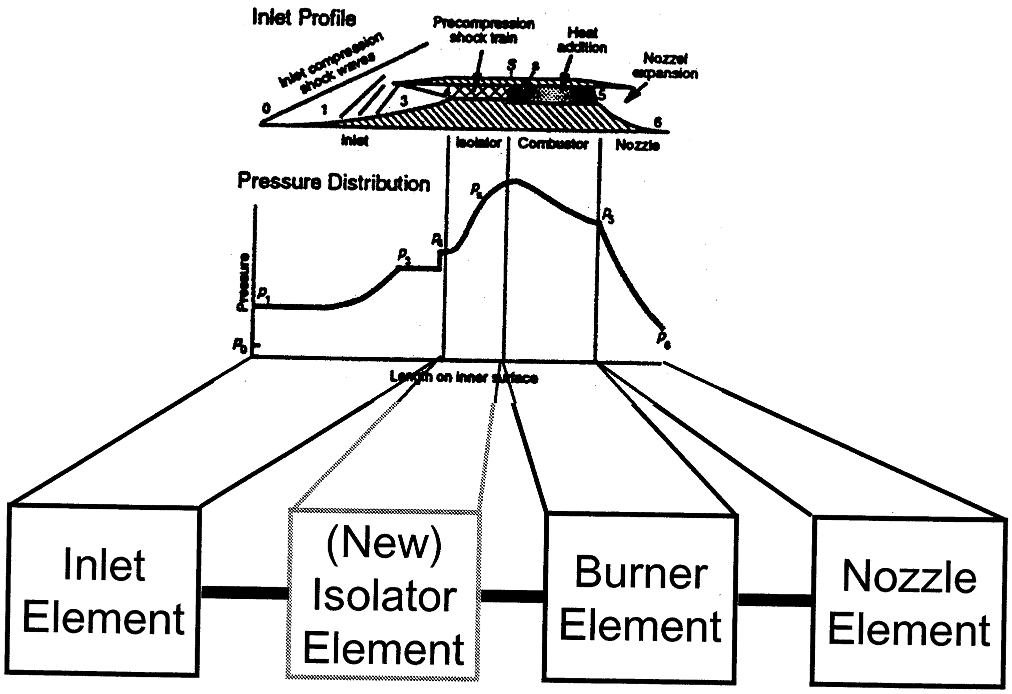
Liquid Rocket Model

- Created NPSS model of a staged combustion liquid hydrogen / liquid oxygen booster engine
- Contains multiple pumps, turbines & valves
- Actively cooled main chamber & nozzle
- Plumbing elements with resistance & transient capability
- Volume elements for transient capability
- ~ 100 Solver balances required for physics
  - Additional balances required for Cycle Match Control
- Validated against ROCETS model
- Will work incorporation of revised component elements into "production" NPSS release



2001 NPSS Review

Isolator Element Required For Ramjet/Scramjet And RBCC Cycle Models



2001 NPSS Review

New Isolator Element Uses Method Employed By MERPAC

- Methodology Based On Distortion Theory Of Ortwerth
- Non-Constant Area Isolator Duct
- One-Dimensional Marching Method
- Implementation Will Be Verified By Comparison To MERPAC
- Extendable to Incorporate LaRC Isolator Model (Auslender) For Off-Design Performance

2001 NPSS Review

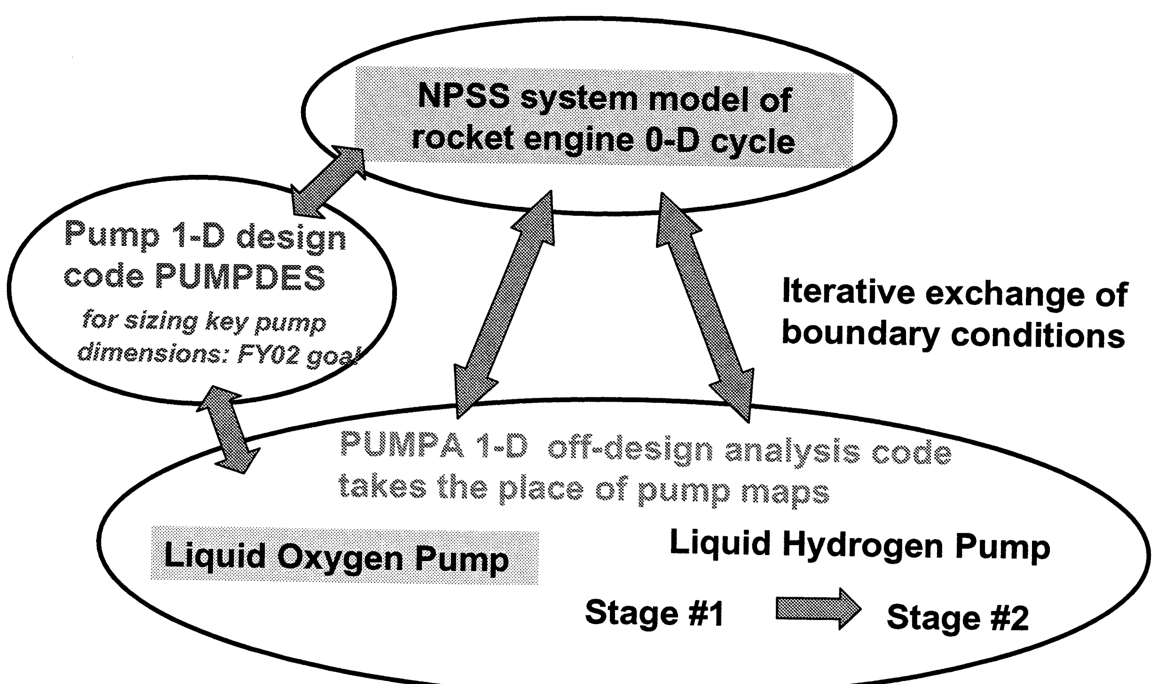
Rocket Engine System Simulation Integrated with 1-Dimensional Flow Models of Hydrogen and Oxygen Pumps

- System Model: Numerical Propulsion System Simulation
- Pump Model: 1-Dimensional Flow Code PUMPA
  Reference:
  "Centrifugal and Axial Pump Design and Off-Design Performance Prediction", J. P. Veres, NASA TM-106745
- Pump Model Integrated with NPSS System Model

2001 NPSS Review

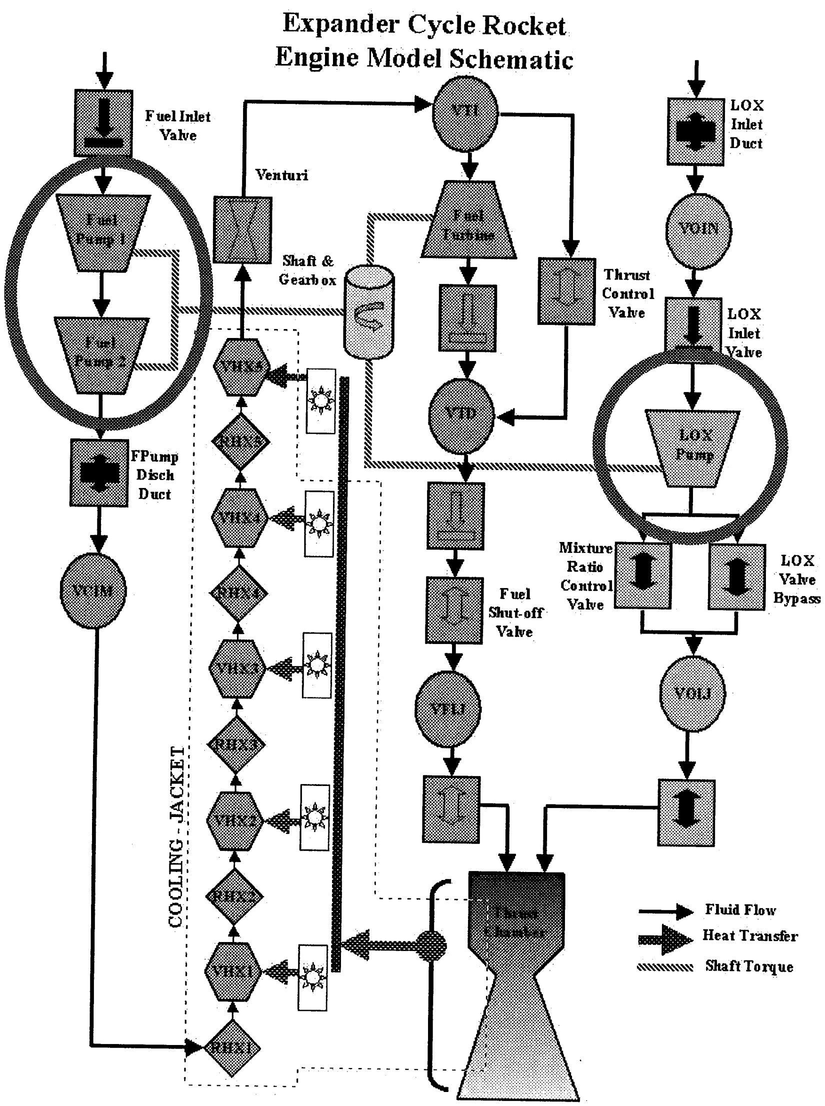
NPSS Expander Cycle Rocket Engine Model

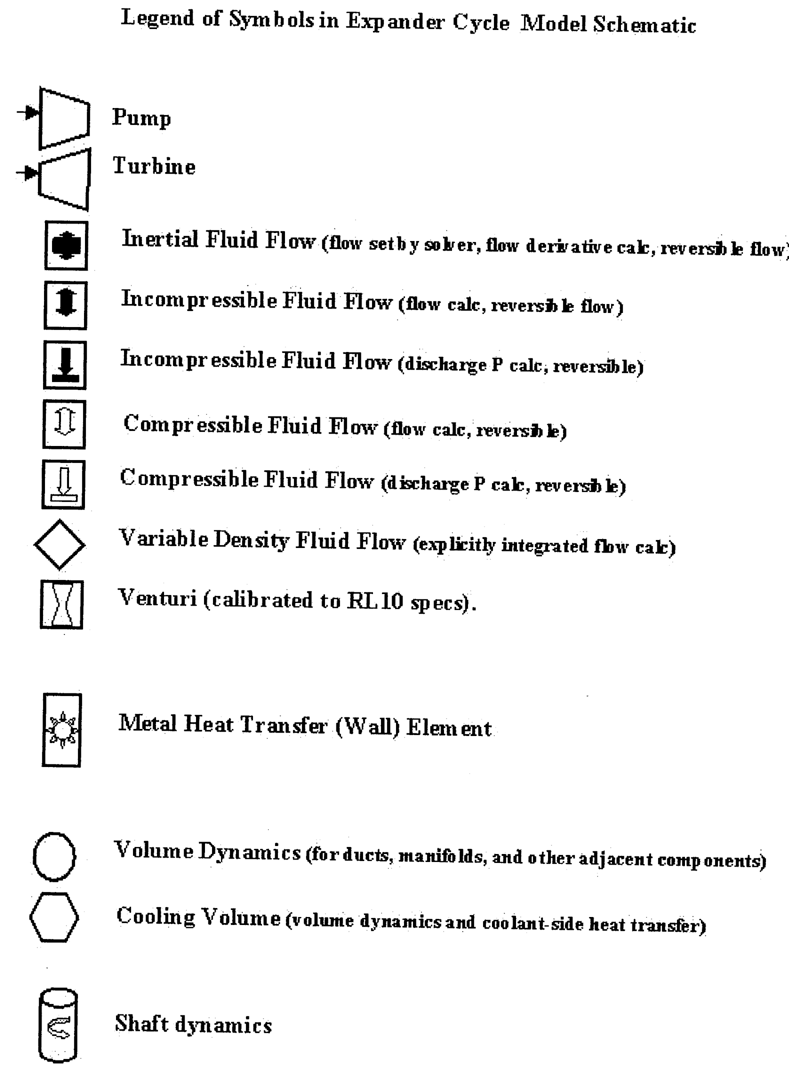
Integration of NPSS cycle code and PUMPA code



2001 NPSS Review

NPSS System Model of Rocket Engine



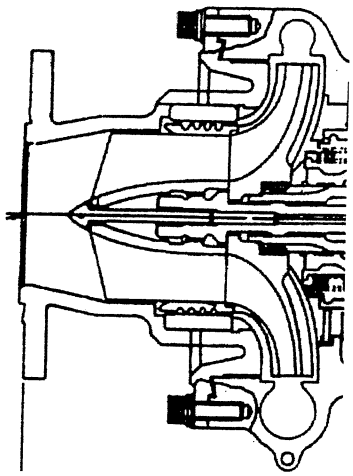


2001 NPSS Review

Pumps in Expander Cycle Rocket Engine

PUMPA 1-D Flow Model of Oxygen Pump:

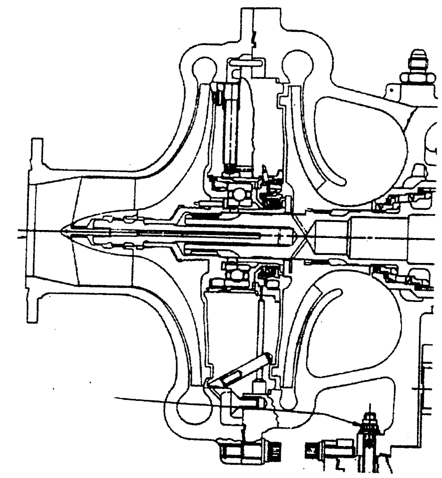
Rotor: ***Inducer***
Centrifugal Impeller
Diffusion System:
Vaneless Radial Diffuser
Volute / Exit Diffuser



PUMPA 1-D Flow Model of Hydrogen Pump

Stage 1
Rotor: ***Inducer***
Centrifugal Impeller
Diffusion System:
Vaneless Radial Diffuser
Volute / Exit Diffuser

Stage 2
Rotor: ***Centrifugal Impeller***
Diffusion System:
Vaneless Radial Diffuser
Volute / Exit Diffuser



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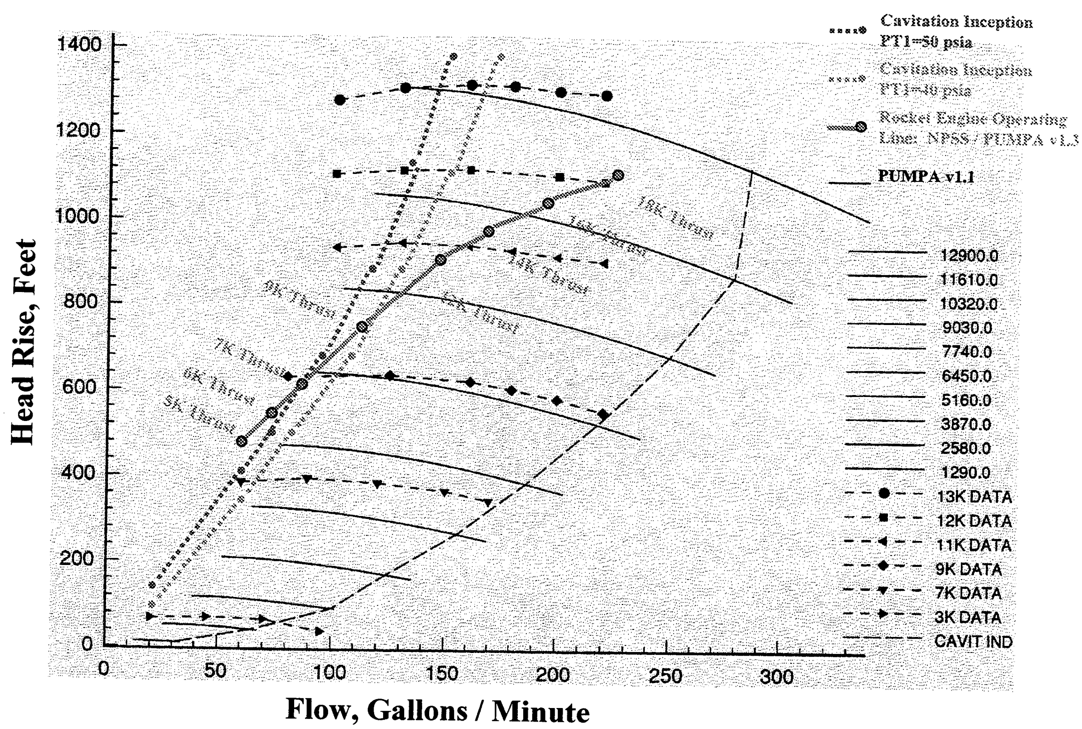
Liquid Oxygen Pump

Inducer + Centrifugal



2001 NPSS Review

Conclusions

- A 1-D method for flow modeling cryogenic pumps (PUMPA) has been integrated with a 0-D NPSS system simulation of an expander cycle rocket engine
- The PUMPA code provides instant transfer of key pump performance parameters at an operating point to the NPSS system model in place of traditional maps
- Zooming was successfully demonstrated between the 0-dimensional NPSS system model (version 1.0) and the 1-dimensional PUMPA code (version 1.3)
- The new capability enables designers to have improved insight into the detailed pump performance in a rocket engine system environment
- The new NPSS rocket engine system modeling capability has potential to reduce the design cycle time required for rocket engines

2001 NPSS Review

Space Transportation
Presentation Outline

- Programmatic Status
- System Level Simulation Modeling
- *Multidisciplinary Coupling Demonstrations*
  - Rocketdyne Enhancement for RBCC Inlet
  - Forebody/Inlet/Isolator/Combustor
  - MSFC Pump Design Unsteady Fluid Structural Analysis
- Summary & Future Directions

2001 NPSS Review

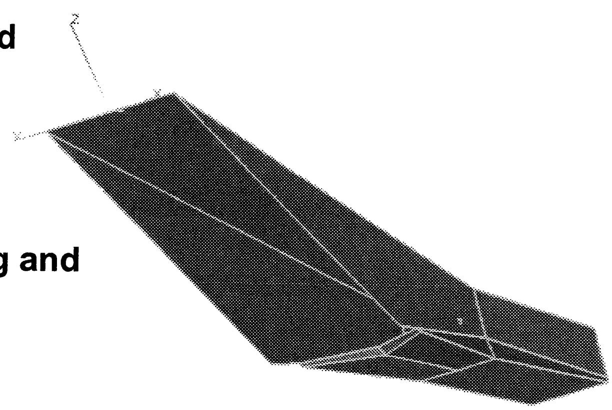
NASA GRC / Boeing-Rocketdyne NPSS Enhancement

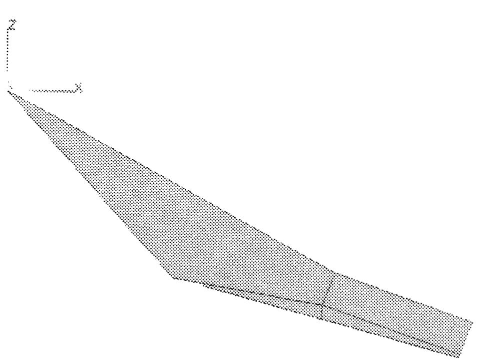
- Objective
  - "... increase the usability of the current NPSS code/architecture by incorporating an advanced space transportation propulsion system capability into the existing NPSS code."
    - Begin defining advanced capabilities for NPSS
    - Provide an enhancement for the NPSS code/architecture
- Complementary with other efforts
  - I^{star}
  - MSFC Intelligent Design Advisor (IDA)
  - Boeing Integrated Vehicle Design System (BIVDS)
- Status
  - Contract initiated 4/01, ECD: 10/01
  - Key enhancement defined (high-fidelity analysis)
  - Enhancement effort completed
  - Groundwork laid for subsequent complementary enhancements

2001 NPSS Review

Key Enhancement Defined: Parametric Geometry Module for 3D Hypersonic Inlet

- Basic design inputs specified in design document
- Output is surface geometry file (arrays of points representing surfaces)
- Includes basic error handling and input checking

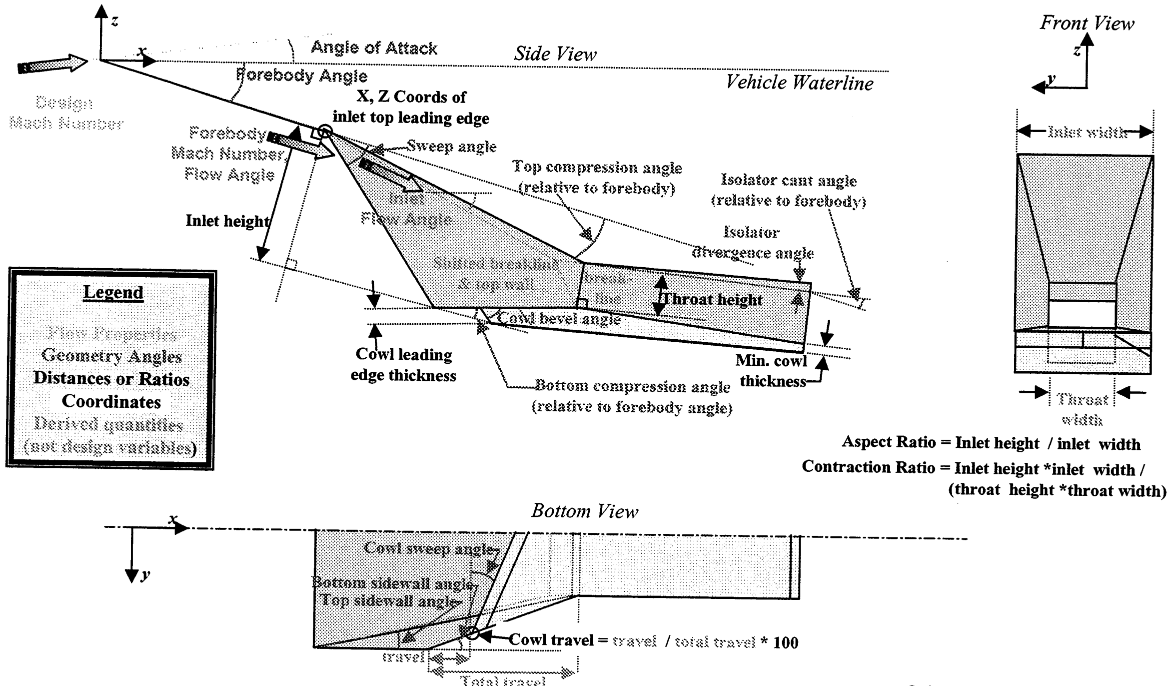




- NPSS Compatible (C++ code)
- Typical workstation runtime << 1s (Sun UltraSPARC)
- Groundwork laid for parametric I^{star}-type inlet geometry module

2001 NPSS Review

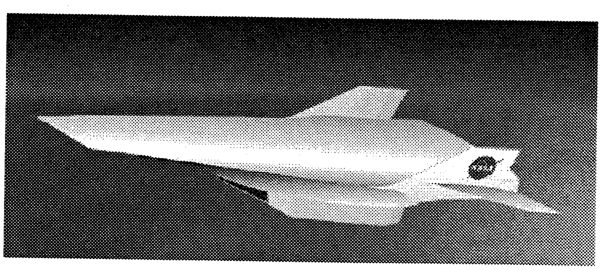
Parametric Geometry Design Variables Defined for 3-D Inlet / Isolator

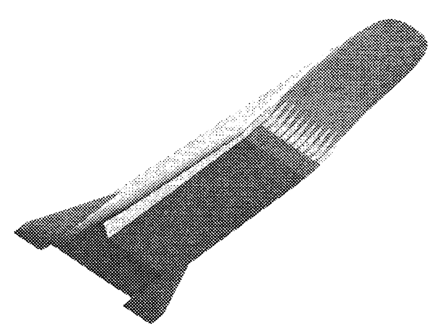


2001 NPSS Review

ISTAR Engine Multidisciplinary Analysis

- Simulation of Approach Flow & Scram Flow for ISTAR Engine
- Inflow Simulated with OVERFLOW; Scram Simulated with VULCAN
- Prelude to Aero/Thermal/Structural Simulation
- CFD Solution Delivered August 2001





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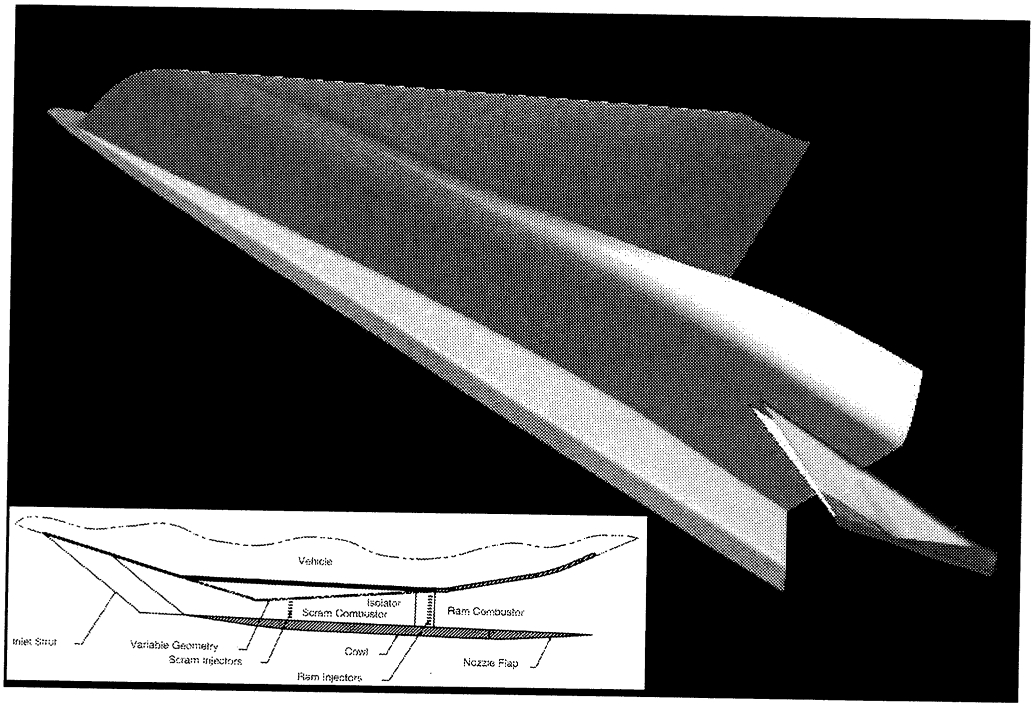
Mach Distribution for ISTAR Engine Approach Flow



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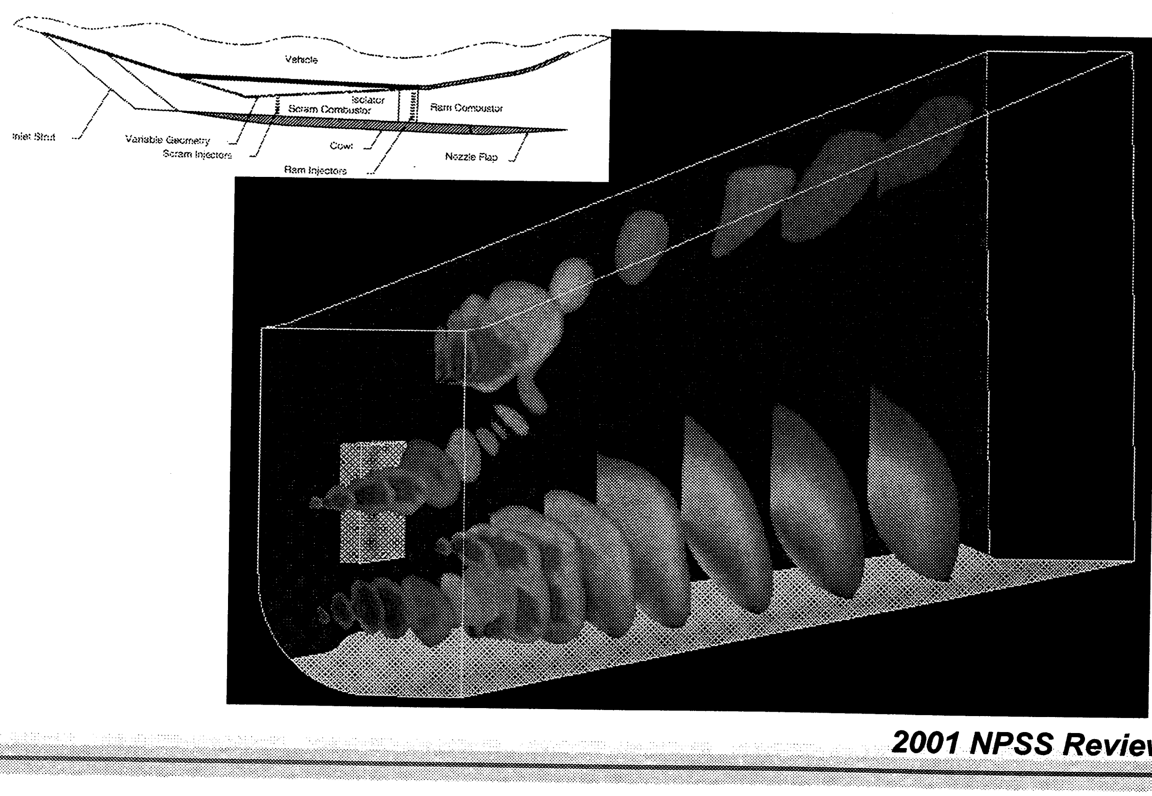
Fuel Mass Fraction in ISTAR Scram Combustor



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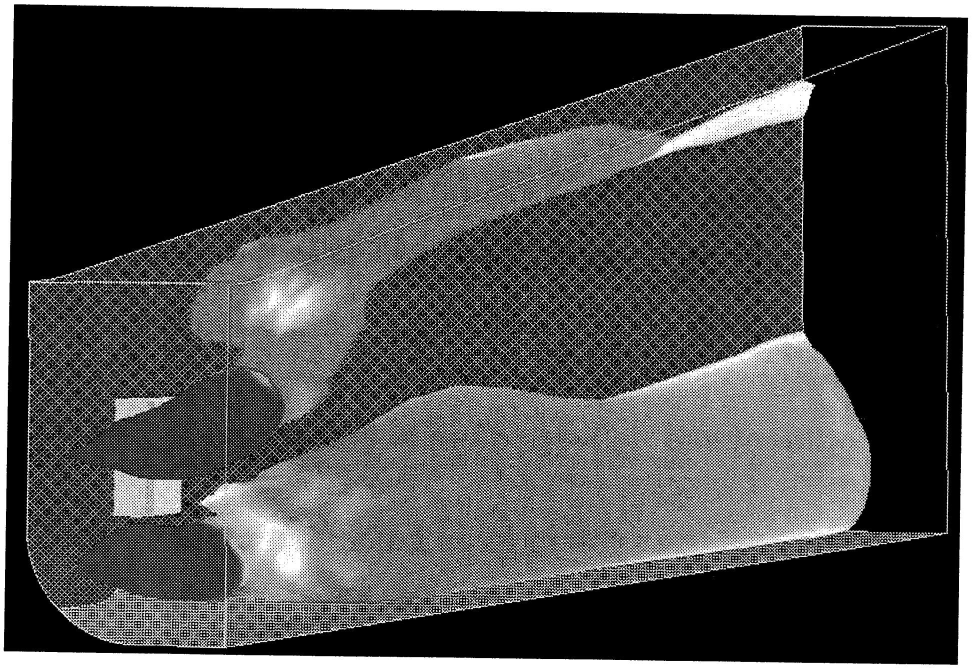
Fuel Iso-Surfaces Colored by Temperature



2001 NPSS Review

Future Work: Aero/Thermal/Structural Simulation

- Thermal/Structural Simulation and Coupling with Existing Aerodynamic/Combustion Code
- Heat Fluxes for Active Cooling Requirements
- Structural Deflections: Balancing Aerodynamic and Structural Requirements
- Thermal Effects on Seals

2001 NPSS Review

Coupled Fluid and Structural Analysis of Pump Stage

2001 Accomplishments:

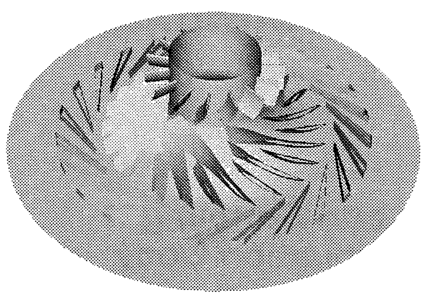
1. Validation of flow code with test measurements.
2. Initial coupling of fluid code output with structural code.
3. Initial validation of cavitation model with flat plate data.

2002 Planning:

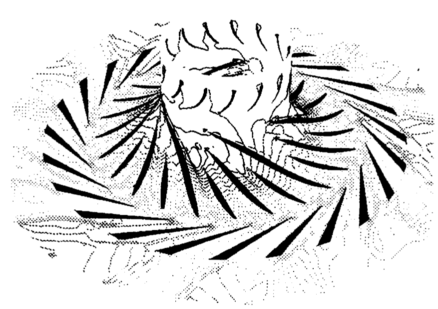
1. Development and delivery of an automatic coupling module.
2. Application of the system to an advanced pump stage.
3. Validation of cavitation model with MSFC pump stage.

2001 NPSS Review

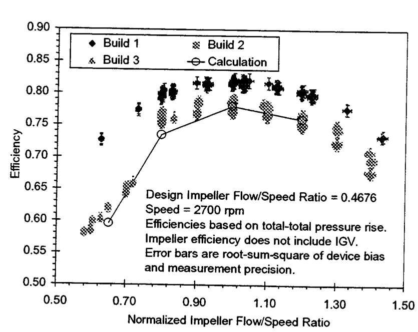
Validation of Unsteady Stage Computation



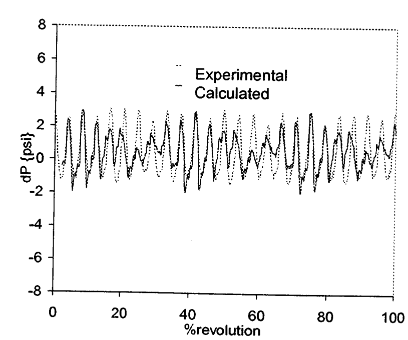
MSFC Pump Stage



Instantaneous Pressure Contours



Calculated and Measured Efficiency



Calculated and Measured Unsteady Pressure

2001 NPSS Review

Coupling of CFD - Structure code

HAH3D ⟺ ANSYS

Develop a bi-directional coupling for a CFD and a Structural code for a Turbopump problem.

Current Status:

CFD analysis was done using HAH3D code. The output contains grid coordinates and pressure change at a grid point.

Structural analysis was done using ANSYS. The grid from CFD analysis was used to create an FEA model. Pressure and boundary conditions were applied. A steady state solution was obtained. New coordinates of the grid were created by adding (or subtracting) the displacement values. The new grid is then transferred for further CFD analysis. Transient analysis is being tested.

Future Plans:

1. Analyze the structural analysis results from the transient dynamic solution and standardize all parameters for transient analysis in ANSYS.
2. Develop the model conditions for the new Turbopump model. (expected arrival time ... September 2001).
3. Test the coupling model tool using a CGNS format and the Developers Kit (Scott Townsend)
4. Implement and test the bi-direction coupling.

2001 NPSS Review

Turbopump Results

IGV blades: 5

Nodes 7200

Elements 3245

Impeller blades: 8

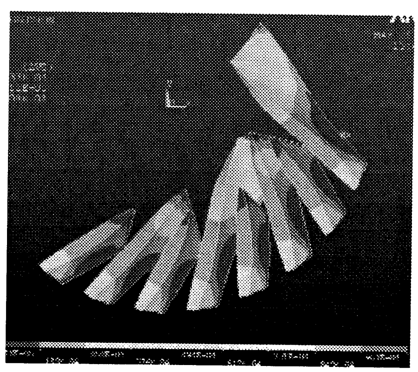
Nodes 12336

Elements 5566

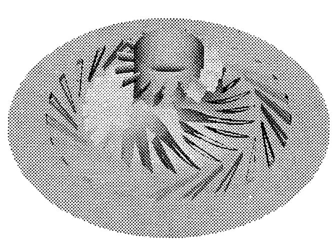
Diffuser blades: 8

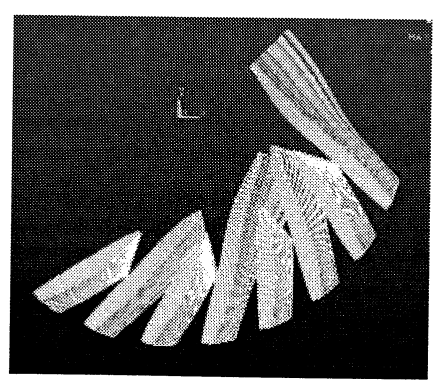
Nodes 8640

Elements 3872



Total Intensity STRAIN

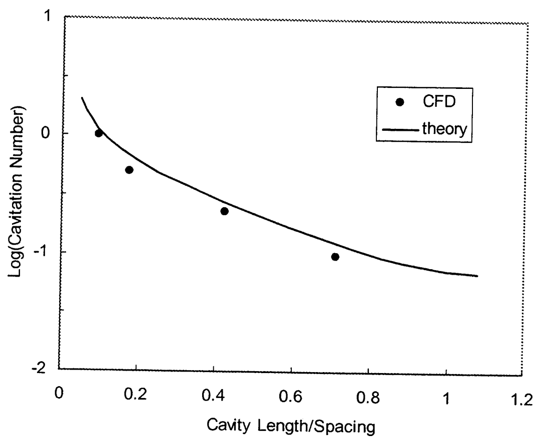




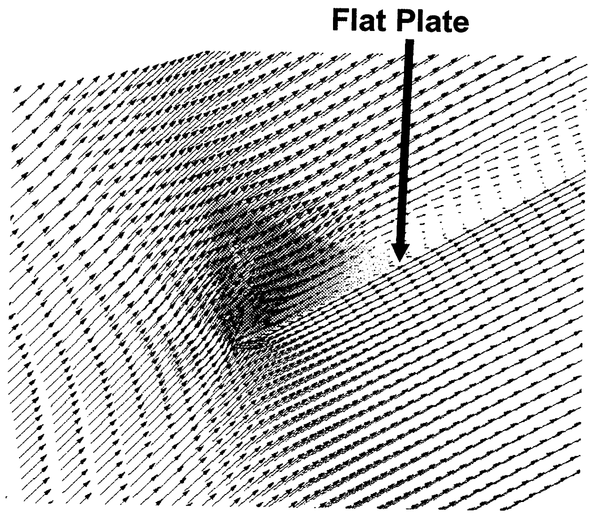
Grid

2001 NPSS Review

Validation of Cavitation Modeling



Comparison of Cavitation Length



CFD Simulation of Cavitation in a Cascade of Flat Plates

2001 NPSS Review

Space Transportation
Presentation Outline

- **Programmatic Status**
- **System Level Simulation Modeling**
- **Multidisciplinary Coupling Demonstrations**
- ***Conclusions & Future Directions***

2001 NPSS Review

Space Transportation
Conclusions

- Work Has Begun
- Excellent Industry/Government Coordination & Mutual Support
- Limited System Level Rocket & RBCC Simulation Capability Delivered
- ISTAR High Fidelity Primary Flow Path CFD Delivered
- Steady & Unsteady Fluid Structural Coupling Methodology Explored – with and without Developer's Kit Tool

2001 NPSS Review

Space Transportation
Future Directions

- Incorporation of Additional System Level RBCC Capabilities
- System Level TBCC Simulation Capability (RTA Support)
- Demonstrate Launch of CFD Solution of RBCC Flowpath from NPSSv1
- Demonstrate Launch of CFD Solution of Turbopump from NPSSv1
- ISTAR High Fidelity MDC Solution => Developer's Kit Improvements
- Unsteady Turbopump MDC Work to Shift to Actual Pump => Developer's Kit Improvements

2001 NPSS Review

Space Transportation
Future Areas of Emphasis

- Increase Interactions with and Involvement of MSFC, LaRC, and ARC
- Increase Interactions with and Involvement of Vehicle Manufacturers
- Expand NPSS Capabilities to More Effectively Support the Space Launch Initiative

2001 NPSS Review

Space Transportation
The Engineering Team

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Robert Creekmore	(Pratt&Whitney)
Christopher Erickson	(Rocketdyne)
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Gregory Johnson	(Rocketdyne)
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Kevin Kincaid	(Pratt&Whitney)
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Thomas Lavelle	(GRC)
Dr. Meng-Sing Liou	(GRC)
Dr. James Loelbach	(OAI)
Dr. Donald Messitt	(Aerojet)
Todd Neill	(Aerojet)
Dr. Duc Nguyen	(Rocketdyne)
Thong Nguyen	(Aerojet)
Dean Olson	(Pratt&Whitney)
John Paris	(Rocketdyne)
Charles Putt	(GRC)
Dr. Mark Stewart	(QSS)
Dr. Ambady Suresh	(QSS)
Joann Swuaim	(GRC)
Kevin Vandyke	(Pratt&Whitney)
Joseph Veres	(GRC)
Dan Vonderwell	(Pratt&Whitney)

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Computing Testbeds and Code Parallelization Efforts

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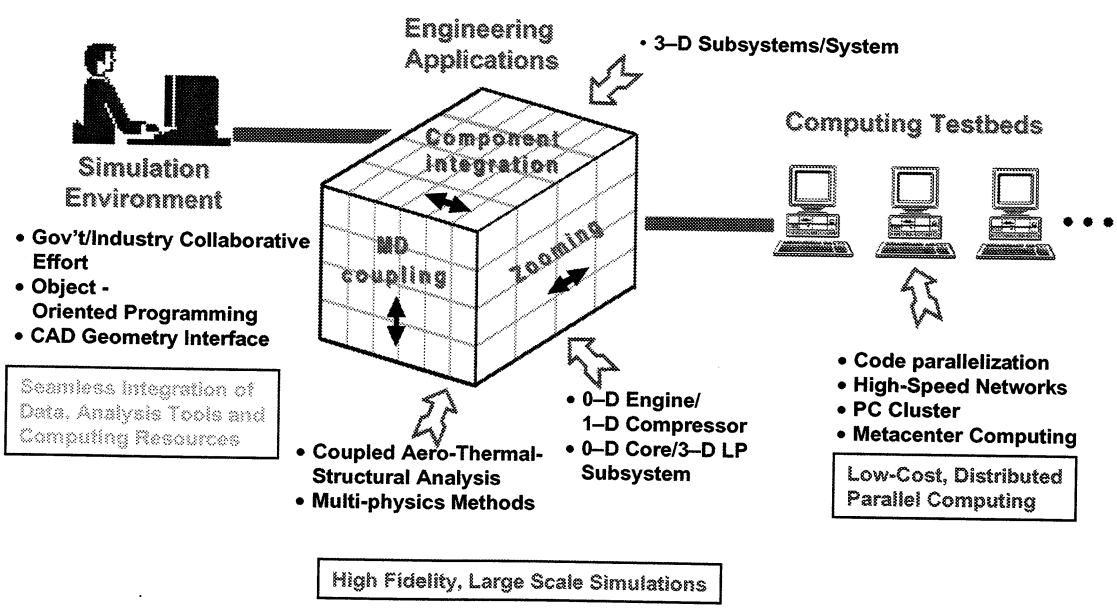
HPCCP/NPSS Work Breakdown Structure



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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 Demonstrate a 100:1 reduction in turnaround time (relative to 1999) of the new parallel MSTURBO code (unsteady) Achieve a three-hour turnaround of a full combustor simulation (1.3 million elements)	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)		Create first CORBA-based IPG Job Brokers Demonstrate distributed engine simulation on NASA distributed testbeds (PIII, 128 CPUs; SGI Origin 2K)	Demonstrate Non-NPSS-based CORBA Application on CORBA-Information Power Grid. Demonstrate 99% availability on distributed computing systems (P?, 128 CPUs; SGI Origin 2K)	Provide Seamless and Autonomous Information Power Grid Support to CORBA-Enabled Applications Demonstrate propulsion application running in 4th generation of commodity-based cluster (P 64 bit?, 512 CPUs?)	

Observation From the IHPTET Development Cost Planning Meeting

- KEY TO REDUCING ENGINE DEVELOPMENT COST

  Avoid Redesign by Discovering and Correcting Problems at the Earliest Possible Time in the Engine Development Process -- the Preliminary & Detailed Design Phase

- SOLUTION

  The Development and Application of an Advanced, Multidisciplinary Design and Simulation System Capable of Accurately Predicting Aerodynamic, Thermodynamic and Structural Performance

NPSS Identified as a Key Element in IHPTET to Achieve Cost Reduction Goals

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Accomplishments

- Demonstrated 10X cost/performance ratio on Pentium III cluster as compared to SGI Origin 3000.
- Achieved a 1.9 hour turnaround time with National Combustor Code on a large scale, fully reacting combustor simulation. This represent a 1716:1 reduction relative to 1992.
- APNASA achieved an overnight turnaround time of 2.5 hours for a full compressor simulation. This represent a 2400:1 reduction relative to 1992.
- A New Lattice Boltzmann model code have been parallelized and tested on NASA Linux cluster. We have for the first time successfully simulated transonic cascade flows using the compressible LB model. As far as we know, no one has applied the LB model to airfoil shapes previously. Preliminary results show that shocks, interactions between shocks, and boundary layer separation due to shock impingement are well captured. For the cases tested, high parallel efficiency is achieved.
- Developed parallel version of unsteady turbomachinery code MSTURBO, documented performance, and compared to serial version.
- Turnaround time using the Parallel CE/SE Code was reduced from 12 days to ~ 15 hrs using 20 processors on Aeroshark PC cluster

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Outline

- Code parallelization efforts
  - National Combustor Code (NCC)
  - APNASA
- Information Power Grid (IPG)
  - Testbeds capability
  - CORBA on IPG

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Code Parallelization Effort

- National Combustor Code (NCC)
  - 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.
- APNASA
  - To achieve a three hour turnaround of a full compressor simulation using APNASA by September of 2001. This will result in a 2400:1 reduction in turnaround time relative to 1992.

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Flow Solver for National Combustion Code (NCC)

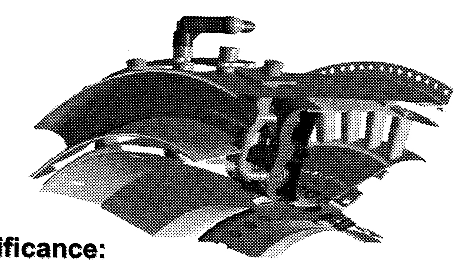
Multidisciplinary Combustor Design and Analysis System with Emissions Modeling

Objective:

To develop a multidisciplinary combustor simulation capability that will provide a detailed analysis during the design process of combustors for gas turbine engines. The combustor code will enable the analysis of a full combustor from compressor exit to turbine inlet.

CORSAIR-CCD:

- Navier-Stokes Baseline flow solver module based on an explicit four-stage Runge-Kutte scheme.
- Unstructured meshes
- Run on networked workstation clusters
- Can be linked to any CAD system via Patran file system



Significance:

The NCC system of codes can be used to evaluate new combustor design concepts. NCC can be integrated into a design system to provide a fast turnaround high fidelity analysis of a combustor, early in the design phase. The improved quality predictive analysis provided by NCC can result in improved confidence in the design, and a reduction of the number of hardware builds and tests thus reducing development time and cost. This capability will play a key role in meeting the national goal to reduce aircraft engine emissions.

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NCC Portability

- NCC has been ported to a variety of platforms
  - SGI Origin 2000
  - IBM SP-2
  - HP Exemplar
  - Network of Workstations (IBM, SGI, SUN, LINUX)
- A windows NT port also exists
- The message passing library (MPI or PVM) can be selected at compile time

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Benchmark Test Case and Hardware Platforms

Test case

- Lean Direct Injection/Multiple Venturi Swirler (1.3 M elements)
- Intrinsic Low Dimensional Manifold (ILDM) Kinetics Module
- Finite rate chemistry
  12 species, 10 steps
- All turbulence, species and enthalpy equations turned on
- Estimated converge at 10K iterations

Hardware platform

- IBM SP-2
  - 144 RS6000/590s
- SGI Origin 2000
  - 64 & 256 250 MHz, R10000 processors
- SGI Origin 2000
  - 256 400 MHz, R12000 processors

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Significant Performance Improvements

- Algorithm Modifications
- Code Streamlining
- Deadlock Elimination
- Hardware Upgrades
- ILDM Kinetics Module
- FORTRAN I/O Library
- METIS Domain Decomposition Strategy
- Message Passing Improvements

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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.

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Code Streamlining

54% of time spent in two chemistry routines

- 40.1 % chdiff
- 13.8 % chprop
- 4.7 % derivatives
- 4.4 % chmsol
- 4.1 % residual_smoothing
- 2.0 % chmscc

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Code Streamlining Continued

- **Streamlined finite rate chemistry operations:**
  - This arithmetic expression "a**0.25" was replace by "sqrt(sqrt(a))" because it executes much faster than the original.
  - 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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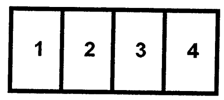
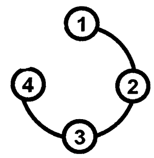
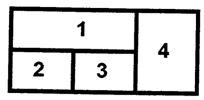
Deadlock Elimination

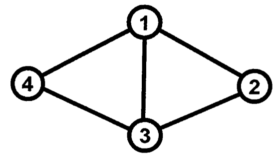
- The existing communication scheme was sufficient with a simple process topology





- 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.

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Hardware Upgrade

- IBM SP-2
  - 96 Processors
  - Speedup = ~80.4
  - Efficiency = ~84%
  - Time/iteration = 13.0 secs

- Origin 2000, 250 MHz R10000
  - 32 Processors
  - Speedup = 26.3
  - Efficiency = 82%
  - Time/iteration = 10.1 secs

- Origin 2000, 250 MHz R10000
  - 96 Processors
  - Speedup = 78.9
  - Efficiency = 82%
  - Time/iteration = 0.69 secs

- Origin 3000, 400 MHz R12000
  - 96 Processors
  - Speedup = 77.1
  - Efficiency = 80%
  - Time/iteration = 0.44 secs

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ILDM Kinetics Module

- Intrinsic Low Dimensional Manifold
- Replaced the existing finite rate chemistry module
  - Solve two scalar equations rather than 12 equations for species.
  - Species are obtain from the IDLM 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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SGI FORTRAN I/O

- Scaling improved by switching to the f90 compiler
  - Performance did not change when using <= 32 processors.
  - Performance improved when using > 32 processors.
  - Initialization time decreased dramatically.
- The f90 I/O library handled multiple processes accessing the same file much more efficiently than the f77 I/O library.
  - Each process was printing a residual to the standard output.

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METIS Domain Decomposition Strategy

- **METIS decomposition attempts to minimize the cells along the process interface boundaries, reducing the size of the messages exchanged between processes.**
- **Scalability improves:**

	Original decomposition	METIS decomposition
# Processors	96	96
Time/iterations:	0.93 secs	0.69 secs
Parallel efficiency	60%	82%

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Message Passing Improvements

- **Multiple messages were packed together into fewer, larger messages reducing the number of messages exchanged between processes from 64 to 11.**
- **Scalability Improved:**

	64 Messages	11 Messages
# Processors	96	96
Time/iterations:	0.44 secs	0.36 secs
Parallel efficiency	80%	96%

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National Combustor Code (NCC)

- 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 – time to solution was 3,072 Hrs
  - 1999 – time to solution was 9 Hrs
  - 2001 – time to solution is 1.9 Hrs
  - A 1716:1 turnaround time

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Recent Accomplishments (April 2001)

- Modified I/O usage to obtain improved scalability, allowing the use of up to 256 processors on NASA/CAS Testbed (SGI Origin 2000).
- The number of messages being exchanged per iteration has been reduced from 64 to 11.
  - Original code exchanged as many as 563 messages per process per iteration
- Eliminated or reduced the frequency of several variables being exchange.
- Achieved a full combustor simulation in 1.9 hours. This represent a turnaround time of 1617:1 relative to 1992.

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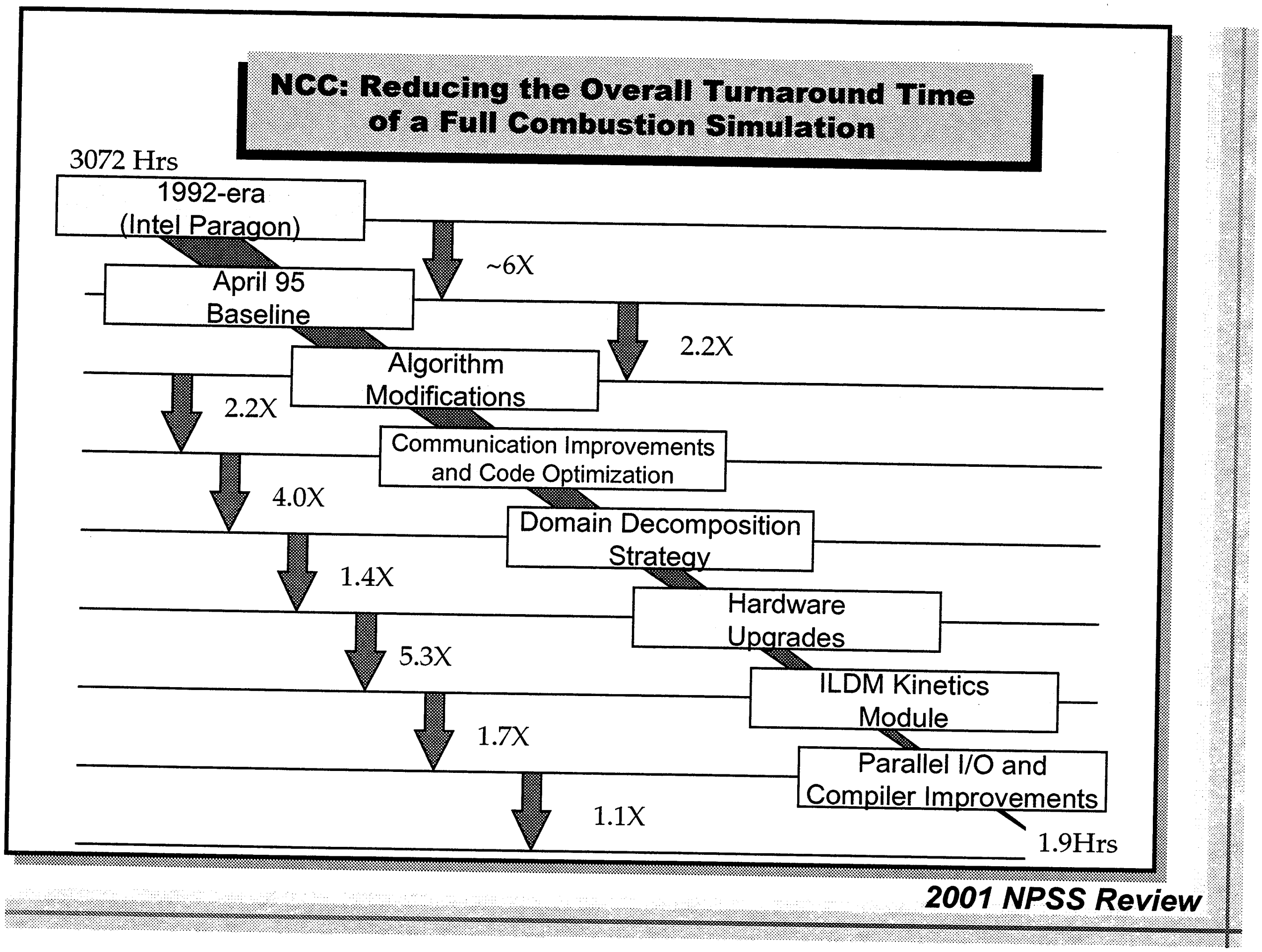
NCC: Reducing the Overall Turnaround Time of a Full Combustion Simulation
3072 Hrs
1992-era (Intel Paragon)
~6X
April 95 Baseline
2.2X
Algorithm Modifications
2.2X
Communication Improvements and Code Optimization
4.0X
Domain Decomposition Strategy
1.4X
Hardware Upgrades
5.3X
ILDM Kinetics Module
1.7X
Parallel I/O and Compiler Improvements
1.1X
1.9Hrs
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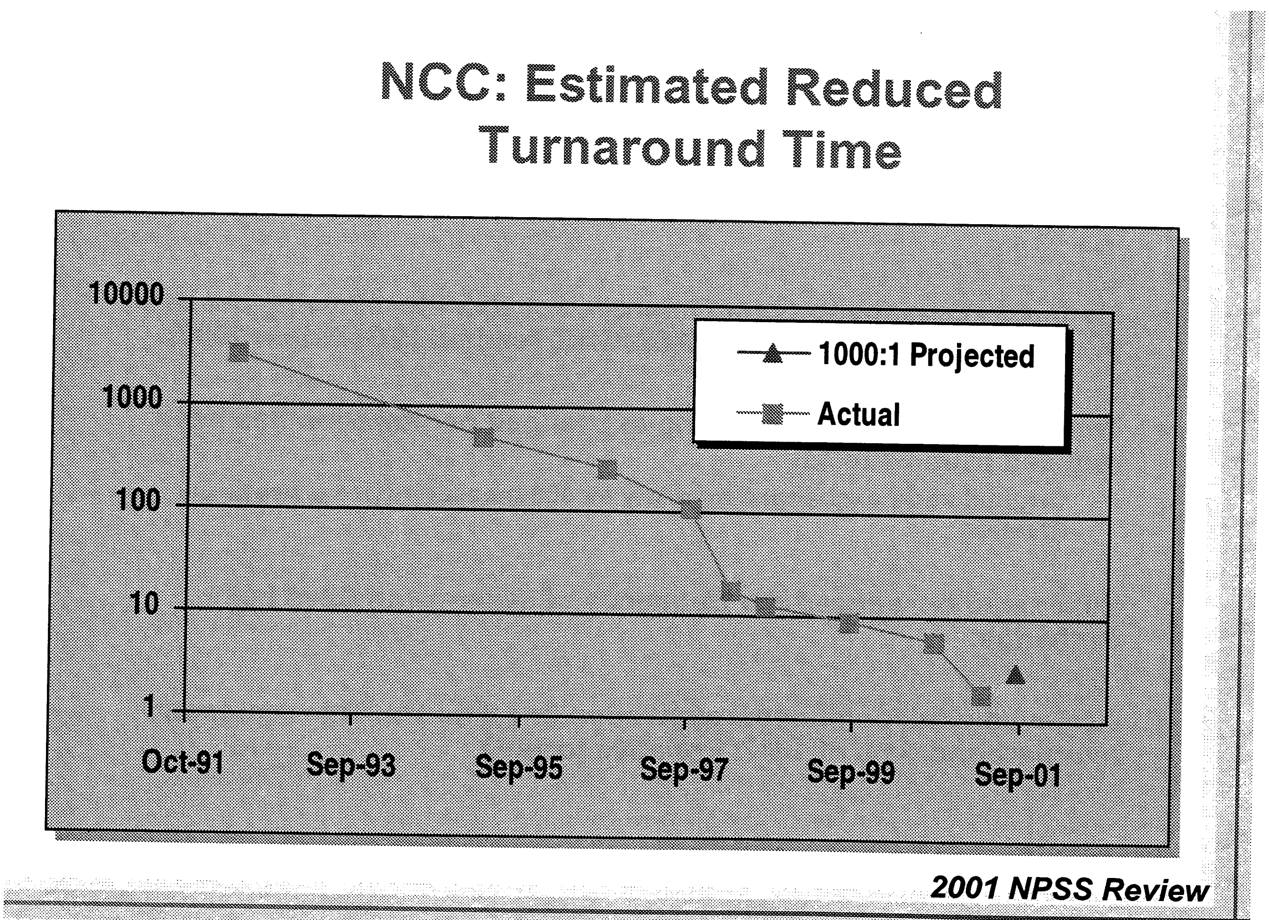
NCC: Estimated Reduced Turnaround Time
10000
1000
100
10
1
Oct-91
Sep-93
Sep-95
Sep-97
Sep-99
Sep-01
1000:1 Projected
Actual
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APNASA Speedup

- **To achieve a three hour turnaround of a full compressor simulation using APNASA by September of 2001. This is a 2400:1 reduction in turnaround time relative to 1992.**
- For the latest speedup of APNASA, credit is given to John Adamczyk, David A. Topp, Kevin Kirtley, Joe Veres, Mark G. Turner, Sohrab Saeidi, and Lyle D. Dailey.

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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. Based on the Average-Passage model developed by John Adamczyk at the NASA Glenn Research Center.

Objective

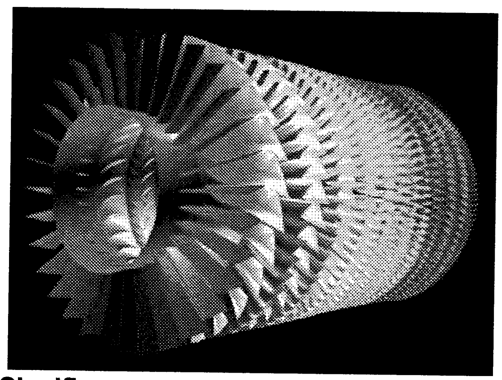
- To develop a turbomachinery simulation capability that will provide a detailed analysis during the design process of gas turbine engines

Accomplishment

- The present effort has achieved an overnight turnaround (15 hours) of a full compressor simulation when using APNASA. This represent a 400:1 reduction in a full compressor simulation turnaround relative to 1992.

Plan

- To achieve a three hour turnaround of a full compressor simulation using APNASA by September of 2001. This will result in a 2400:1 reduction in turnaround time relative to 1992.



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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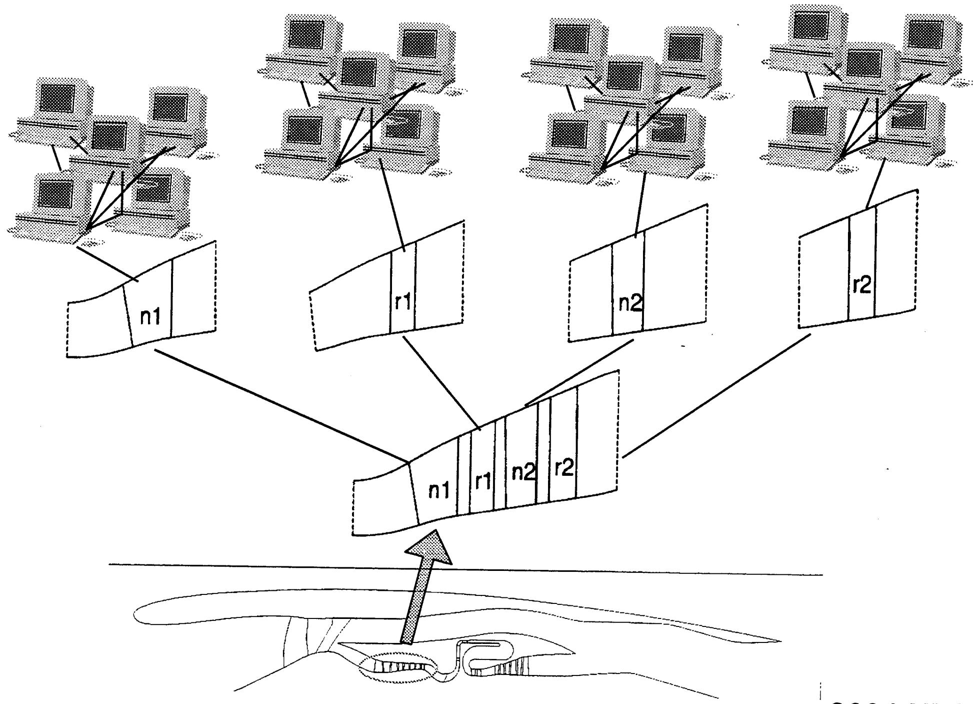
Two Levels of Parallel Capability in APNASA Average Passage Code



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Code Improvements

- Each blade row is decomposed in the axial direction with MPI Message Passing used to pass data between domains.
- Chapman is an SGI Origin 3000 with 512 processors each running at 400 MHz. 8 processors are dedicated for I/O and other functions, leaving 504 available for calculations.
- One processor is used for running the Master Script.
- Load balancing divides the remaining 503 processors among the 21 blade rows of the GE90 based on grid size. The number of processors per blade row ranged from 16 to 27.
- The "Grab and Hold" approach has been used so that every blade row is started only once. There is only one time the grid is read in and geometry initialization takes place. The exchange of information (a flip) between blade rows is controlled by the Master Script. This exchange of information took place 200 times for this simulation.
- The 3D flow file was only written 5 times during the simulation, rather than once per flip.
- The overall solution has been very scalable with respect to the number of blade rows. The regions for solving the axisymmetric equations has been reduced, and the size of the axisymmetric files and body force files have also been reduced.
- The -Ofast=ip## option of the optimizing compiler reduced run time greatly. It allows cache memory to be used more effectively which benefits a parallel computation.

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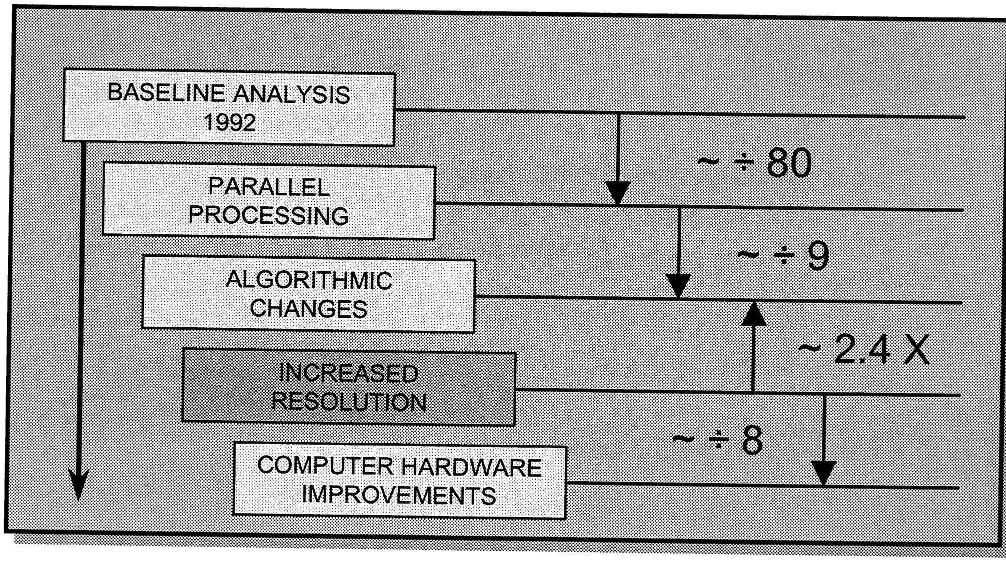
APNASA
Factors Influencing Turnaround Time



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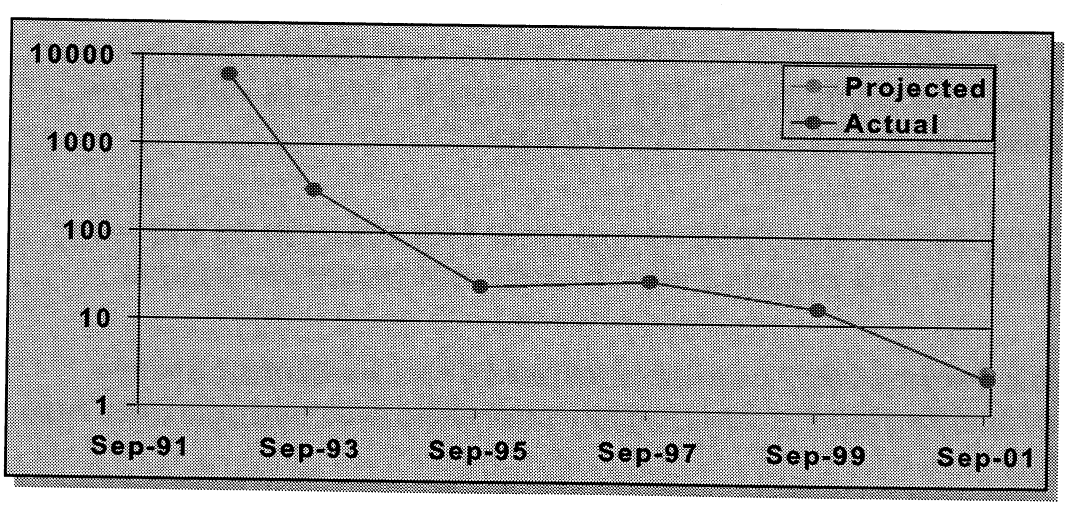
APNASA
Estimated Turnaround Time



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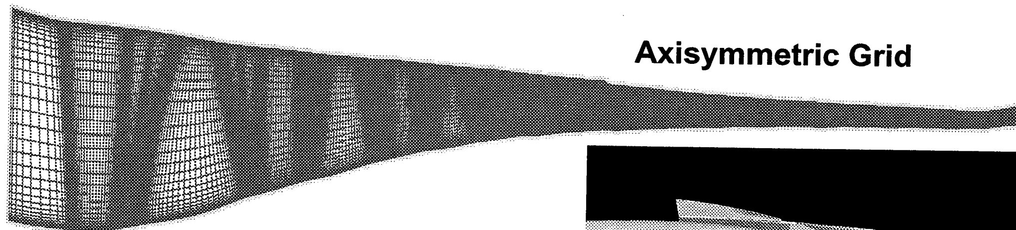
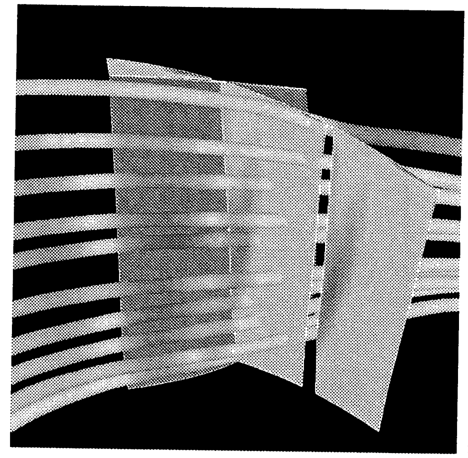
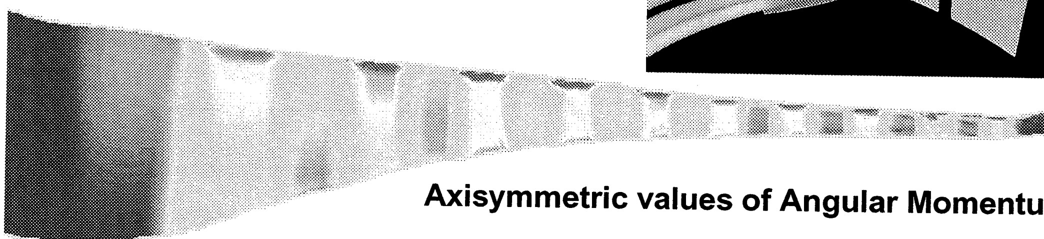
Simulation Results



Axisymmetric Grid



Streamtubes in Rotor 2 of the GE90 HPC showing Total Temperature



Axisymmetric values of Angular Momentum

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APNASA Conclusions

- CAS milestone met of obtaining a compressor simulation in less than 3 hours. The 21 blade row GE90 compressor took 2.5 hours using 504 processors. This is 400 times faster than available 4 years ago.
- Component simulations are now fast enough to explore designs and physics which were not possible before.
- This technology can be applied to the turbomachinery components of a full engine simulation to reduce that run time.

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Future Plans

- The speedup milestones have been completed.
- Efforts will focus:
  - Unsteady turbomachinery simulations
  - New Revolutionary algorithms that take advantage of large numbers of processors.
- What will the next 10 years bring us?

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Information Power Grid at Glenn

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Motivation for IPG

- **Large-scale science and engineering are done through the interaction of people, heterogeneous computing resources, information systems, and instruments, all of which are <u>geographically and organizationally dispersed</u>.**
- ***The overall motivation for "Grids" is to facilitate the <u>routine interactions</u> of these resources in order to support large-scale science and engineering.***

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What are Grids?

- Grids provide uniform, secure, and highly capable access to large-scale computing, data, and instrument resources across organizations through:
  - tools for the dynamic construction of *execution* environments supporting complex distributed applications (e.g., Virtual National Air Space)
  - middleware for standardized access to *data* archives and standardized publication of data catalogues
  - services for *co-scheduling* many resources to support, e.g., transient and complex, science and engineering experiments that require combinations of instruments, compute systems, data archives, and network bandwidth at multiple locations
  - persistent and reliable *infrastructure (e.g., IPG)*

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Applications Motivating Grid Computing Environments

- Multi-disciplinary simulations are a good example of a class of applications that are very likely to require aggregation of widely distributed computing, data, and intellectual resources.
- Such simulations – e.g., whole system aircraft simulation and whole system living cell simulation – *require integrating applications and data that are developed by different teams of researchers* frequently in different locations.
- *The research teams are the only ones that have the expertise to maintain and improve the simulation code and/or the body of data that drives the simulations.* This results in an inherently heterogeneous distributed computing and data management environment.

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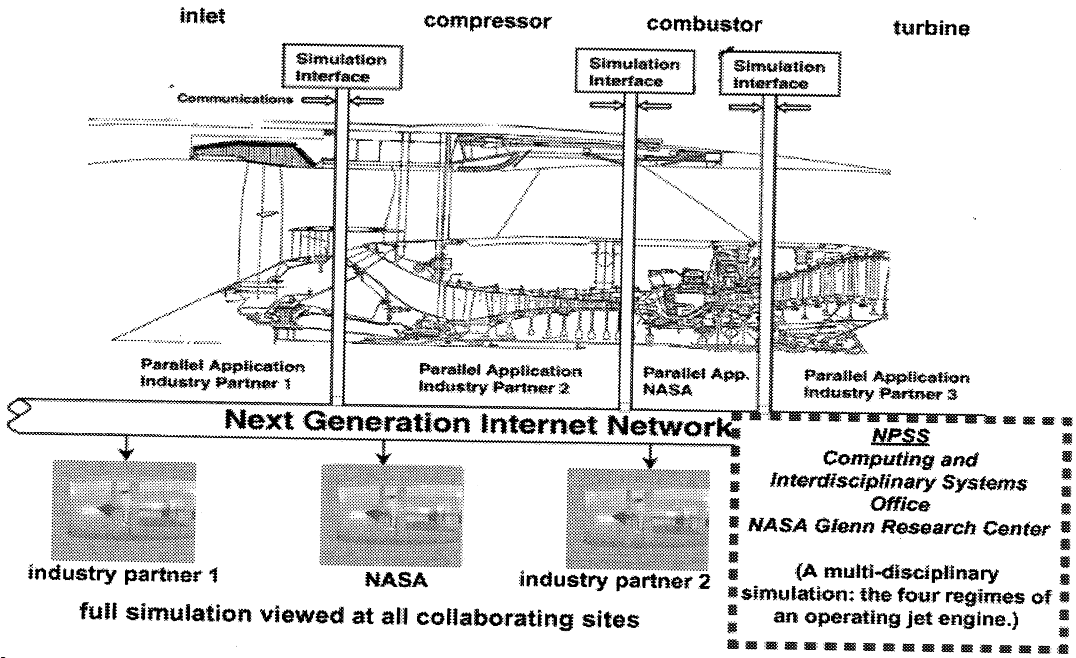
Multi-disciplinary Simulations: Aviation Safety



The NPSS framework allows component simulations to be combined to get sub-system (e.g., a jet engine) simulations

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The State of IPG

- Computing resources:
  - ≈1100 *CPU nodes* in half a dozen SGI Origin 2000s at NASA Ames, Glenn, and Langley
  - 1024 node, single system image O2K and Cray SV-1 at Ames are almost ready to add to IPG (both are currently under test)
  - several *workstation clusters* at Ames, Glenn, Langley, and JPL
  - ≈300 nodes in a *Condor pool*
- Wide area *network* interconnects of at least 100 Mbit/s
- Storage resources: 50-100 Terabytes of *archival information/data storage* uniformly and securely accessible from all IPG systems via *MCAT/SRB* and GSIFTP / *GridFTP*
- *Globus* providing the Grid Common Services
- IPG is building and operating infrastructure, and developing and deploying Grid services for NASA's persistent Grid.

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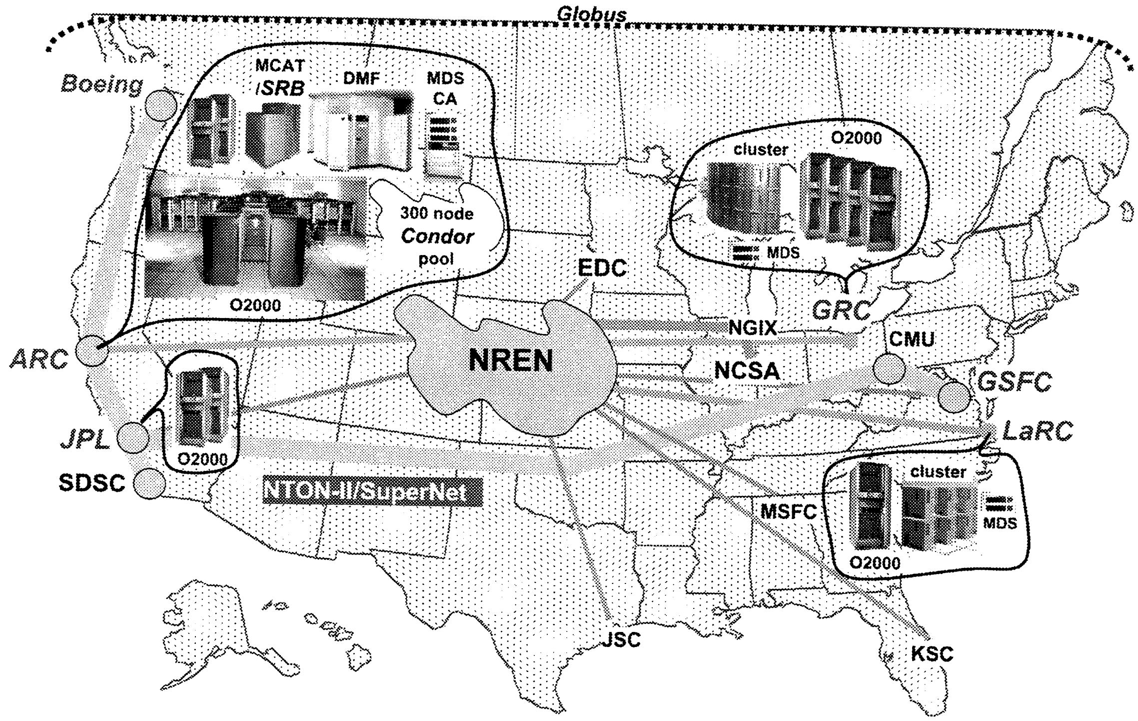
IPG Baseline System and High Data-Rate Testbed



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The State of IPG

- IPG is providing and/or supporting research, development, and deployment work in numerous Grid technologies:
  - CORBA - Globus integration
  - Integration of Legion*
  - CPU resource reservation
  - High throughput computing
  - Programming services
  - Distributed debugging
  - Grid enabled visualization
  - Parameter study frameworks
  - Network bandwidth reservation

*Legion is middleware; it connects networks, workstations, supercomputers, and other computer resources together into a system that can encompass different architectures, operating systems, and physical locations. (i.e., similar type of software as GLOBUS.

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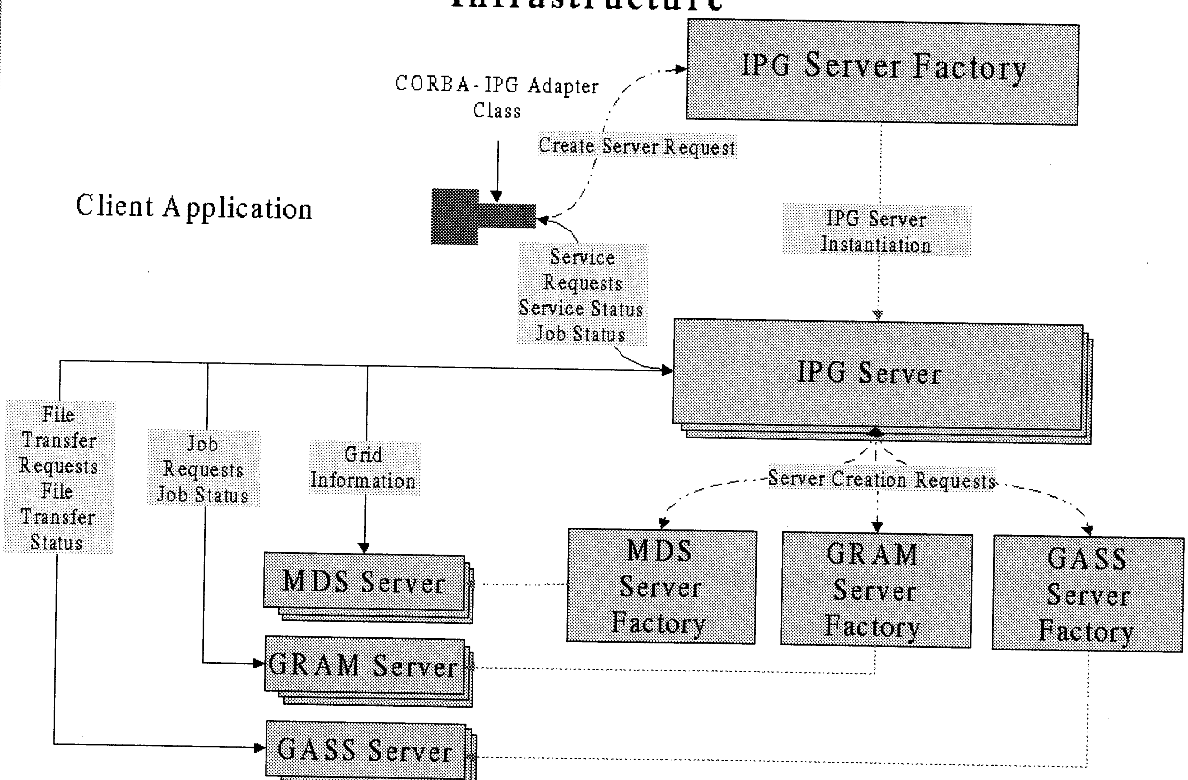
CORBA on the Information Power Grid

***Long Term Milestone*: Provide Seamless and Autonomous Information Power Grid Support to CORBA-Enabled Applications by 2004.**

Robert Griffin

2001 NPSS Review

CORBA-IPG Infrastructure



Robert I. Griffin NASA Glenn Research Center 2001

Globus Components That We Are Providing Access to *Via* CORBA

Security

Information

Grid Resources

Access to Secondary Storage

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Globus Target Services - Security

- Grid Security Infrastructure (GSI)
  - Fundamental Component for all Grid-related activities.
  - Proper Authentication Provides Access to Grid Resources, Information, Secondary Storage.
  - Functionality of the "grid-proxy-init" Globus command-line tool.
  - Can be used in tandem with other "Secure" CORBA applications (CORBASec-Enabled).
  - All parts of the CORBA-IPG infrastructure rely on the CORBA GSI service.

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Globus Target Services - Information

- **Metacomputing Directory Service (MDS)**
- ***aka* Grid Information Services (GIS)**
  - **Based on the Lightweight Directory Access Protocol (LDAP)**
  - **Contains Information for**
    - **IPG Hosts (Machines) - e.g., Processor Count, Operating System, Host Names**
    - **Job Queues - Type (LSF, PBS, Fork), Load, Job Status**
    - **Users and Other Resources**

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CORBA MDS Service

- **Methods provided by CORBA MDS Application Programming Interface (API) to access an IPG MDS Service**

  connect **- simple connection to IPG MDS server.**

  disconnect **- disconnect from IPG MDS server.**

  getAttrib **- return a set of Attributes for a given Distinguished Name.**

  getSelectedAttrib **- return a filtered set of Attributes for a given Distinguished Name.**

  getList **- return a list of entries (subordinate values) for a given Distinguished Name.**

  Search **- return a scoped (with or without recursion) list of entries.**

  selectedSearch **- return a scoped and filtered list of entries.**

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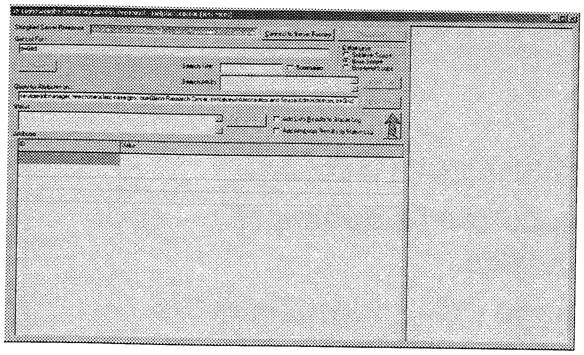
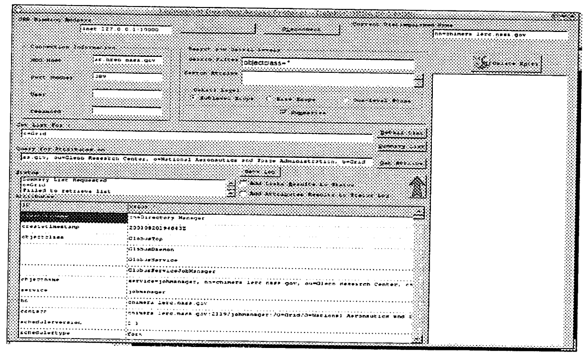
CORBA MDS Applications



Windows Platforms



Linux Systems

- Windowed applications such as these will serve as the model for future work with IPG Brokers. IPG Brokers may, in turn, be used for Grid-Deployed Processing as the 'hook' into the CORBA-IPG Infrastructure
- Unified Toolkit (*Inprise* Products) allows Reduced Cross-Platform Development Time
- We Are Currently Developing Object-Oriented Procedures Identify and Classify Grid Computing Resources

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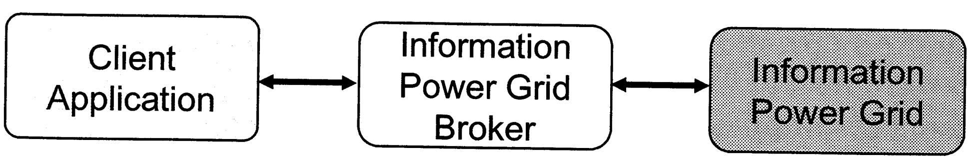
CORBA-IPG Process Broker System



- Client Application needs no knowledge of the Information Power Grid.
- The CORBA-IPG Broker submits processing requests to IPG Hosts on behalf of the Client Application.
- Target Hosts or Host Services are autonomously chosen by the Broker on the basis on the availability of resources. This information is contained within the Metacomputing Directory Service (MDS).
- Results are returned to the Client from the Information Power Grid *via* the CORBA-IPG Broker.

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Globus Target Services - Grid Resources

- **Grid Resource Allocation Manager (GRAM)**
  - **Responsible for Deploying Execution Requests to Remote Grid Computing Resources.**
  - **Resource Specification Language (RSL) formalizes the requests for executions on remote machines.**
  - **Target Functionality contained in "globus-job-run" and similar command line tools.**
  - **Requires Grid Authentication that is provided by the Grid Security Infrastructure.**

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CORBA GRAM Service

- **Methods provided by CORBA GRAM Application Programming Interface (API)**

  connect **- simple connection to IPG GRAM server.**

  disconnect **- disconnect from IPG GRAM server.**

  SubmitRSL **- Submits a threaded RSL-style job to the GRAMServer.***

  SubmitRSL_noLock **- Submits an unthreaded RSL-Style job.***

  SubmitShortJob, SubmitShortIOJob, SubmitLongJob **- Submit threaded Jobs using specifications contained within Short, ShortIO, and Long Job Objects.**

  ****Threaded Jobs that have been submitted are capable of returning Job Status and remote Job Name information after their submission to the IPG GRAM Server.***

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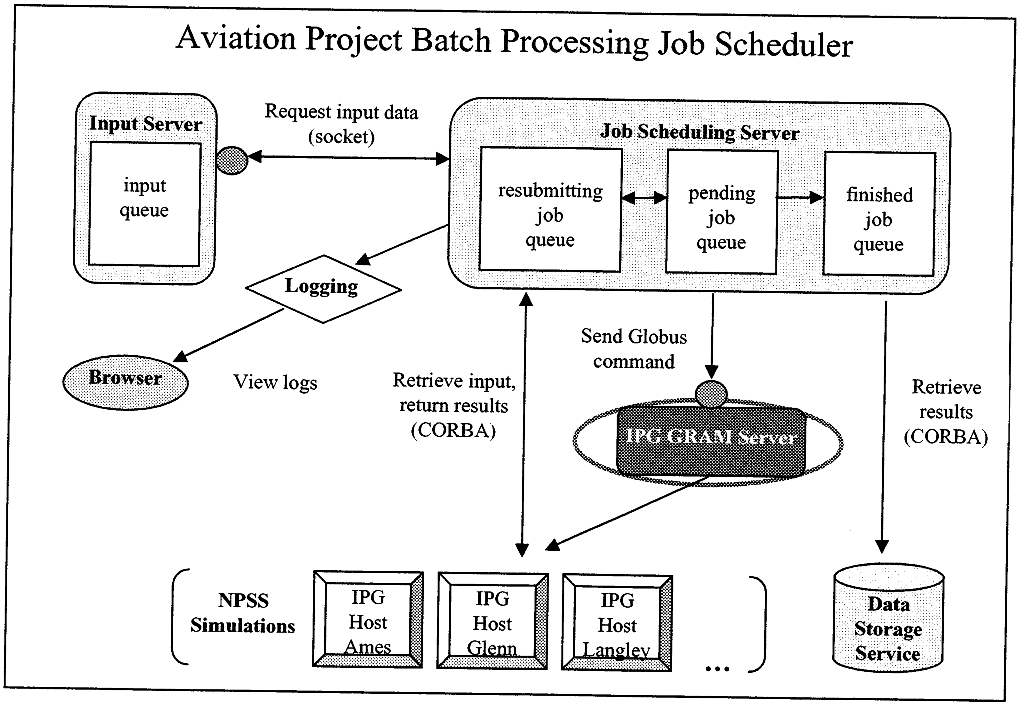
CORBA GRAM Service at Work in Applications



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Globus Target Services – Access to Secondary Storage

- Grid Access to Secondary Storage (GASS)
  - Essential for Automation and Remote Deployments
  - Functionality encapsulated by the command line calls (e.g., "gass-url-copy")
  - GASS Server and Client need to be emulated by CORBA.
  - Next Area for Development Effort in the CORBA-IPG Infrastructure.
  - CORBA-IPG work will eventually provide support for the GSIFTP protocol which also provides access to secondary storage *via* FTP

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Future Directions for the CORBA-IPG Effort

Date	Objective
1/1/2002	Completion of CORBA-Information Power Grid Infrastructure.
4/1/2002	Demonstrate CORBA-IPG based Simple Application Executions (0-D NPSS)
7/1/2002	Inclusion of CORBA Event Services, Naming Service and Implementation Repositories
10/1/2002	Create first CORBA-based IPG Job Brokers
1/1/2003	Maintenance for CORBA-Information Power Grid Infrastructure.
4/1/2003	Load-Balance and Job Optimizations for IPG Job Brokers.
7/1/2003	Demonstrate Integration of Job Results with commercial applications (e.g., Excel)
10/1/2003	Demonstrate Non-NPSS-based CORBA Application on CORBA-Information Power Grid.
2/1/2004	Demonstrate CORBA-IPG based Complex Application Executions (Zoomed NPSS)
6/1/2004	Deploy CORBA-IPG across Multiple Sites
10/1/2004	Offer CORBA-IPG based CAPRI (3D Geometry) services for Higher-Fidelity Component Codes.

Acronym List

0-D	0-Dimensional
1-D	1-Dimensional
3-D	3-Dimensional
ADPAC	Advanced Ducted Propfan Analysis Code
AEDC	Arnold Engineering Development Center
ANSYS	Commercial Structural Analysis Software Code
API	Application Program Interface
APNASA	Average Passage Turbomachinery Flow Code
ASME	American Society of Mechanical Engineers
Autodoc	Auto Documentation
BC	Boundary Condition
BOA	Basic Object Adaptor
CAD	Computer Aided Design
CAPRI	Computational Analysis Programming Interface
CCDK	CORBA Component Development Kit
CORBA	Common Object Request Broker Architecture
CORBASec	CORBA Security
CPU	Central Processing Unit
CSPAN	Compressor Conceptual Design Code
DES	Data Encryption Standard
Dev Kit	NPSS Development Kit
DLM	Dynamically Loadable Module
DOCSec	Distributed Object Computing Security
DOE	Department of Energy
FPI	Fast Probabilistic Integration
GEAE	General Electric Aircraft Engines
GRC	Glenn Research Center
HP	Hewlett Packard
HPC	High Pressure Compressor
HPCCP	High Performance Computing and Communications Program
HPT	High Pressure Turbine
HSS	Hitachi Security Service
Ht	Total Enthalpy
IGTI	International Gas Turbine Institute
JANNAF	Joint Army Navy NASA Air Force
JSF	Joint Strike Fighter
KBE	Knowledge Based Engineering
LSF	Load Sharing Facility
MD	Multi-Disciplinary (Fluid-Thermal-Structural)
MHz	Mega Hertz
MIT	Massachusetts Institute of Technology
MPI	Message Passing Interface
NICE	NASA Industry Cooperative Effort
NCC	National Combustion Code
NPSS	Numerical Propulsion System Simulation

OGV	Outlet Guide Vane
OMG	Object Management Group
ORB	Object Request Broker
PBS	Portable Batch System
PDM	Product Data Manager
POA	Portable Object Adaptor
PSAO	Propulsion Systems Analysis Office
Pt	Total Pressure
PUMPA	One-Dimensional Pump Analysis Code
P&W	Pratt & Whitney
r Cu	Radius times Tangential Velocity
RFP	Request For Proposal
RRC	Rolls-Royce Corporation
SGI	Silicon Graphics, Inc.
SIP	Strategic Implementation Plan (at NASA Glenn Research Center)
SSL	Secure Socket Layer
TGIR	Turning Goals Into Reality
TPBSS	TPBroker Security Service
u	Axial Component of Velocity
UEET	Ultra-Efficient Engine Technology
V	Version
v	Radial Component of Velocity
VBS	Visual-Based Syntax
WI	Williams International
WPAFB	Wright Patterson Air Force Base

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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 2000 effort and the actions taken over the past year to respond to that feedback. NPSS was supported in fiscal year 2001 by the High Performance Computing and Communications Program.

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