NASA/TM—2003-211896

2002 Computing and Interdisciplinary Systems Office Review and Planning Meeting

John Lytle and Gregory Follen
Glenn Research Center, Cleveland, Ohio

Isaac Lopez
U.S. Army Research Laboratory, Glenn Research Center, Cleveland, Ohio

Joseph Veres, Thomas Lavelle, Arun Sehra, Josh Freeh, and Chunill Hah
Glenn Research Center, Cleveland, Ohio

August 2003

The NASA STI Program Office . . . in Profile

Since its founding, NASA has been dedicated to the advancement of aeronautics and space science. The NASA Scientific and Technical Information (STI) Program Office plays a key part in helping NASA maintain this important role.

The NASA STI Program Office is operated by Langley Research Center, the Lead Center for NASA's scientific and technical information. The NASA STI Program Office provides access to the NASA STI Database, the largest collection of aeronautical and space science STI in the world. The Program Office is also NASA's institutional mechanism for disseminating the results of its research and development activities. These results are published by NASA in the NASA STI Report Series, which includes the following report types:

- TECHNICAL PUBLICATION. Reports of completed research or a major significant phase of research that present the results of NASA programs and include extensive data or theoretical analysis. Includes compilations of significant scientific and technical data and information deemed to be of continuing reference value. NASA's counterpart of peer-reviewed formal professional papers but has less stringent limitations on manuscript length and extent of graphic presentations.
- TECHNICAL MEMORANDUM. Scientific and technical findings that are preliminary or of specialized interest, e.g., quick release reports, working papers, and bibliographies that contain minimal annotation. Does not contain extensive analysis.
- CONTRACTOR REPORT. Scientific and technical findings by NASA-sponsored contractors and grantees.
- CONFERENCE PUBLICATION. Collected papers from scientific and technical conferences, symposia, seminars, or other meetings sponsored or cosponsored by NASA.
- SPECIAL PUBLICATION. Scientific, technical, or historical information from NASA programs, projects, and missions, often concerned with subjects having substantial public interest.
- TECHNICAL TRANSLATION. English-language translations of foreign scientific and technical material pertinent to NASA's mission.

Specialized services that complement the STI Program Office's diverse offerings include creating custom thesauri, building customized databases, organizing and publishing research results . . . even providing videos.

For more information about the NASA STI Program Office, see the following:

- Access the NASA STI Program Home Page at ***http://www.sti.nasa.gov***
- E-mail your question via the Internet to help@sti.nasa.gov
- Fax your question to the NASA Access Help Desk at 301–621–0134
- Telephone the NASA Access Help Desk at 301–621–0390
- Write to:
  NASA Access Help Desk
  NASA Center for AeroSpace Information
  7121 Standard Drive
  Hanover, MD 21076

NASA/TM—2003-211896

2002 Computing and Interdisciplinary Systems Office Review and Planning Meeting

John Lytle and Gregory Follen
Glenn Research Center, Cleveland, Ohio

Isaac Lopez
U.S. Army Research Laboratory, Glenn Research Center, Cleveland, Ohio

Joseph Veres, Thomas Lavelle, Arun Sehra, Josh Freeh, and Chunill Hah
Glenn Research Center, Cleveland, Ohio

Prepared for the
2002 CISO Review and Planning Meeting
sponsored by the NASA Glenn Research Center
Middleburg Heights, Ohio, October 9–10, 2002

National Aeronautics and
Space Administration

Glenn Research Center

August 2003

Available from

NASA Center for Aerospace Information
7121 Standard Drive
Hanover, MD 21076

National Technical Information Service
5285 Port Royal Road
Springfield, VA 22100

Available electronically at http://gltrs.grc.nasa.gov

TABLE OF CONTENTS

2002 COMPUTER AND INTERDISCIPLINARY SYSTEMS OFFICE ANNUAL REVIEW

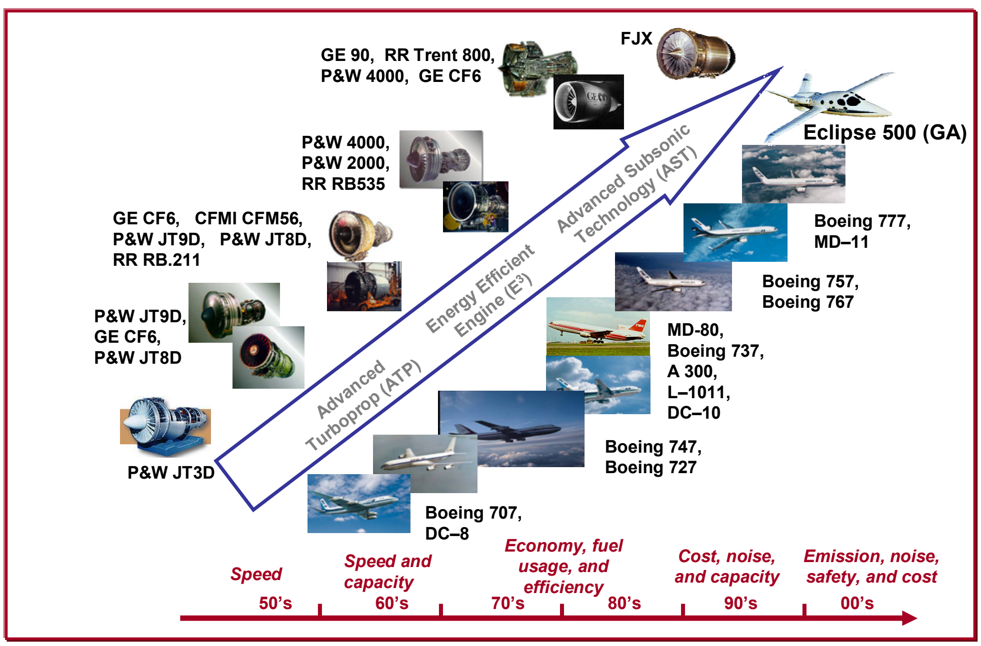
J. Lytle, G. Follen, I. Lopez, J. Veres, T. Lavelle, A. Sehra, C. Hah, and J. Freeh

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 NASA Glenn's Propulsion program, NASA Ames, 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. In support of this direction, NASA Glenn has been pursuing the development of a concept called the Numerical Propulsion System Simulation (NPSS). NPSS consists of three main elements: (1) engineering models that enable multi-disciplinary 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. With recent successes from the early work in developing NPSS V 1.0 that have been recognized by winning a 2002 R&D100 award, NASA Glenn has moved its focus to developing the computing infrastructure necessary for coupling large 3–D CFD codes together and deploying these simulations over the Information Power Grid. Collectively this work is known as the Object Oriented Development Kit. This year's review meeting describes the current status of the NPSS and the Object Oriented Development Kit with specific emphasis on the progress made over the past year on air breathing propulsion applications for aeronautics and space transportation applications. Major accomplishments include the first 3-D simulation of the primary flow path of a large turbofan engine in less than 15 hours and the formal release of the NPSS Version 1.5 that includes elements of rocket engine systems and a visual based syntax layer. Also, included are examples of how General Electric and Pratt & Whitney are using NPSS in their aircraft engine design and development processes to increase engineering productivity. The versatility of NPSS as a general modeling framework for complex systems is also described through the application of NPSS to fuel cell systems. Also presented this year will be the future Development Kit's 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, a summary of the feedback received from industry partners on the fiscal year 2002 effort and the actions taken over the past year to respond to that feedback will be presented. NPSS and the Development Kit are managed by the Computing and Interdisciplinary Systems Office (CISO) at the NASA Glenn Research Center and financially supported in fiscal year 2002 by the Computing, Networking and Information Systems (CNIS) project managed at NASA Ames, the Glenn Aerospace Propulsion and Power Program and the Advanced Space Transportation Program.

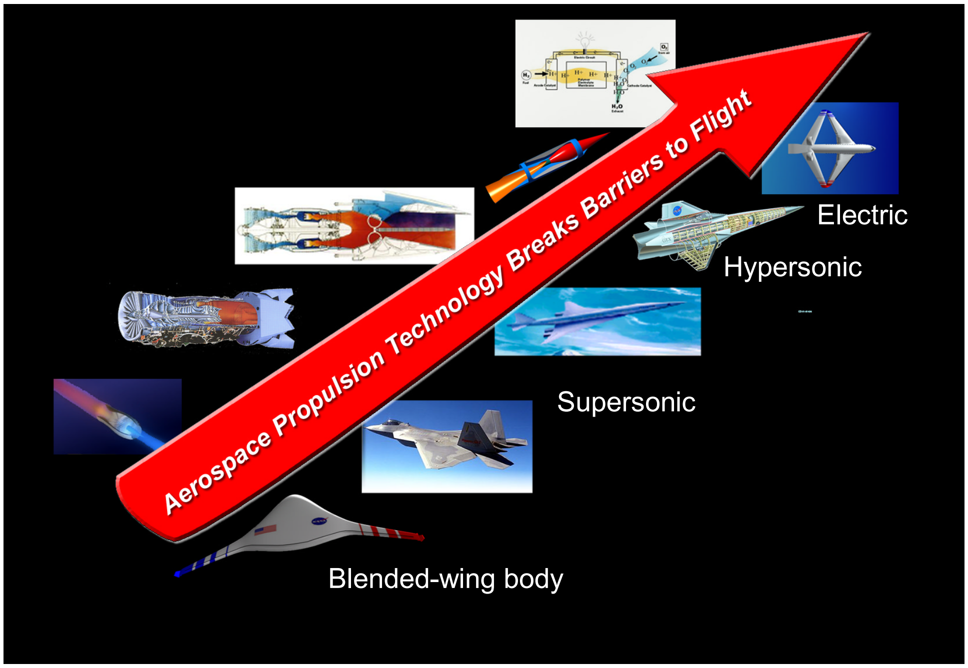
Propulsion System Leads the Aviation Revolution (Milestones in Aviation)



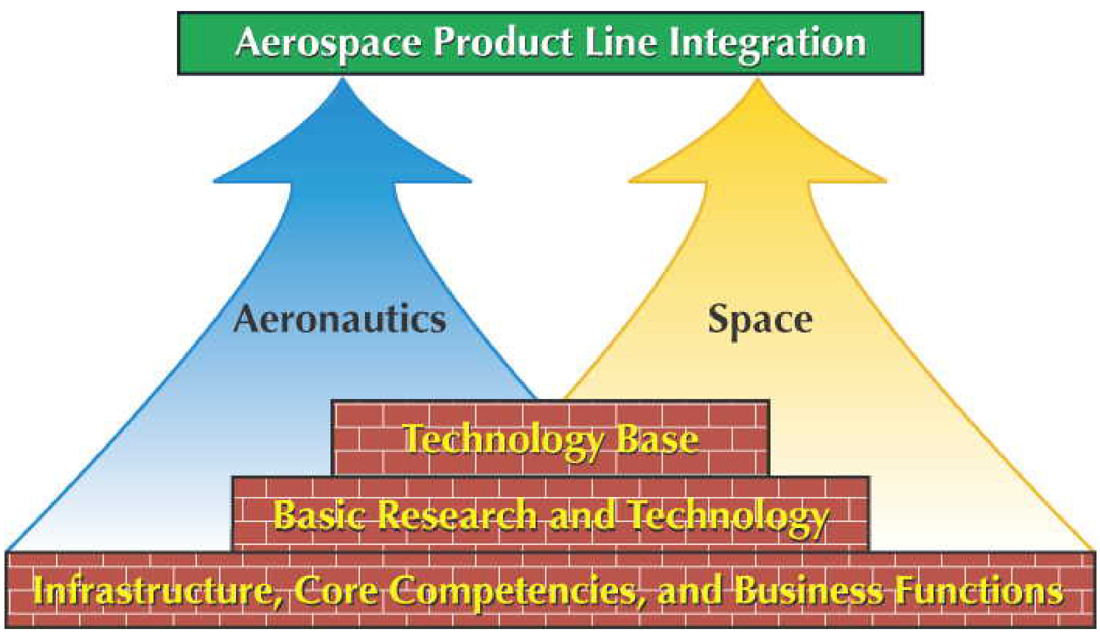
2

Glenn Research Center
Aeronautics Directorate
at Lewis Field
4/4/2000

Propulsion System Leads the Aviation Revolution (Future Directions)

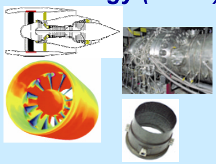


GRC Technology Infusion



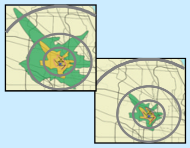
GRC Aeronautics

Ultra Efficient Engine Technology (UEET)



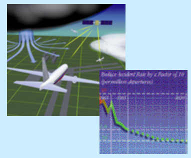
On-going

Quiet Aircraft Technology (QAT)



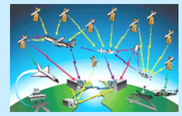
On-going

Aviation Safety



On-going

Aviation Capacity



On-going

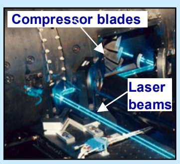
Small Air Transportation System (SATS

On-going

FOCUSED PROGRAMS

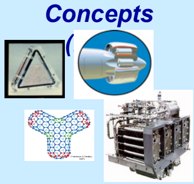
Fundamental Research

Laser Anemometry Used to Measure Detailed Flow Field



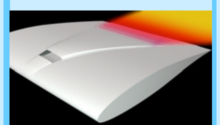
On-going

Revolutionary Aeropropulsion Concepts



On-going

21st Century Aircraft Propulsion



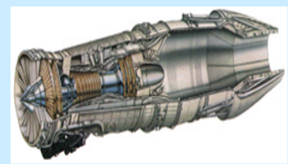
New Start FY 02

Computing, Information & Communications Technology (CICT)

New Start FY02

BASE R&T

Revolutionary Turbine Accelerator (RTA)



On-going

ADVANCED SPACE TRANSPORTATION

5

Glenn Research Center

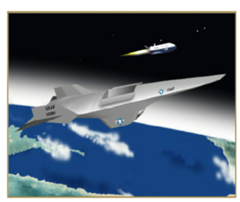
Aeronautics Directorate at Lewis Field

4/4/2000

GRC Space

Communications

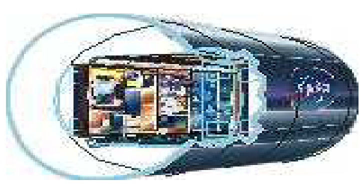
Modeling/Analyses
Antennas
Solid-state devices
Digital communications
Vacuum electronics
Satellite/terrestrial networks
Spectrum Management



Space Transportation

Advanced Concepts/Analyses
Airbreathing Propulsion
Propulsion Materials/Structures
Subsystems (Power, Actuators)
Propellants
Vehicle Health Management

Microgravity Science



Fluid Physics
Combustion science
BioScience and Engineering
Acceleration measurements
Flight exp. development & operations
Space Station utilization

Power

Architecture/Analyses
Generation
Storage
Distribution/Control
Environmental durability
Space Station support

Space Propulsion

Modeling/Analyses
Electric
Chemical
Thrusters/Controls & Electronics/Feed Sys.

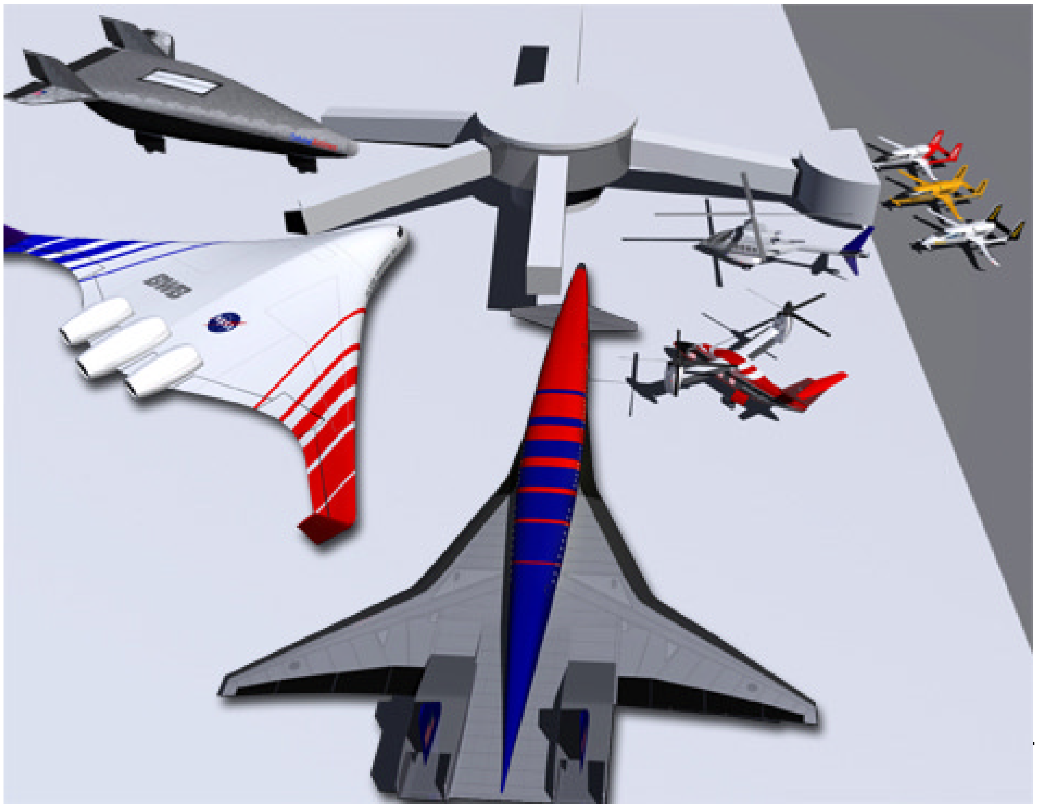
6

Glenn Research Center

Aeronautics Directorate at Lewis Field

4/4/2000

Terminal of the Future

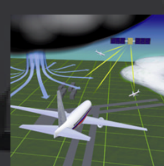


7

4/4/2000

NASA's Aeropropulsion Vision For 21st-Century Aircraft

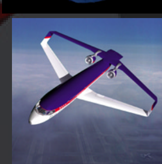
25 Years Goal to Revolutionize Aviation



Reduce Accident Rates: 10x (90%)
Make a safe air transportation system even safer

Reduce Emissions: NO_x 5X (80%), CO_2 2X (50%)
Protect local air quality and our global climate

Reduce Noise: 4x (75%)
Reduce aircraft noise to benefit airport neighbors, the aviation industry, and travelers



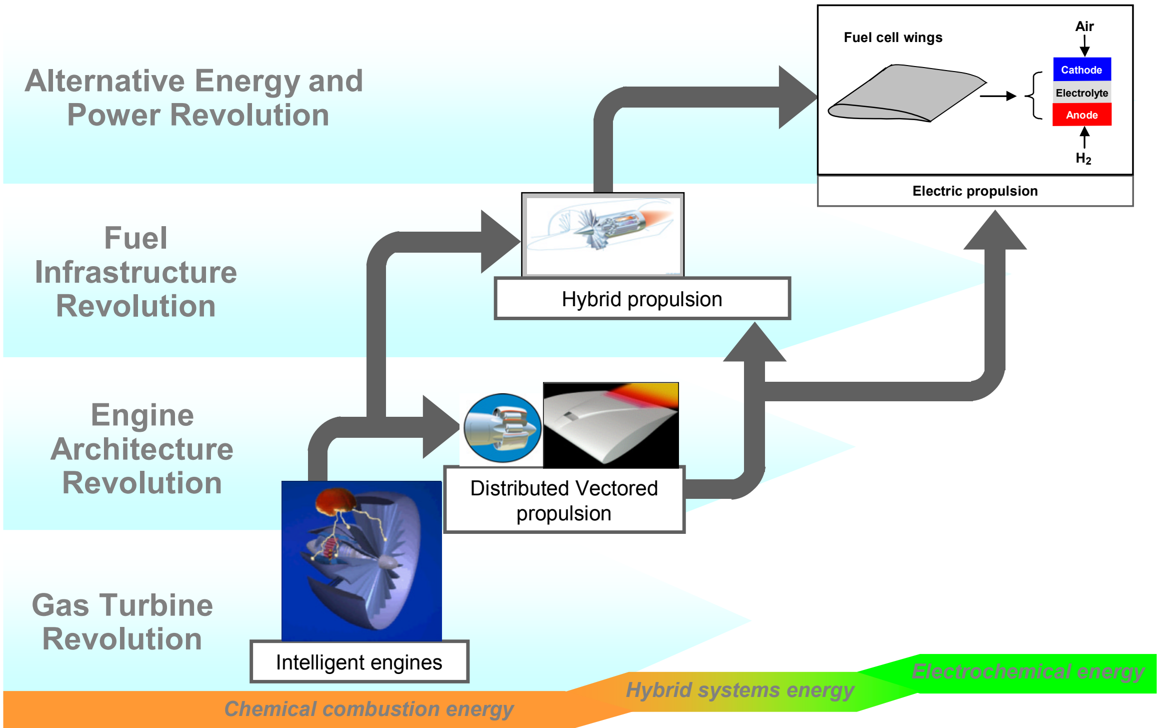
Increase Capacity: 3x
Enable the movement of more air passengers with fewer delays

Increase Mobility: Intercity 3x (67%) , Transcontinental 2x (50%)
Enable people to travel faster and farther, anywhere, anytime

8

4/4/2000

Aeropropulsion–NASA's Future Direction



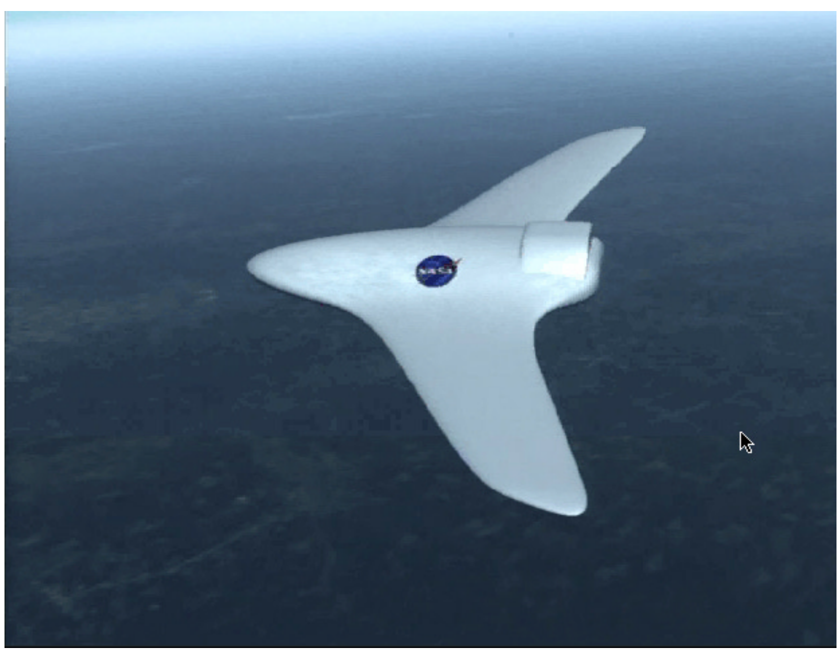
9

Glenn Research Center

Aeronautics Directorate at Lewis Field

4/4/2000

Revolutionary Aircraft Enabled by Aeropropulsion and Power Revolutions



10

Glenn Research Center

Aeronautics Directorate at Lewis Field

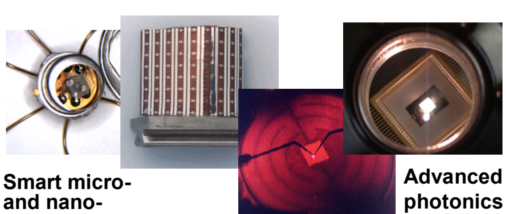
4/4/2000

Gas Turbine Revolution

Ultraclean, Quiet, Intelligent Engine: Fundamental Technologies

Intelligent Engine System Asset Management

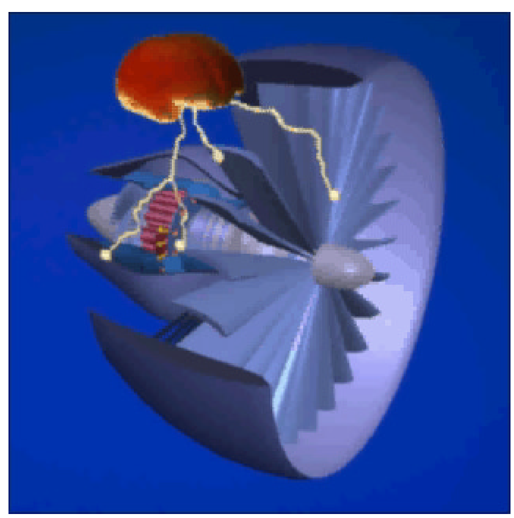
- Embedded micro- and nanosensors
- Coupled simulation and data-feedback health and performance management
- Autonomic engine control strategies



Smart micro- and nano- sensing, computation, and actuation

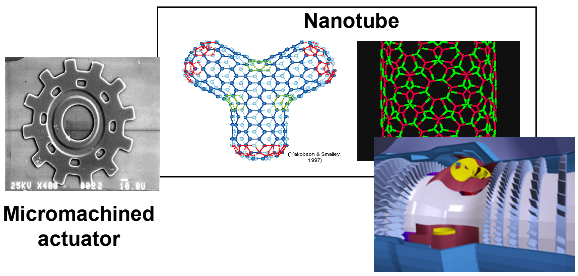
Advanced electronics

Advanced photonics



Ultraclean, Quiet, Intelligent Engine: Fundamental Technologies

- Microflow management
- Acoustic masking
- Innovative combustion strategy
- Morphing structures
- Adaptive/Self Healing structures
- Adaptive engine cycles

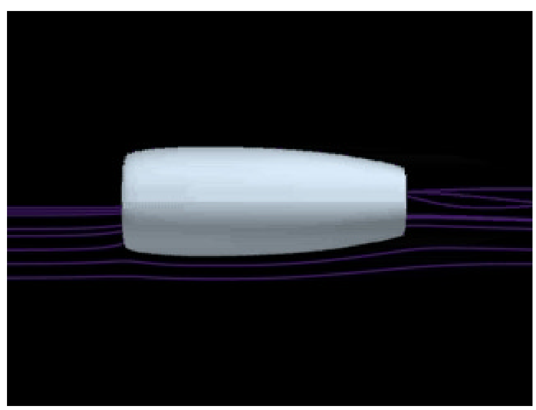


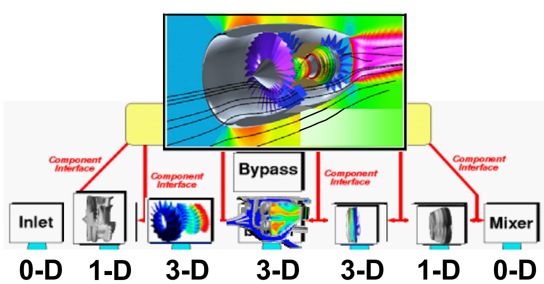
Micromachined actuator

Ultraclean, Quiet, Intelligent Engine: Fundamental Technologies

Intelligent Computing

- 0-D modeling zooming to 3-D fidelity
- Probabilistic design and analysis
- Coupling of multiple disciplines: fluids, structures, thermal
- Virtual numerical test cell

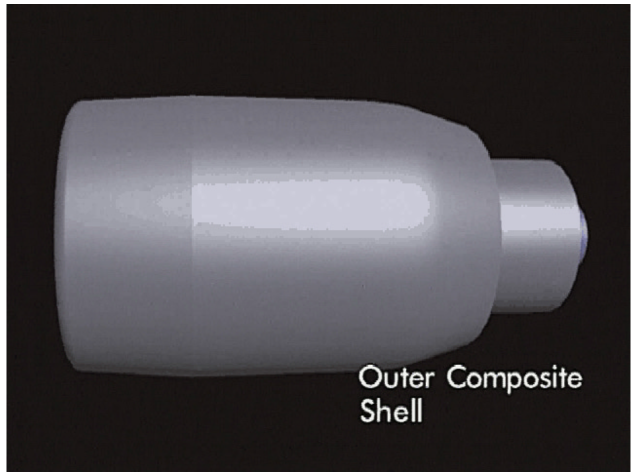


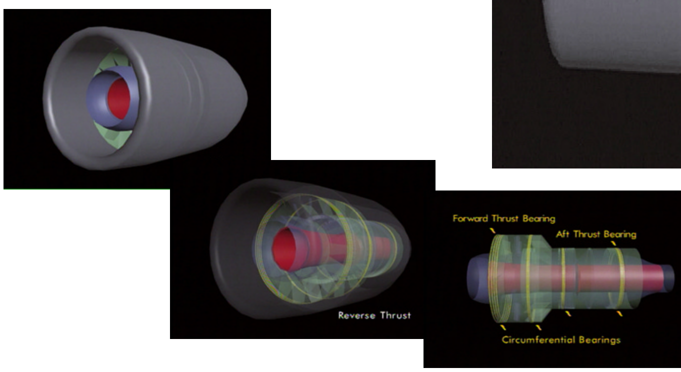


Variable Capability, Ultra High Bypass Ratio Intelligent Engines: Fundamental Technologies

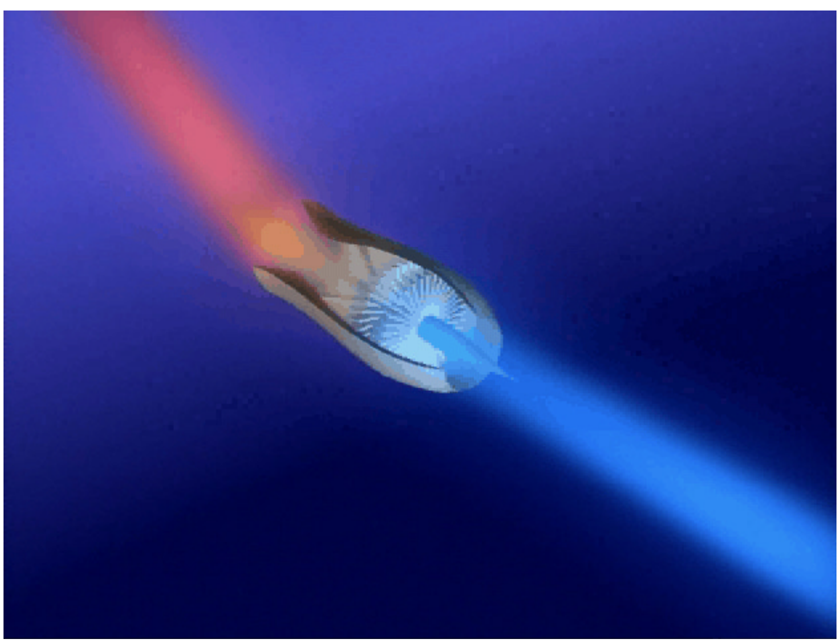
Exoskeletal Engine

- Outer shell rotating
- All composite engine
- Magnetic bearings





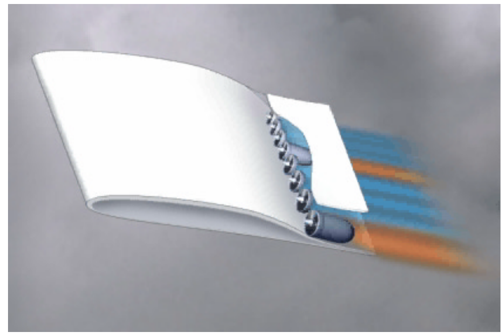
Engine Architecture Revolution (Distributed Vectored Propulsion)



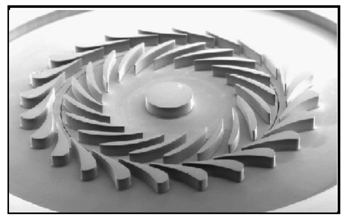
Distributed Vectored Propulsion

Distributed Engines

- Multiple low-cost, low-power engines deployed along wing
- Distributed thrust and thrust vectoring
- Aircraft boundary layer ingestion
- Microturbine engines distributed over aircraft wings



Mini-engines:
High-efficiency cores powering multiple fans

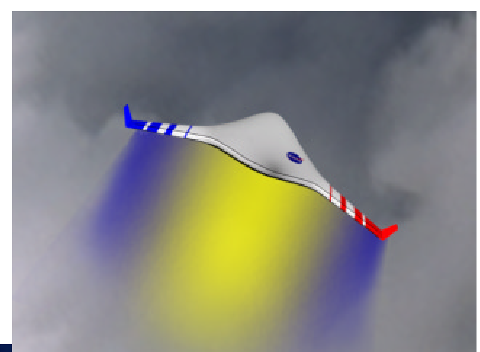


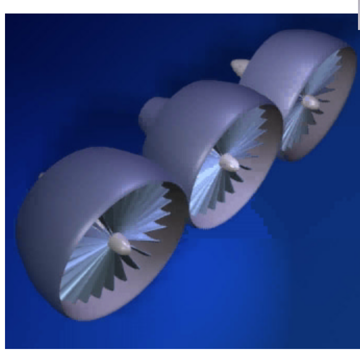
Silicon carbide microturbine

Distributed Vectored Propulsion

Multifan Core

- High-efficiency cores powering multiple fans (propulsors)
- Advanced mechanical power transmission

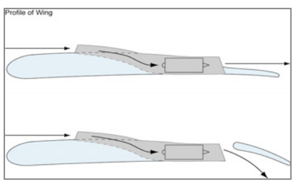


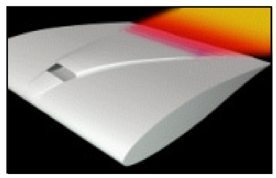


Distributed Vectored Propulsion

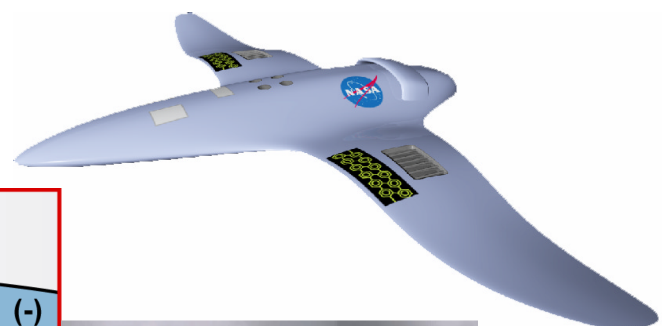
Distributed Exhaust

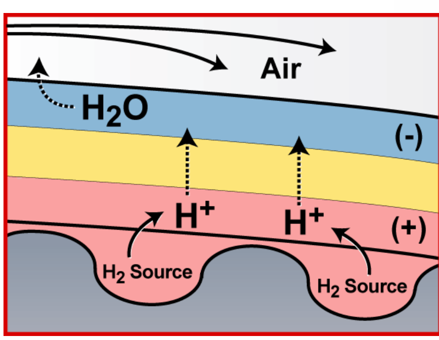
- High-aspect-ratio nozzles embedded in the wing trailing edge
- Ducted polymer matrix composite (PMC) nozzles
- Embedded inlets and nozzles employing flow control



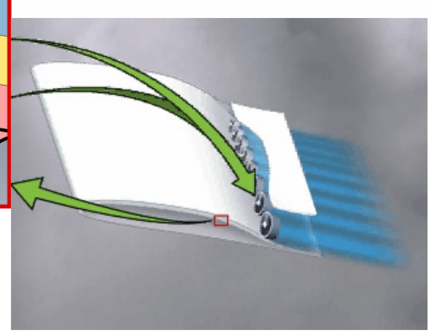


Fuel Infrastructure and Alternative Energy and Power Revolutions (Hybrid Combustion and Electric Propulsion)





Fuel Cell Wing

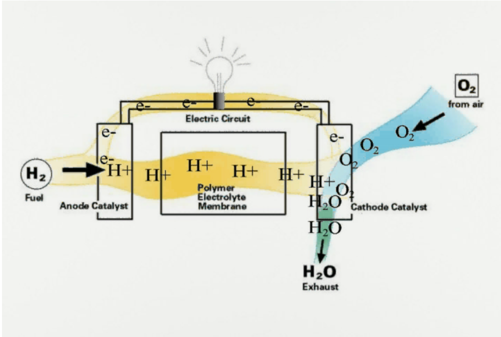


Distributed Propulsors

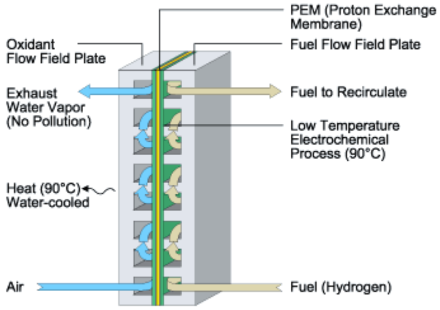
Alternative Energy Propulsion

Fuel Cell-Powered Electric Propulsion System

- Proton exchange membrane (PEM) fuel cell
- Zero NO_x and HC emissions
- Water emission or use of chemical reformer

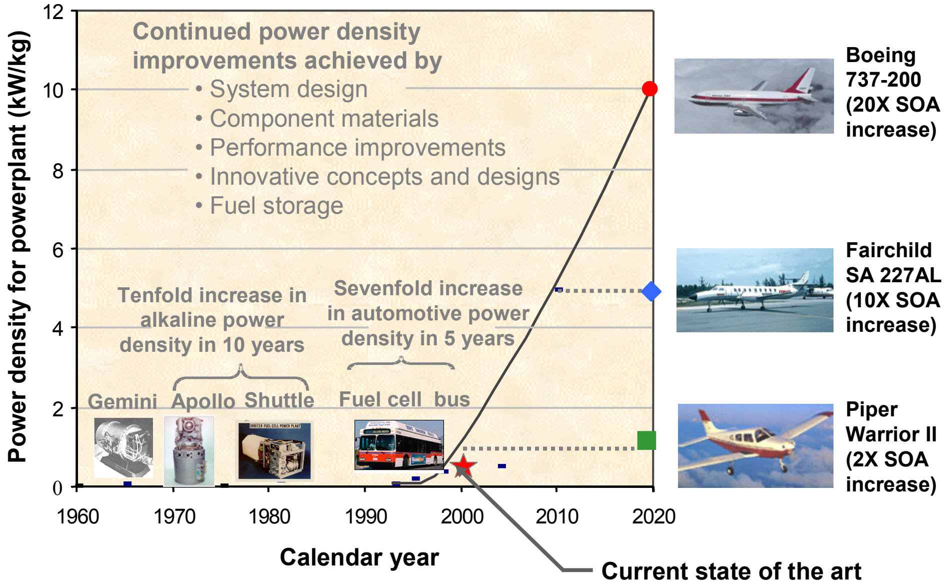


Basic hydrogen PEM fuel cell operation and hardware



Alternative Energy Propulsion

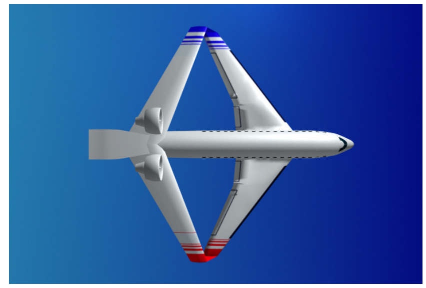
Potential Fuel Cell-Enabled Electric Propulsion

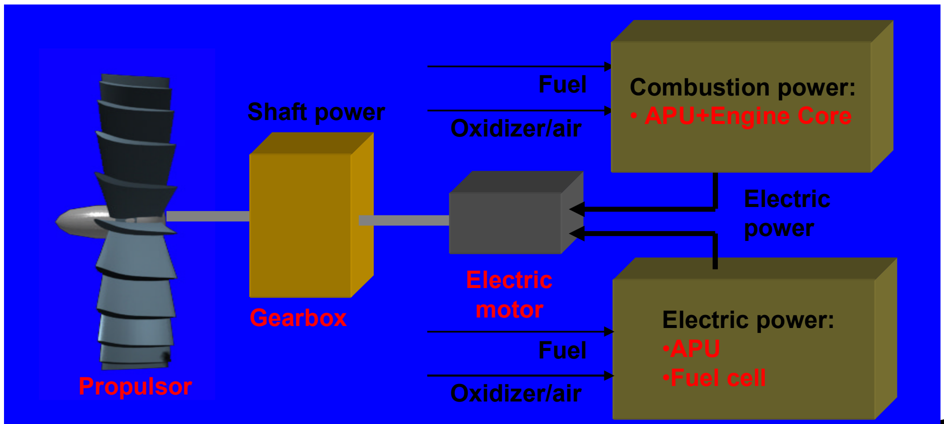


Alternative Energy Propulsion

Hybrid Combustion and Electric

- Takeoff thrust-augmenting auxiliary power unit (APU)
- Onboard electric power for zero emissions fan thrust

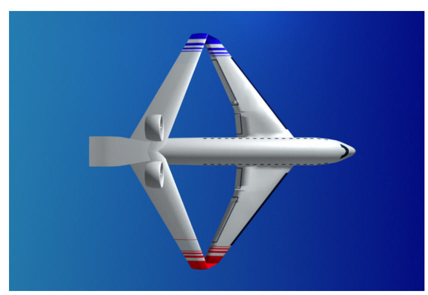


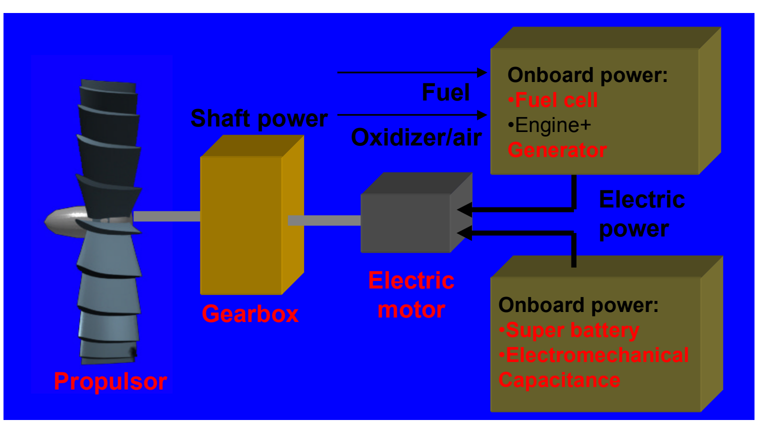


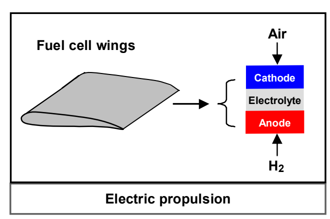
Alternative Energy Propulsion

Fuel Cell Onboard Electric Power

- Multiple fuel options including conventional hydrocarbon, hydrogen, and solid oxide
- Shared structural components with aircraft



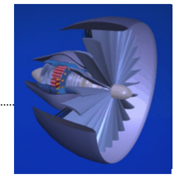




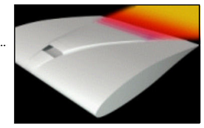
Summary

Twenty-first-century aeropropulsion and power research will enable new transport engine and aircraft systems.

- Emerging ultralow noise and emissions with the use of intelligent turbofans

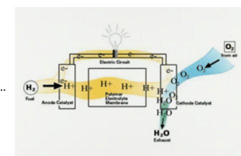


- Future distributed vectored propulsion with 24-hour operations and greater community mobility



- Research in hybrid combustion and electric propulsion systems leading to silent aircraft with near-zero emissions

- The culmination of these revolutions will deliver an all-electric-powered propulsion system with zero-impact emissions and noise and high-capacity, on-demand operation



25

Glenn Research Center

Aeronautics Directorate at Lewis Field

4/4/2000

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

Dr. John K. Lytle

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Outline

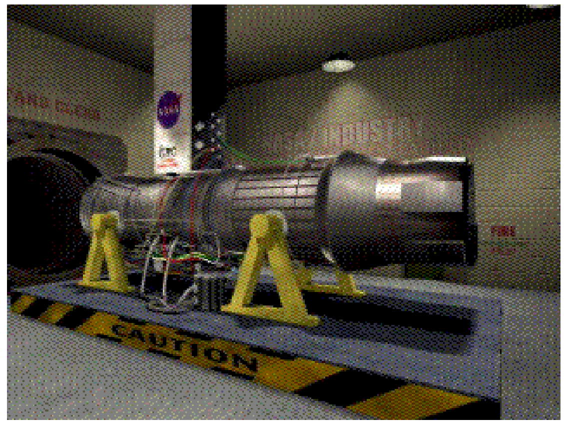
- Vision and Objective
- General Description
- Schedule
- Customer Survey Results
- FY02 Accomplishments
- FY03 Milestones
- Future Direction
- Agenda

2002 CISO Review

The Vision

Develop an advanced engineering analysis system that enables high-fidelity, multi-disciplinary, full propulsion system simulations to be performed early in the design process….

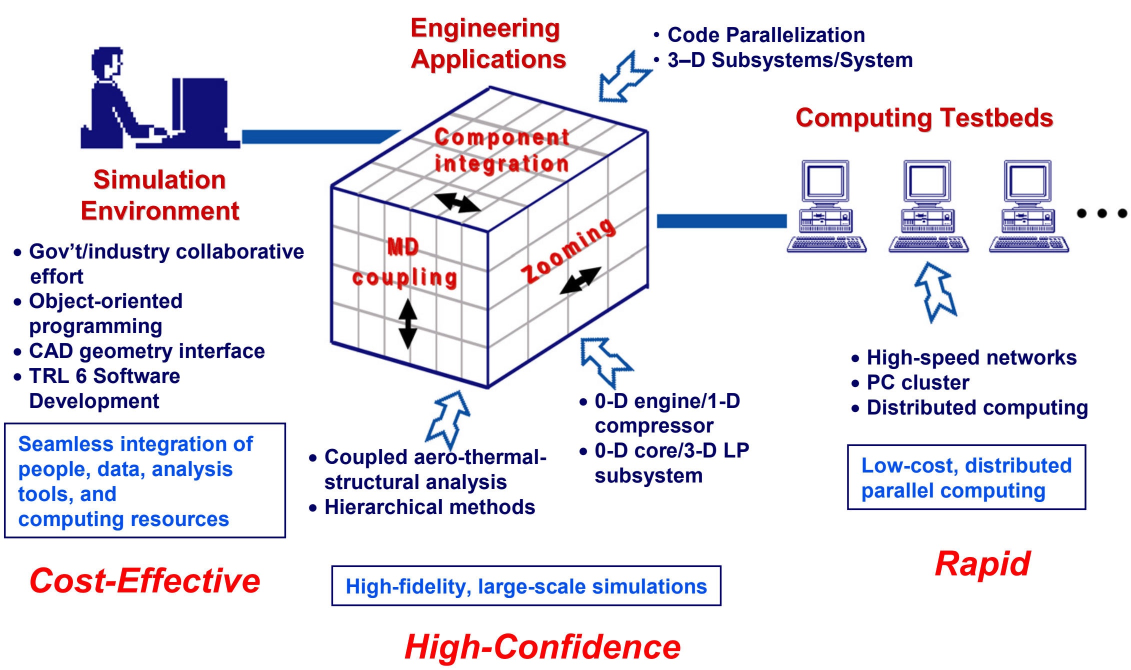
…a virtual test cell that integrates propulsion and information technologies…



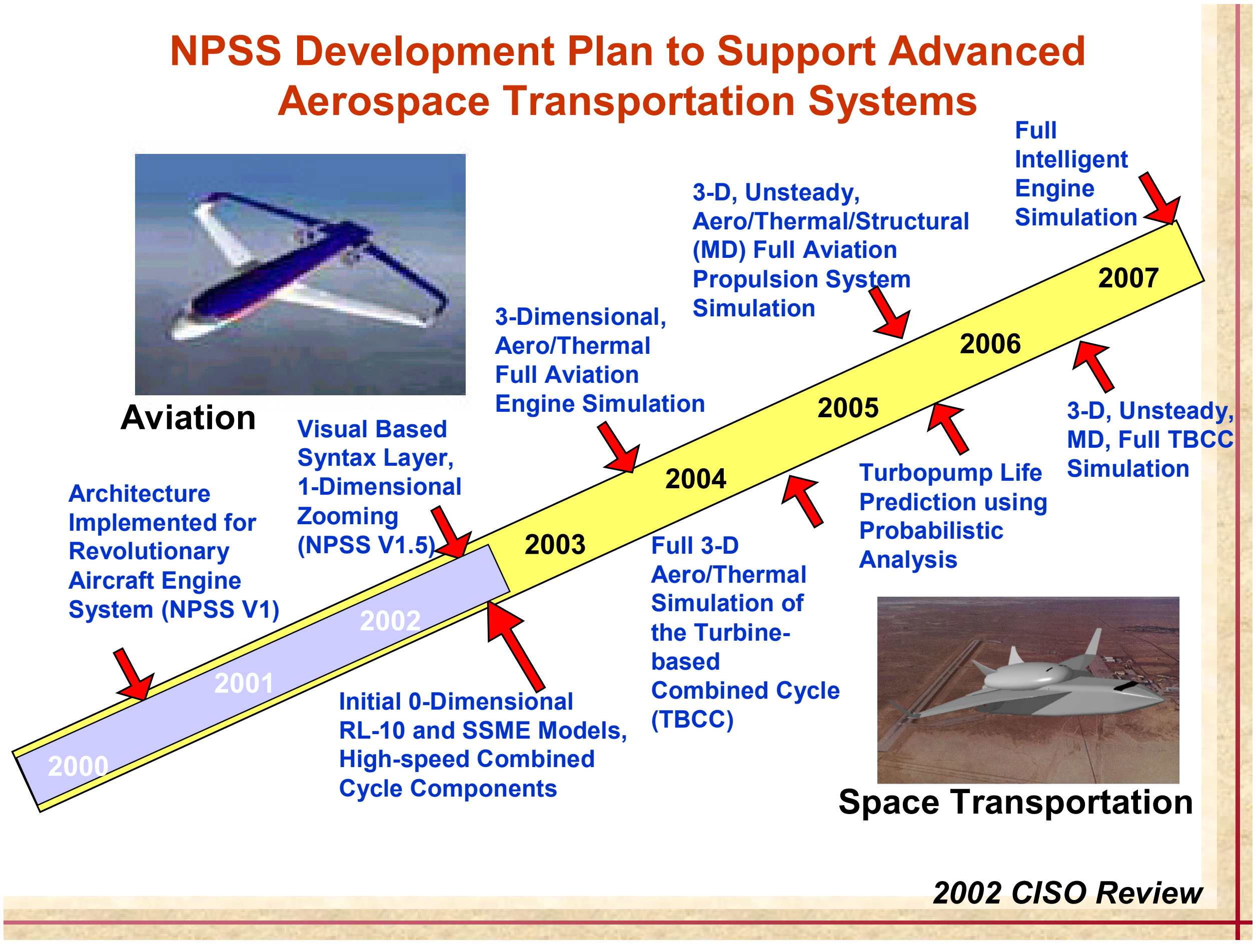
To enable rapid, high-confidence, cost-effective design of revolutionary systems. (AST Goal 3: Pioneering Revolutionary Technology)

2002 CISO Review

Major Elements of Virtual Testing

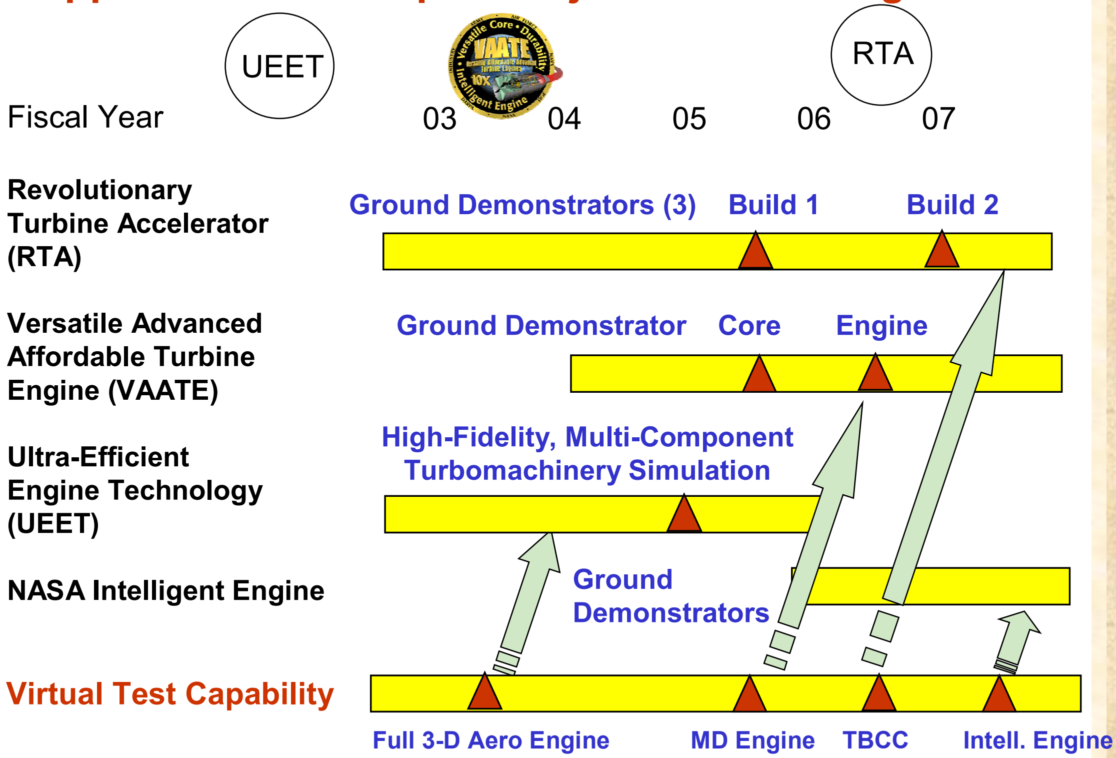


2002 CISO Review


NPSS Development Plan to Support Advanced Aerospace Transportation Systems
Aviation
Architecture Implemented for Revolutionary Aircraft Engine System (NPSS V1)
Visual Based Syntax Layer, 1-Dimensional Zooming (NPSS V1.5)
3-Dimensional, Aero/Thermal Full Aviation Engine Simulation
3-D, Unsteady, Aero/Thermal/Structural (MD) Full Aviation Propulsion System Simulation
Full Intelligent Engine Simulation
2000
2001
2002
2003
2004
2005
2006
2007
Initial 0-Dimensional RL-10 and SSME Models, High-speed Combined Cycle Components
Full 3-D Aero/Thermal Simulation of the Turbine-based Combined Cycle (TBCC)
Turbopump Life Prediction using Probabilistic Analysis
3-D, Unsteady, MD, Full TBCC Simulation
Space Transportation
2002 CISO Review

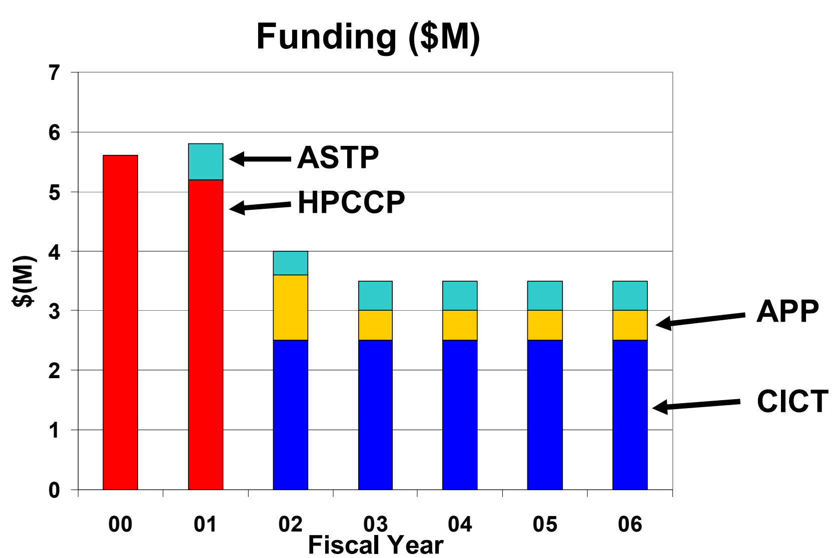

Software Development Strategy
Software Products
NPSS V1
V 1.5
NPSS
component interfaces
BYPASS
0-D
INLET
0-D
2-D
0-D
2-D
1-D
3-D
2000
2001
2002
2003
2004
2005
2006
Developers Kit: Tools for Integrating Legacy Code into the NPSS Engineering Environment
•CICT Information Environments
•CICT Computing, Networking, and Testbeds
3-D Prototype Simulations & Infrastructure
•CICT Grand Challenges
•Aerospace Propulsion and Power Base
•Space Transfer and Launch Technology
2002 CISO Review

Virtual Testing
Opportunities to Impact Major National Programs



2002 CISO Review

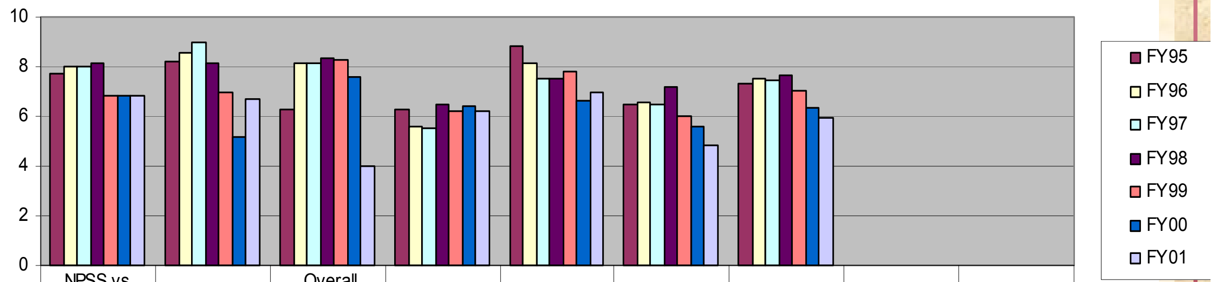
Programmatic Support



HPCCP - High Performance Computing and Communications (Revolutionize Civil Aviation)
APP - Aerospace Propulsion and Power (Revolutionize Civil Aviation)
ASTP - Advanced Space Transportation Program (Advanced Space Transportation)
CICT - Computing, Information, and Communications Technology (Pioneering Revolutionary Technology)

2002 CISO Review

OVERALL NPSS PROGRAM RATINGS



	NPSS vs Other NASA Programs	Relevance to Industry	Overall Program Balance	Technology Transfer	Industry Participation	Meeting Expectations	Overall Average
FY95	7.7	8.2	6.3	6.3	8.8	6.5	7.30
FY96	8	8.57	8.14	5.57	8.14	6.57	7.50
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
FY01	6.8	6.7	4	6.2	7	4.8	5.92

2002 CISO Review

Consistent Themes from Customer Survey

- **Concern over strong emphasis placed on these (rocket) capabilities at the expense of air breathing simulations**
- **We would be more interested in using Engineering Application and High Performance Computing tools if they were more readily deployed into our system…**
- **The development of this environment to support high fidelity components has not been as effective as desired.**
- **The current approach of trying to coalesce an approach from a variety of different, company proprietary approaches does not appear to be leading to an effective plan that benefits all NPSS members.**
- **Release policy prohibits widespread acceptance.**

2002 CISO Review

Selected FY02 Highlights

- Received two major awards
  - NorTech
  - R&D 100
- Completed prototype of first integrated 3-D aero simulation of the primary flow path of a large turbofan engine.
- Released NPSS V1.5 with visual assembly of complete propulsion system, zooming to 1-dimensional analysis, CORBA security, and rocket engine component modules.
- Demonstrated coupling objects for an object-based multi-disciplinary simulation using ADPAC and ANSYS.
- Demonstrated a 400:1 speed-up using the Lattice Boltzmann method with 500 processors to simulate a transonic compressor cascade.
- Completed a 3-D simulation (VULCAN) using distributed computing resources via CORBA over the Information Power Grid.
- NPSS Release Policy signed by NASA Headquarters.

2002 CISO Review

FY03 Major Milestones

- Automate execution of the 3-dimensional engine simulation through integration with the 0-dimensional simulation
- Complete 0-dimensional models of the advanced combined cycles for the space transportation
  - Rocket-based combined cycle
  - Turbine-based combined cycle
- Complete multi-disciplinary, unsteady simulation of a turbopump for rocket engine applications.
- Complete multi-disciplinary simulation of the integrated forebody, inlet and combustor of a high-speed vehicle and propulsion system.
- Demonstrate coupling high fidelity aerospace application codes using CORBA on the Information Power Grid.
- Develop data translation and system solver objects supporting multi-component simulations
- Implement commercialization space act agreements for NPSS V1.X

2002 CISO Review

Future Directions

- Despite substantial funding reductions in FY 02, NASA will continue to invest in an advanced engineering environment for propulsion.
- Increased emphasis on completing Developers Kit to bring in high-fidelity, multi-disciplinary analysis tools.
- Identify and cultivate commercialization opportunities for NPSS V1.x
- Work through the Propulsion System Technical Committee to address issues associated with reduction in support for Aeronautics applications. Need Executive Committee Help.
- Establish stronger partnerships with related Programs
  - DOE Accelerated Strategic Computing Initiative
  - DOD Versatile Affordable Advanced Turbine Engine Program
  - NASA Ultra-Efficient Engine Technology Program
  - NASA Advanced Space Transportation Program

2002 CISO Review

Propulsion System Technical Committee

Dr. M. J. Benzakein	General Manager, Advanced Engineering Programs	GE Aircraft Engines
Dr. Arun K. Sehra	Director of Aeronautics	NASA Glenn Research Center
Mr. Gerald (Scott) Cruzen	Director, Advanced Technology	Williams International
Mr. Ted Exley	Director of Advanced Programs	Teledyne Continental Motors
Mr. Jeff Jenson	Division Director of Business Development	The Boeing Co./Rocketdyne Propulsion & Power
Professor Awatef Hamed	Dept. of Aerospace Engineering	University of Cincinnati
Professor Wesley L. Harris		Massachusetts Institute of Technology
Ms. Sandra Hoff	Chief Power Systems Division	Aviation Applied Technology Directorate
Mr. Robert J. May Jr.	Executive Director	Air Force Research Lab
Mr. John Meier	Director, Advanced Programs	Honeywell
Mr. J. Walter Smith	Engineering Director, Compression Systems Module Center	Pratt & Whitney
Mr. Jan Syberg	Propulsion Technology Leader, Phantom Works	The Boeing Co.
Dr. Ronald York	Chief Operating Officer	Allison Advanced Development Co.
Mr. John R. Arvin	Vice President Programs	Allison Advanced Development Co.

2002 CISO Review

Agenda

- Simulation Environment
- Engineering Applications
- Cost-effective Computing Testbeds

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

Information Environments

Gregory J. Follen
Cynthia Naiman

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Agenda:

- CNIS organization
- NPSS V1.5 milestone
- FY'02 milestones accomplished
- Status of Information Environments
- FY'03 plans

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

CNIS - Organization

Project Office
Jerry Yan, Manager
Catherine Schulbach, Deputy Manager

Mission Needs and System Analysis
Tom Cochrane

Grand Challenge Applications

- Space Flight Simulation — Goetz Klopfer
- MER CIP — Joan Walton
- Intelligent Virtual Station — Robert Mah

Information Environments
Piyush Mehrotra

Grid Common Services
Bill Johnston

Advanced Networking & Computing Testbed Research
Ken Freeman
Rupak Biswas

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Information Environments

The **objective** of GRC CNIS/IE work is to build a plug-n-play infrastructure that provides the Grand Challenge Applications with a suite of tools for coupling codes together, numerical zooming between fidelity of codes and gaining deployment of these simulations onto the Information Power Grid. The GRC CNIS/IE work will streamline and improve this process by providing tighter integration of various tools through the use of object oriented design of component models and data objects and through the use of CORBA (Common Object Request Broker Architecture).

Approach:

Interface Layer
Assembly of the simulation, this could be simple to sophisticated. It defines the order of execution, linking of components, and validity check of components.

Execution Layer
Startup, control, shutdown of simulations, events, provide batch to command switching with strong ties to the generic needs of the Grand Challenge Applications.

Simulation Services Layer
Initially, this layer will be populated with objects/agents to provide security of data, coupling infrastructure, zooming infrastructure, visualization, temporal data storage, portals for collaboration. The Simulation Services layer ends up closest to Grid Common Services.

Programming Services
Best practices in developing a stable, accurate, repeatable simulation. Definitions of expected simulation behavior. Automated Tools for wrapping code, data parameter extraction and movement.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Information Environments –FY02 Milestones

Demonstrate the Visual assembly of a complete aerospace propulsion system with 1 Dimensional zoomed analysis. 2nd QY 2002

Develop a mechanism for component based models to read/write standard formats such as XML/HDF/CCA/CGNS. 4th QY 2002.

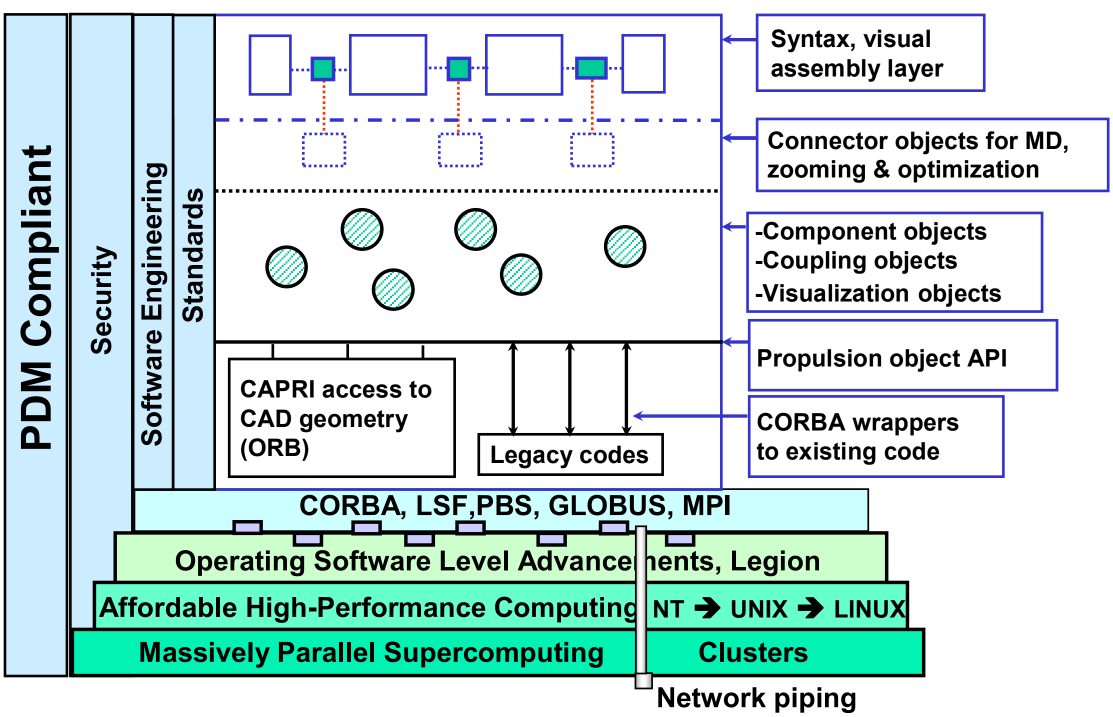
CORBA wrap the Information Power Grid Services , meta-computing directory services (MDS), resource management (GRAM) and access to secondary storage (GASS supporting a zoomed propulsion parameter study. 4th QY 2002.

Demonstrate coupling objects for an object-based multidisciplinary simulation using ADPAC, ANSYS. 4th QY 2002

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Information Environments - Object-Oriented Architecture



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

NPSS 1.5.0W Release Highlights

- Space Transportation Components & Capabilities
- New/Enhanced Engineering Components
- Improved Socket Design
- Enhanced CIAPP Development Kit
- CIAPP CORBA Server Mode
- Initial Visual Based Syntax Capability
- Plug-n-Play Thermo
- Enhanced Customer Deck
- Enhanced Solver: Discrete State Variables, Constraints
- Enhanced C++ Converter, Autodoc, Message Handler
- Unit Conversions
- NT Port
- Linear Model Generation

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

NPSS 1.5.0W Release Statistics

Active CRs = open, assigned, scheduled, ready_test, and ready_merge states
Finished CRs = built and closed since V1.0.0 released (March '00).

DEFECTS		ENHANCEMENTS	
Active	291	Active	84
Finished	310	Finished	117
Deferred	34	Deferred	19
Rejected	3	Rejected	0
Total DEFECTs	638	Total ENHANCEMENTs	220

REQUIREMENTS

Active CRs (REQs) 11 (cover 20 reqs)
Finished since 3/00 25 (cover 43 reqs)

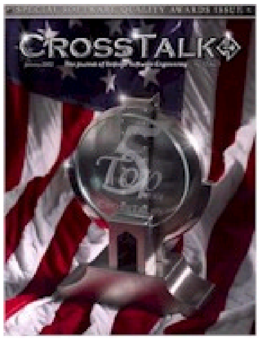
Total REQs 36 (cover 60 reqs)*
* 1 REQ covered 12 VBS reqs.
NOTE: Total aero & space SRS reqs = 193

Total Active CRs	386
Total finished since 3/00	452
Total Currently Deferred	53
Total Currently in Rejected State	3
TOTAL Version 1.5.0W CRs	894

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Award Winning Software



- **Finalist to *CrossTalk: The Journal of Defense Software Engineering* TOP Software Projects for 2001 (top 16 out of 87 entries)**
- **2002 NorTech Innovation Award Winner**
- **2002 R&D 100 Award Winner**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

NPSS V1.5+ current usage

•Georgia Institute of Technology: specifically the Aerospace Systems Design Laboratory of the School of Aerospace Engineering, is using the NPSS software strictly for NASA contract work for the Ultra Efficient Engine Technology Program.

•Rolls-Royce plc: (in Bristol, England), under contract to Pratt & Whitney for the Joint Strike Fighter LiftFan (R), will probably present LiftFan (R)aerodynamic performance to Pratt & Whitney in the form of NPSS input. Rolls-Royce Corp. (in Indianapolis) will assist Rolls-Royce plc in this event.

•GEAE:Besides GP7000, we are currently using it for selected PD/new engine studies and are using it to support the CF34-10, our latest commercial engine certification program. The support work and test data analysis for the recent CF34-10 first engine to test (FETT) was done using NPSS. We have trained over 50 people on NPSS and will have trained more than 80 people by the end of the year. We are in the process of migrating some current models and all of our future engine performance simulation work to NPSS.

•Boeing: We have used NPSS to model two systems that contain fuel cells. NPSS is lacking in many of the components needed for this type of simulation, but elements are fairly easy to construct using the interpreted code which is a plus for these kind of studies. Both GE and P&W have delivered sample models preliminary to models later this year for the sonic cruiser program.

•DRFC: Long term plan is to eventually use NPSS to analyze ram/scramjets, RBCC, and TBCC propulsion systems that we might flight test here in Dryden. I also might need to use it to analyze rockets, as we spool up a small rocket flight test capability here. We are looking at solid-fuel rockets, but we will probably look at liquid-fuels as well as hybrids.

•PWFL: We are currently involved in the process of validating NPSS for use in modeling liquid rocket engines (NASA SLI via P&W / AEROJET COBRA engine) and for use in modeling Hypersonic engines (ISTAR) here at Pratt & Whitney Space Propulsion.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

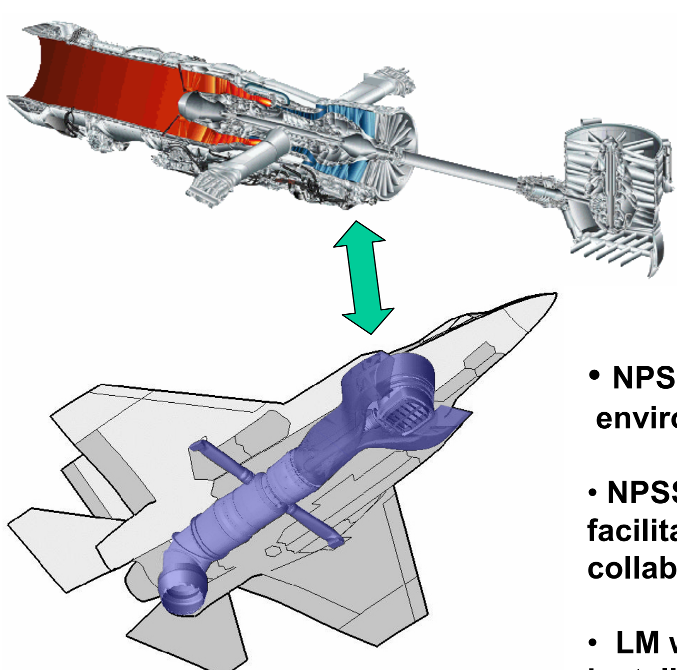
NPSS V1.5 current usage

•FTT has been using NPSS for almost a year now, primarily in support of advanced DoD programs in the Air Force and Navy. FTT has also been evaluating NPSS as regards application to industrial gas turbines, electric power plants, and chemical process facilities. Our future intentions for use (provided a continuing agreement for NPSS usage is obtained from NASA)include expansion of these activities to additional programs in military and civilian aviation, power systems, and process industries, and eventual integration of NPSS into the design process at FTT.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Lockheed Martin Utilizing NPSS to integrate propulsion simulations of PW and GE engines into the F-35 Joint Strike Fighter



Pratt & Whitney F135
General Electric F136

- **NPSS will allow a common modeling environment between all JSF partners.**
- **NPSS Component based architecture facilitates the JSF STOVL variant collaborative propulsion system.**
- **LM will be transitioning to total NPSS installed engine performance models in 2003.**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

NPSS/Linear Model Generator

- **What**
  - **Linear Models relate changes in selected State Derivatives and output variables to changes in the corresponding States and selected input variables.**
  - **Linear Model represented by 4 sensitivity matrices, referred to as the ABCD matrices, that contain these sensitivities.**
- **Why**
  - **Provides characteristic response data to control design tools**
  - **Provides individual Linear Models that collectively represent a piece-wise linear model of an engine.**

NPSS/Linear Model Generator

- **How**
  - **Validate against P&W SOAPP generated linear model of the same engine.**
  - **Number match not exact due to small differences between SOAPP and NPSS non-linear models.**
  - **Matlab analysis shows responses of the SOAPP and NPSS linear models are essentially identical.**
- **Status**
  - **Initial version completed and release.**

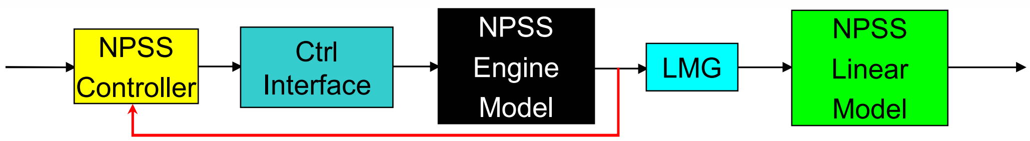
Engineering for Complex Systems (ECS)
ECS WBS 2.2.5 Subsystem Model Integration Methods
L5: Propulsion Subsystem Performance Modeling

Tasks for 2002

- Setup NPSS in SimLab. Completed
- Deliver 90K NPSS Engine model to Controls Group. Completed
- Develop and Validate linear/non-linear XTE46 NPSS Models.
  Near Completion
- Establish Initial Communication between NPSS and MatLab. Completed
- Incorporate Simple Controller with NPSS. Completed

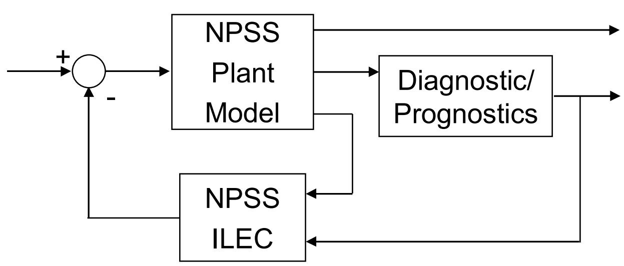
NEAR-TERM TASK GOALS

- Develop NPSS controller interface Completed
- Give NPSS the ability to model 1-D transients.
- Develop a Linear Model Generator (LMG) Completed



NPSS Plant Model

ECS WBS 2.2.5 Subsystem Model Integration Methods
L5: Propulsion Subsystem Performance Modeling
LONG-TERM GOALS

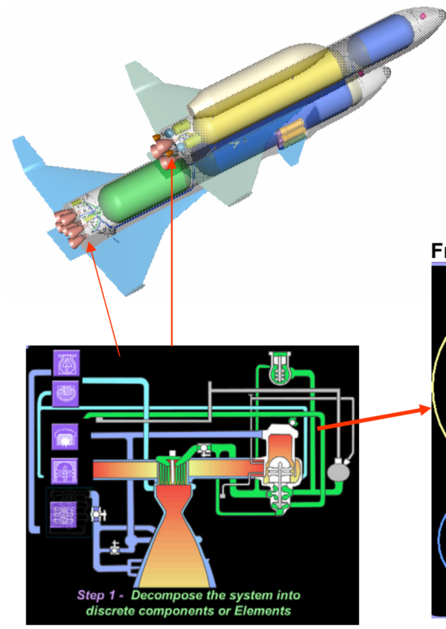


- Add health monitoring parameters and diagnostic/prognostic capability.
- Add life models to NPSS model.
- Use NPSS with updated capability to develop and validate Intelligent Life Extending Control (ILEC).

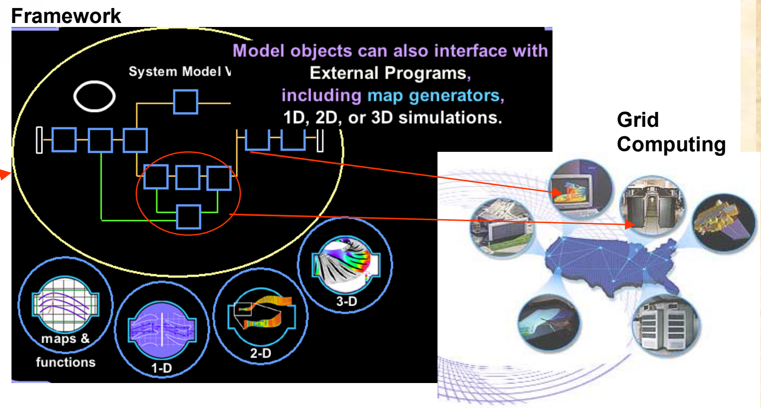
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

NASA/GRC – CNIS Framework for Grid Enabling of Multi-Discipline & Multi-Fidelity Aerospace Simulations



Demonstrates the use of the CNIS Framework for Grid Enabling of High Fidelity modeling for space propulsion simulations.

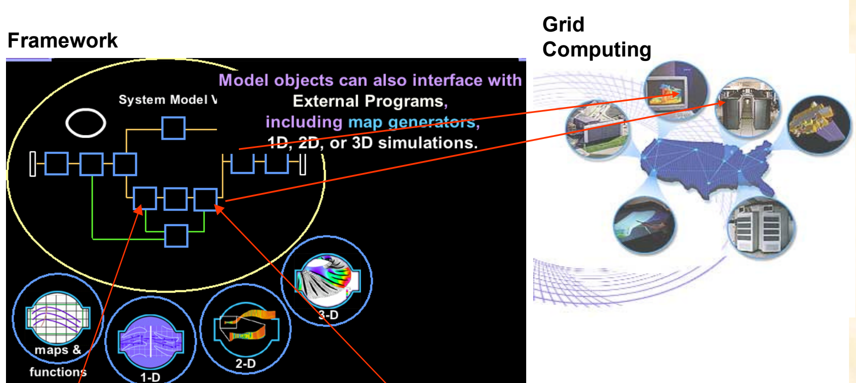


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

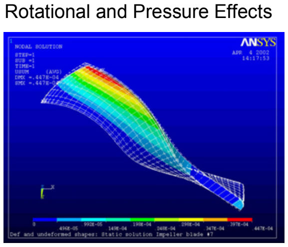
2002 CISO Review

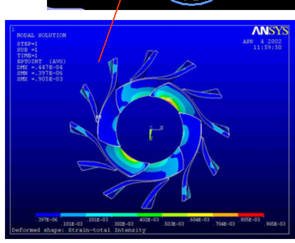
NASA/GRC – CNIS Framework for Grid Enabling of Multi-Discipline & Multi-Fidelity Aerospace Simulations

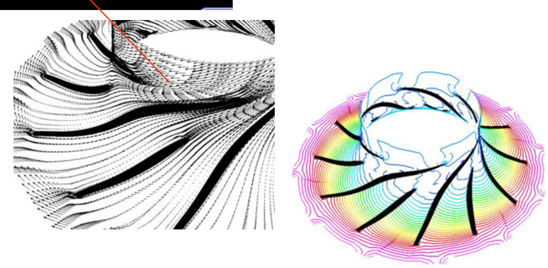
Demonstrates the use of the CNIS Framework for coupling ANSYS and HAH3D analyses of a MSFC Pump design.



Pump Impeller Deflections Resulting from Rotational and Pressure Effects





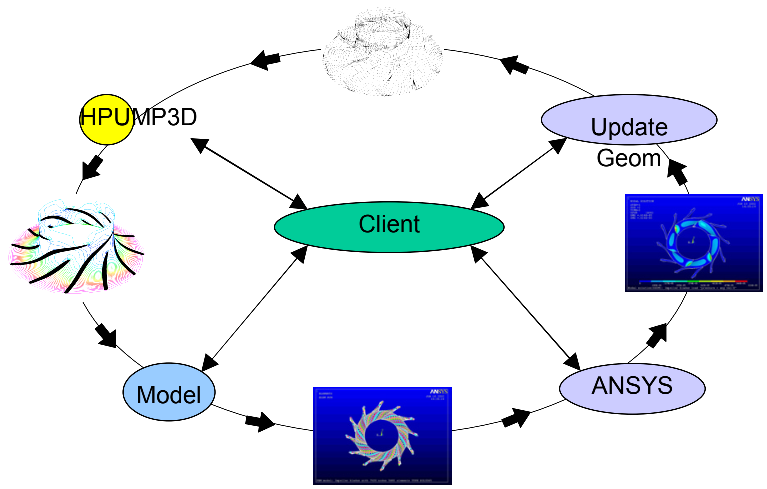


Velocity Vectors/Pressure Contours Impeller Fluid Solution

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

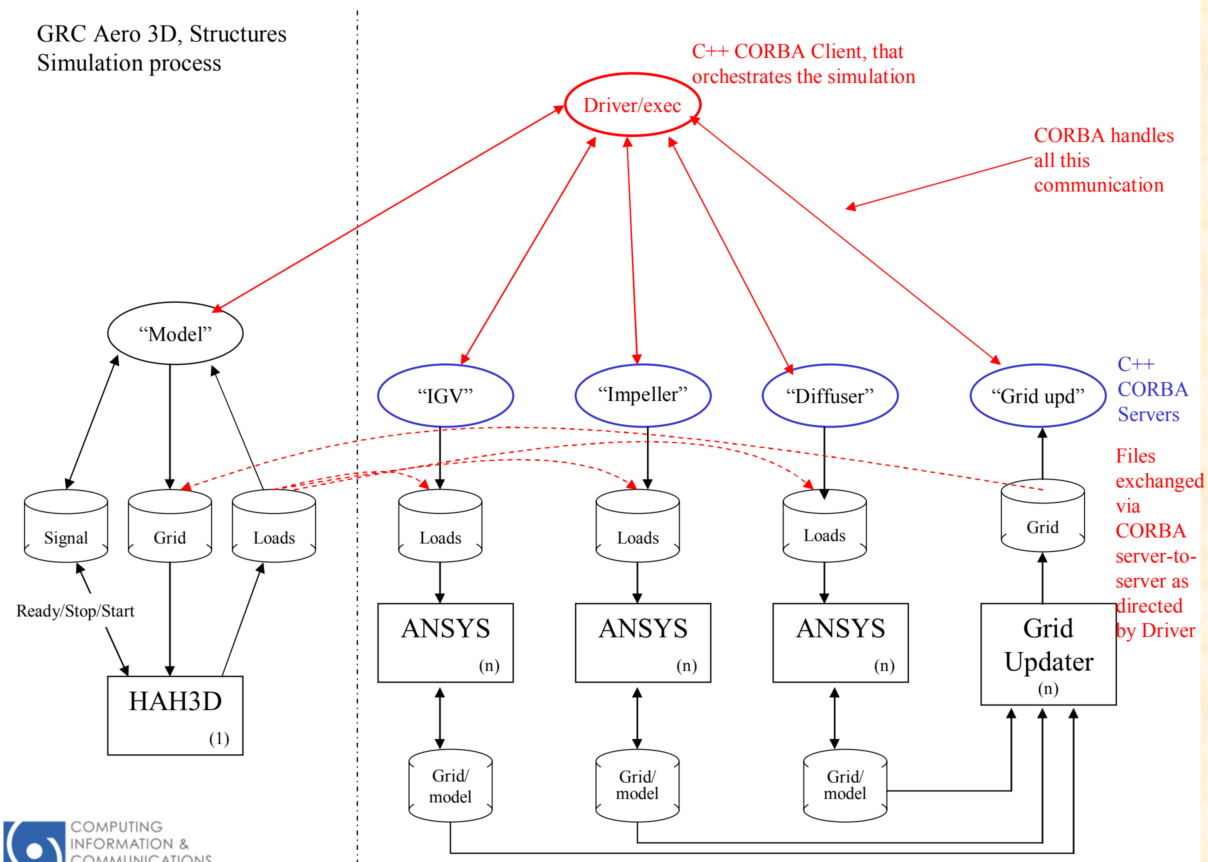
2002 CISO Review

Coupling between HPUMP3d and ANSYS under CORBA Development Kit



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

(n) – means multiple times called

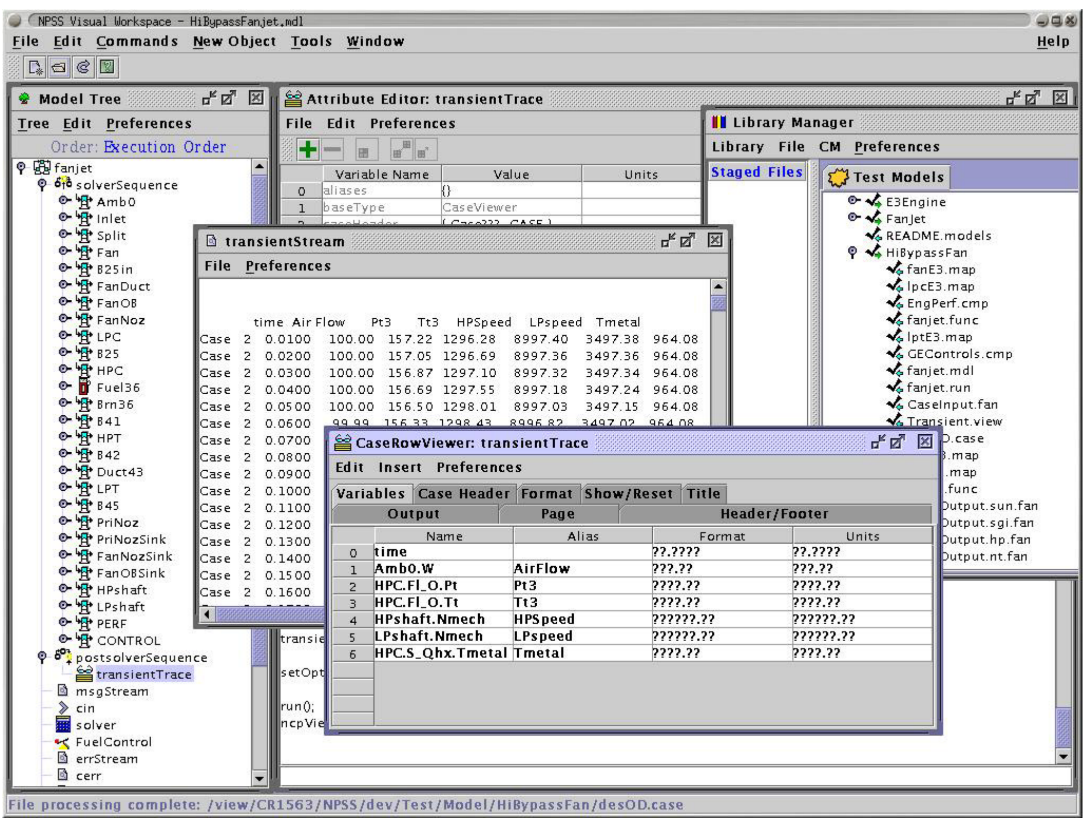
2002 CISO Review

Information Environments - Visual Assembly

- First release with NPSS version 1.50
- Object editor framework, with CaseRow, CaseColumn and VarDump Viewer editors
- Preferences Editor
- Library Manager
- Printing
- Alternate NPSS Interface (non-CORBA)
- GUI for solver setup

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

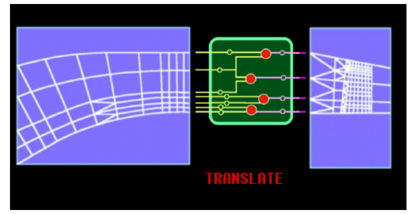
2002 CISO Review



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments



Overall

- Linux port - New Sun compiler port - MICO port for all platforms except NT (requires patched MICO 2.3.7) - Unified IDL: now server mode can be external component (no ports), and includes file transfer support. - 3rd party file & variable transfers. HDF capability added to VOB.

CCDK developments in VOB

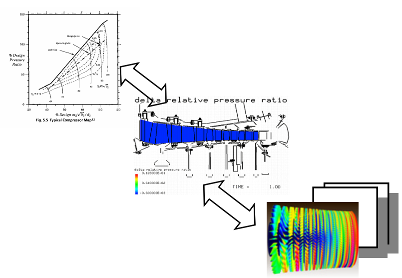
* - Higher fidelity support in a separate deliverable (HiFi.tar.gz)* - PUMPA is now a separate deliverable (CCDKrockets.tar.gz)* - C++ standalone client support includes Prof. Sang's caching scheme, support for all array types. - New CORBA security technique incorporated, but not tested with a secure ORB. (update of Tammy Blaser's code)

CCDK developments not in VOB

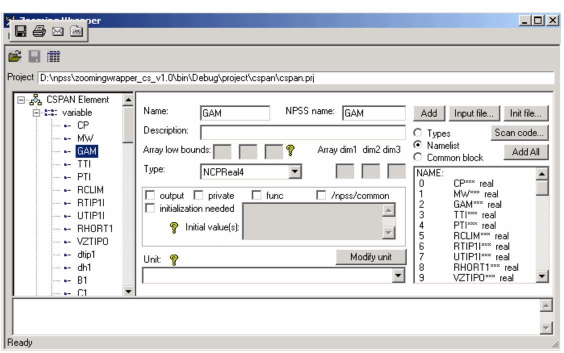
- BRSTK component - ptyWrapper tool (from last year, but now portable and in standard build form) - Simple indirect wrapper support, 'file signaling' wrapper support.

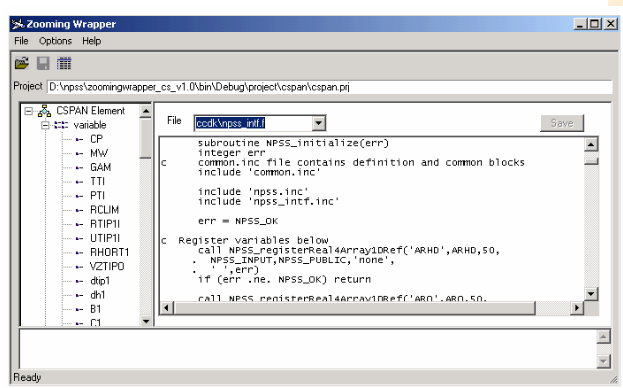
I.E. - Development Kit FY02 Accomplishments

Zooming & CORBA Wrapping



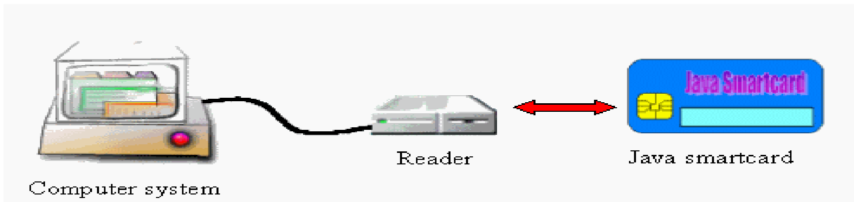
- A GUI based tool to aid in the wrapping of DLM's and CORBA elements is being developed.





I.E. - Development Kit FY02 Accomplishments
CORBA Security, Smart Card Prototyping

CNIS Smart Card High Level Architecture Based On JavaCard Technology



COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments
CORBA Security, Smart Card Prototyping

CNIS Prototyping using JavaCard And Biometric Devices

Development JavaCard
EEPROM 18K

Main Development JavaCard
Common Criteria EAL 5+
FIPS 140-1
EEPROM 57K

Biometrics fingerprint smart card
reader for C & C++ developments
EEPROM 8K (Learning Tool)

Development JavaCard
EEPROM 28K

Development JavaCard
with pre installed Java PKI
digital certificate applet
EEPROM 21K

Biometrics fingerprint smart card (JavaCard) reader
with preinstalled Java Bio applet (On Order)

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments CORBA Security, Smart Card Prototyping

- **Development Approach: Use JavaCards technology to develop web based cryptographic prototypes to support:**
  - Generation of key pairs on a card, Store X.509 certificates on a card
    - X.509 most widely used standard (International Telecommunication Union (ITU) recommendation) for defining a digital certificate
  - Use private key for digital signing of an electronic document and encryption/decryption of messages
  - Use certificates to authenticate CNIS card holder users for access to CNIS distributed Web Services and Applications
    - Simple Object Access Protocol (SOAP) and Extensible Markup Language (XML) based Web Services and Globus Web Services
  - Common Object Request Broker Applications (CORBA) Applications
  - Experiment with porting JavaCard applets to various operating system environments (Win2K, Linux, Solaris) by leveraging off of open standards
- **Future Plans:**
  - Integrate JavaCard prototype efforts with biometric fingerprint devices
  - Integrate prototype with Organization for the Advancement of Structured Information Standards (OASIS)
    - Integrate enterprise technologies Security Assertion Markup Language (SAML)
  - Integrate Entrust compatible on card X.509 Rivest, Shamir and Adleman asymmetric algorithm (RSA) Personalization
  - Integrate CNIS web services and CORBA applications to include delegation security models
  - Demonstrate multiple applet JavaCard configuration supporting multiple card holder (user) authorized tasks

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments CORBA Security, Smart Card Prototyping

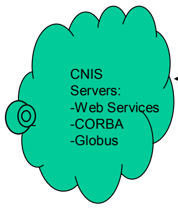
- **Significance:**

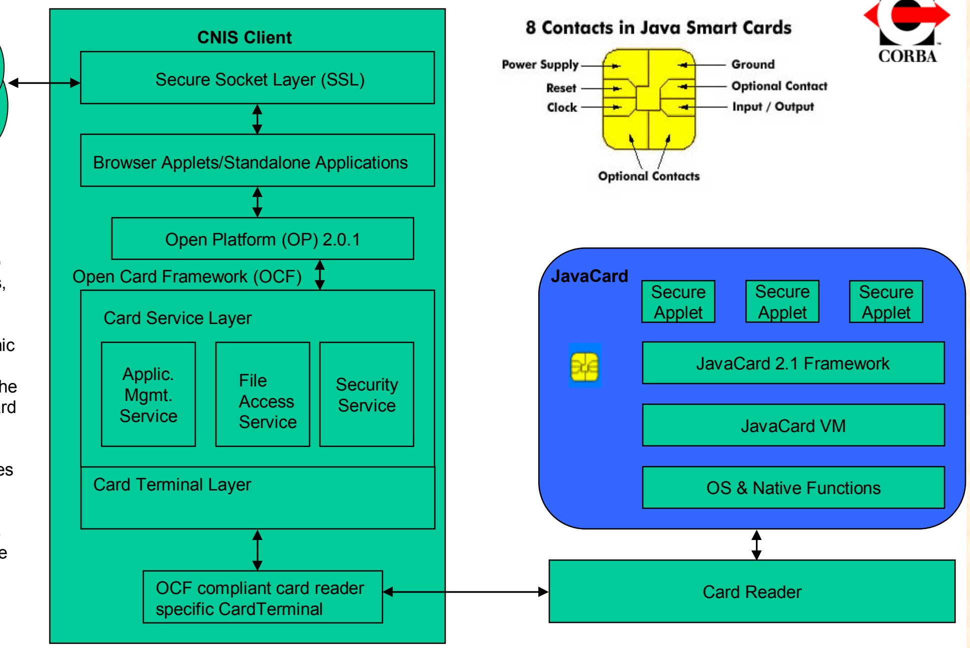
  In order to support NASA's heterogeneous computing base a generic smart card prototype architecture design is being developed …
  - The prototype will consist of a profile driven set of generic authentication JavaCard applets
    - User's ONE JavaCard can be used at various different computer platforms to do different authorized tasks
  - JavaCard development is a technical leveraging point to implement wireless security.
  - Entrust Personalization supports NASA Certificate Authority (CA) signing
    - Allows integration crossover from CNIS JavaCard research to NASA JavaCard deployment.
  - BIG ENCHALOTA: Future development will include multiple-factor authentication by combining techniques
    - Biometric (something users are)
    - Digital certificates and/or SecurID (something users have)
    - PIN (something users know)

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments CORBA Security, Smart Card Prototyping





Why JavaCards? Prior to smart cards or JavaCards, Public Key Infrastructure (PKI) storage and processing of cryptographic keys was a very challenging task to keep the private keys safe. JavaCard technology also supports platform independence; prior authentication devices are unique designs. JavaCards also provide application growth with its support for secure multiple applet development.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments CORBA Security, Smart Card Prototyping

- **Digital certificate generation and storage on JavaCard**
  - **Commercial CA and self signed on card X.509 RSA Personalization (initial phases)**
  - **Entrust compatible on card X.509 RSA Personalization signed by NASA Ames CA (future phase)**
- **Secure communications channel between JavaCard and CardTerminal Manager using X.509 RSA Authentication, Data Encryption Standard (DES) Integrity, DES Confidentiality**
  - **CardTerminal Manager (Card Issuer Management)**
  - **PIN and X.509 card holder authentication (initial phase)**
  - **Fingerprint card holder authentication (future phase)**
  - **Uses digital certificate on JavaCard**
  - CNIS User PKI Authentication Applet
- **Delegation management between JavaCard and CardTerminal Application (Client or Server) using token driven X.509 RSA certificates and DES encryption/decryption**
  - **Ensures that the files being transmitted to the JavaCard and the applications being installed upon a JavaCard by an entity other than the card issuer (i.e. CardTerminal Application Client or Server) has been previously "Authorized" by the card issuer (i.e. CardTerminal Manager).**
  - **Uses CNIS User PKI Authentication Applet**
  - **Delegation Applet**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments CORBA Security, Smart Card Prototyping

- **SSL or CORBASec session between "Authorized" CardTerminal CORBA Client and "Authorized" CardTerminal CORBA Server using on card secure applets (future phase)**
  - **Uses CNIS User Authentication Applet**
  - **Uses Delegation Applet**
  - SSL CORBA Applet
  - CORBASec Applet

- **SSL session between "Authorized" CardTerminal Web Service Client and "Authorized" CardTerminal CORBA Server using on card secure applets (future phase)**
  - **Uses CNIS User Authentication Applet**
  - **Uses Delegation Applet**
  - SSL Web Service/CORBA Applet

- **Secure SAML session between "Authorized" CardTerminal CORBA Client and "Authorized" CardTerminal CORBA Server using on card secure applets (future phase)**
  - **Uses SSL CORBA Applet Development**
  - Secure SAML CORBA Applet

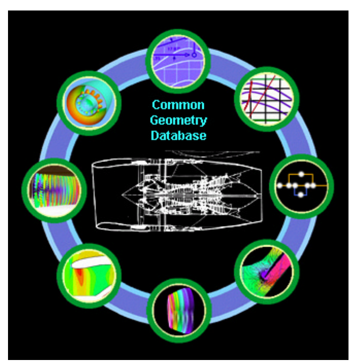
- **Secure SAML session between "Authorized" CardTerminal Web Service Client and "Authorized" CardTerminal CORBA Server using on card secure applets (future phase)**
  - **Uses SSL Web Service/CORBA Applet Development**
  - Secure SAML Web Service/CORBA Applet

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments

CAD Services V 1.0, A CORBA Interface for Geometry Information Sharing



Russ Claus (claus@grc.nasa.gov)
Turbomachinery and Propulsion Systems Division
NASA Glenn Research Center
and
Ilan Weitzer (iweitzer@ford.com)
CADCAM Systems
Ford Motor Company

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments

CAD Services V 1.0, A CORBA Interface for Geometry Information Sharing

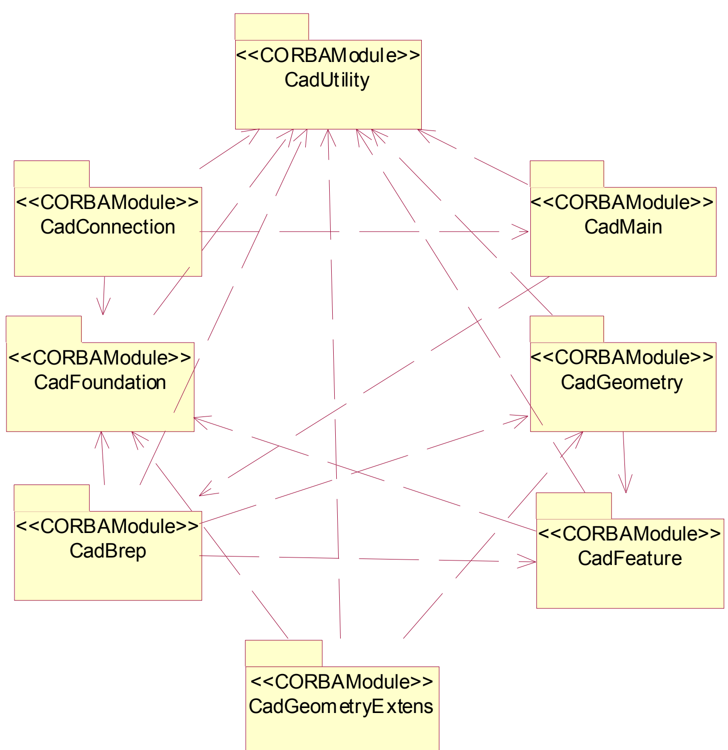
Features

- Geometry and topology queries for both manifold and non-manifold geometries
  - Tessellated representation and point queries
- Parametric regeneration of solid models
- Tagging geometric entities with application-specific information
- Geometry creation

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

CAD Services V 1.0 Modules



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

I.E. - Development Kit FY02 Accomplishments

Current Status

June 28, 2002 CAD Services Standard made "Available" By Object Management Group – highest level of standard

- **CAD Services commercial software available soon**
  - ITI TranscenData (available now- built on CADscript)
  - Unigraphics (available next year)
  - Catia (?)
- **Open Source Implementation**
  - OpenCASCADE (http://www.opencascade.org/3dwb/cadservices)
    - (beta available now – email: m-kazakov@opencascade.com)
    - Full commercial version early next year
- **Future Efforts:**
  - Solid Modeling RFP to be released Oct. 2002

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Information Environments – Milestones FY03-FY05

	Develop data translation and system solver objects supporting multi-component simulations.	Couple ANSYS, HPUMP3d using translation methods.	Sep-03	GRC
	Develop a Visual Assembly capability to allow the assembly, coupling of high fidelity codes for distributed systems.	AssembleANSYS, HPUMP3D into a simulation using Visual tool.	Sep-03	GRC
	Develop the object middleware to setup a simulation, start/stop servers, component codes, and simulation application	Start and stop a code such as CIAPP coupled with ANSYS, HPUMP3D	Sep-03	GRC
	Develop a grid aware application API definition for GCA	Deploy the Vulcan or Hah3D code on the Grid using the API	Sep-04	GRC
	Develop a web-enabled visual assembly capability for coupling codes over a distributed system.	Assemble Vulcan and Overflow into a simulation using Visual tool.	Jun-04	GRC
	Develop multiple cross-dimensional data translation methods to support multi-fidelity component models automated reasoning features, celestial networks.	Couple at least two aeropropulsion CFD codes (ie ANSYS, HAH3D, VULCAN) using translation methods.	Sep-04	GRC
	Extend Visual Assembly capabilities to include sensory interface	Assemble 3Dimensional CFD (ie Vulcan and Overflow) into a simulation using Visual tool.	Sep-05	GRC
	Develop the infrastructure allowing a mixed Dimensional, Aero/Thermal/Structural CFD Propulsion System Simulation incorporating wireless sensor input deployed over a Celestial/Terrestrial Information Power Grid (IPG).	Deploy a simulation using mixed fidelity CFD (ie CIAPP, ANSYS, and Vulcan) over the IPG.	Sep-05	GRC

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Summary & Takeaways

- Information Environment (IE) focus is on Coupling, Zooming, Wrapping and, in general, the building of the CORBA Development Kit for Grand Challenge Applications over the Information Power Grid.
- FY'02 has been a transition year that has begun to move away from the 0-Dimensional focus toward the object middleware to deploy higher fidelity simulations securely over the Information Power Grid.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

NPSS with Nested Solvers for Zooming

Steve Sirica
Pratt & Whitney

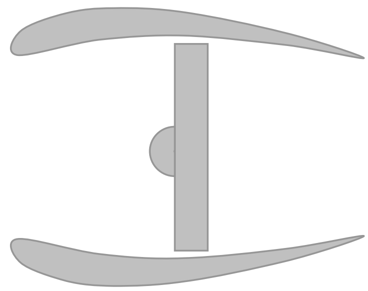
Application of Nested Solver to Modeling

- Initial Usage of Nested Solver
  - Free Stream / Inlet Continuity
  - Multiple Engine Sizing / Rating Scheme
    - Design and Off-Design
      - Cruise (Aero Design Point), Takeoff (Mechanical Limits)
  - Engine Test / Data Reduction
- High Fidelity Engine Simulations
  - 0-D, 1-D, 2-D, 3-D, and Response Surfaces
    - Steady State and Transient Operation
- Design Optimization
  - Hierarchal Approach
    - Thermodynamic, Aerodynamic, Mechanical, Structural, Manufacturing
    - Local and Global Optimization Schemes

2002 CISO Review

Free Stream / Inlet Continuity

- Define Localized Solver Associated with Flight Conditions Module
  - Control via Solver Sequencing
- Independent Variables
  - Pressure Altitude
  - Δ Ambient Temperature
  - Flight Mach Number
- Dependent Variables
  - Ambient Pressure
  - Ambient Temperature
  - True Air Speed
  - Calibrated Air Speed
  - Engine Inlet Pressure
  - Engine Inlet Temperature
- Enables Definition of Flight Module with one set of Calculations



Pressure Altitude
(Std Temperature)
Δ Amb Temperature

Ambient Pressure
Ambient Temperature

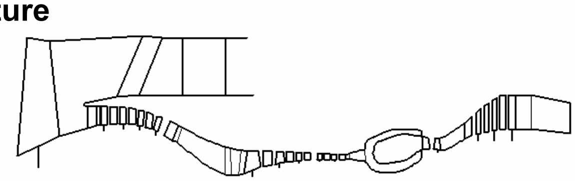
Flight Mach Number

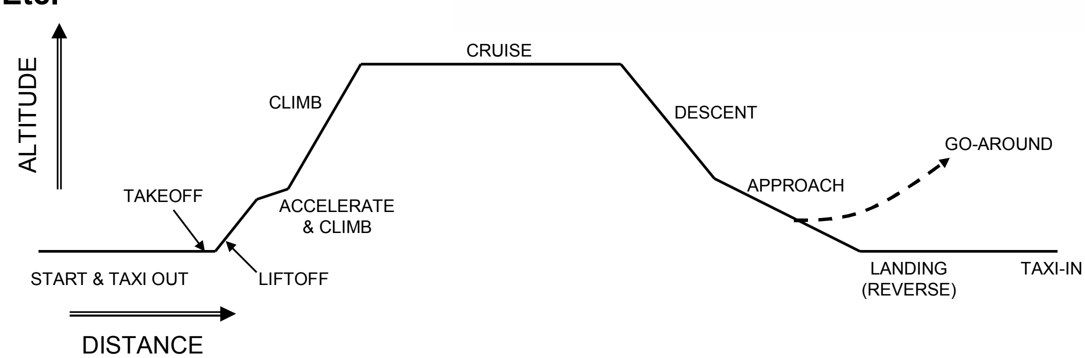
True Air Speed
Calibrated Air Speed
Engine Inlet Pressure
Engine Inlet Temperature

2002 CISO Review

Multiple Engine Sizing / Rating Scheme

- Design Point at Typical Cruise Rating
- Run Off-Design Takeoff, Climb…
- Use Nested Solver to Satisfy Constraints (Modify Design Point)
  - Takeoff Compressor Exit Temperature
  - Takeoff HP Turbine AN^2
  - Size Fan at Top of Climb
  - Etc.

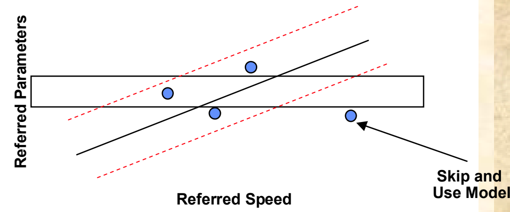




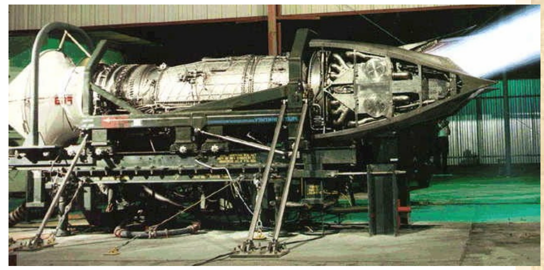
2002 CISO Review

Engine Test / Data Reduction

- **Normal Match on Core Speed and Input Ambient Conditions (Temperature, Pressure, Humidity…)**
- **Up-front Profiling and Averaging**



Data Reduction Matrix	
Independent Variable	**Dependent Variable**
Fan Airflow Scalar	Measured Inlet Static Pressure
Fan Efficiency Scalar	Measured Fan Exit Temperature
CD Bypass Nozzle	Measured Fan Exit Pressure
LPC Efficiency Scalar	Measured LPC Exit Temperature
HPC Speed Scalar	Measured LPC Exit Pressure
HPC Efficiency Scalar	Measured HPC Exit Temperature
HPT Airflow Scalar	Measured HPC Exit Pressure
LPT Airflow Scalar	Measured Thrust
CD Core Nozzle	Measured Low Spool Speed
LPT Efficiency Scalar	Measured Fuel Flow
Overboard Leak	HP Turbine Flow Capacity
LPC Airflow Scalar	Measured LPT Exit Pressure



- **Screening of Data Used in Selection of Matrix Variables**
- **Nested Solver Option Provides Additional System Stability**

2002 CISO Review

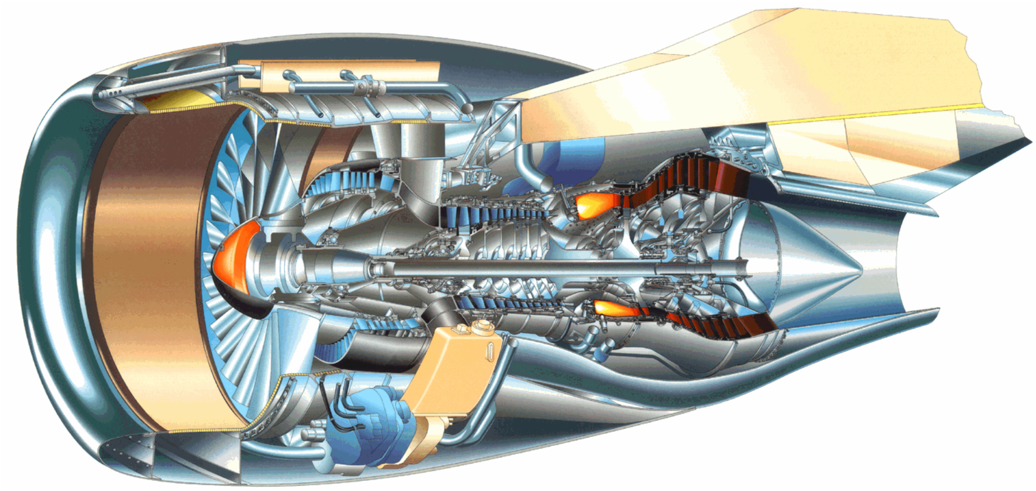
Application of Nested Solver to Modeling

- Initial Usage of Nested Solver
  - Free Stream / Inlet Continuity
  - Multiple Engine Sizing / Rating Scheme
    - Design and Off-Design
      - Cruise (Aero Design Point), Takeoff (Mechanical Limits)
  - Engine Test / Data Reduction
- **High Fidelity Engine Simulations**
  - **0-D, 1-D, 2-D, 3-D, and Response Surfaces**
    - **Steady State and Transient Operation**
- Design Optimization
  - Hierarchal Approach
    - Thermodynamic, Aerodynamic, Mechanical, Structural, Manufacturing
    - Local and Global Optimization Schemes

2002 CISO Review

High Fidelity Engine Simulations

A Modeling System that Ties Aero and Systems Codes with Steady State and Transient Performance Models for the Purpose of Integrating Design and Analysis Of Propulsion Systems and their Components

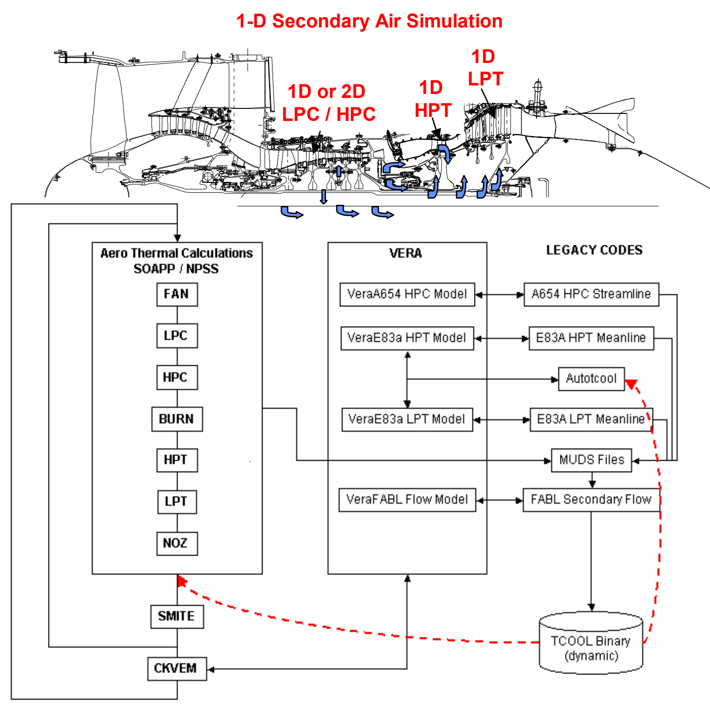


System Model / Control
NPSS

2002 CISO Review

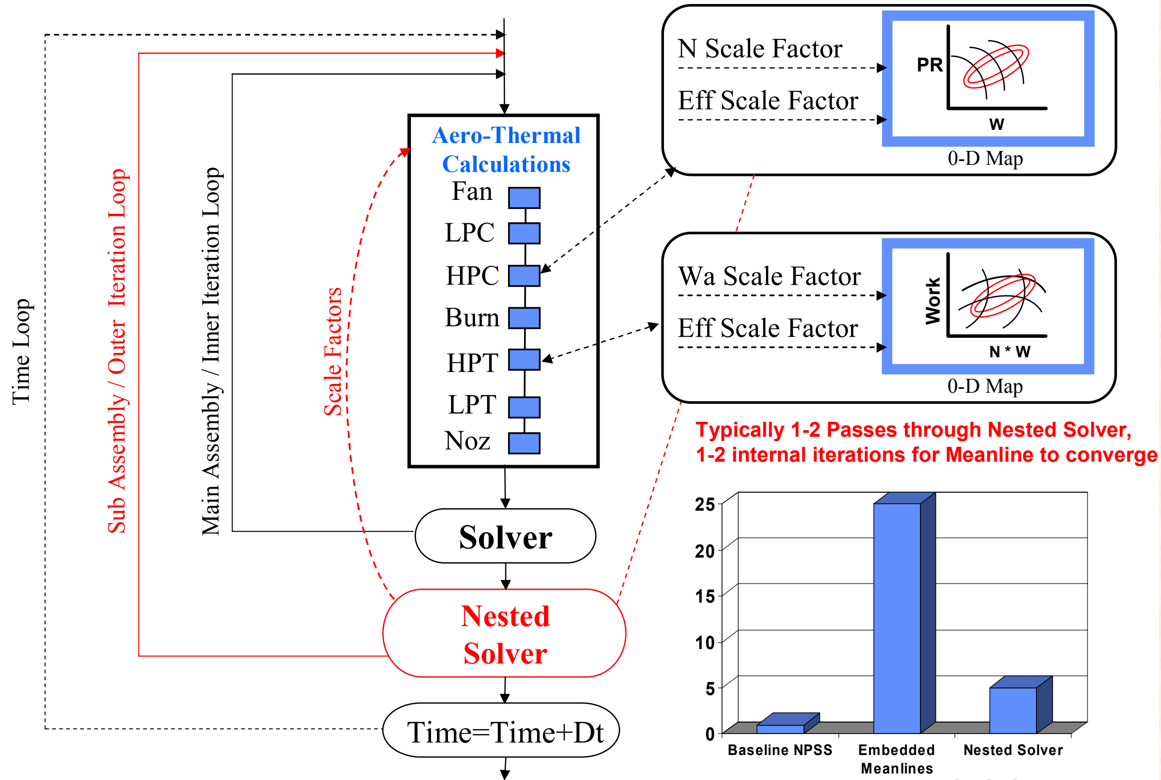
Current Focus has been Off-Design

- **Improved Engine System Model Fidelity**
- **1-D & 2-D Aero and Secondary Systems Models**
- **Engine Performance and Stall Margin Prediction Tools**
    - **Steady State and Transient**
- **Improved Sensitivities for Incorporation Into Follow-on Analysis**



2002 CISO Review

Nested Solver Moves Time Consuming Meanline Runs to "Outer Loop" Resulting in Better Efficiency / Robustness

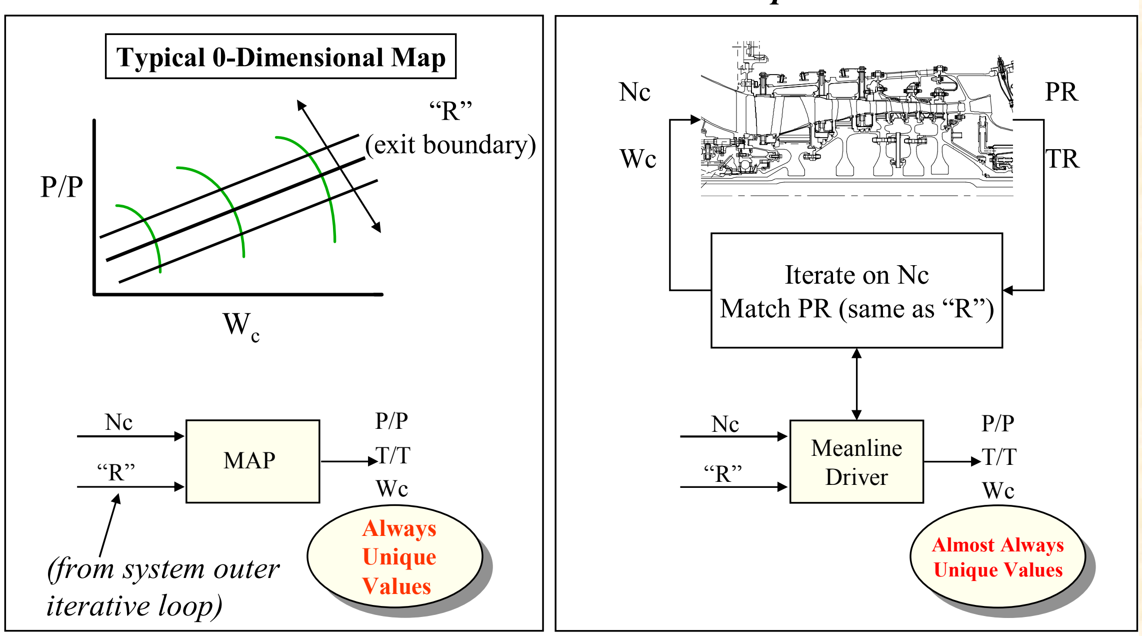


2002 CISO Review

Method to Zoom to 1-D Meanline

Physics Constrains 1-D Meanline Model to Speed / Flow Domain

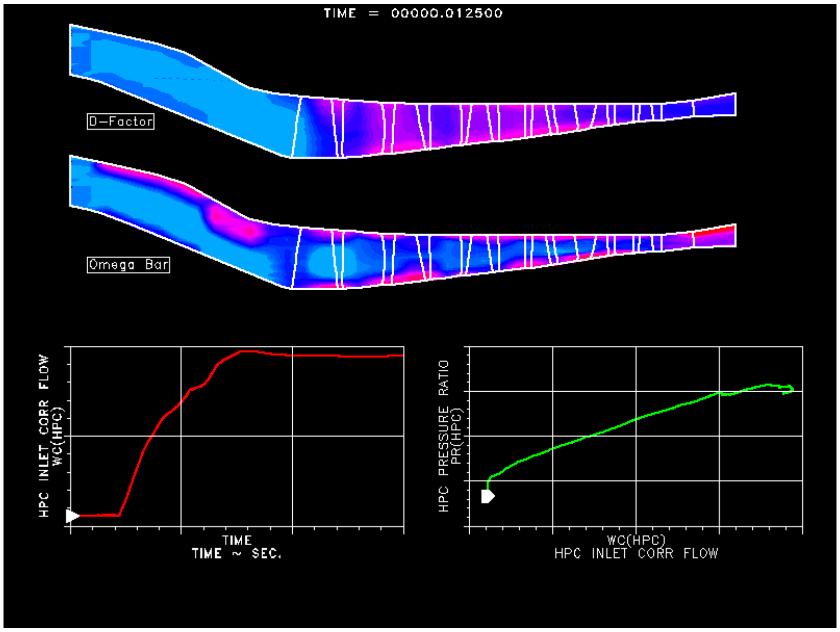
Trick is to make the meanline look like a map to Simulation



2002 CISO Review

2-D Visualization Example

2-D Problem Statement is becoming one of what to do with the data (how to turn it into useful information)



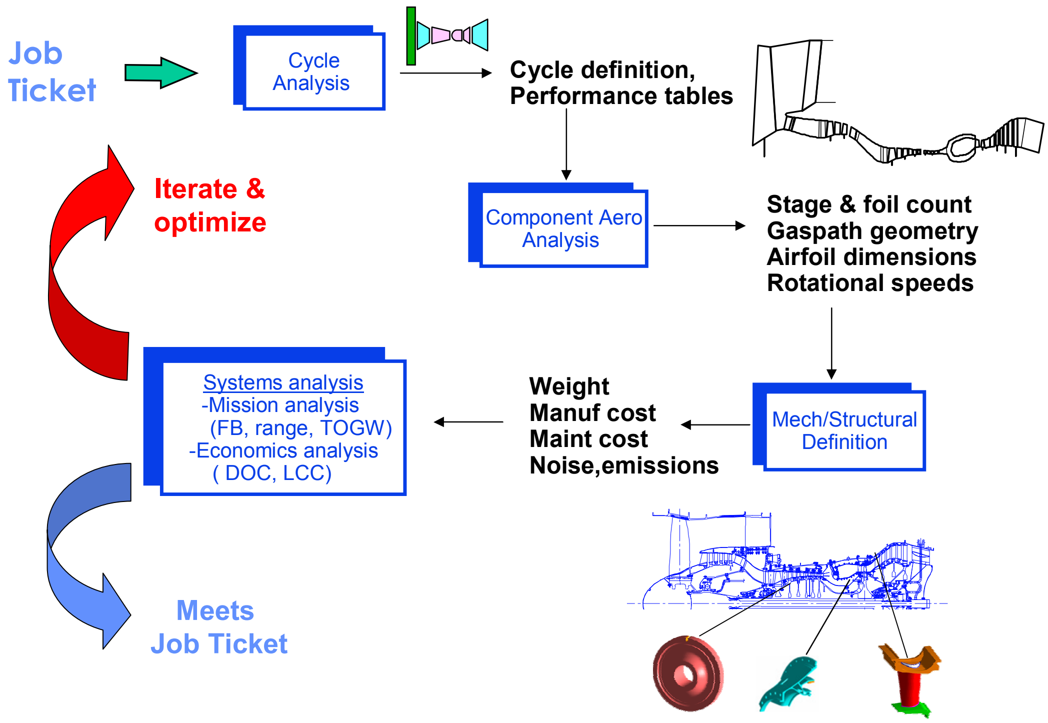
2002 CISO Review

Application of Nested Solver to Modeling

- Initial Usage of Nested Solver
  - Free Stream / Inlet Continuity
  - Multiple Engine Sizing / Rating Scheme
    - Design and Off-Design
      - Cruise (Aero Design Point), Takeoff (Mechanical Limits)
  - Engine Test / Data Reduction
- High Fidelity Engine Simulations
  - 0-D, 1-D, 2-D, 3-D, and Response Surfaces
    - Steady State and Transient Operation
- **Design Optimization**
  - **Hierarchal Approach**
    - **Thermodynamic, Aerodynamic, Mechanical, Structural, Manufacturing**
    - **Local and Global Optimization Schemes**

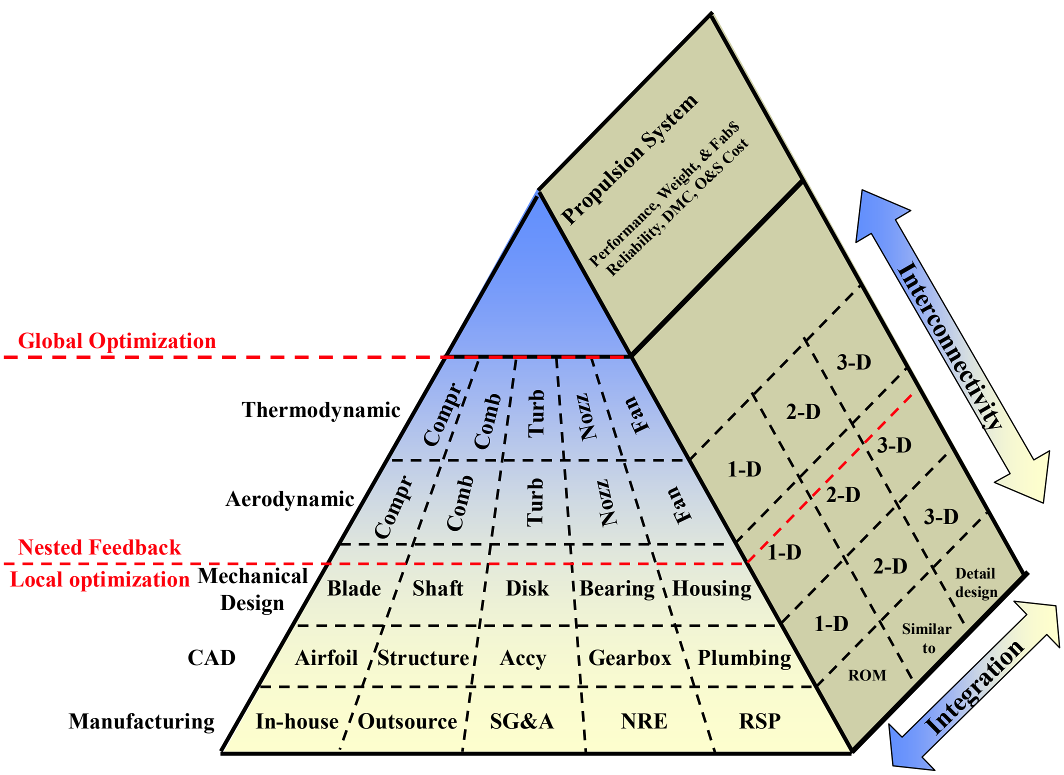
2002 CISO Review

Design Optimization / Preliminary Engine Design



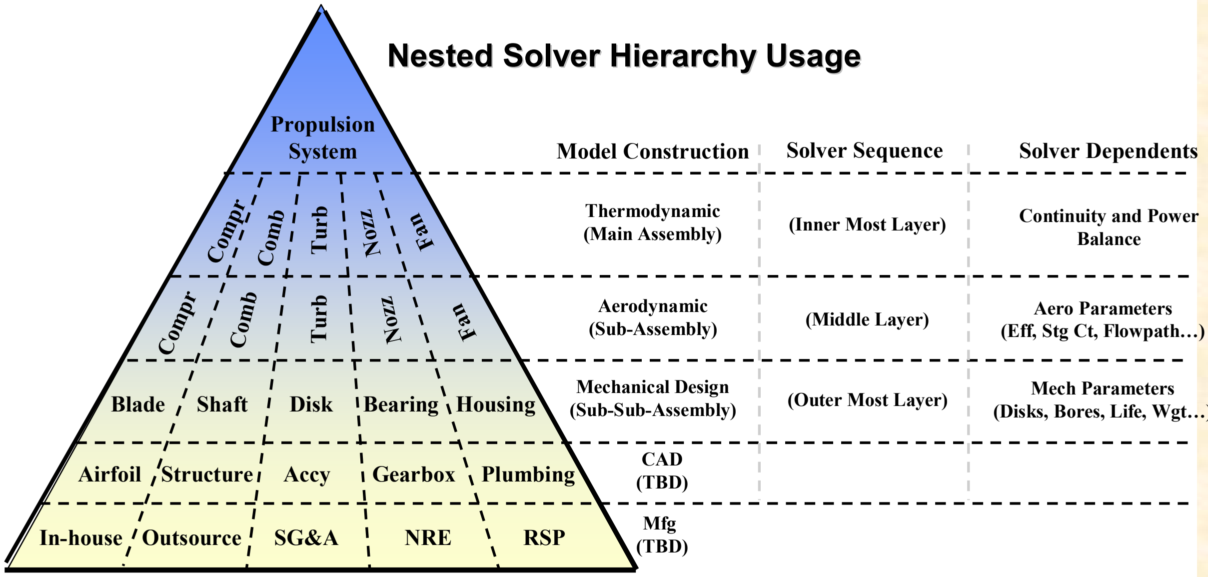
2002 CISO Review

Hierarchal Design Optimization Approach

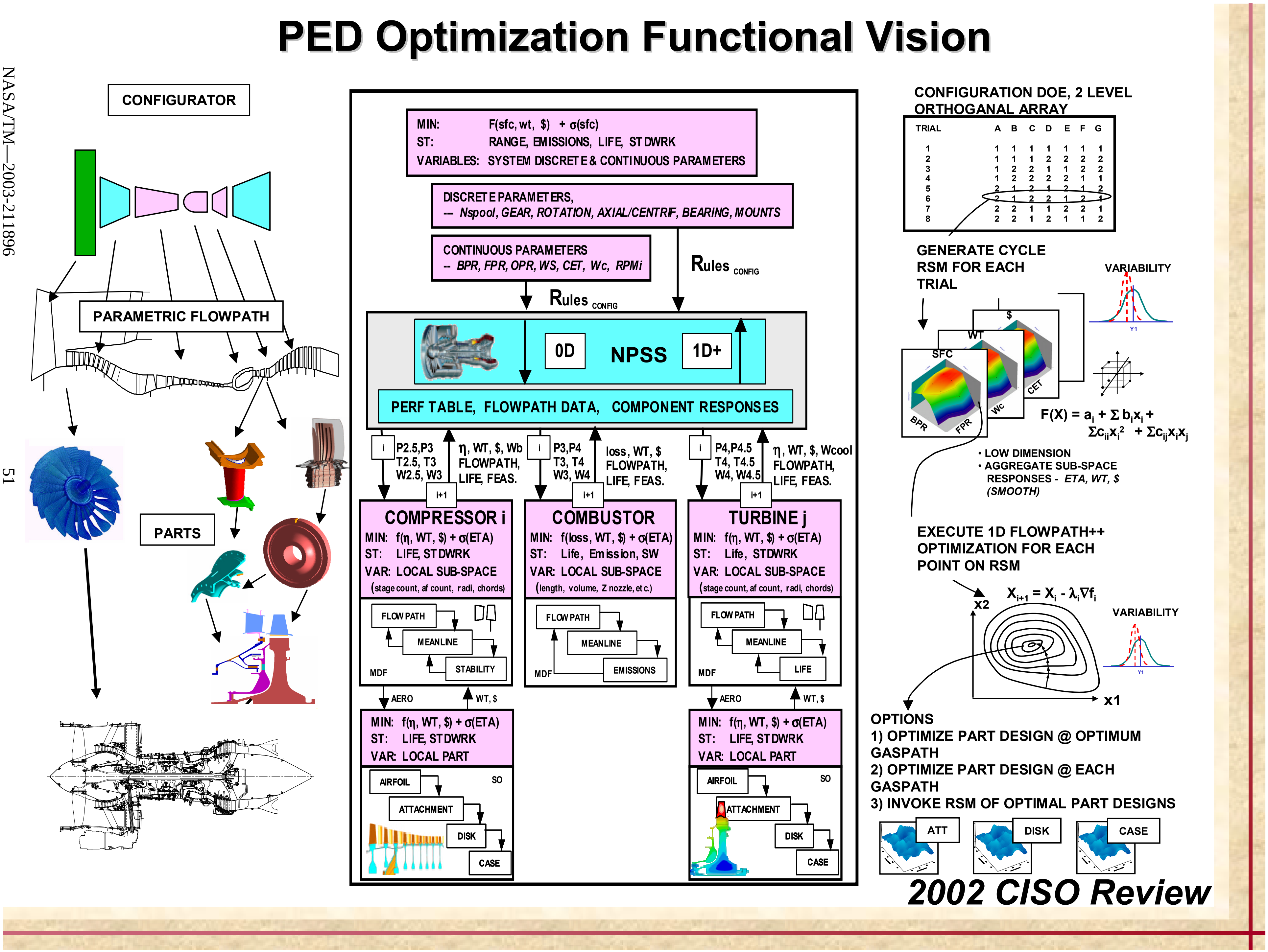


2002 CISO Review

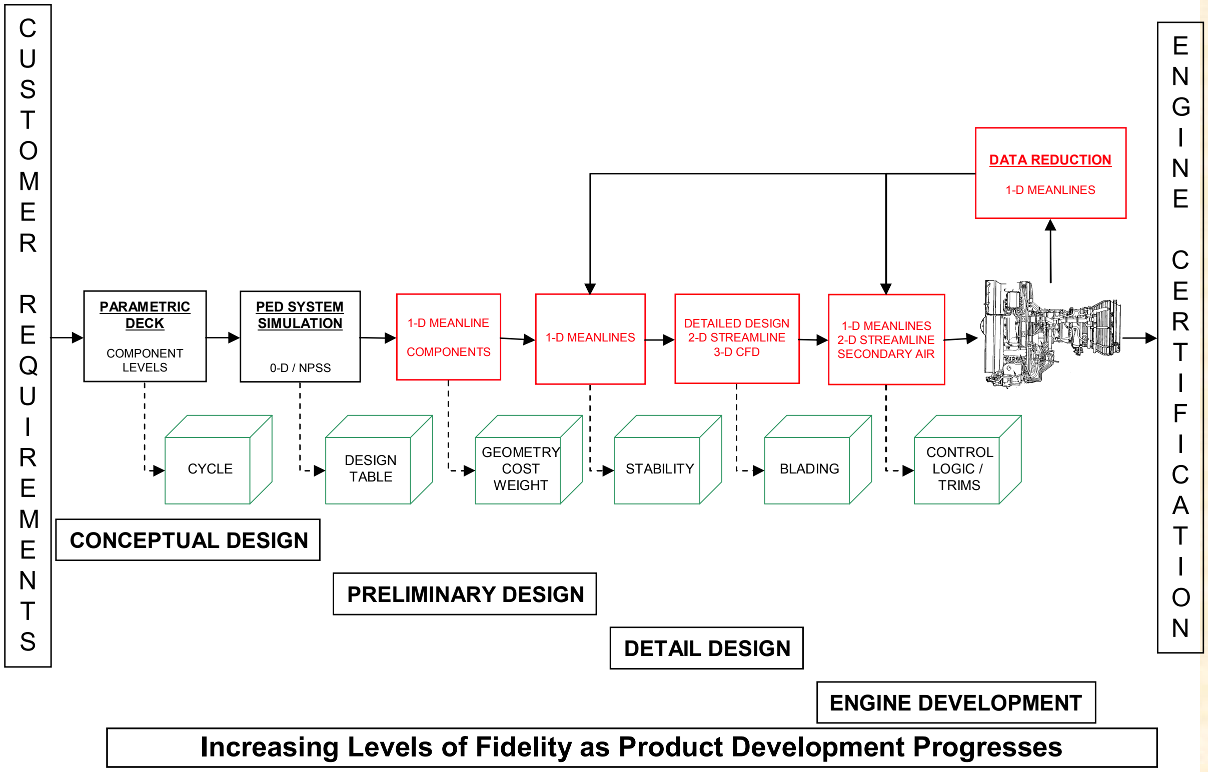
Nested Solver Hierarchy Usage



2002 CISO Review


PED Optimization Functional Vision
CONFIGURATOR
PARAMETRIC FLOWPATH
PARTS
MIN: F(sfc, wt, $) + σ(sfc)
ST: RANGE, EMISSIONS, LIFE, STDWRK
VARIABLES: SYSTEM DISCRETE & CONTINUOUS PARAMETERS
DISCRETE PARAMETERS,
-- Nspool, GEAR, ROTATION, AXIAL/CENTRIF, BEARING, MOUNTS
CONTINUOUS PARAMETERS
-- BPR, FPR, OPR, WS, CET, Wc, RPMi
Rules CONFIG
Rules CONFIG
0D
NPSS
1D+
PERF TABLE, FLOWPATH DATA, COMPONENT RESPONSES
i
P2.5,P3
T2.5, T3
W2.5, W3
η, WT, $, Wb
FLOWPATH,
LIFE, FEAS.
i+1
i
P3,P4
T3, T4
W3, W4
loss, WT, $
FLOWPATH,
LIFE, FEAS.
i+1
i
P4,P4.5
T4, T4.5
W4, W4.5
η, WT, $, Wcool
FLOWPATH,
LIFE, FEAS.
i+1
COMPRESSOR i
MIN: f(η, WT, $) + σ(ETA)
ST: LIFE, STDWRK
VAR: LOCAL SUB-SPACE
(stage count, af count, radi, chords)
FLOWPATH
MEANLINE
STABILITY
MDF
COMBUSTOR
MIN: f(loss, WT, $) + σ(ETA)
ST: Life, Emission, SW
VAR: LOCAL SUB-SPACE
(length, volume, Z nozzle, etc.)
FLOWPATH
MEANLINE
EMISSIONS
MDF
TURBINE j
MIN: f(η, WT, $) + σ(ETA)
ST: Life, STDWRK
VAR: LOCAL SUB-SPACE
(stage count, af count, radi, chords)
FLOWPATH
MEANLINE
LIFE
MDF
AERO
WT, $
MIN: f(η, WT, $) + σ(ETA)
ST: LIFE, STDWRK
VAR: LOCAL PART
AIRFOIL
ATTACHMENT
DISK
CASE
SO
AERO
WT, $
MIN: f(η, WT, $) + σ(ETA)
ST: LIFE, STDWRK
VAR: LOCAL PART
AIRFOIL
ATTACHMENT
DISK
CASE
SO
CONFIGURATION DOE, 2 LEVEL
ORTHOGANAL ARRAY
TRIAL A B C D E F G
1 1 1 1 1 1 1 1
2 1 1 1 2 2 2 2
3 1 2 2 1 1 2 2
4 1 2 2 2 2 1 1
5 2 1 2 1 2 1 2
6 2 1 2 2 1 2 1
7 2 2 1 1 2 2 1
8 2 2 1 2 1 1 2
GENERATE CYCLE
RSM FOR EACH
TRIAL
VARIABILITY
SFC
WT
$
BPR
FPR
Wc
CET
$F(X) = a_i + \Sigma b_i x_i + \Sigma c_{ii} x_i^2 + \Sigma c_{ij} x_i x_j$
• LOW DIMENSION
• AGGREGATE SUB-SPACE
RESPONSES - ETA, WT, $
(SMOOTH)
EXECUTE 1D FLOWPATH++
OPTIMIZATION FOR EACH
POINT ON RSM
$X_{i+1} = X_i - \lambda_i \nabla f_i$
x2
x1
VARIABILITY
OPTIONS
1) OPTIMIZE PART DESIGN @ OPTIMUM GASPATH
2) OPTIMIZE PART DESIGN @ EACH GASPATH
3) INVOKE RSM OF OPTIMAL PART DESIGNS
ATT
DISK
CASE
2002 CISO Review

Zooming in the Design / Development Process



2002 CISO Review

Closing Remarks

- **NPSS Design Provides System Flexibility**
  - Nested Solver Implementation / Usage
- **Usage is Expanding Beyond Original Design Intent**
  - Inner / Outer Loops
- **Potential Follow On Work**
  - Nested Solver Execution in Transient Mode
  - Use of Inner Sub Assembly as Outer Solver
  - Local Optimization vs. Nested Solver Approach
  - Integration of Response Surfaces in place of Higher Fidelity Codes
  - Develop High Fidelity Plug In Modules for NPSS
  - Ability to DLM Assemblies (potential speed issue?)

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting

October 9-10, 2002

Zooming from NPSS Cycle to Intermediate and High Fidelity

Ron Plybon
GE Aircraft Engines

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Outline

- Goals
- Approach
- Plan
- Intermediate Fidelity Component Modeling
- Geometry Morphing
- Demonstration

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

UEET High Fidelity System Simulation - Goals

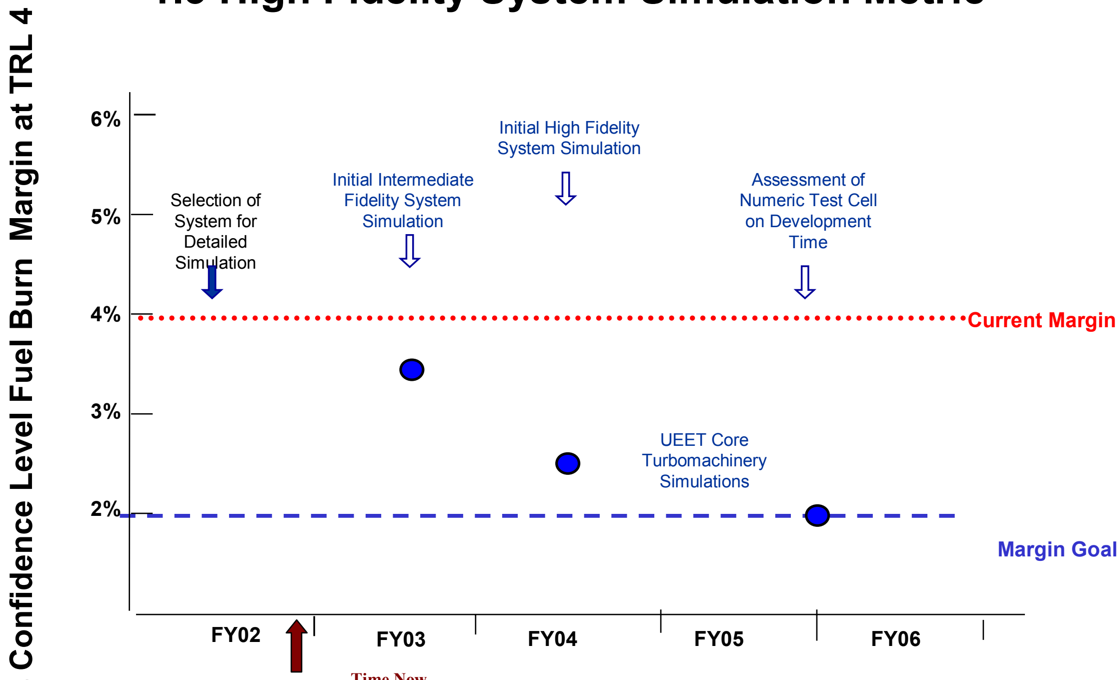
- **Leverage NPSS, UEET and Other Engine Technology Efforts to Develop a High Fidelity Simulation Capability That Supports the UEET Vision and Goals**
  - **Reduce Engine Development Time Through High Fidelity System Analysis at Early TRL**
  - **Address System Issues While Configuration Changes Are Still Possible**
  - **Achieve TRL 6 System Uncertainty at TRL 4**

- **Reduce Uncertainty in System Performance From Integration of UEET Component Technologies**
  - **Improved System Performance By Optimizing Configuration and System Design With Reduced Uncertainty on Component Performance and System Constraints.**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

1.3 High Fidelity System Simulation Metric



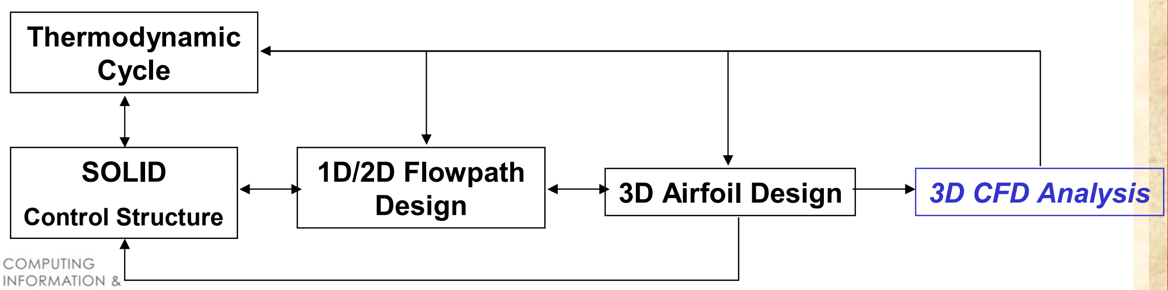
Goal – TRL 6 Confidence at TRL 4 in Key Areas

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

UEET High Fidelity System Simulation - Approach

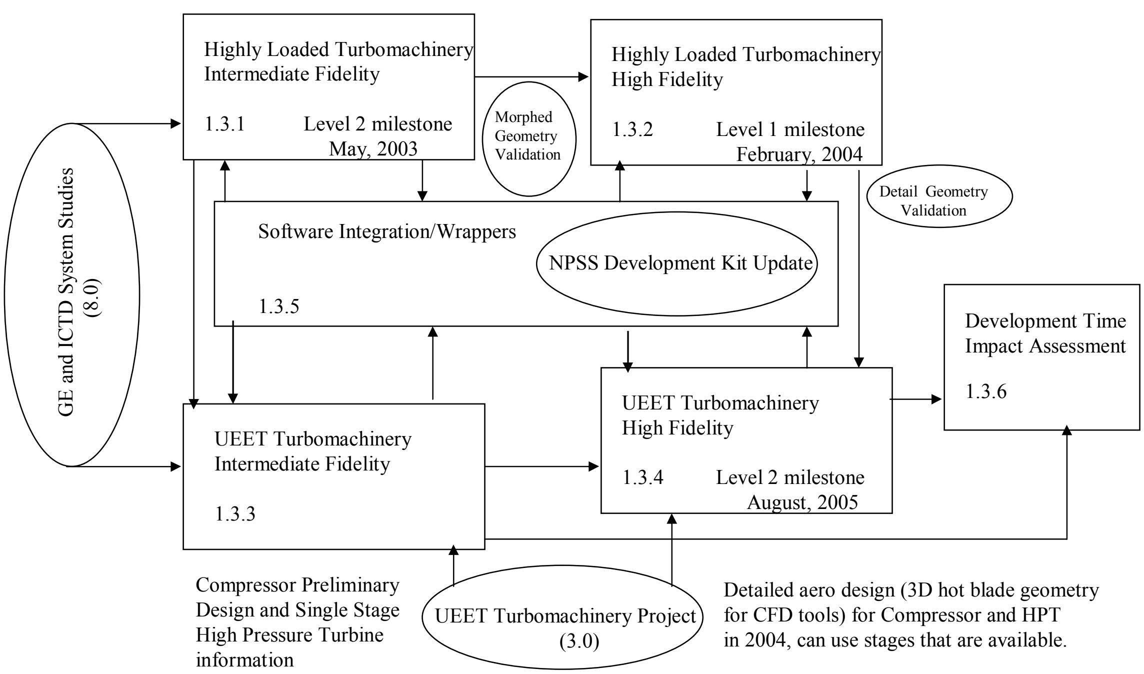
- **Develop and Validate Intermediate Fidelity NPSS Model Using Current Highly Loaded Turbo-machinery (HLTM)**
- **Apply Model Where Morphed Geometry is Adequate for Validation.**
- **Extend High Fidelity NPSS Model by Overlaying Detail Geometry to Validate CFD Against HLTM Data**
- **Apply Validated Approach to UEET for PD Geometry and for Detailed Geometry to Address Key UEET Issues.**



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

High Fidelity System Simulation Logic



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Deliverable Schedule

- 3D Mechanical Aerodynamic and Thermal Design – 5/15/03
  - HLTM System Simulation at Intermediate Fidelity with Morphed Geometry and Linked Analysis.
  - Validation of HLTM Overlay of Detail Geometry on Morphed Airfoils at a Component Level.
- Initial High Fidelity System Simulation – 2/27/04
  - HLTM System Simulation Validation with Overlay of Detail Geometry.
  - Mechanical/Thermal/Cooling Applied to UEET Morphed Geometry
- Assessment of Numeric Test Cell on Development Time – 8/30/05
  - UEET Detail Geometry Design Overlay to Demonstrate Impact on Development Time for UEET.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

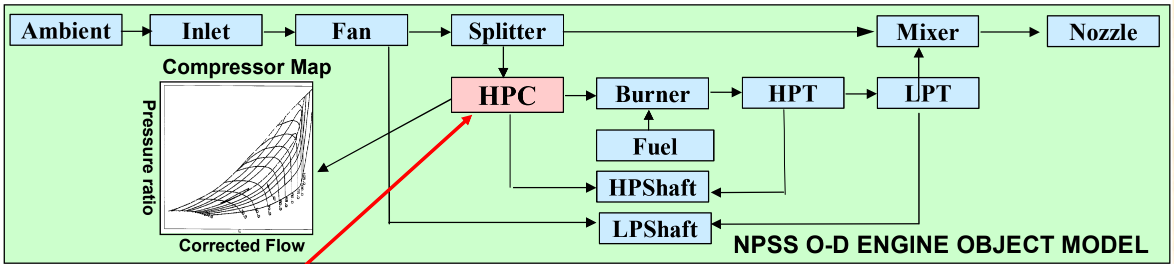
Current Activity

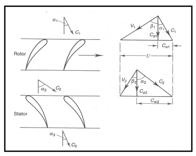
- Initial High Fidelity Model Development
  - Key Technology Barriers/Issues for CFD Based Off-Design System Simulation Identified.
  - Process Defined for Detail Geometry Integration with Morphed Flowpath for CFD .
- Intermediate Fidelity Model Development for HLTM
  - Geometry Morphing for non-CFD Aero Analysis and Mechanical Analysis.
  - NPSS Integration of Intermediate Fidelity Tools for Automated Zooming and Integration with Base NPSS Model.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Blade Row Model (BRM) Dynamic Linked Module (DLM)





BRM DLM

1D Pitchline Blade-Row Analysis

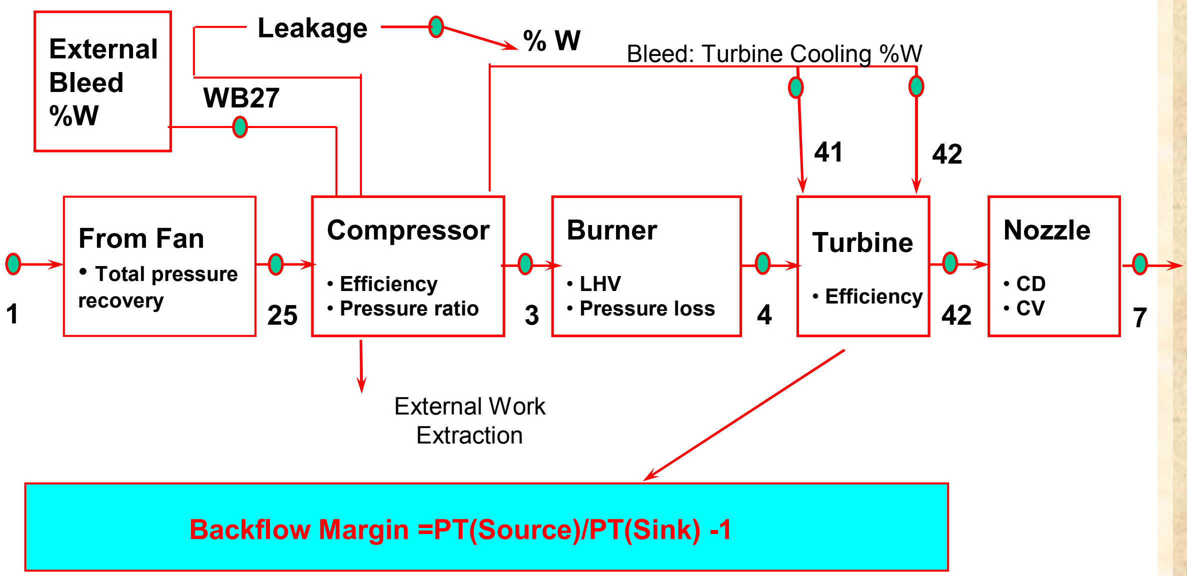
Power, Total Temperature, Total Pressure, Fuel-Air Ratio, VSV effects, Bleed effects, clearance effects, Wall static pressure, Blade forces

- ***Compile the modified zooming code and the class into object codes and link them into a DLM element***
- ***Add the DLM element into the*** *postexecute()* ***function of the compressor element of the cycle model***
- ***Replace the compressor map predicted values with the BRM predicted values and iteratively converge the cycle model using the Map or BRM at User Selection.***
- ***Calculate interstage data such as pressures, temperatures, D-factors, blockages, loss coefficients, etc as a post-processing step***
- ***Includes Design Point Performance Prediction module***

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Intermediate Fidelity Cooling Flow Estimates

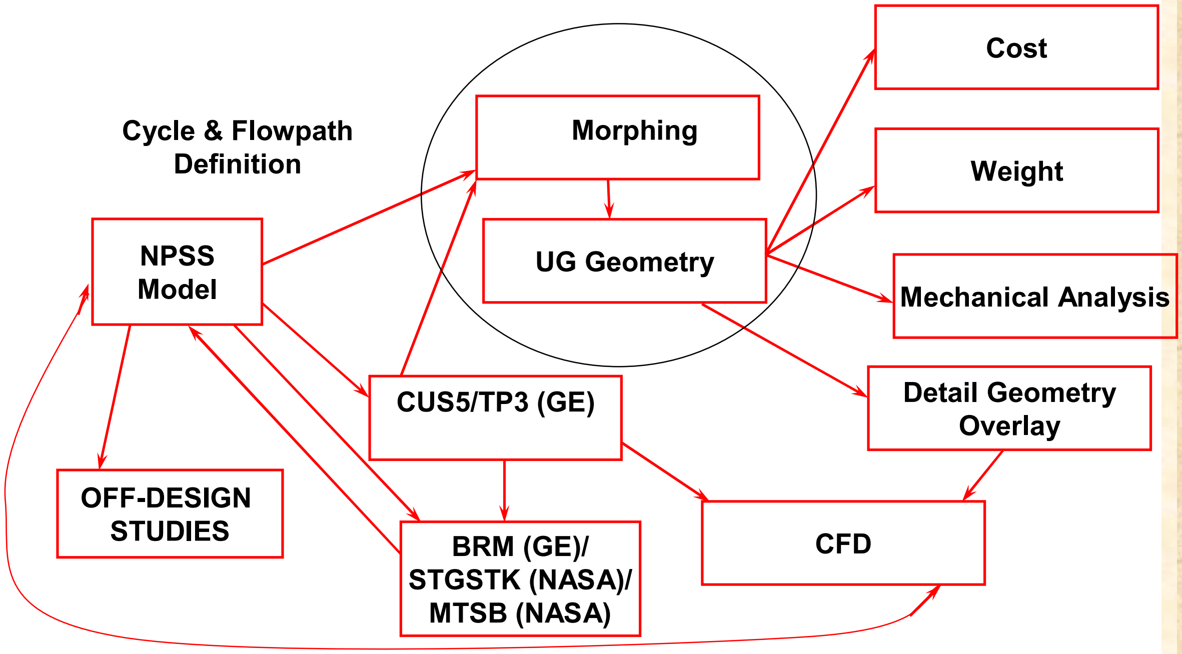


Initial Cooling Assessment Over Envelope with Intermediate Fidelity Tools. Common Interface for GLENN-HT Assessment with High Fidelity Tools.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

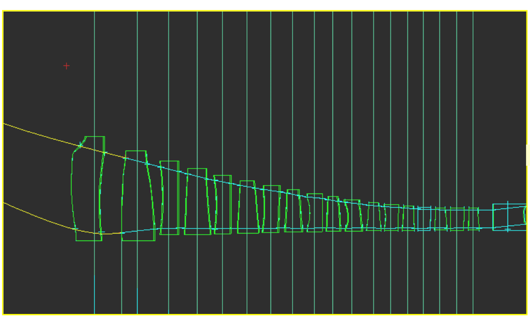
Next Steps – Automated Geometry



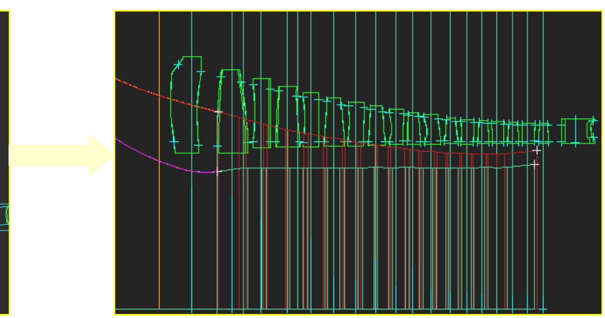
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Updating Flowpath Geometry



Original Geometry



Initial Flowpath Change

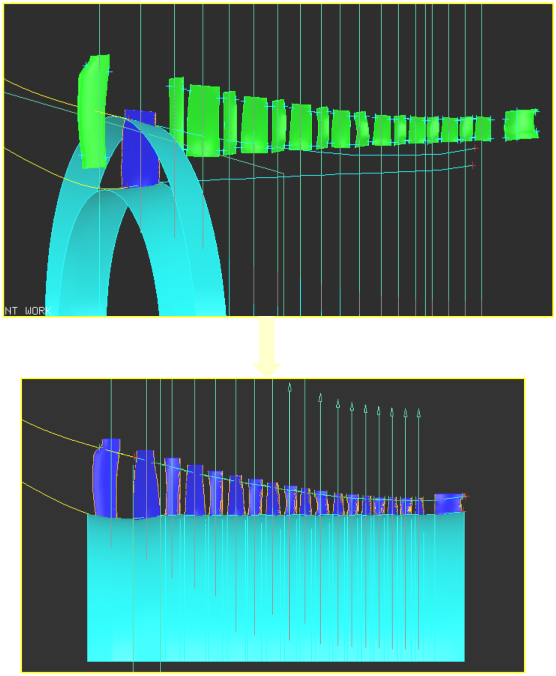
- ***Engine Part File - Interface Points***
- ***Aero Part File – New Flowpath curve***

Morphed 3D Airfoil = Library 3D Airfoil + Delta_Flowpath

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Airfoil Reparenting / Swapping

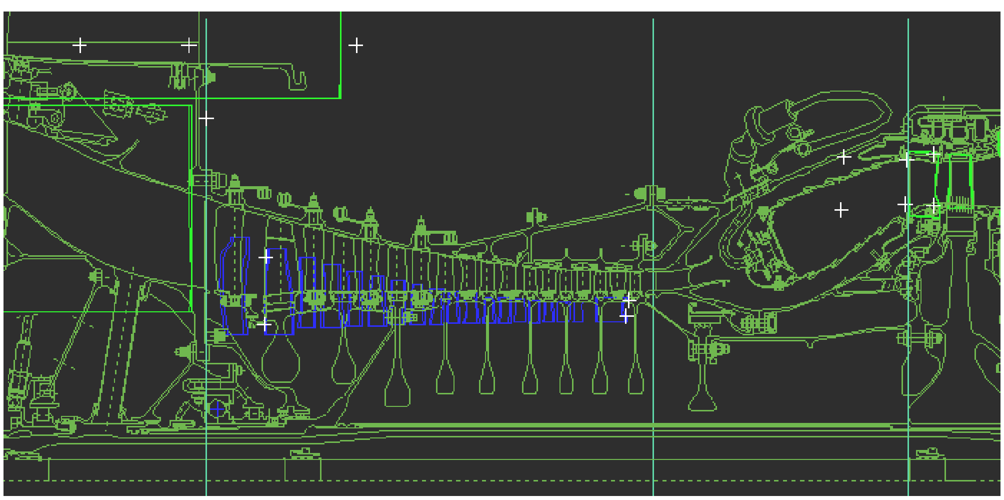


- ***Create new untrimmed airfoils from GDS data in Aero part file***
- ***Need for Reparenting***
  - ***WAVE Linked Geometry Structure***
  - ***Inserting new elements would destroy the links and tagging for automated analysis***
  - ***Retain/Update Linked structure***
- ***Process can be used to swap Detailed Airfoils***

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

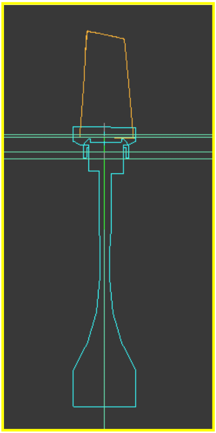
Updated Engine with New Airfoils



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Updating Disk Geometry



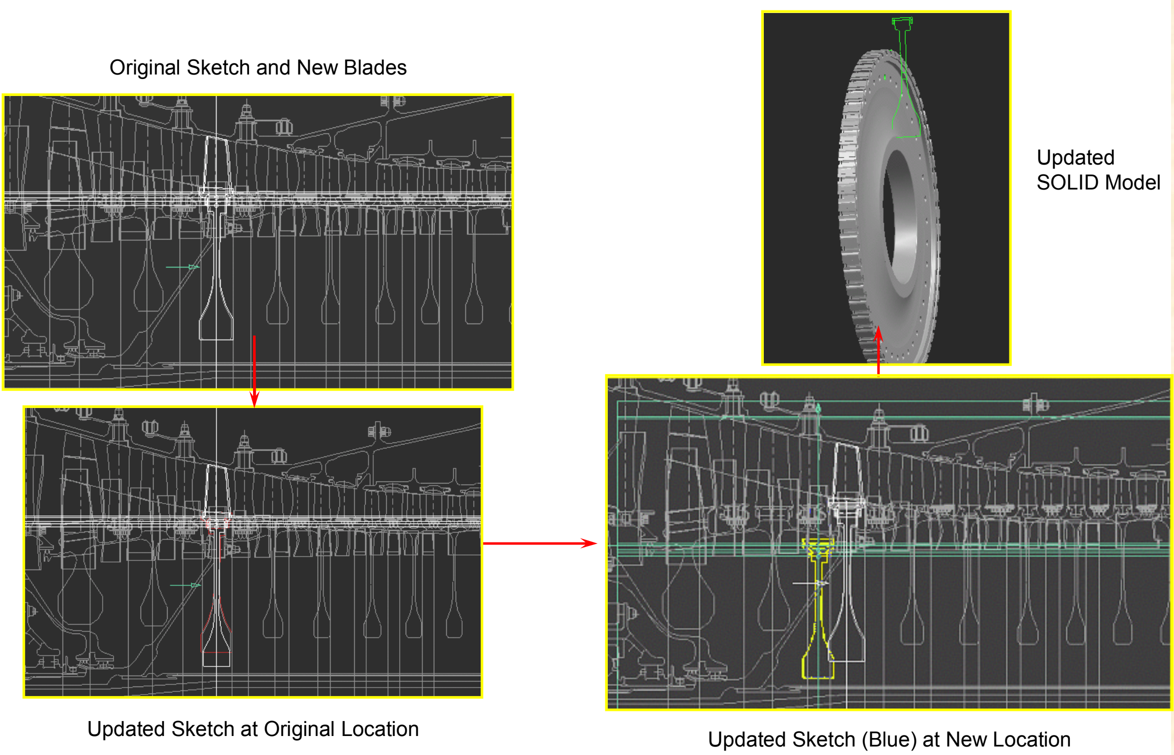
- ***Disk ReLocation***
  - ***Centroid of Trimmed Airfoil***
- ***Disk Resizing***
  - ***Mass of Trimmed Airfoils***
  - ***RPM from Engine Part file***
  - ***Shape and Mechanical Stress Update from Calculations in Spreadsheet***
  - ***Linked Analysis With Persistent Tags for Detailed Studies***

Time Reduced from Days/Weeks to Minutes/Hours
- Reduced Errors -Repeatable Process - Reusable Work
- Build on Experience and Capture Lessons Learned.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Disk Resizing and Relocation



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Integration of Geometry with NPSS

- **_Common Interface for Multiple Modes_**
  - *Interpreted Component*
    - ***Limited Integration Options - No Interface to Part Libraries (GDS) or Geometry, Limited Input/Output Control***
  - *DLM Component*
    - ***Adds direct communication with Part Data Libraries (GDS) and UG. Can can be made seamless to user with properties file.***
  - *CORBA Mode*
    - ***Most Capability and Flexibility. DLM capability without direct linkage.***

•Geometry Interface Objects

•GDSINSTANCE DLM

•Query GDS Data

•COMPMORPH DLM

• Invokes Compressor Morphing

•UGOBJECT DLM

•Loadpart

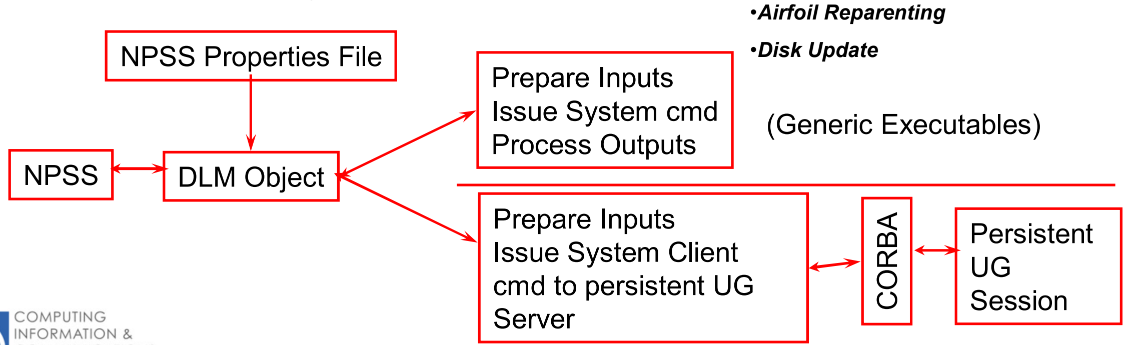
•Savepart

•Closepart

•GDS—SOLID Expression Update

•Airfoil Reparenting

•Disk Update

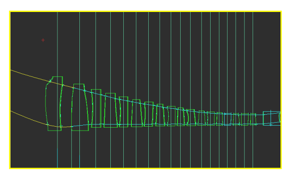


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

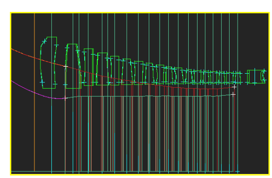
2002 CISO Review

NPSS-UG Movie

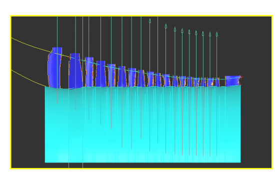
Load Base Geometry (UGOBJECT)
- Bring Up Geometry in Persistent UG Session



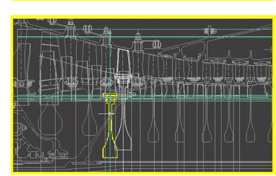
Morph Geometry (COMPMORPH)
- Revise Flowpath



Reparent Airfoil Geometry (UGOBJECT/GDSINSTANCE)
- Update Airfoil Solid Models

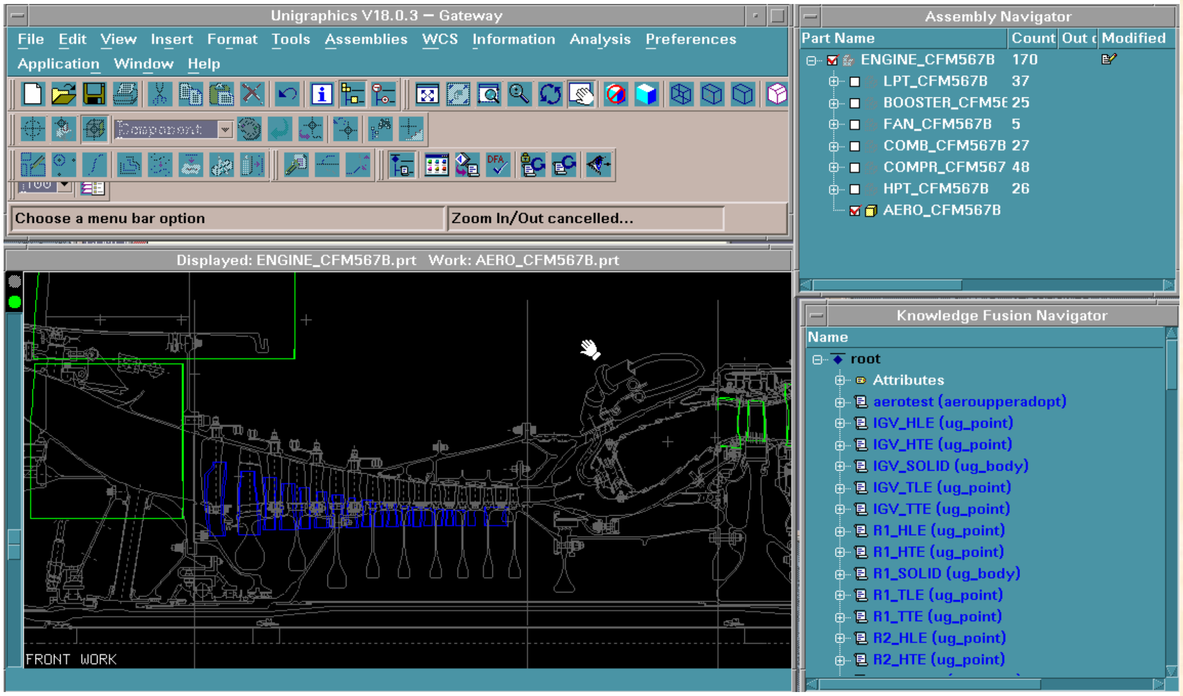


Update Sketches (UGOBJECT)
- Disk Update



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review



Summary

- NPSS Based Zooming for Aero, Geometry and Multi-Disciplinary System Analysis.
- Initial Validation on Existing Highly Loaded Turbo-Machinery (HLTM) with Future Application to UEET.
- High Fidelity Component Modeling Efforts Started.
- Intermediate Fidelity System Modeling and Geometry Efforts Well Underway.

Higher Fidelity System Analysis for Engine Programs at TRL 4

- **Reduce Program Risk and Uncertainty**
- **Find & Address Issues When the Cost of Change is Low**

Incorporation of Electrical Systems Models into an Existing Thermodynamic Cycle Code

Josh Freeh

Aeropropulsion Systems Analysis Office

NASA Glenn Research Center

October 9, 2002

Extracted from SAE Power Systems 2002 Conference Presentation

AEROSPACE

2002 CISO Review

Overview

- **Background**
  - **NPSS – the existing thermodynamic code**
  - **NASA electrical systems modeling**
- **Incorporation of electrical systems models into NPSS**
- **Basic inputs and outputs**
- **Sample results**
- **Limitations of the codes**
- **Future plans and possible analyses**
- **References**
- **Contact information**

AEROSPACE

2002-01-3257

2002 CISO Review

NASA Electrical Systems Modeling

High-altitude, long-endurance aircraft power and propulsion

- Colozza, Anthony J., *Effect of power system technology and mission requirements on high altitude long endurance aircraft*, NASA CR-194455
- An analysis that determined how various power system components and mission requirements affect the sizing of a solar and regenerative fuel cell-powered long endurance aircraft

Planetary science aircraft power and propulsion

- Colozza, Anthony J., Miller, Christopher J., Reed, Brian D., Kohout, Lisa L., and Loyselle, Patricia L., *Overview of Propulsion Systems for a Mars Aircraft*, NASA TM-2001-210575
- An exploration of Mars aircraft propulsion systems with an emphasis on the constraints of the Martian atmosphere

High-altitude stationkeeping airship power and propulsion

- Ongoing studies addressing different missions and concepts including earth science, communications, and surveillance

SAE AEROSPACE

2002-01-3257

2002 CISO Review

NASA Electrical Systems Modeling

Flywheel electrical power storage

- Truong, Long V.,Wolff, Frederick J., and Dravid, Narayan V., *Simulation of a Flywheel Electrical System for Aerospace Applications*, NASA TM-2000-210242
- A flywheel electrical system model was developed as a replacement for the battery system of the International Space Station
- Model included a permanent magnet synchronous motor/generator, power electronics, system controller and the flywheel

General aviation power and propulsion

- NASA FY02 internal study of the feasibility of fuel cell-powered general aviation aircraft and the technology improvements required for the application
- Larger 50 and 100-place aircraft were also analyzed at a lower level of fidelity to determine scalability of systems

Fuel cell Auxiliary Power Units (APUs) for commercial aircraft

- Current NASA contract with Boeing to study the replacement of the current gas turbine aircraft APU with a fuel cell-powered APU on future commercial aircraft

SAE AEROSPACE

2002-01-3257

2002 CISO Review

Why NPSS?

- Integration of entire system
  - Fuel cells, motors, propulsors, thermal/power management, compressors, etc.
- Use of existing, pre-developed NPSS capabilities
  - Optimization tools
  - Gas turbine models for hybrid systems
  - Increased interplay between subsystems
  - Off-design modeling capabilities
  - Altitude effects
  - Existing transient modeling architecture
- Easier transfer between users and groups of users
- General aerospace industry acceptance and familiarity
- Flexible analysis tool that can also be used for ground power applications

SAE AEROSPACE

2002-01-3257

2002 CISO Review

Basic I/O: Gas Turbines

- Inputs
  - Mach no. and altitude are main input for cycle deck
  - Design point conditions such as compressor design pressure ratio and speed
  - Primary performance data for components are typically input in a performance map or table
  - Other correlations from experimental data, CFD, etc.
- Outputs
  - Thrust, fuel and air flow, power, node thermodynamic data such as pressures, temperatures
  - Outputs are typically organized in a form that is readable for airframe sizing codes

SAE AEROSPACE

2002-01-3257

2002 CISO Review

Basic I/O: Electrical Systems

- Inputs
  - Design point conditions such as fuel cell current density, motor rotational speed
  - Any performance data or correlations such as motor power/speed/efficiency map or fuel cell polarization curve
  - Fuel and airflow characteristics
- Outputs
  - Power, fuel and air flow, physical requirements for the fuel cells, node thermodynamic data such as pressures, temperatures
- Data is transferred to and from gas turbine components depending on the system design

SAE AEROSPACE

2002-01-3257

2002 CISO Review

Sample results

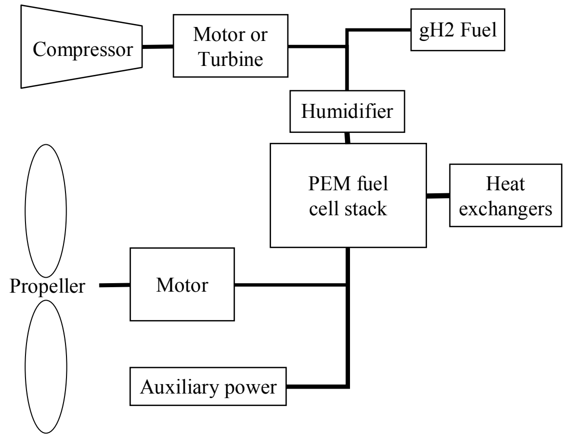
- NASA ZeroCO_2 Project (FY02)
  - First application of the integrated thermodynamic cycle analysis/electrical systems model
  - The objective was to determine the feasibility of electrically-powered flight and identify the technology required for success
  - Two general aviation airplanes were chosen as baseline airframes and electrical systems were developed and analyzed within those systems
  - Larger airplanes were included at a lower fidelity to provide further insight into scalability
  - A summary paper and presentation were prepared as the final deliverables

SAE AEROSPACE

2002-01-3257

2002 CISO Review

ZeroCO$_2$ Model Organization



- Model can evaluate altitude and Mach Number effects on entire system
- For example:
  - High altitude, low Mach Number
    - More compressor power required for constant fuel cell inlet pressure
      - Therefore, less fuel cell power available for propeller motor
        - And less propeller thrust

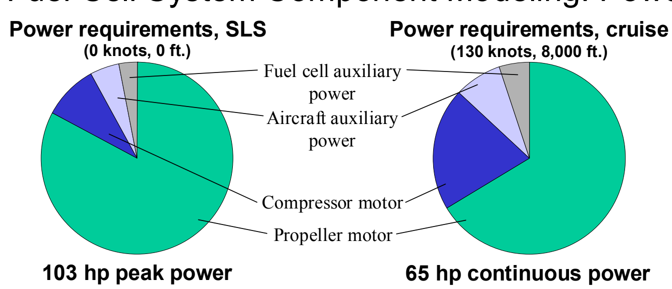
SAE AEROSPACE

2002-01-3257

2002 CISO Review

ZeroCO$_2$ Results

PEM Fuel Cell System Component Modeling: Power



- Propeller: 79% of total power at SLS, 62% of total power at cruise
- Compressor: 9% of total power at SLS, 19% of total power at cruise
- Auxiliary powers remain constant, therefore higher percentage at cruise

➢ Percent power to propeller motor decreases with altitude due to increased compressor requirements

AT Electric Power and Propulsion Modeling — NASA Intercenter Systems Analysis Team, ZeroCO$_2$ FY02 Final Presentation 7

* Reference 2

SAE AEROSPACE

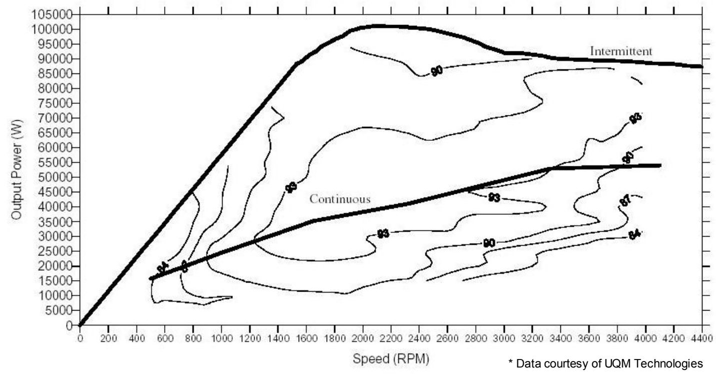
2002-01-3257

2002 CISO Review

ZeroCO$_2$ Results

Electric Motor Modeling

- Motor efficiency map vs. power and speed from Unique Mobility data
- The map was coded into NPSS and provided a more accurate efficiency value over off-design conditions



* Data courtesy of UQM Technologies

NASA Intercenter Systems Analysis Team 11
Electric Power and Propulsion Modeling
ZeroCO$_2$ FY02 Final Presentation

* Reference 3

2002-01-3257

AEROSPACE

2002 CISO Review

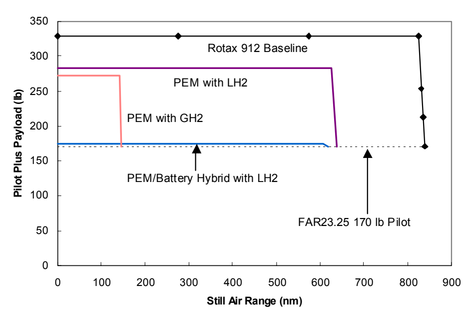
ZeroCO$_2$ Results

MCR01 ULM Fuel Cell Conversion

Payload-Range Assessment (Rotax and Current Technology Fuel Cell Engines)

Concessions Made for Fuel Cell Installation:

- Reduced power propulsion system relative to Rotax 912.
- Reduced payload / pilot baggage.
- Reduced cruise speed and altitude.
- But, with these weight, performance, and packaging assumptions, it *does work!*



NASA Intercenter Systems Analysis Team 21

* this chart produced with output data from NPSS used as input for FLOPs airframe sizing code

* Reference 4

2002-01-3257

AEROSPACE

2002 CISO Review

Model Limitations

- NPSS was not designed as an electrical systems software package
  - Retrofit has not been difficult, but further detail may be challenging
- NPSS primarily developed and maintained at NASA
  - Funding and personnel required for new components and algorithm/configuration changes
  - Validation of software also requires
- Electrical components have been developed in-house and validation of electrical <u>system</u> has not been completed due to lack of funding/personnel

SAE AEROSPACE

2002-01-3257

2002 CISO Review

Future Plans

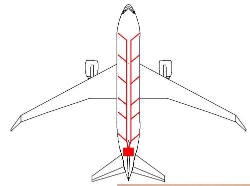
- Model improvement
  - Solid oxide fuel cell and reformer models are currently being incorporated in partnership with the National Fuel Cell Research Center
  - Electric motor and power electronics models are being improved in partnership with other NASA GRC offices
  - Possible sources for higher-fidelity electrical systems models are being investigated for tie-in with NPSS
- Model validation
  - NASA GRC is developing an electrical systems testbed for development and testing of entire electrical system for aerospace applications and model validation

SAE AEROSPACE

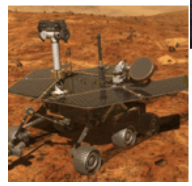
2002-01-3257

2002 CISO Review

Potential Future Analyses



- Full electric auxiliary power unit for airplanes with fuel cell as primary power source
- Electrical high-altitude, long-endurance airplanes/airships
- On-board space electrical power sources
- Ground power applications such as distributed, hybrid fuel cell/gas turbine systems



References

1. NPSS User's Guide and Reference, NASA Publication, 2002
2. ZeroCO_2 Final Summary Presentation, NASA Publication, September 2002
3. PowerPhase100.pdf, www.uqm.com/Technologies/products.html, UQM Technologies, Boulder, CO
4. FLOPs Manual, NASA Publication, 2002
5. Computer Program for Calculation of Complex Chemical Equilibrium Compositions and Applications, NASA RP 1311

Contact Information

- Electrical system modeling and related NASA programs
  - Josh Freeh, NASA GRC, (216) 433-5014
    - Joshua.E.Freeh@grc.nasa.gov

- NPSS software
  - Tom Lavelle, NASA GRC, (216) 977-7042
    - Thomas.M.Lavelle@grc.nasa.gov

SAE AEROSPACE

2002-01-3257

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

Aircraft Engine Systems

Joseph P. Veres

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Aircraft Engine Systems

- Organization
- Vision and Objective
- General Description
- Schedule / Milestones
- FY02 Accomplishments
- FY03 Plans
- Technical talks to follow
- Summary

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Organization

Office of Aerospace Technology (Code R)
Dr. Jerry Creedon, Associate Administrator (HQ)

Revolutionize Aviation Theme Area
Terry Hertz, Program Director (HQ)

Vehicle Systems Program
Richard Wlezien (HQ)
Level 1

Aerospace Propulsion and Power Program
Dr. Gary Seng (NASA GRC)
Level 2

Propulsion Fundamental Research Project
Pete McCallum (NASA GRC)
Level 3

Turbine Engine Simulation
Joe Veres (NASA GRC)
Level 4

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

Vision and Objective

The objective is to develop the capability to numerically model the performance of gas turbine engines used for aircraft propulsion. This capability will provide turbine engine designers with a means of accurately predicting the performance of new engines in a system environment prior to building and testing. The 'numerical test cell' developed under this project will reduce the number of component and engine tests required during development. As a result, the project will help to reduce the design cycle time and cost of gas turbine engines. This capability will be distributed to U.S. turbine engine manufacturers and air framers. This project focuses on goals of maintaining U.S. superiority in commercial gas turbine engine development for the aeronautics industry.

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

General Description

This project will develop computer modeling and simulation capabilities that are of long-term strategic importance to future subsonic and supersonic propulsion. This research is mainly computational and aimed at developing modeling capabilities that could offer significant reductions in design and development cost of next generation subsonic and supersonic propulsion systems. This will enable the designers of new engines to use physics-based predictions of engine performance early in the design process. The Navier-Stokes flow simulations will enable detailed modeling of component aerodynamic interaction effects on engine performance. Key unknowns will be predicted such as radial profiles of flow conditions at component boundaries that are typically unknown to the designer until after the first engine is built and tested. Multi-disciplinary interaction effects on engine performance will also be modeled. This will help to reduce the reliance on component test data and also reduce the number of engine design-build-test iterations.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

Schedule / Milestones

	FY02	FY03	FY04	FY05
3-D Turbofan Engine Simulation	△1	△3	△4	△6
CIAPP Cycle Code Development	△2		△5	△7

1. 3-D flow simulation of an aircraft turbofan engine in under 15 hours of CPU wall clock time
   using APNASA turbomachinery code and the National Combustion Code (NCC)
2. CIAPP cycle code enhanced with a Visual Based Syntax assembly of complete engine
3. Demonstrate CIAPP V2.0 to automate zooming to the 3-D steady-state aero-thermal engine simulation
4. Demonstrate prototype of a 3-D unsteady turbomachinery simulation in turbofan engine
5. Demonstrate prototype "intelligent engine" using CIAPP cycle code coupled to controls code
6. Demonstrate prototype of a 3-D multidisciplinary simulation in turbofan engine
7. Demonstrate CIAPP V3.0 to automate zooming for 0-D to 3-D multi-disciplinary engine simulation using APNASA / NCC and structural / thermal codes

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

FY02 Accomplishments

- 3-D flow simulation of the GE90 turbofan engine has been successfully run in under 15 hours of CPU wall clock time using the APNASA and NCC codes. This was a Strategic Implementation Plan (SIP) fiscal year 2002 milestone for NASA GRC (01A6.1).

- CIAPP V1.5 thermodynamic cycle code has been enhanced with a Visual Based Syntax assembly of complete engine.

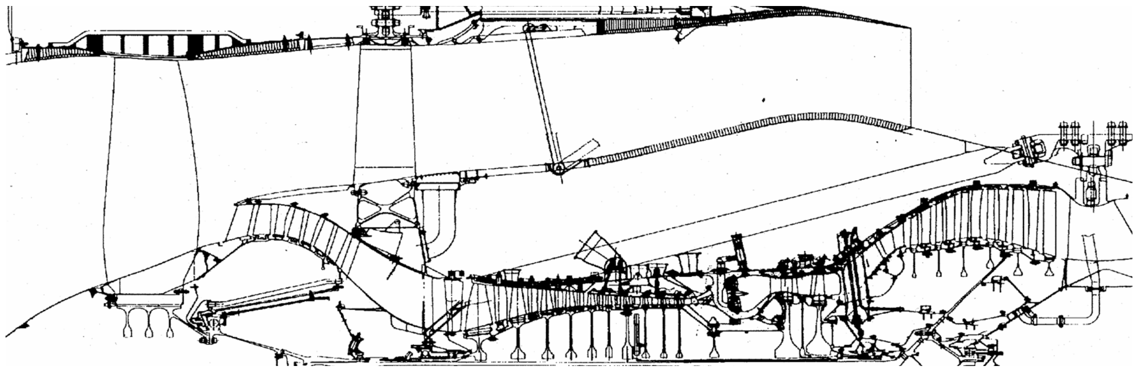
Phase 3 Meeting was held on March 13, 2002. The results were presented in the area of high fidelity simulations and lessons learned from coupling of high fidelity and multi-disciplinary codes.

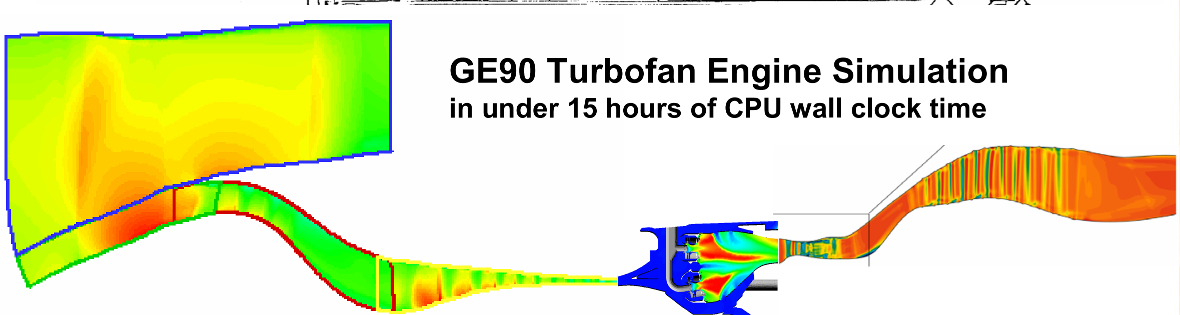
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

FY02 Accomplishments (continued)





GE90 Turbofan Engine Simulation
in under 15 hours of CPU wall clock time

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

FY03 Plans

Demonstrate CIAPP V2.0 to automate zooming to the 3-D steady-state aero-thermal engine simulation of the GE90 turbofan engine.

The CIAPP V2.0 code and the 3-D engine component simulations with APNASA and NCC will generate "mini maps" around the operating point of interest for the engine components. These maps will be passed back to the CIAPP thermodynamic cycle code, which will then be run to convergence (*see flow chart next page*).

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

FY03 Plans (continued)

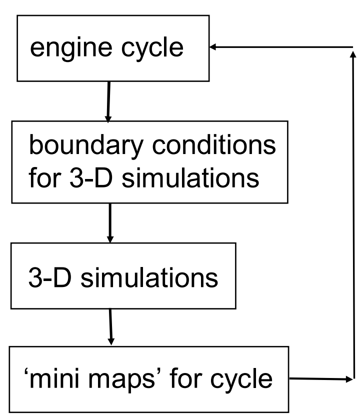
Iteration (n)

The engine cycle code (CIAPP V2.0) will be run at the operating point of interest using 'initial guess' component maps

Cycle will generate 0-D BC's for the fan, LP and HP compressors, combustor and LP and HP turbines.

CIAPP V2.0 will spawn execution of 3-D component simulations (fixed inlet profiles)

3-D simulations will create 'mini maps' around operating point of interest, and pass the maps to the cycle code



Iteration (n+1)

The engine cycle run with new 'mini-maps'

Cycle generate new 0-D BC's

CIAPP V2.0 spawn execution of 3-D simulations with real inlet radial profiles

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

Technical talks to follow:

"High Fidelity Simulation of the GE90 Turbofan Engine"
Mark G. Turner (AP Solutions / University of Cincinnati)

"NCC Simulation of the GE90 Combustor"
Andrew Norris (OAI)

Engine Simulation Team	
Mark G. Turner	Compressor and turbine simulations with APNASA
Rob Ryder	Combustion simulations with NCC, grid generation
Andrew Norris	Combustion simulations with NCC, code coupling
John Adamczyk	APNASA turbomachinery flow code
Nan-Suey Liu	National Combustion Code (NCC)
John Gallagher	Combustor CAD geometry
John Reed	Thermodynamic cycle of GE90 engine with CIAPP
Scott Townsend	Code coupling toolkit development
Bill Pavlik	CIAPP engine cycle model

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Aircraft Engine Systems

Summary

The GRC SIP Milestone number 01A6.1 has been successfully achieved in FY02. The title of the milestone is:

"Turbofan Flow Path Simulation"

The full primary flow path simulation of a modern two spool turbofan engine has been achieved running on hundreds of processors in less than 15 hours of CPU wall clock time.

A paper have been presented at the 2002 Joint Propulsion Conference titled:

"High Fidelity 3D Turbofan Engine Simulation with Emphasis on Turbomachinery-Combustor Coupling", AIAA-2002-3769

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

High Fidelity Turbofan Engine Simulation

Mark G. Turner
University of Cincinnati

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

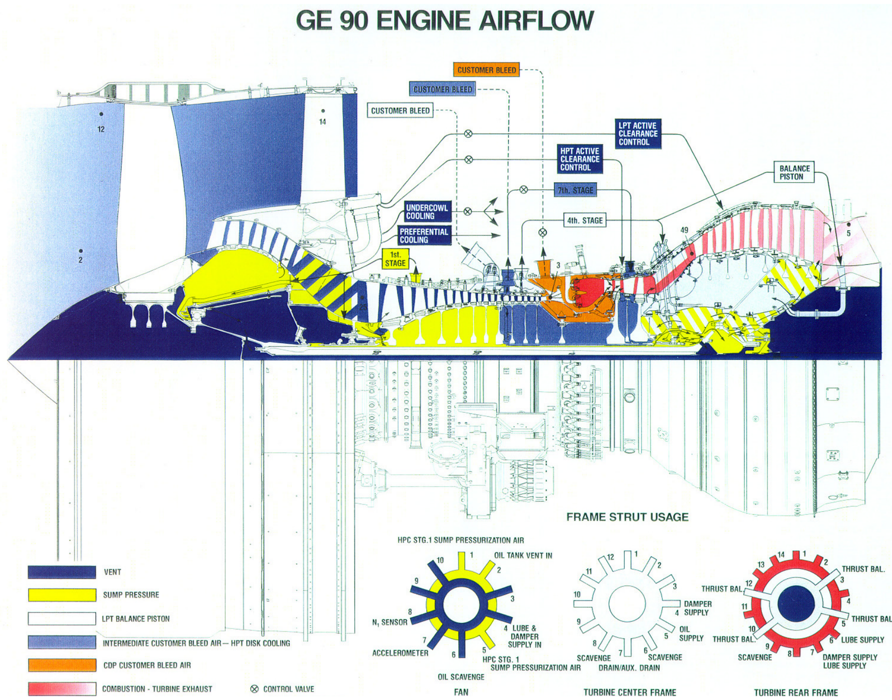
Outline

- GE90 Full Engine Simulation
- Method for Turbomachinery Simulation
- Combustor Details Presented by Andrew Norris
- Computer Timings
- Turbomachinery Solutions
- Power Balance
- Future Plans

2002 CISO Review

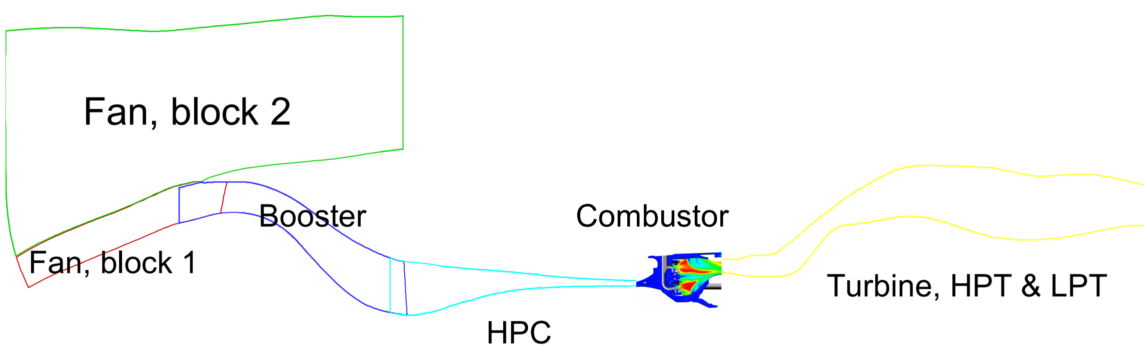
The GE90 Full Engine Simulation is a Coupled Combustor-Turbomachinery Simulation

at a Sea Level Mach 0.25 Take Off Condition



2002 CISO Review

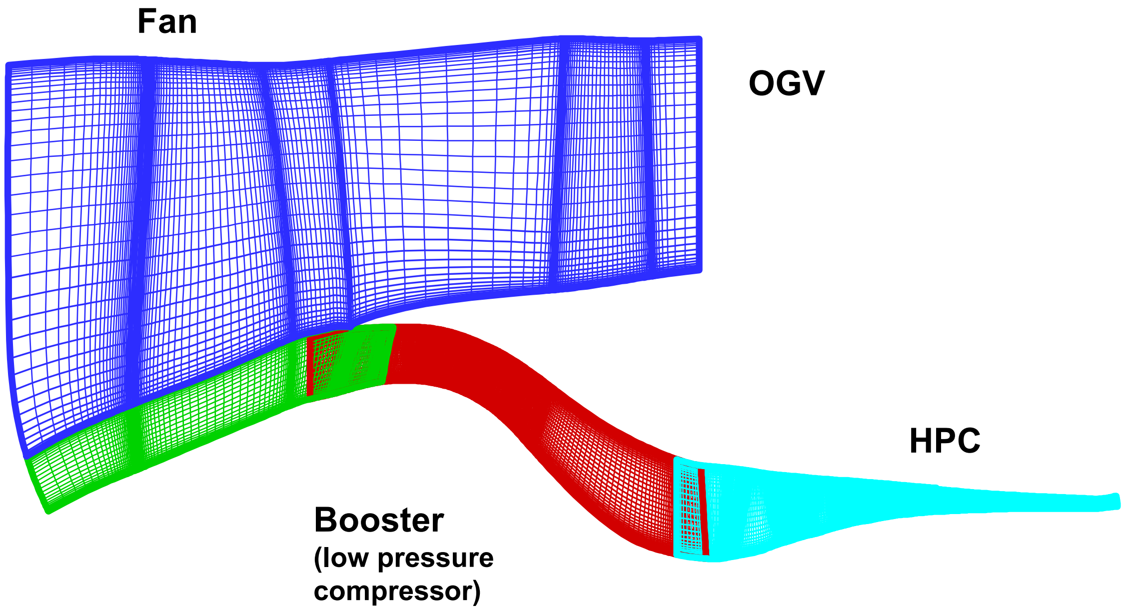
Simulation Domains



Five Domains Simulated in
Sequence Inlet to Exit

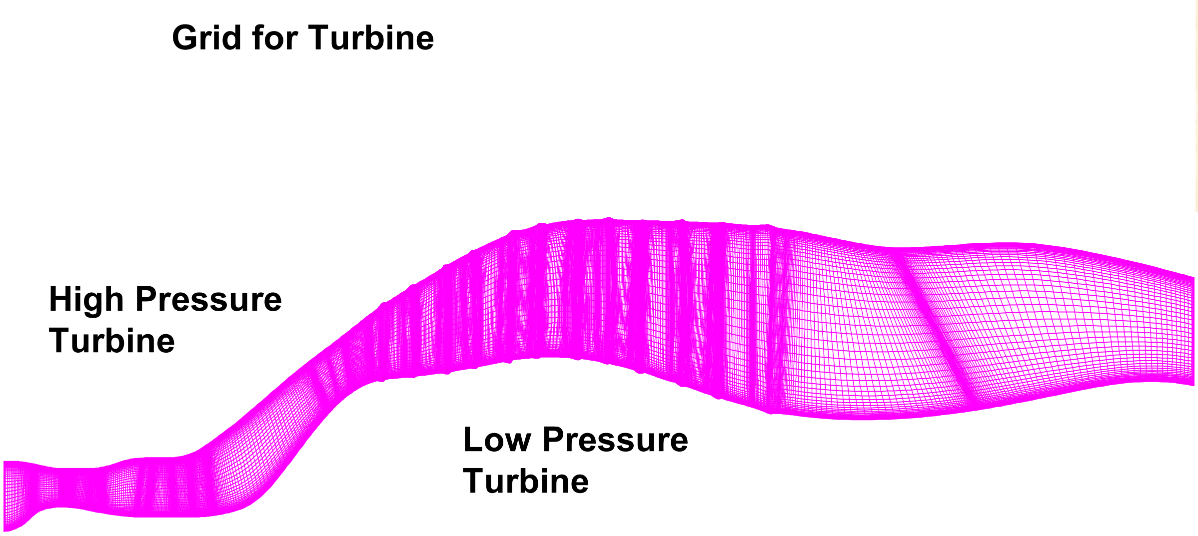
2002 CISO Review

Grid for Full Compressor Simulation
with APG Grid Generator for APNASA Turbomachinery Flow Code



2002 CISO Review

Grid for Full Turbine Simulation
with APG Grid Generator for APNASA Turbomachinery Flow Code



2002 CISO Review

Full Engine Simulation Execution

qsb_fan
- Run APNASA in multi-block mode
  - Fan, OGV and first stage booster stator
- Post process fan
- Pass block 1 profile to booster

qsb_boost
- Run APNASA
  - 4 stators, 3 rotors & strut
- Post process booster exit
- Pass profile to hpc

qsb_hpc
- Run APNASA
  - IGV, 10 rotors & 10 stators
- Post process hpc exit
- Pass profile to combustor

2002 CISO Review

Full Engine Simulation Execution

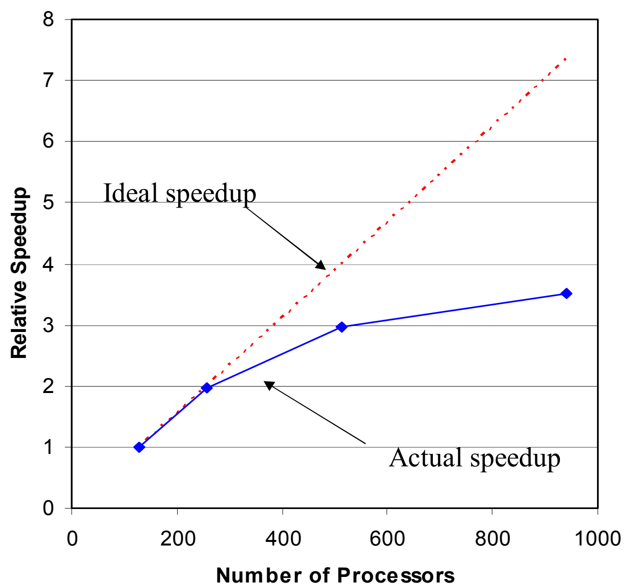
qsb_hpc

qsb_comb
- Run NCC
  - 24 degree sector (pair of DAC nozzles)
- Post process combustor
- Pass combustor profile to hpt

qsb_turb
- Run APNASA
  - HPT is 2 nozzles and 2 rotors
  - mid frame strut
  - LPT is 6 nozzles and 6 rotors
  - Exit Guide Vane strut stators
- Stop Run

2002 CISO Review

APNASA Computer Timings for 21 Blade Row HPC



600 MHz Origin 3000

10,000 iterations, 200 flips

With 512 processors:
- 116 minutes wall clock time
- 16-27 processors per blade row
- 74% parallel

With 940 processors:
- 98 minutes wall clock time
- 30 seconds per flip
- Factor of 3700 speed up relative to 1992

Key Enhancements:
- One processor for script
- Grab and Hold
- Write restart infrequently

2002 CISO Review

Computer Timings

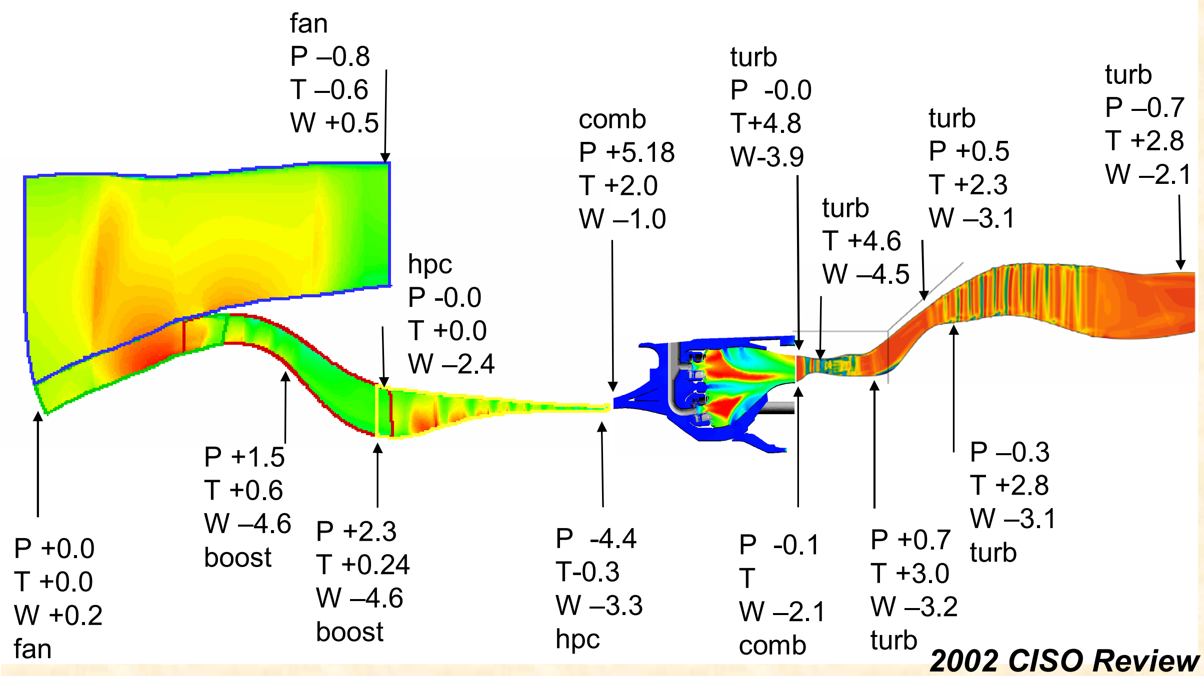
GE90 Full Engine Simulation								
						Case from Scratch (extrapolated)		
component	number of blade rows	number of iterations	number of processors	wall clock time		number of iterations	number of processors	wall clock time
fan	3	50	16	0:02:04		8000	64	1:22:40
booster	8	6000	256	1:15:01		6000	256	1:15:01
hpc	21	10000	512	1:53:17		10000	512	1:53:17
combustor		1000	256	0:11:07		31000	256	3:53:00
turbine	18	10000	512	1:56:36		10000	512	1:56:36
total				5:18:05				10:20:34

Fan Simulation and Combustor Simulation Started as Converged Solutions. Few iterations were required.

Actual Simulation would take just over 10 hours of wall clock time with an empty queue.

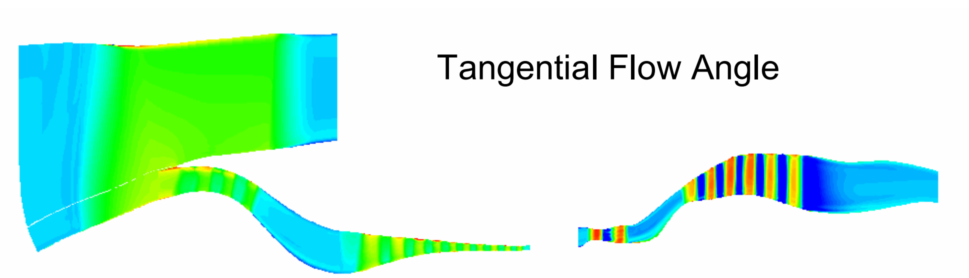
2002 CISO Review

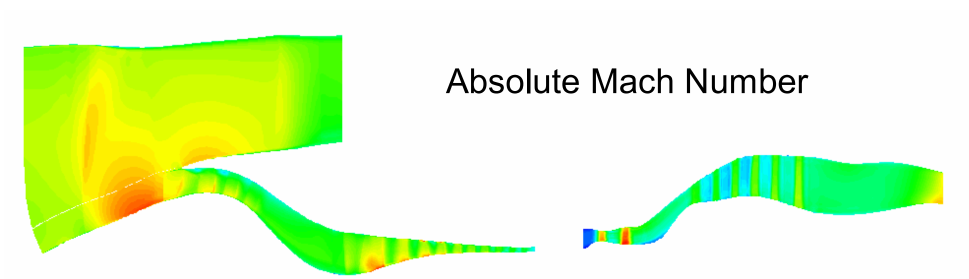
Full Engine Simulation Comparison to Cycle
(percent difference)



2002 CISO Review

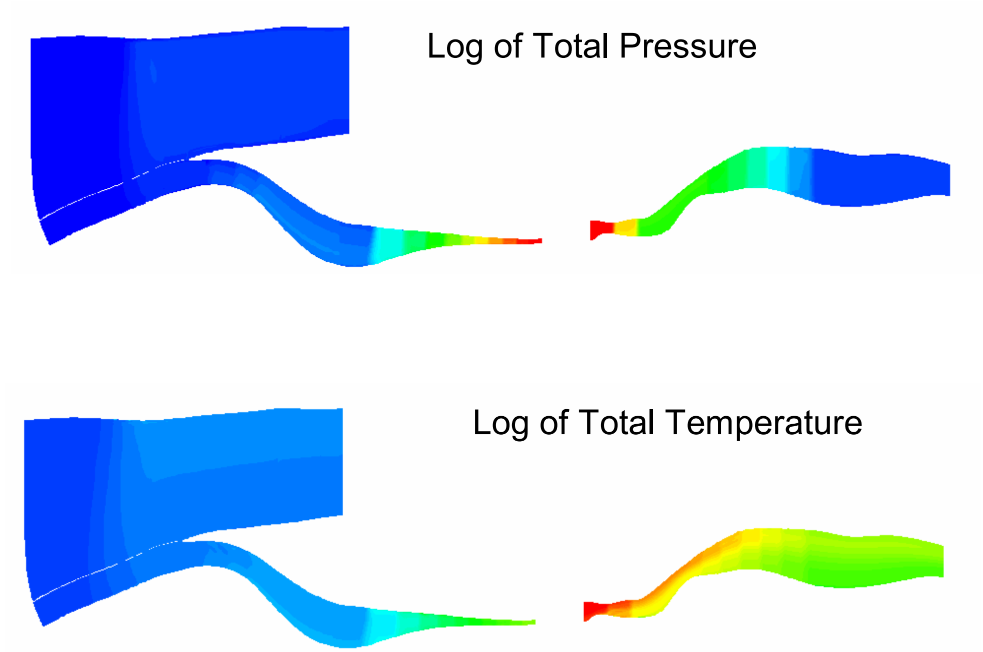
Turbomachinery Simulation





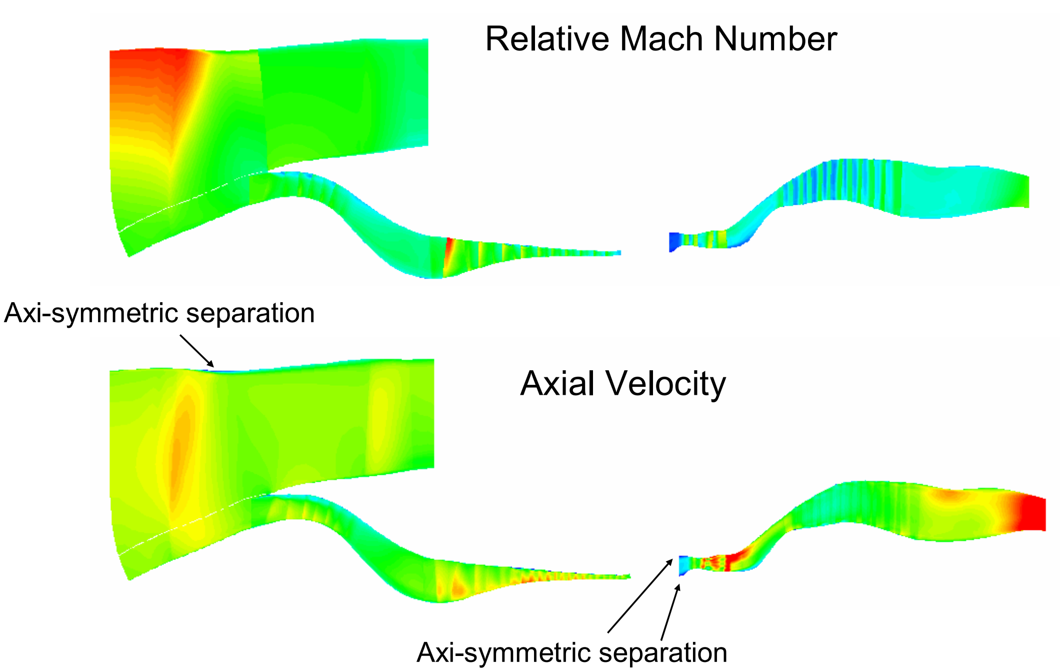
2002 CISO Review

Turbomachinery Simulation



2002 CISO Review

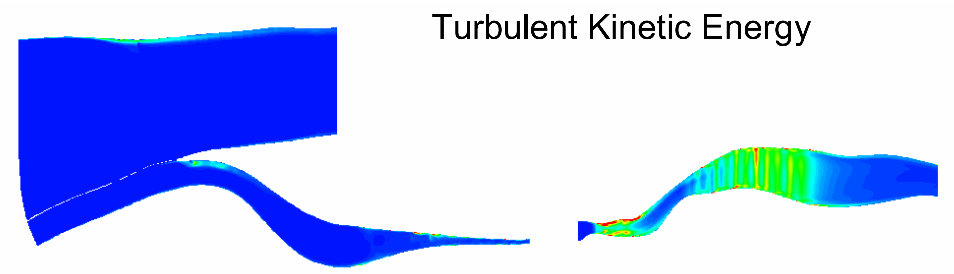
Turbomachinery Simulation



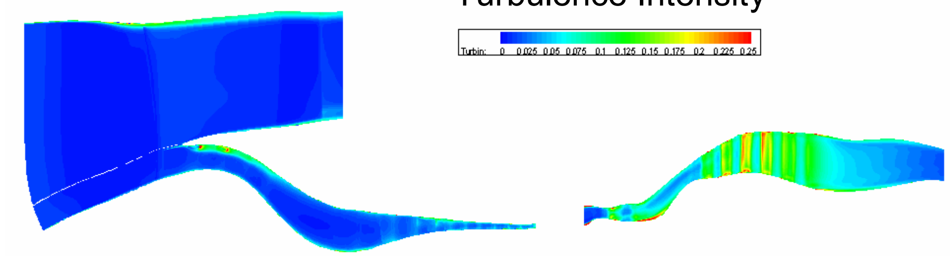
2002 CISO Review

Turbomachinery Simulation

Turbulent Kinetic Energy



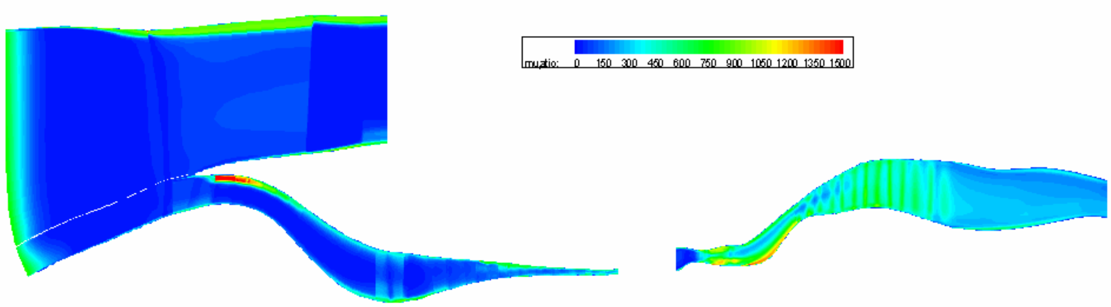
Turbulence Intensity



2002 CISO Review

Turbomachinery Simulation

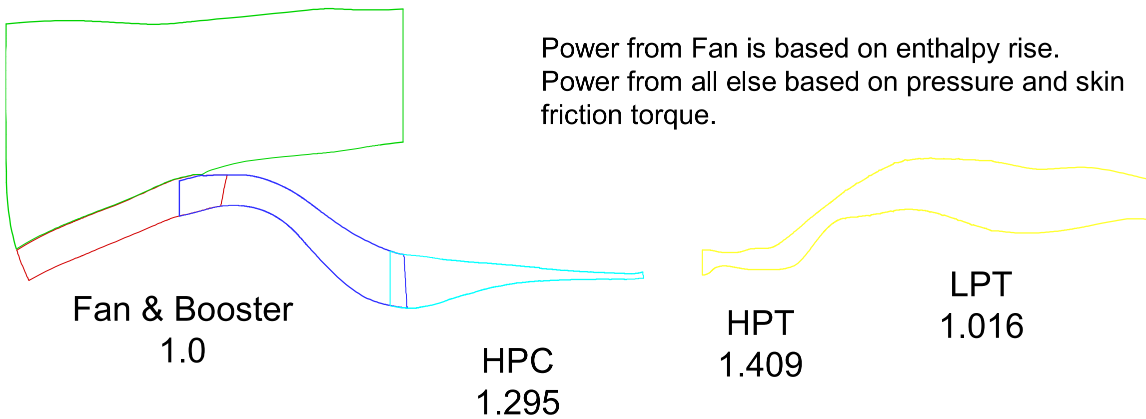
Turbulent-Laminar Viscosity Ratio



2002 CISO Review

Power Balance

Power normalized by Fan and Booster



Power to pump cooling flows not subtracted from HPT.
Work by HPC under-predicted.

2002 CISO Review

Future Plans

- **Run Fan Simulation out**
- **Get Rid of Separation in HPT inlet**
- **Improve HPC simulation**
- **Create Component Maps**
- **Tie to Engine Thermodynamic Cycle**
- **Add capability for cycle to launch simulation jobs to:**
  - **Set exit corrected flow**
  - **Set rotation speed**
  - **Scale pressure and temperature**
  - **Scale cooling Flows**
- **Run From Cycle for Design and Off-Design**

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

Combustor Simulation

Andrew Norris
(ICOMP / OAI)

Aerospace Propulsion Power
AP&P Program

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Combustor Simulation

- **Introduction**
- **Combustor description**
- **Simulation of combustor:**
  - **Transfer of boundary conditions**
  - **Run-time scripts**
- **Results**
  - **Code execution times**
  - **Parallel efficiency of code.**
- **Summary**

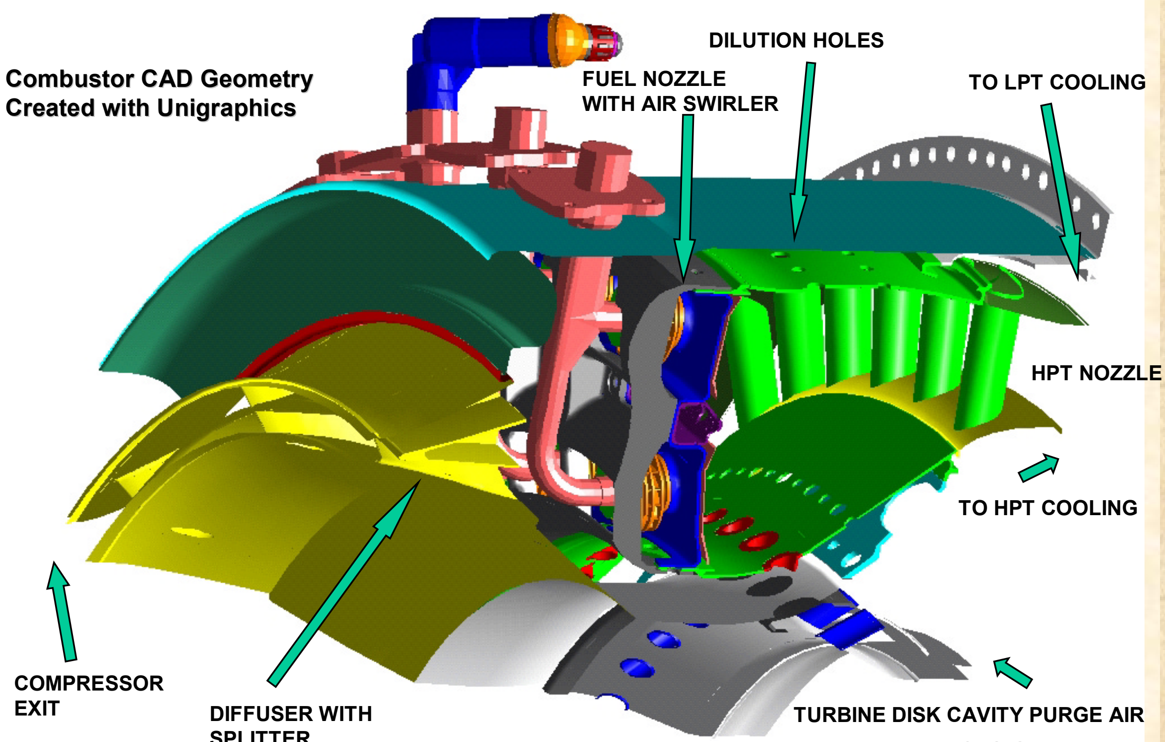
2002 CISO Review

Introduction

- Goal was to perform 3D simulation of GE90 combustor, as part of full turbofan engine simulation.
- Requirements of high fidelity as well as fast turn-around time require massively parallel code.
- National Combustion Code (NCC) was chosen for this task as supports up to 999 processors and includes state-of-the-art combustion models.
- Also required is ability to take inlet conditions from compressor code and give exit conditions to turbine code.

2002 CISO Review

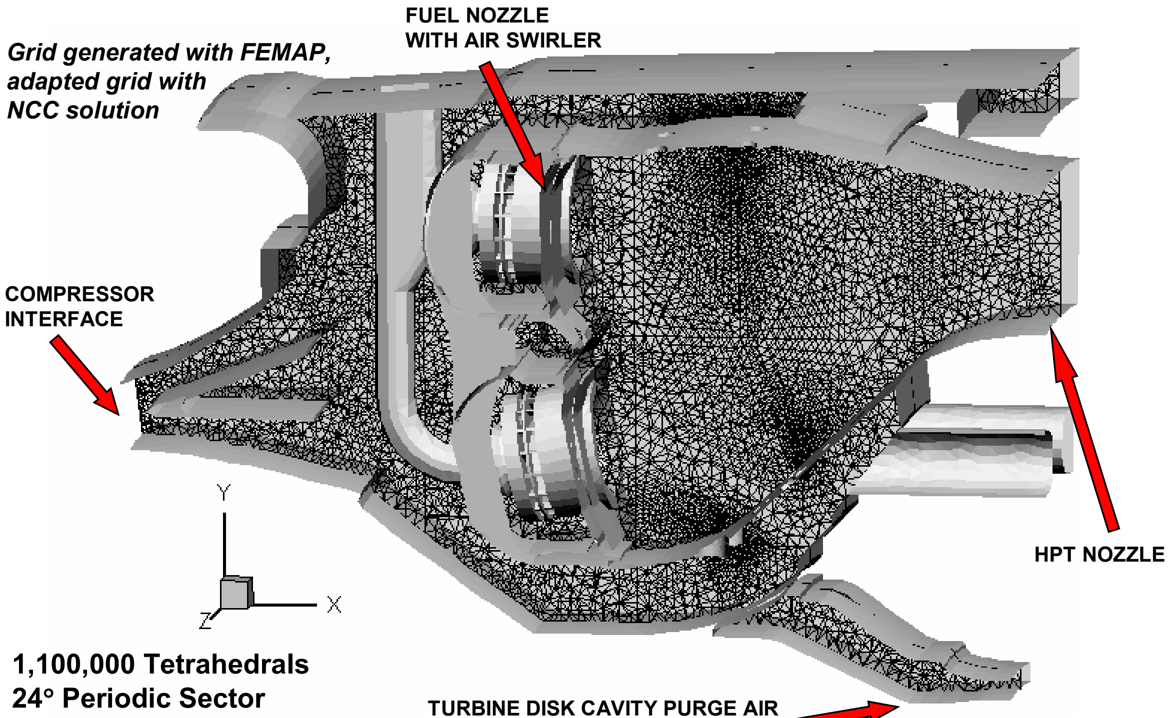
Detailed Simulation of Aircraft Turbofan Engine



2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

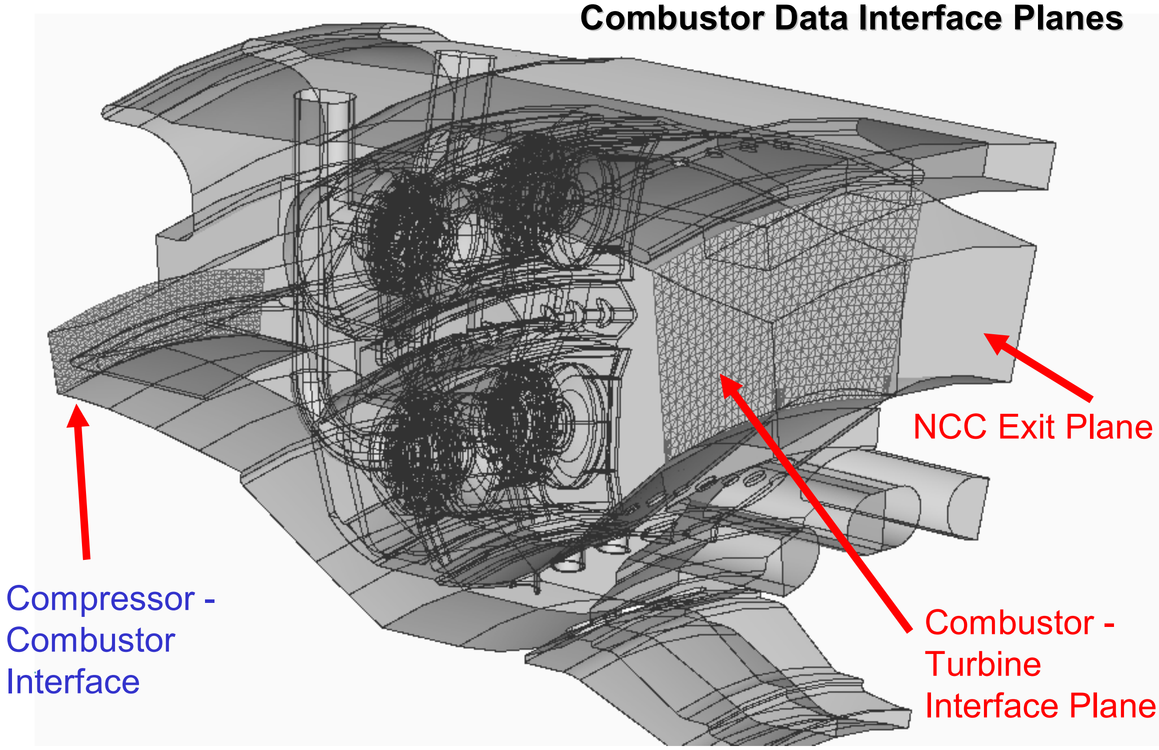
Combustor Grid with Adaptation



2002 CISO Review

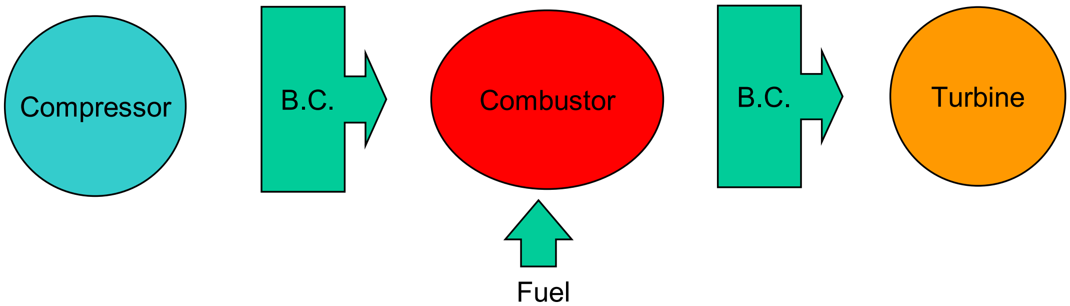
Detailed Simulation of Aircraft Turbofan Engine

Combustor Data Interface Planes



2002 CISO Review

Boundary Condition Transfer



- **Data translators used to exchange boundary conditions between components of engine.**
- **Separate stand-alone codes written to provide flexibility and avoid modifications to main flow solvers.**
- **Standardization of BC formats proposed for future.**

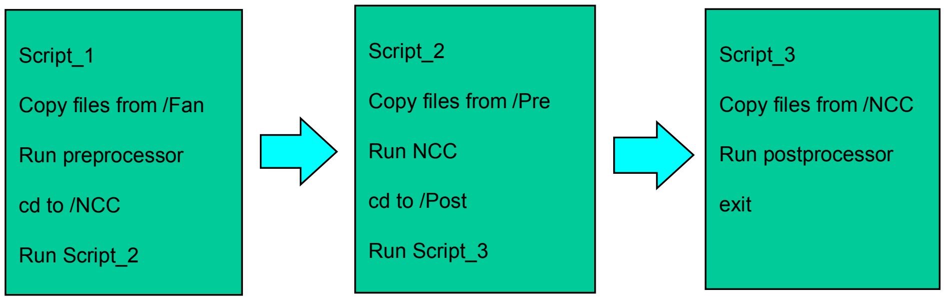
2002 CISO Review

Boundary Condition Data Translators

- **Compressor to Combustor (APNASA to NCC)**
  - **Radial profiles extracted from data file.**
  - **Velocity, density, temperature and turbulent velocity passed.**
  - **Turbulent dissipation calculated from k and length scale.**
  - **Species (air) composition specified.**
- **Combustor to Turbine (NCC to APNASA)**
  - **Interface data extracted from flow field.**
  - **Mass and tangentially averaged radial profiles calculated.**
  - **Polar velocities, angles, Ptot, Ttot, turbulent intensity, turbulent velocity, turbulent viscosity ratio passed.**
  - **Units changed from SI to Imperial Units.**

2002 CISO Review

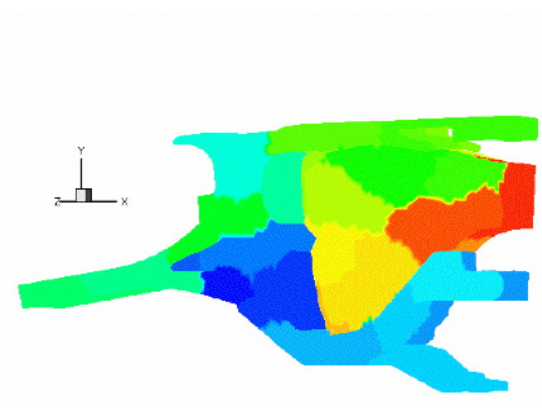
Run-time Scripts



- **Separate scripts used to fit under computer wall-clock limit.**
- **Based on the batch (LSF) scripts used to submit jobs.**
- **Codes run in separate directories, with files copied over.**
- **Execution started by submitting first script.**

2002 CISO Review

Combustor Simulation on Multiple Processors

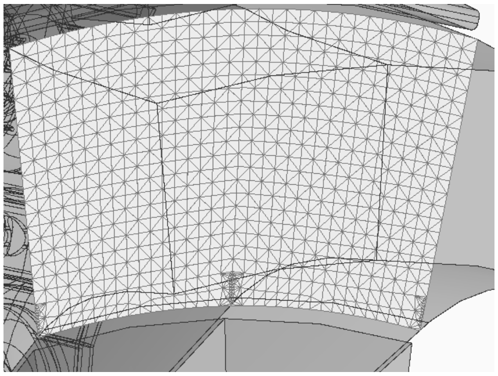


- **Metis scheme used to divide up flow domain.**
- **Goal is to minimize the amount of message passing.**
- **Possible for inlets and exits to reside on several different processors.**
- **16 processors shown here. 256 processors used in simulation.**

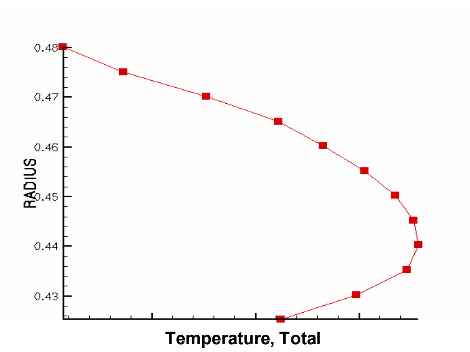
2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

Combustor - Turbine Interface



Grid the turbine interface plane with a structured polar mesh. This yields a more accurate procedure for circumferential mass averaging. 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.



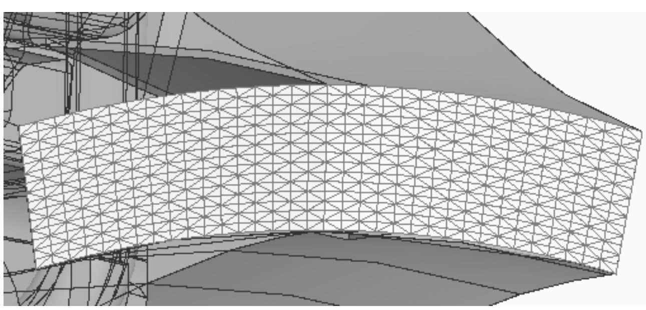
Mass averaged profiles for **velocities** were transferred at the combustor-turbine interface plane.

Mass averaged profile for **temperature** was transferred at the combustor exit plane.

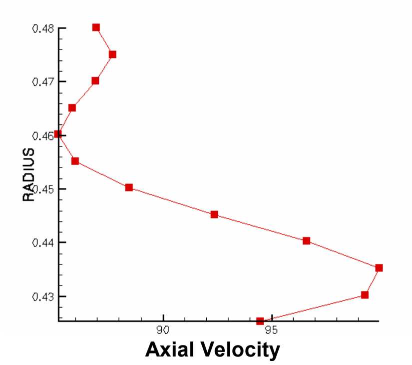
2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

Combustor - Compressor Interface



The compressor-combustor interface is gridded with a structured polar mesh and this yields a more accurate procedure for circumferential mass averaging. This mesh is then split into triangles and used as the surface mesh for the volumetric tetrahedral mesh. This is a loosely coupled approach.



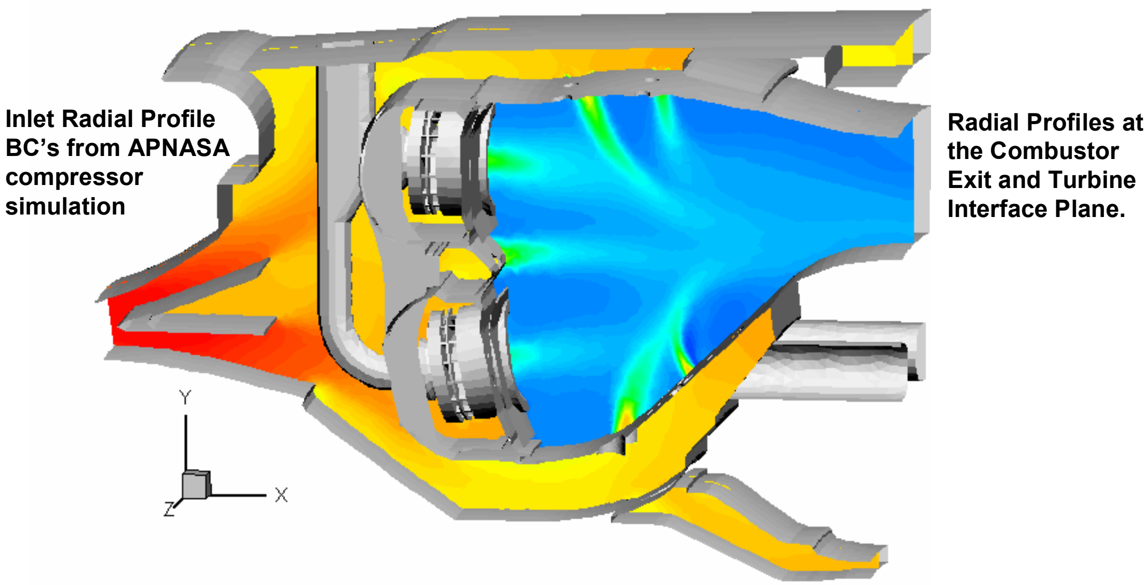
At this interface, the mass flow is preserved between the APNASA mesh and the NCC mesh by maintaining the shape of the circumferentially mass averaged profiles for velocities, while scaling the magnitudes of the velocities.

2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Pressure

National Combustion Code



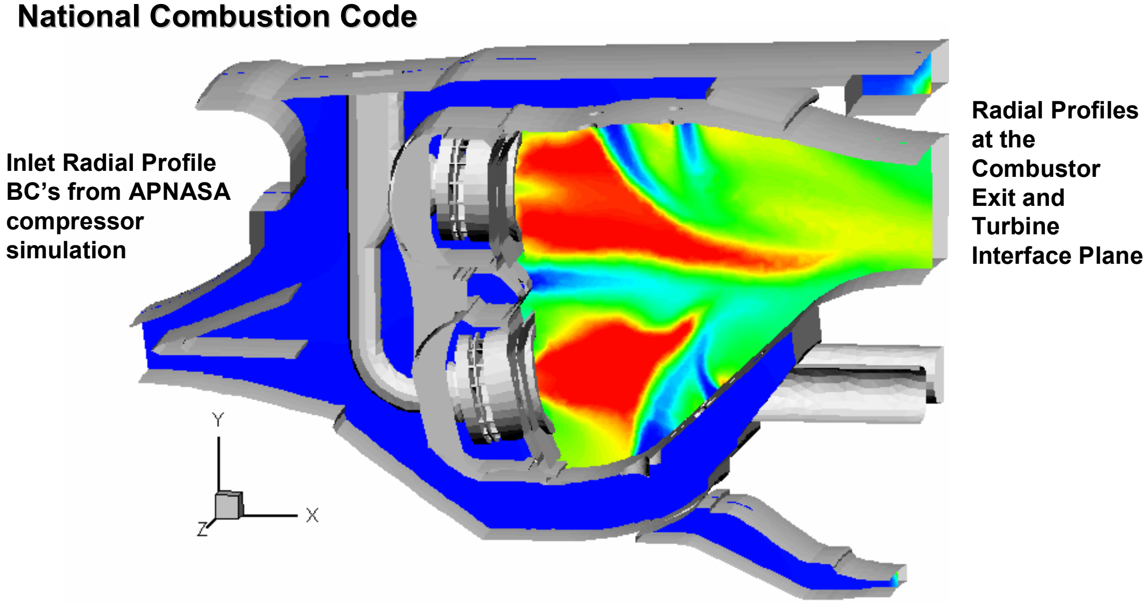
Aerodynamic mass averaged profiles were transferred at the Combustor-Turbine interface plane

2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Temperature

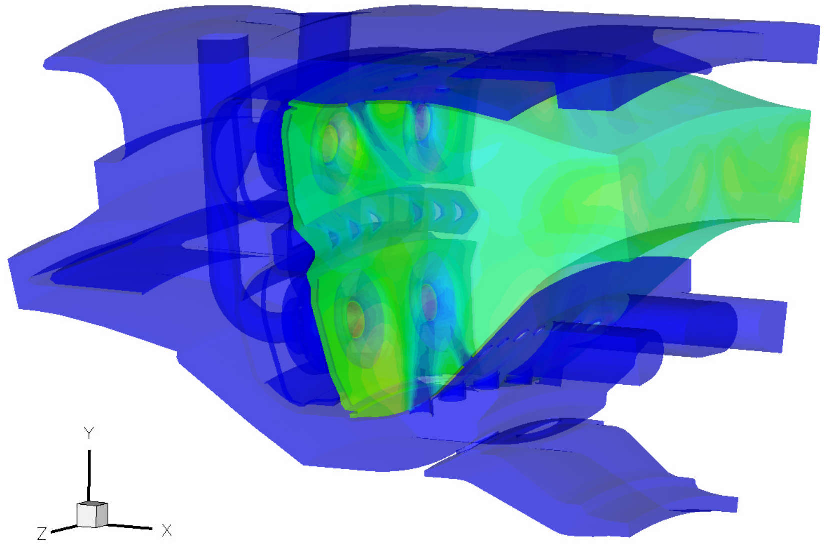
National Combustion Code



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

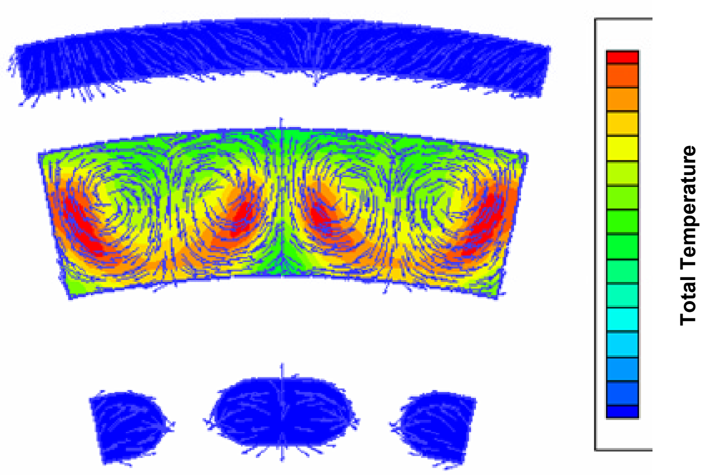
2002 CISO Review

Total Temperature For GE90 Combustor



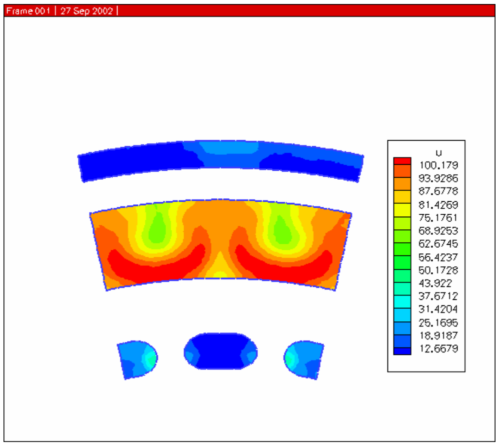
2002 CISO Review

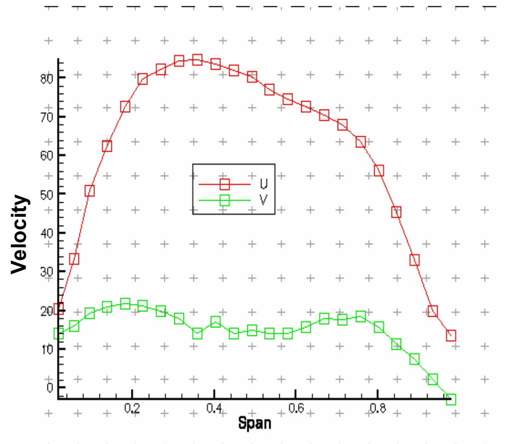
Combustor Exit Plane Vector Plot



2002 CISO Review

Combustor Velocity Exit Profile Data

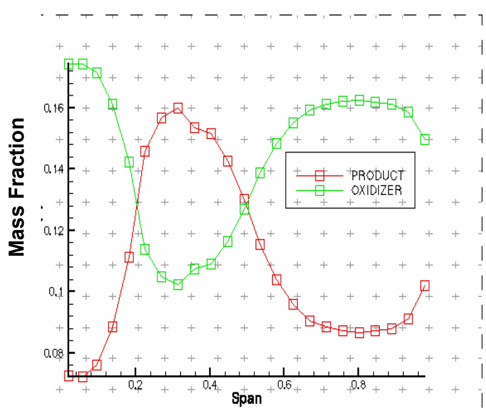


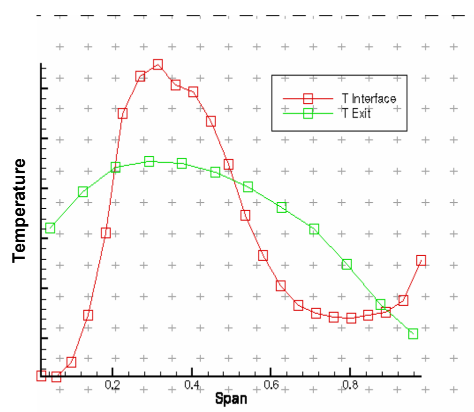


U - Axial Velocity
V - Radial Velocity

2002 CISO Review

Species and Temperature Exit Profile Data





2002 CISO Review

Parallel Performance of NCC on NAS (Chapman)

GE90 12 Degree Combustor Sector

CPU number	32	64	128	256	512
Time (per 1000 iteration)	875 s	408 s	216 s	121 s	63.0 s
Efficiency	1.0	1.08	1.01	0.90	0.86
Notes	Does not fit into cache memory	Fits into cache memory	Fits into cache memory	Fits into cache memory	Fits into cache memory

2002 CISO Review

Detailed Simulation of Aircraft Turbofan Engine

Computer Timings for Combustor Simulations

Computer timing for the combustor for a converged National Combustion Code (NCC version 1.0.9) simulation of the GE90 combustor on the parallel computer at NASA Ames Research Center (Chapman; SGI Origin 3000 workstation, 600 MHz):

Wall Clock Time: **3.5** hours

CPU Time: **872** CPU hours

The combustor simulation converged in 31,000 iterations.

A total of 256 processors were used.

Size of the 3D grid is 1,100,000 elements for a 24 degree 4 fuel nozzle case.

Parallel efficiency of over 90% shown for 512 processor run.

2002 CISO Review

Summary

- NCC code has been used to successfully model a 24 degree sector of the GE90 combustor.

- Mass averaged radial profiles from compressor transferred to combustor, and used as inlet boundary conditions.

- Mass averaged radial profile boundary conditions transferred from combustor to turbine and utilized as inlet boundary conditions.

- Using 256 processor, total time for converged solution was 3.5 hours on an SGI Origin 3000 computer.

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

NPSS SPACE TEAM

Tom Lavelle

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Introduction

- NASA working to expand NPSS to space applications
- Working with Aerojet, Rocketdyne and PW to develop this capability
- Working both conventional rockets and combined cycles
  - Combined cycles of interest to NASA (TBCC, RBCC)
- Combined cycle needs are driving us to develop a heat transfer and hypersonic capability

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Pratt & Whitney
Space Propulsion
NPSS Activities

Development of NPSS for
Space Propulsion Applications

NPSS Annual Review
October 9-10, 2002

2002 CISO Review

P&W Space Propulsion Modeling

Pratt & Whitney
A United Technologies Company

- Updated NPSS model of 2GRLV COBRA LH_2 / LO_2 engine
- Validated throttle transient operation against ROCETS model of COBRA engine
- **Supported development of the Hypersonic ISTAR engine NPSS component elements to enable simulation of full trajectory performance**
- Submitted revised NPSS component elements to NASA

2002 CISO Review

P&W Space Propulsion Modeling

Why does P&W Space Propulsion Want to Develop NPSS?

- NPSS would be a Corporate-wide application (P&W Jets, IFC, UTRC, etc.,)
- NPSS would create a Common Rocket - Airbreathing modeling system
  - Enables RBCC, TBCC modeling within single architecture
    - Eliminates requirement for manual data transfer for systems integration
    - Enables overall system optimization
- NPSS should reduce Joint Venture long-term modeling and analysis costs and reduce potential for confusion between multiple models
  - Applicable to I^{STAR} Consortium
  - No Need to Translate Methods Between P&W, Aerojet & Rocketdyne
  - No Need to Resolve Differences Between Multiple System Models
  - Enables Multi-site Real-time analysis
- NPSS has the Potential to become an Industry and DoD Standard
  - Lockheed & Boeing participating in NPSS Development
  - Aerojet & Rocketdyne participating in NPSS Development
- NPSS is a Flexible and Growth-Capable Architecture
  - Multidisciplinary "Zooming" inherent capability - single environment for 0-D through 3-D Analysis
  - Modern Object-Oriented programming that facilitates code re-usability

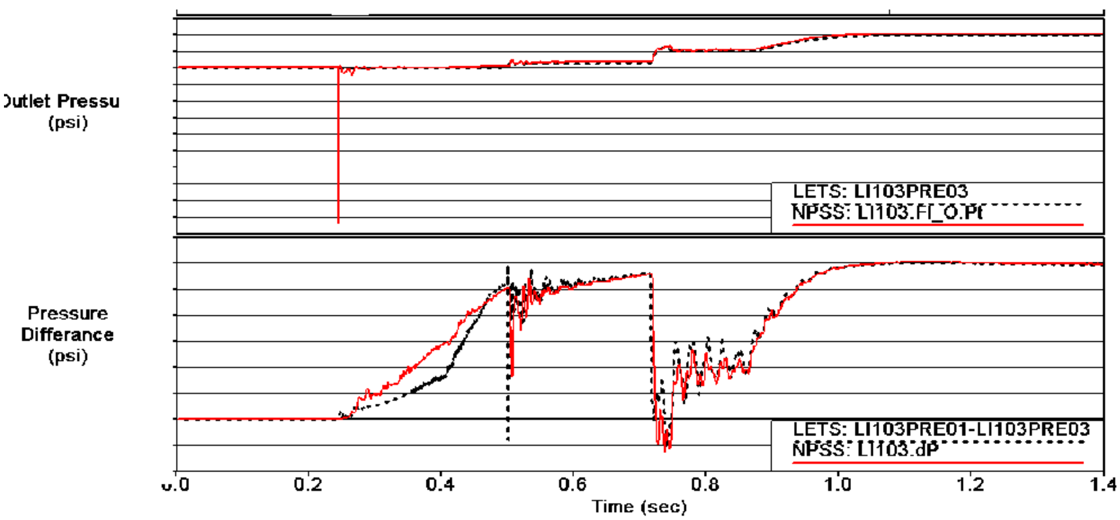
2002 CISO Review

Aerojet GFY 2002 Tasks

- Support Development and Evaluation of RBCC & Ramjet/Scramjet Components
  - Scramjet entropy limit burner control volume model implemented
- Develop Liquid Rocket Engine Model
  - Create system simulation of existing engine
  - Verify against existing system model and applicable test data
  - New components useful for rocket and RBCC application
- Titan Stage 2 Engine Selected For Simulation
- Focus On Transient Model

2002 CISO Review

Initial Results Are Promising



Results shown for dummy sample pipe

AEROJET

2002 CISO Review

NPSS Benefits

- Integrated Model Reduces Amount Of Manual Iteration
- Ability To Specify Solver Dependents And Independents Very Useful For Design Studies
- Engine Model Easily Integrated With Facility Model To Support Wind Tunnel Testing
- NPSS Modeling Is Being Used To Support Scramjet Engine Development For The DARPA/ONR HyFly Program

AEROJET

2002 CISO 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}
  - Air Force Supersonic/Hypersonic Vehicle Design (SHVD) program
  - NASA MSFC Intelligent Design Advisor (IDA)
  - Boeing Integrated Vehicle Design System (BIVDS)
- **Status**
  - Key enhancement defined (high-fidelity inlet analysis)
    - 2001: 3-D inlet geometry module completed; basis for automated inlet analysis module in IDA
    - 2002: 3-D geometry module enhanced to include I^{star} features; basis for future automated inlet analysis in SHVD
  - Groundwork laid for subsequent complementary enhancements

BOEING
Rocketdyne Division

2002 CISO Review

NPSS: CEA, Janaf, GasTbl Comparison

Hi-Mach Afterburning Turbojet, OPR 10

Janaf & GasTbl

LHV = 1875

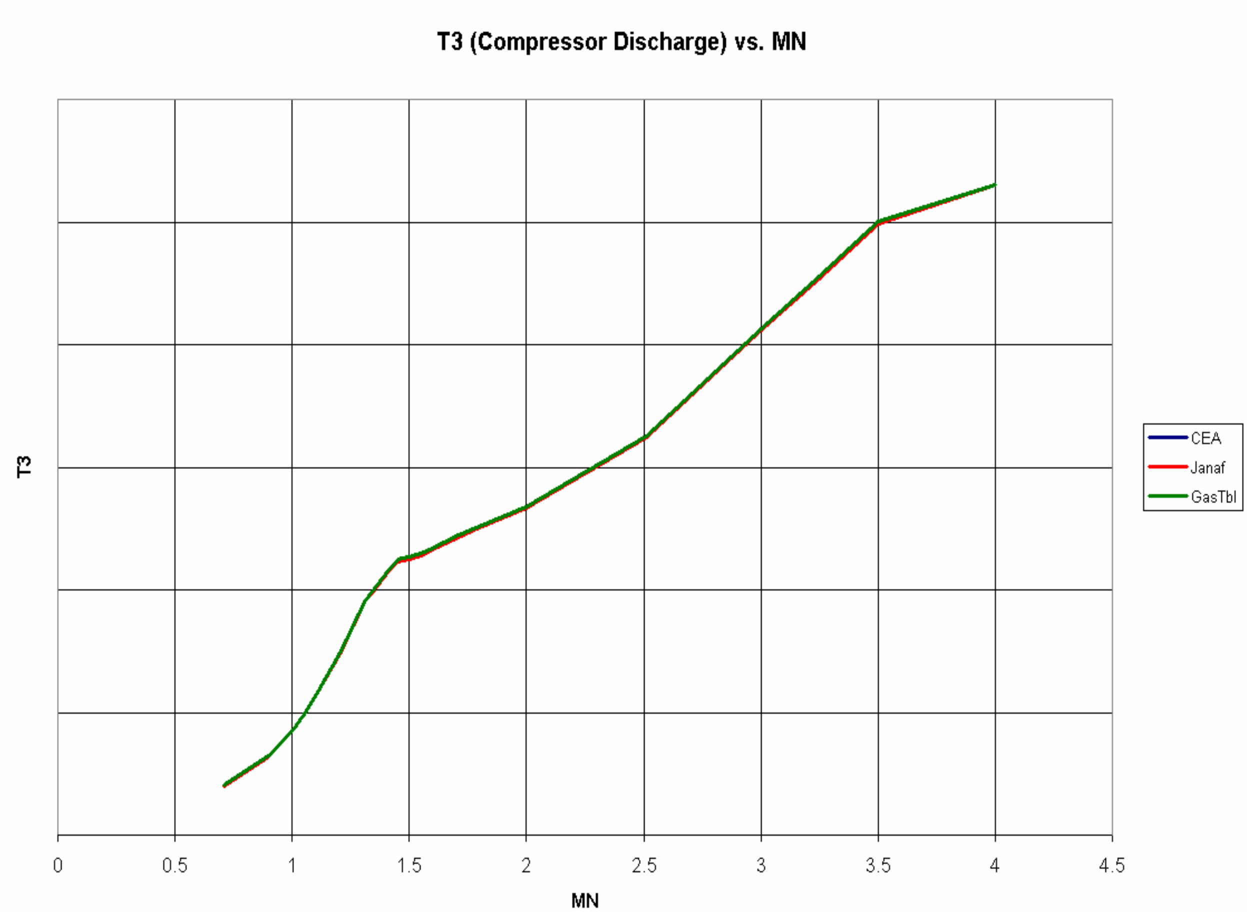
CEA (fuel JP-7)

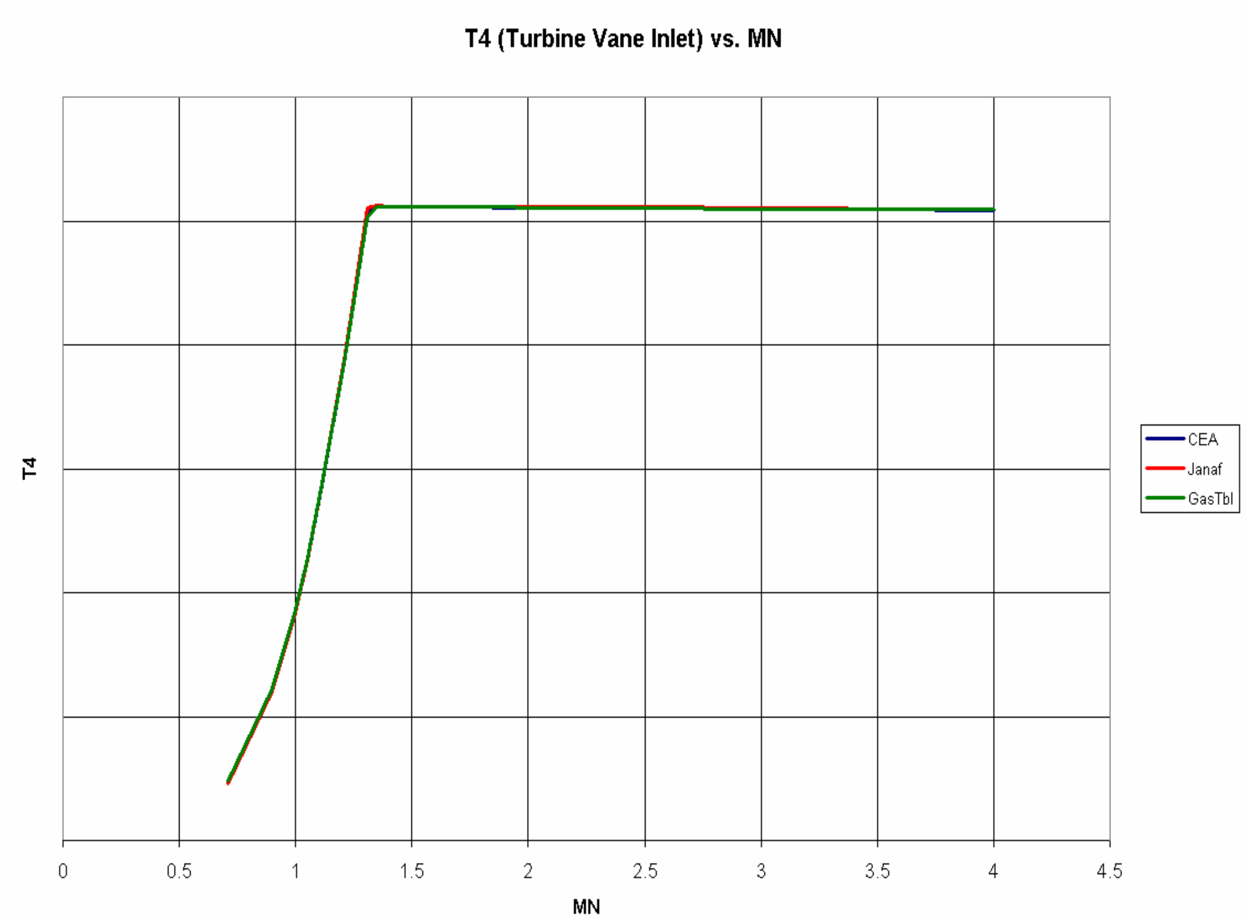
Primary Burner: hRef= -782

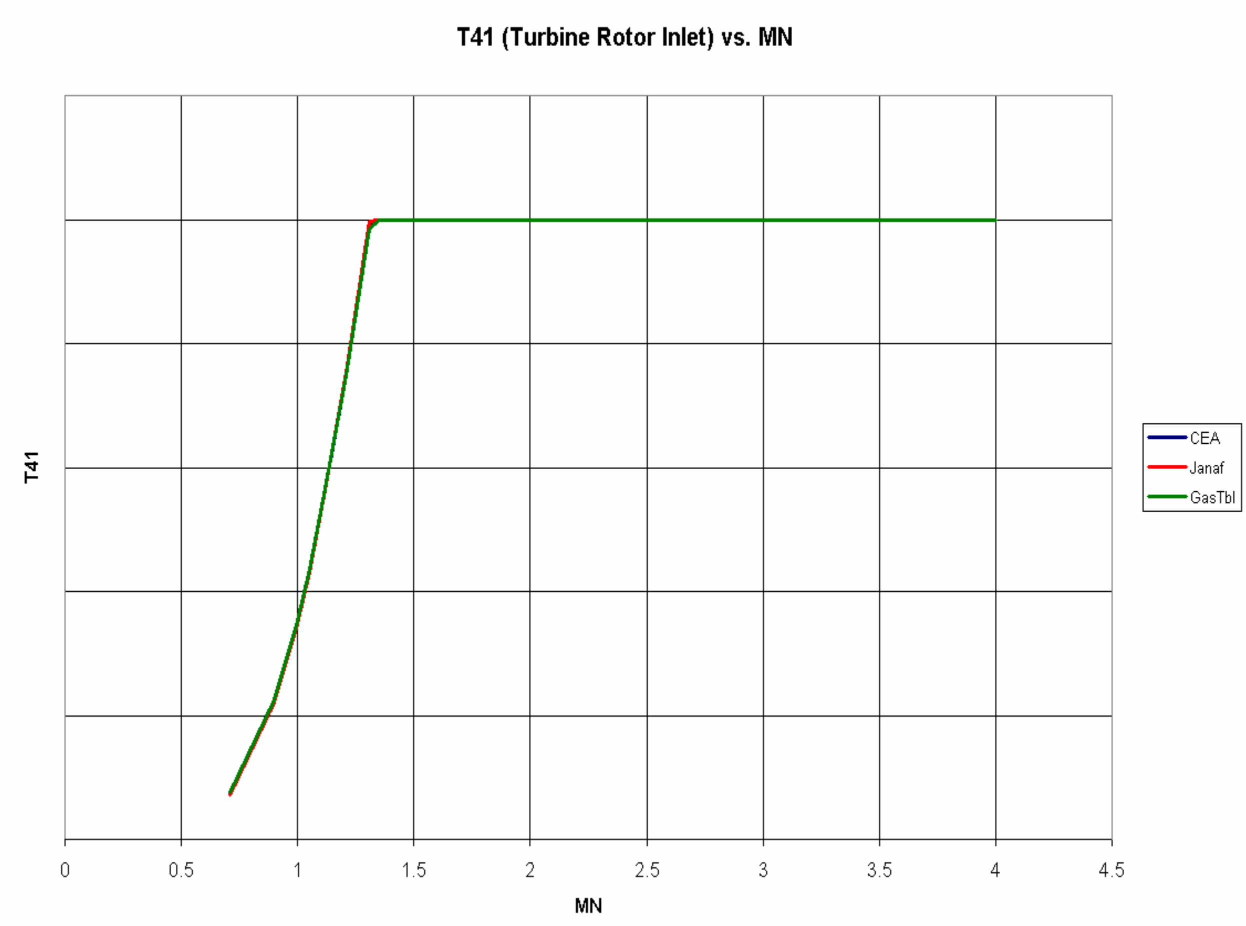
Afterburner: hRef = -1284

Run Time: Janaf ~ 100 times faster than CEA

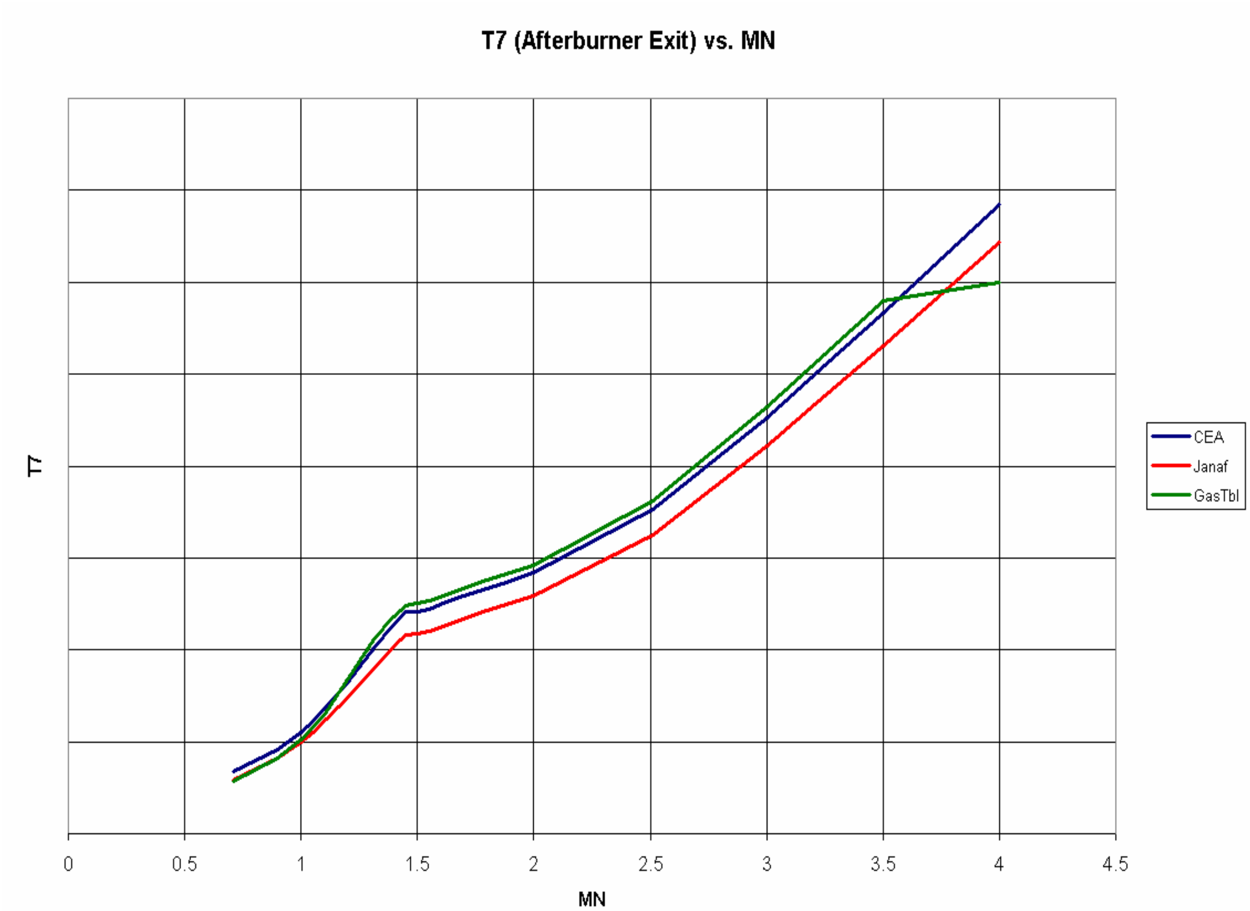
2002 CISO Review


T3 (Compressor Discharge) vs. MN
T3
MN
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl

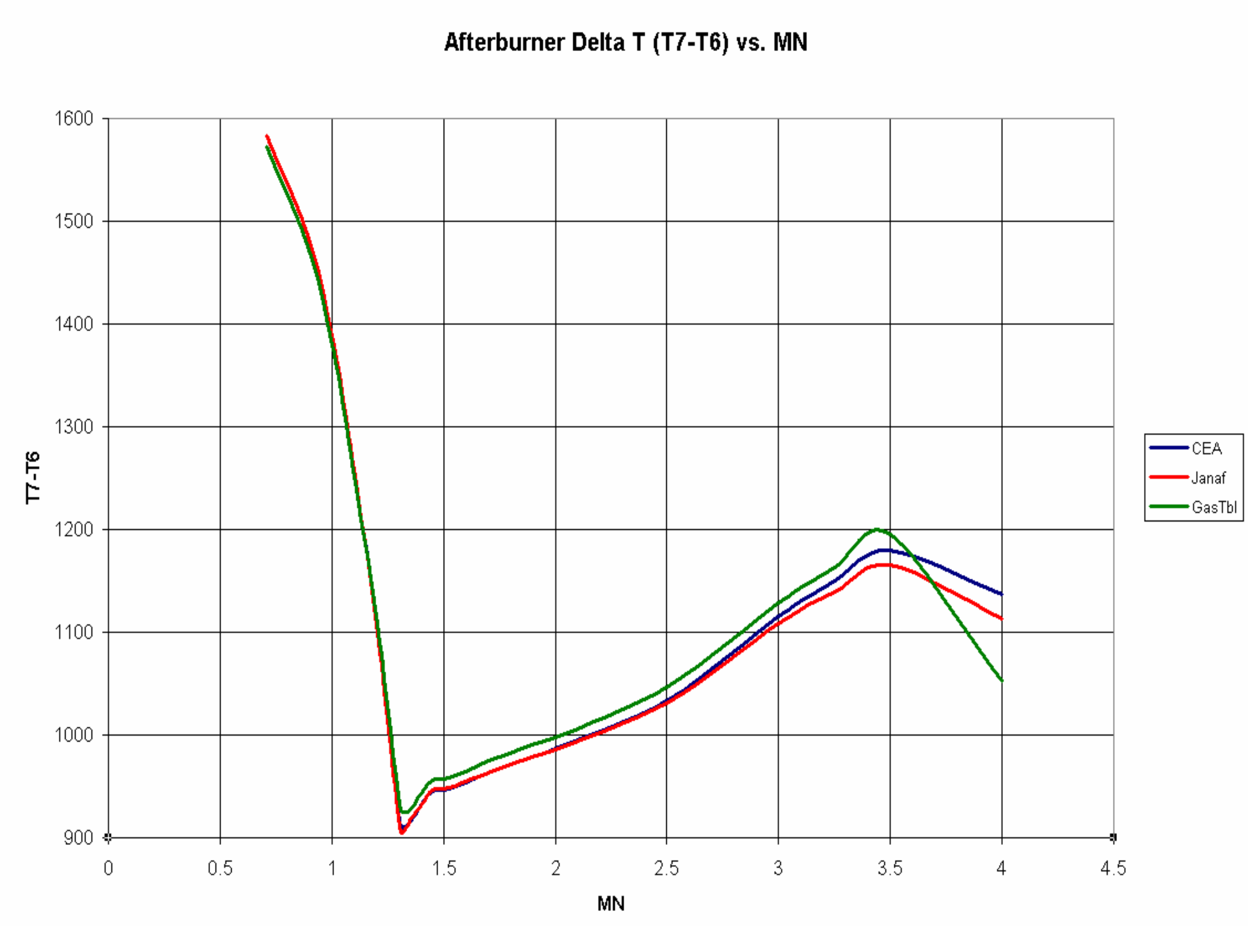

T4 (Turbine Vane Inlet) vs. MN
T4
MN
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl



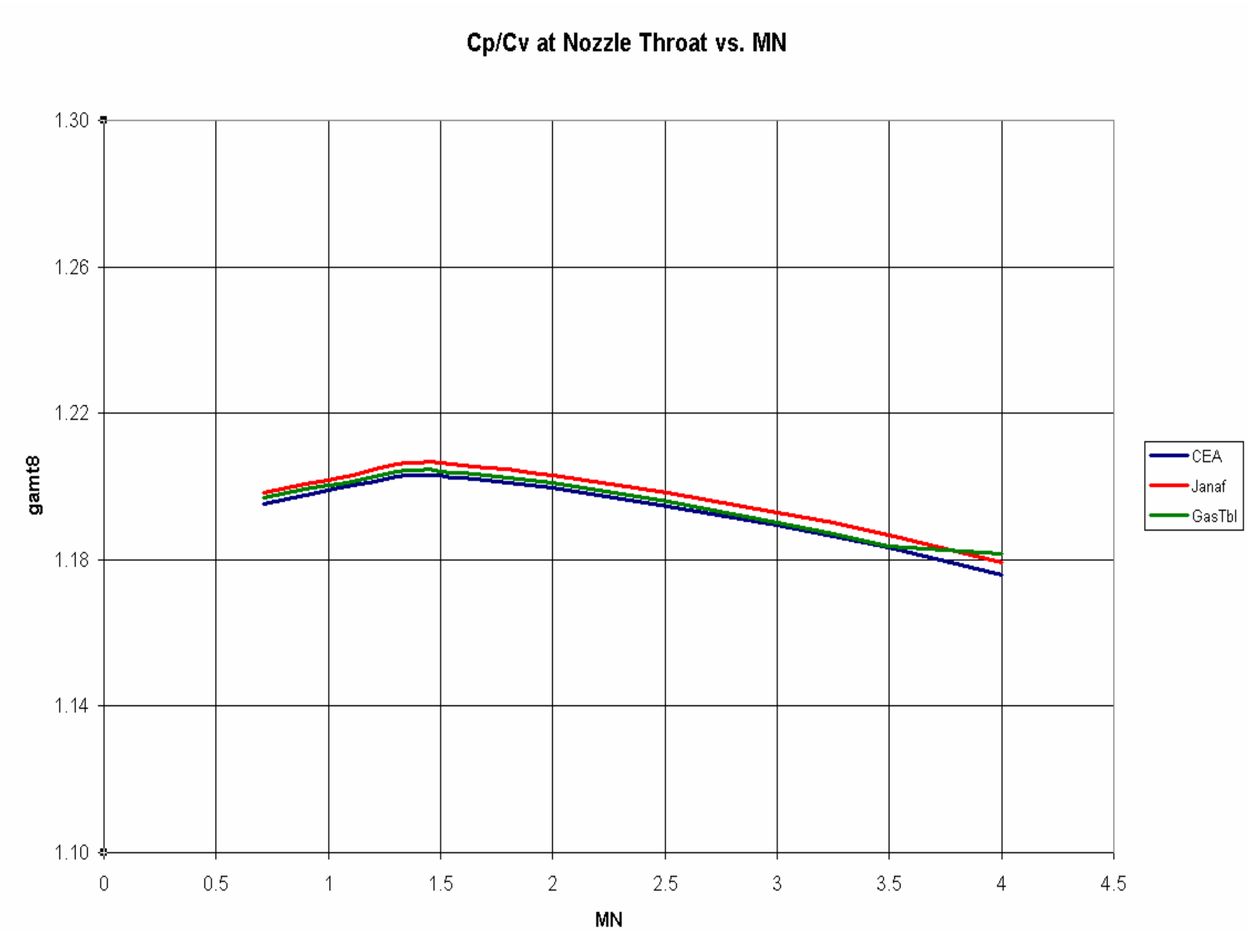
T41 (Turbine Rotor Inlet) vs. MN
T41
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
MN
CEA
Janaf
GasTbl



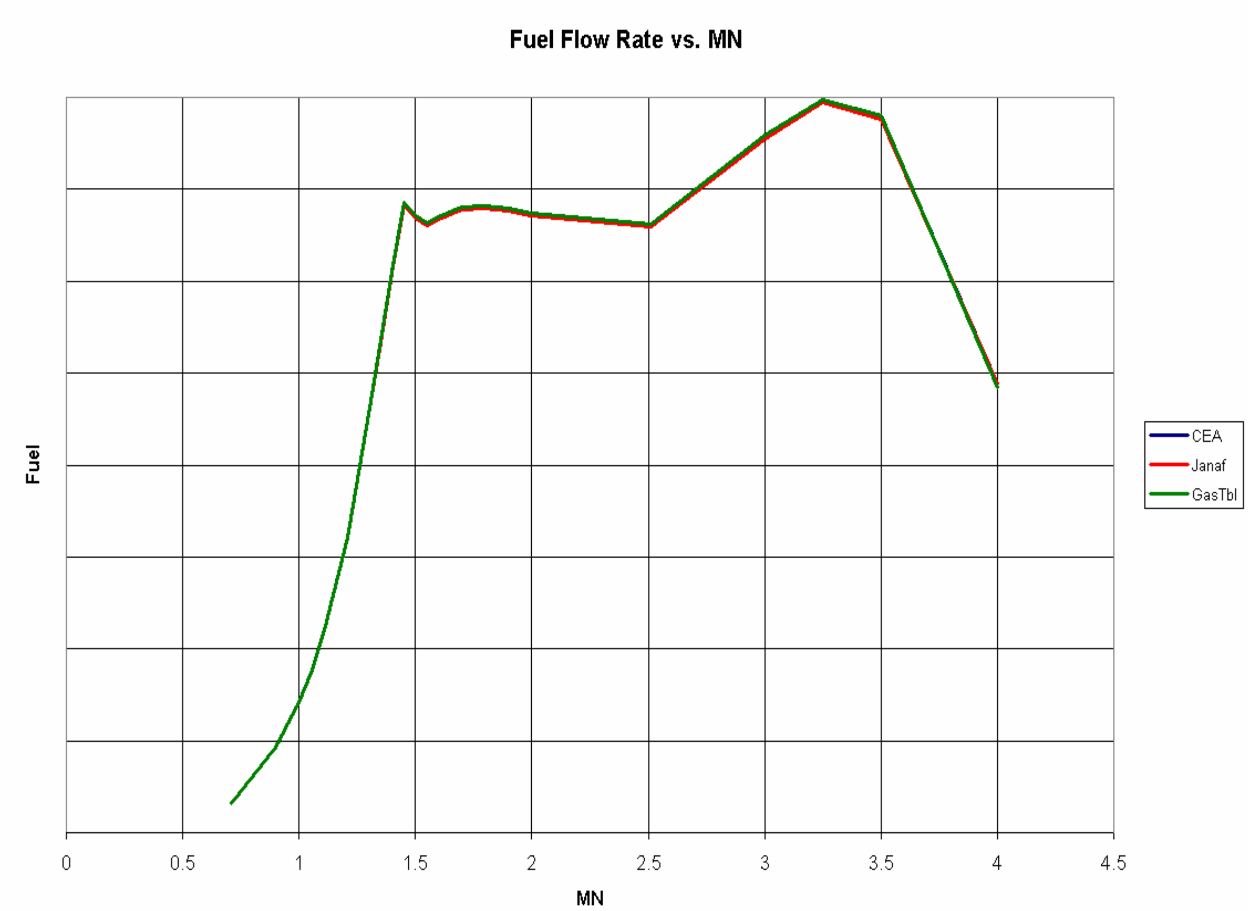
T7 (Afterburner Exit) vs. MN
T7
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
MN
CEA
Janaf
GasTbl

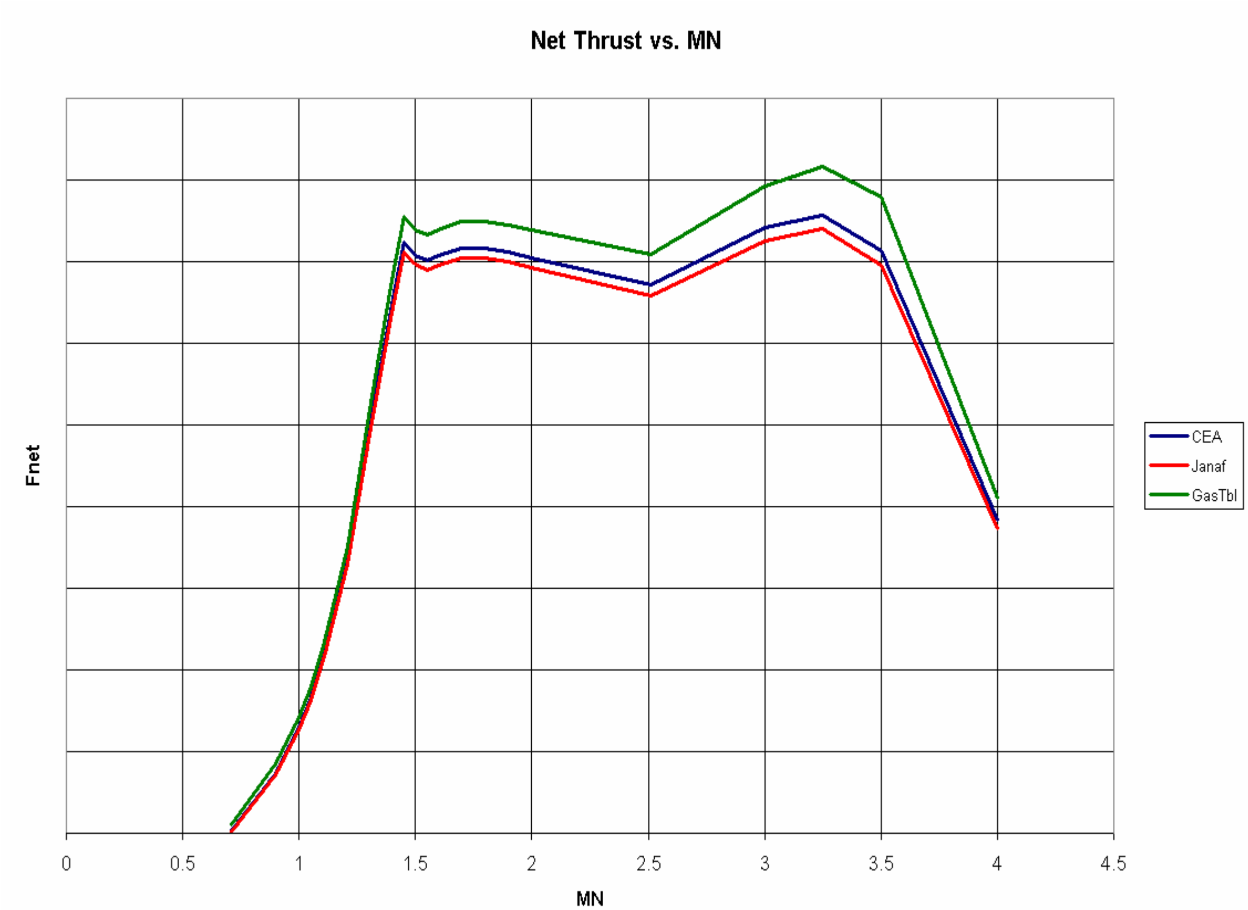


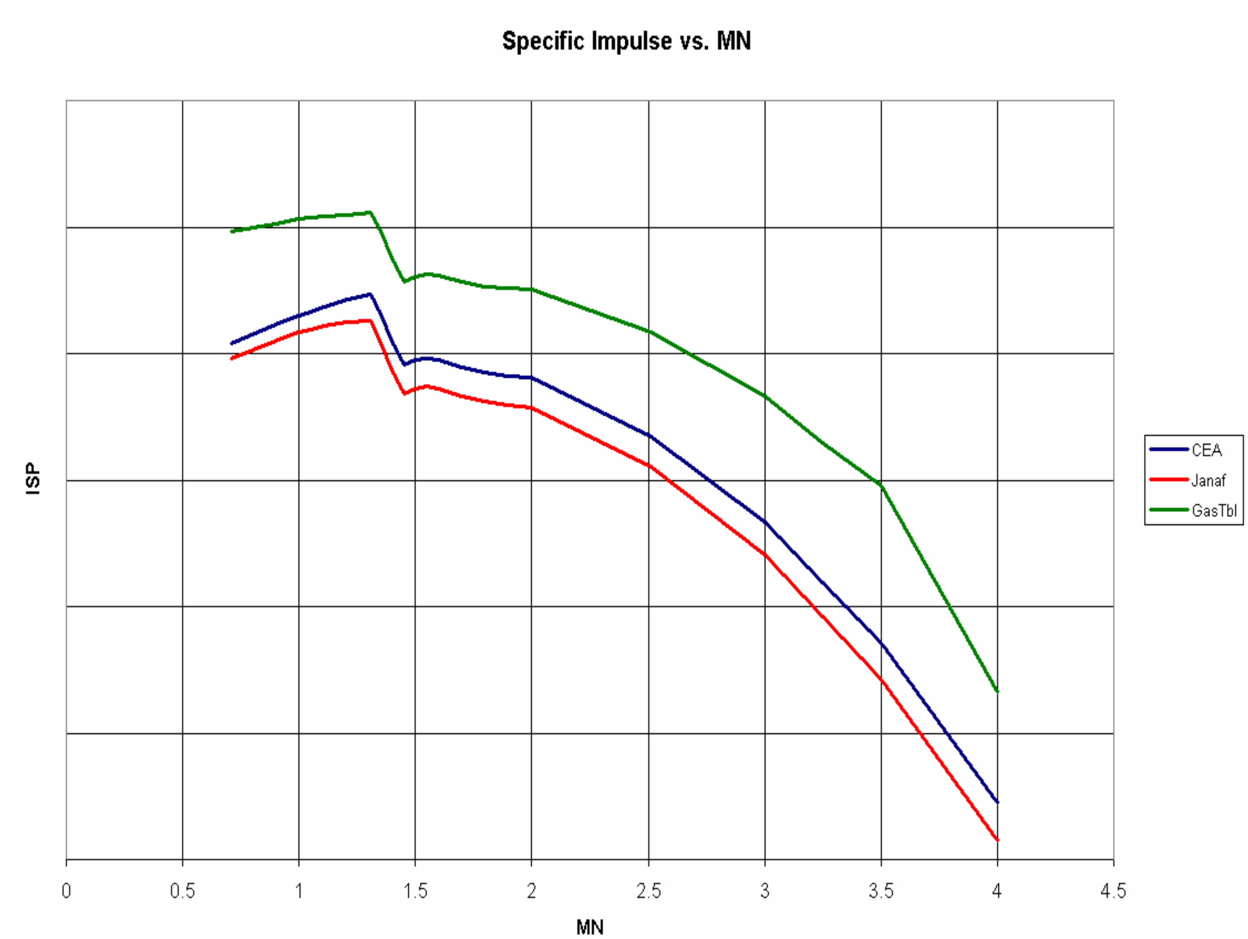
Afterburner Delta T (T7-T6) vs. MN
T7-T6
MN
1600
1500
1400
1300
1200
1100
1000
900
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl



Cp/Cv at Nozzle Throat vs. MN
gamt8
MN
1.30
1.26
1.22
1.18
1.14
1.10
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl


Fuel Flow Rate vs. MN
Fuel
MN
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl


Net Thrust vs. MN
Fnet
MN
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
CEA
Janaf
GasTbl



Space Shuttle Main Engine (SSME) Modeling in NPSS

- **Purpose**

  To develop and verify the use of NPSS for space propulsion system modeling using an established benchmark system – the SSME.

- **Approach**
  - **Validate the NPSS model results against those from an established simulation program – the Rocket Engine Transient Simulator (ROCETS) software.**
  - **Demonstrate NPSS benefits, enhanced capabilities and flexibility relative to existing simulation software.**
  - **Develop a library of space component models (turbines, pumps, ducts, combustors, etc.) which can be used generically to model other space systems.**

BOEING
Rocketdyne Division

2002 CISO Review

SSME Modeling with NPSS (continued)

- Progress
  - Select library of generic space components developed.
  - Component models unit tested.
  - Preliminary modifications to NPSS thermo package interface completed.
  - SSME system model completed.
  - Beginning SSME system model testing (to be completed Oct 2002).
- Lessons Learned
  - Space propulsion systems have a very different set of data flow requirements than air-breathing elements typically do. The NPSS architecture will handle this, but requires the component programmer to clearly understand differences.
  - Space propulsion systems require fluid input and output port interfaces that are more flexible than those typically required for air-breathing system models. We need to disable some of the features included to prevent users from doing something unintended.

BOEING
Rocketdyne Division

2002 CISO Review

Status of Combined Cycle Work (CC)

- Team has developed an initial hypersonic library
- Team has developed an initial heat transfer capability
- Test models created of ISTAR at different operating points
  - Operating points run as separate design points
  - Not an NPSS issue, don't have off-design data

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Hypersonic/Heat Transfer Library

- Created new elements
  - Isolator, Burner, RocketMixer, Heat Transfer
- Heat transfer based on expander cycle (cool-side) and new heat transfer module (hot-side)
- Serve as a good first pass
  - Need to be upgraded to be accepted by the hypersonic community
- Major part of this years work will be to get a first rate hypersonic/heat transfer capability

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

ISTAR Demo Models

- Model the feed system and flowpath together
  - Truly are combined cycle models
- Feed system has an oxidizer and fuel legs
- Rocket exhausts into the flowpath in a mixer element
- Heat transfer from flowpath has a major impact on feed-system balance and feed system obviously effects flowpath solution
- Need combined solutions

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Future Plans for Space Team

- Develop first-rate rocket analysis capability
- Develop first-rate hypersonic capability
- Support NASA programs
  - TBCC/RTA
  - ISTAR????

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting

October 9-10, 2002

Coupled Fluid and Structural Analysis of Pump Stages for Space Propulsion Systems

Chunill Hah

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Coupled Fluid and Structural Analysis of Pump Stages for Space Propulsion Systems

C. Hah
NASA Glenn Research Center

J. Loellbach
ICOMP

A. K. Owen
NASA Glenn Research Center

S. Khandelwal
RS Information Systems, Inc.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Objective

- Develop a coupled fluid/structure analysis tool for rocket turbopumps.
- Advance hardware concepts and designs.
- Improve safety, reliability, and cost of space transportation.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Background

- High power density of rocket engine pumps requires high-fidelity definition of pump environments.
- Currently, pump stage interaction effects and fluid/structure interaction effects are not modeled properly during the design cycle.
- Cavitation is not modeled during pump design cycle.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Coupled Fluid/Structure Analysis with Cavitation Modeling

- **Flow: HPUMP3D (3D, unsteady Navier-Stokes code)**
- **Structure: ANSYS**
- **Coupling: Unified NPSS tool**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

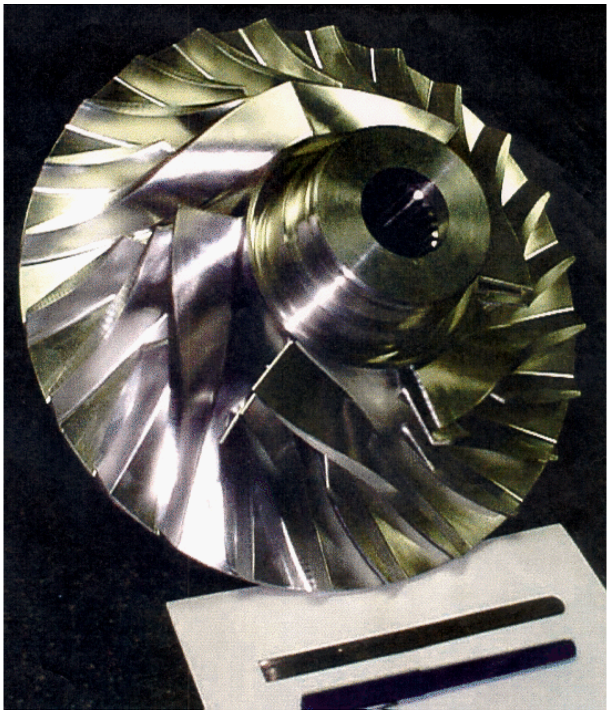
Validation of Flow Code for Rocket Engine Pumps

- **RLV pump stage**
- **Deep-throttle turbopump stage**
- **Cavitation in a cascade of pump blades**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Impeller from RLV Pump Stage



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

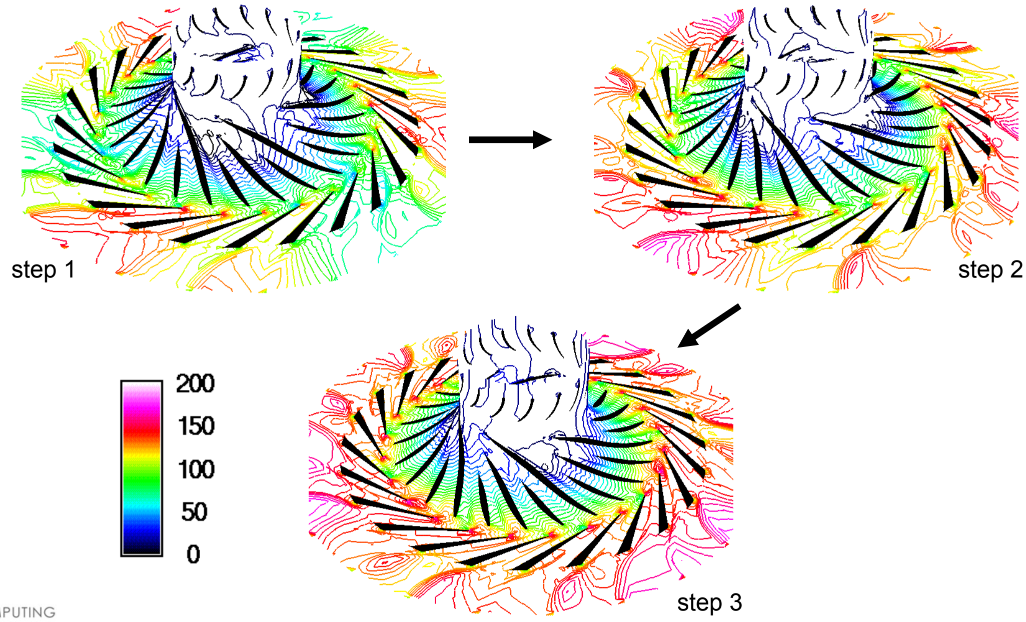
2002 CISO Review

Computational Grid for Numerical Flow Analysis of RLV Pump Stage

COMPUTING INFORMATION COMMUNICATIONS TECHNOLOGY

2002 CISO Review

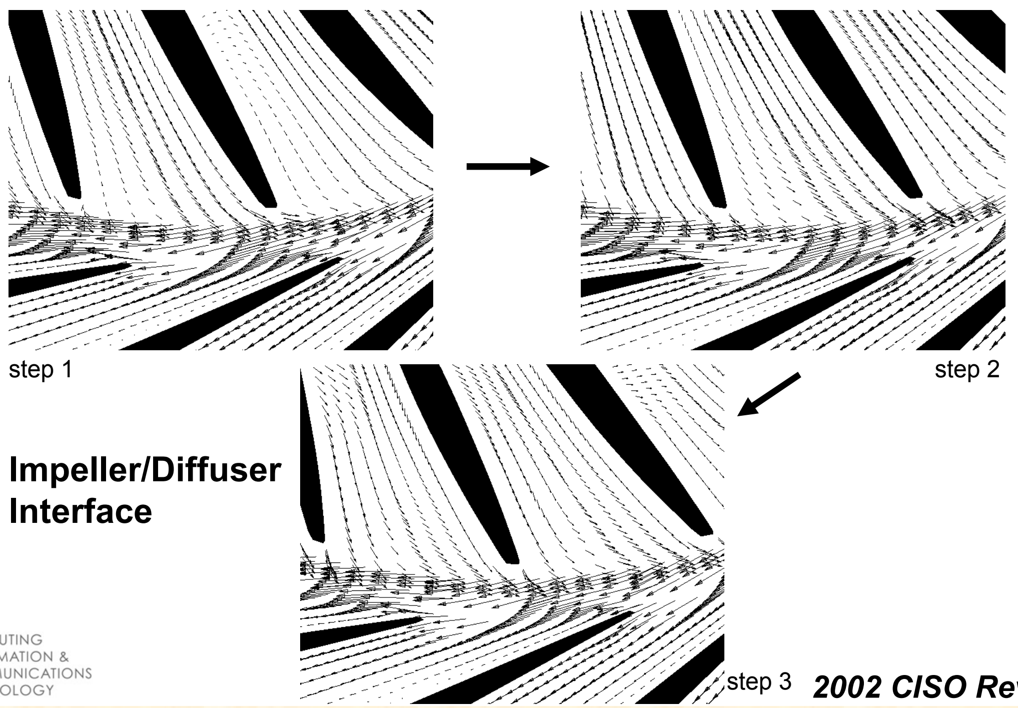
Mid-Span Pressure Contours at Three Different Time Steps (65% Mass Flow)



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

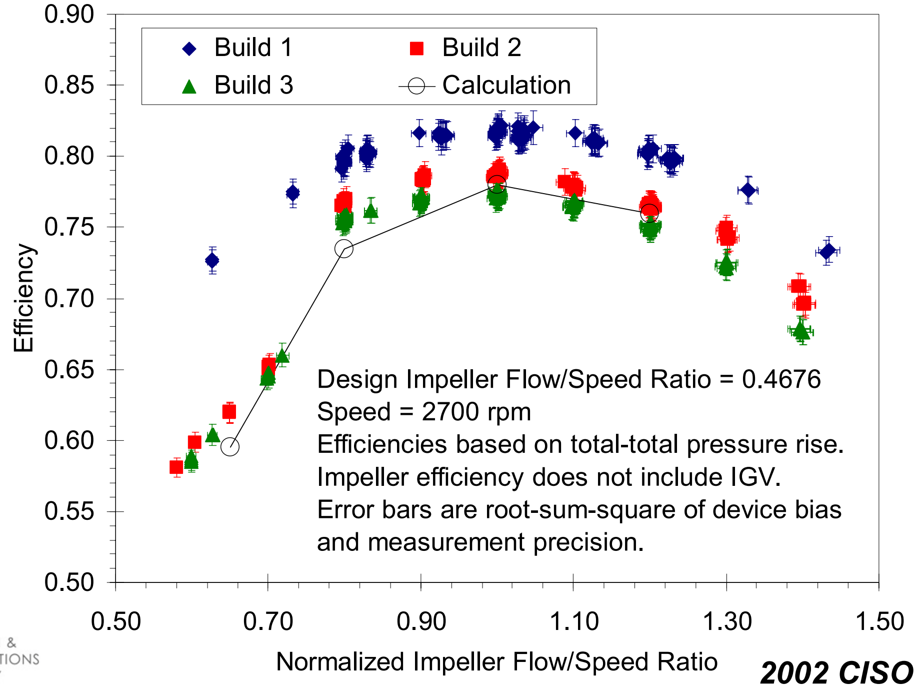
Mid-Span Velocity Vectors at Three Different Time Steps (65% Mass Flow)



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

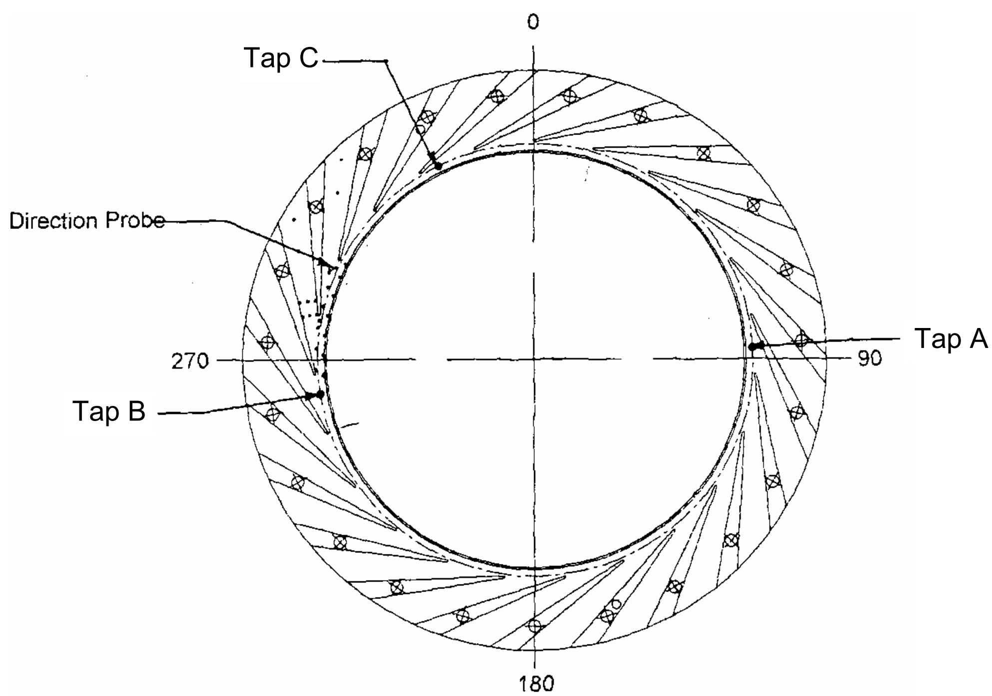
Comparison of Measured and Calculated Stage Hydraulic Efficiency



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

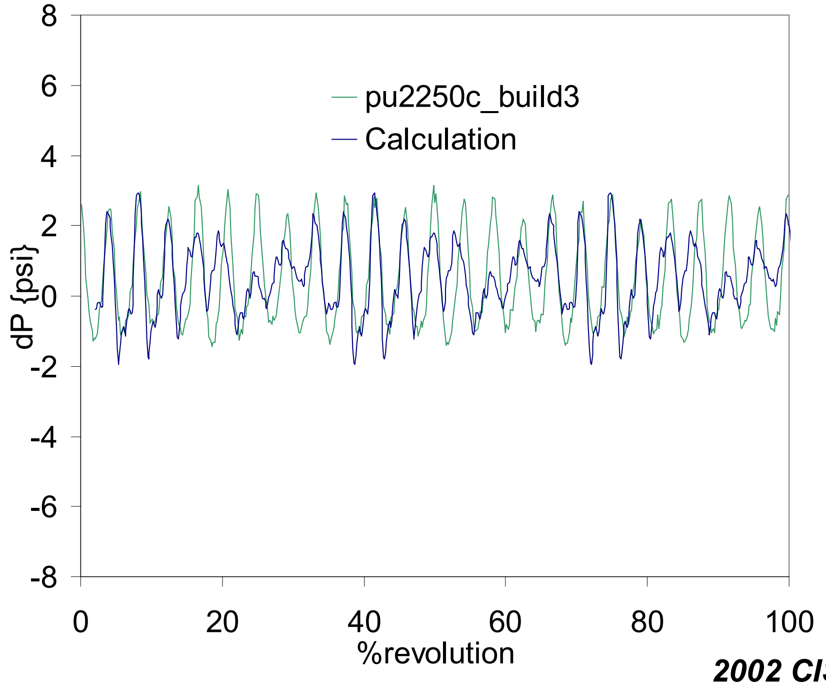
Unsteady Pressure Instrumentation



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

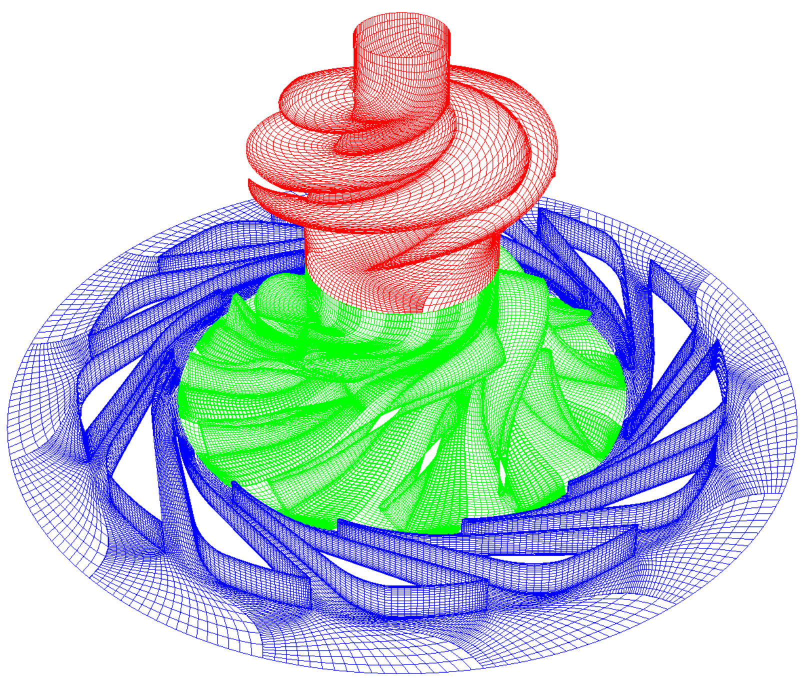
Comparison of Measured and Calculated Unsteady Pressure from Tap C



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

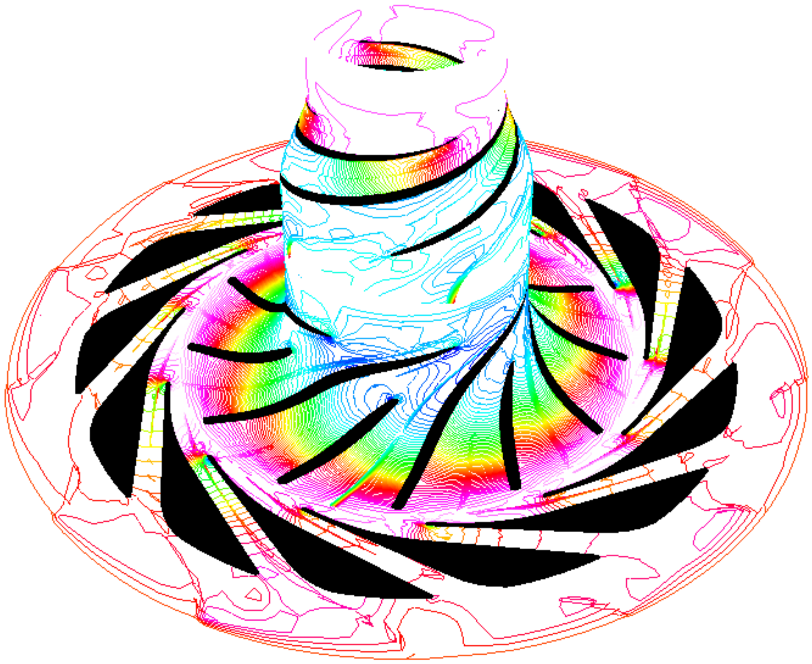
Deep-Throttle Stage Grids (inducer + impeller + diffuser)



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

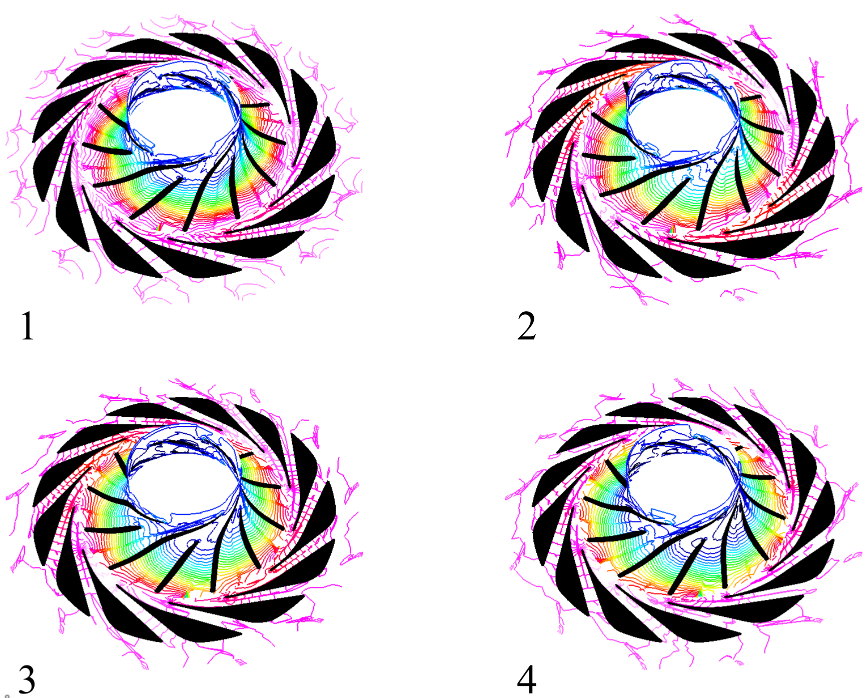
3D Steady Combined Pressure Field at Midspan



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

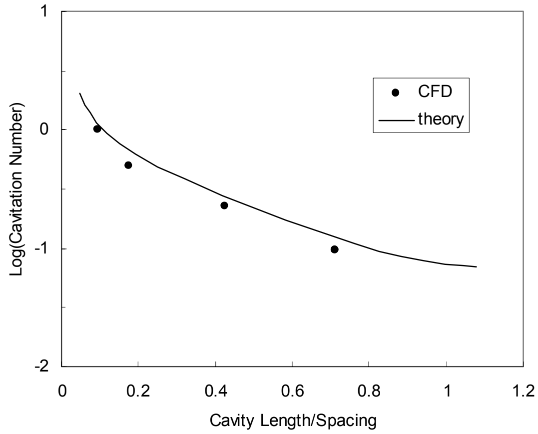
Midspan Static Pressure Distribution



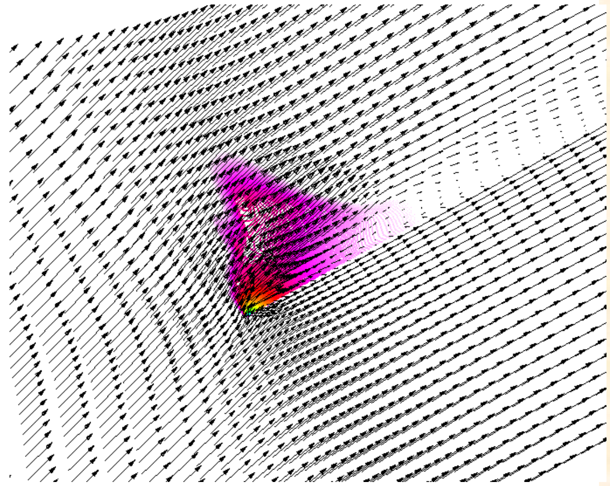
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Validation of Cavitation Modeling



Comparison of cavitation length.

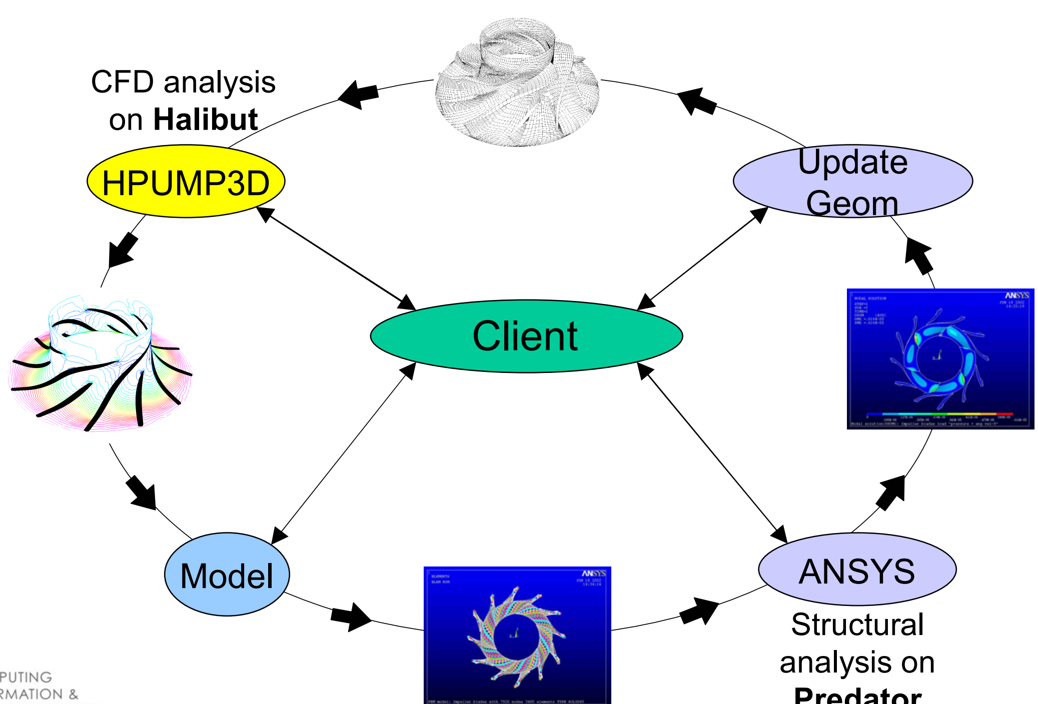


CFD simulation of cavitation in a cascade of flat plates.

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

HPUMP3D ↔ ANSYS



COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

Coupling of HPUMP3D and ANSYS

- HPUMP3D - cfd code
- ANSYS - structure code

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Executing Codes Using CCDK

- **C**orba **C**omponent **D**evelopment **K**it using indirect wrapper approach.
- Using IOR's as location identifiers.
- Allows bi-directional exchange of data files.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Demo - program in unix script (bourne shell)

- start all remote servers.
- run 'program Client'.
- kill all servers.

Client - written in C++.

- creates a new copy of all remote servers.
- executes all programs in sequence as defined.
- each server is connected to an executable program.
- controls execution loop, allows exchange of data.
- catches exceptions (unix signal 1 2 3 15) and stops.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

cfd - executes cfd code - HPUMP3D

- creates output files (for grid and solution)

Model - executes a program model.f

- reads grid and solution files (from cfd code).
- creates data files for nodes, elements and pressure to be read by ANSYS. Only blade geometry data are used.

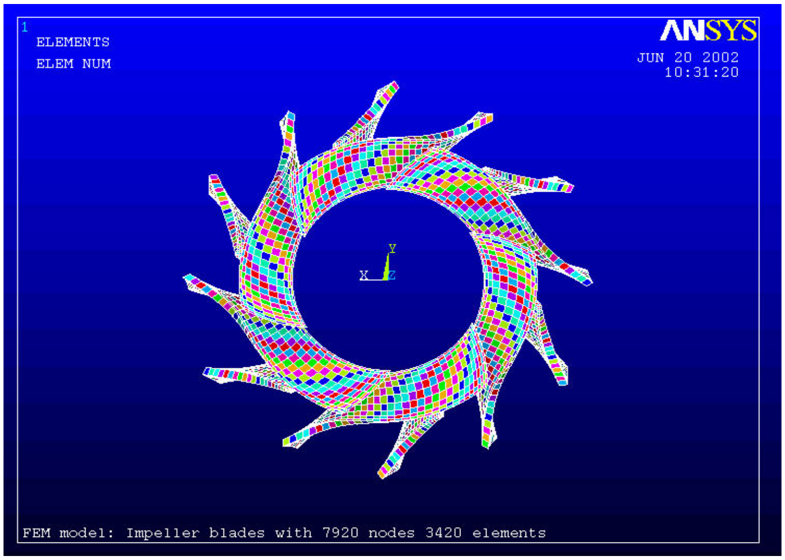
ANSYS impeller

- creates finite element model (FEM) by reading node and element data for impeller blades.
- find solution for load " pressure + angular vel".
- writes the new blade coordinates after solution.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

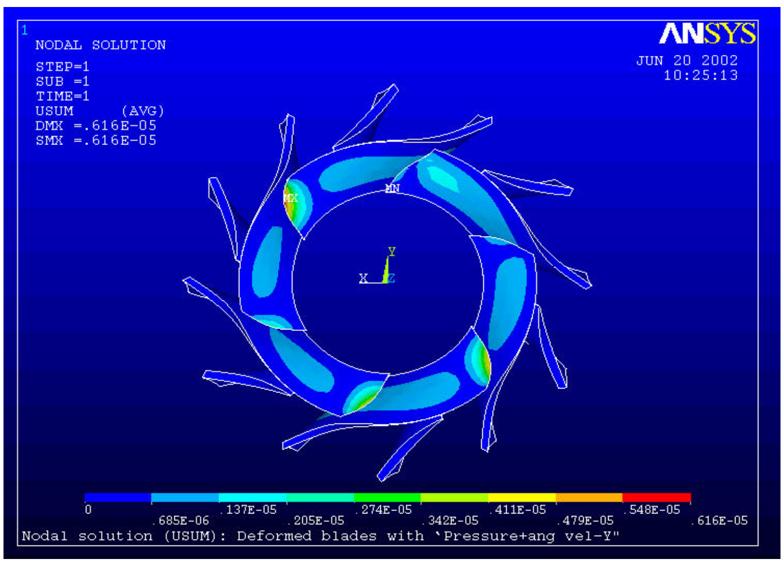
Impeller Blades: FEM Model



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Impeller Blades: Deformed Shape



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Update geom - program in Fortran (updgrid.f)

- creates new geometry data by replacing updated blade geometry (from ANSYS) in the original cfd grid data.

- generates a new grid for cfd calculations.

Current and Future Developments

- Complete transient coupled analysis of impeller.
- Full pump stage coupled analysis (IGV + impeller + diffuser).
- Implementation and validation of cavitation capability.

Multidisciplinary Analysis of a Hypersonic Engine

ISTAR Flowpath

Ambady Suresh
Mark Stewart

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

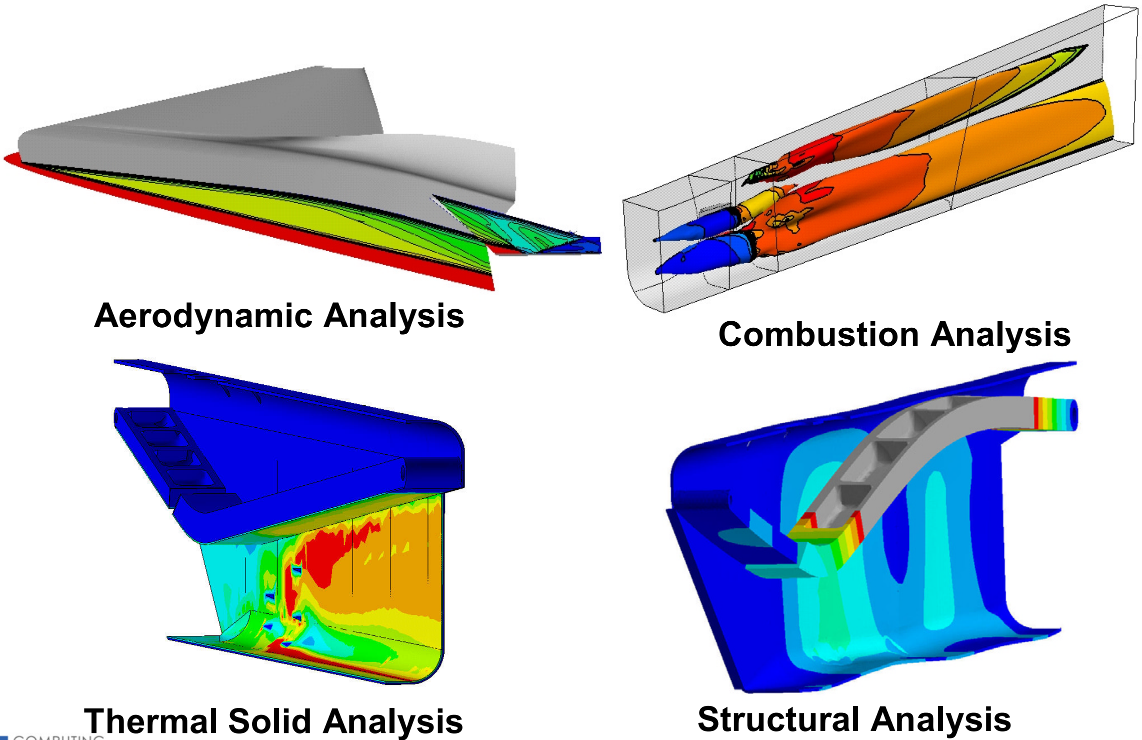
Outline

- Overview & Motivation
- Description of Component Simulations
- Consistent Multidisciplinary Solutions
- Code Coupling Issues
- Benefits & Costs of MD Analysis

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Multidisciplinary High Fidelity Analysis by Coupling Simulations



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

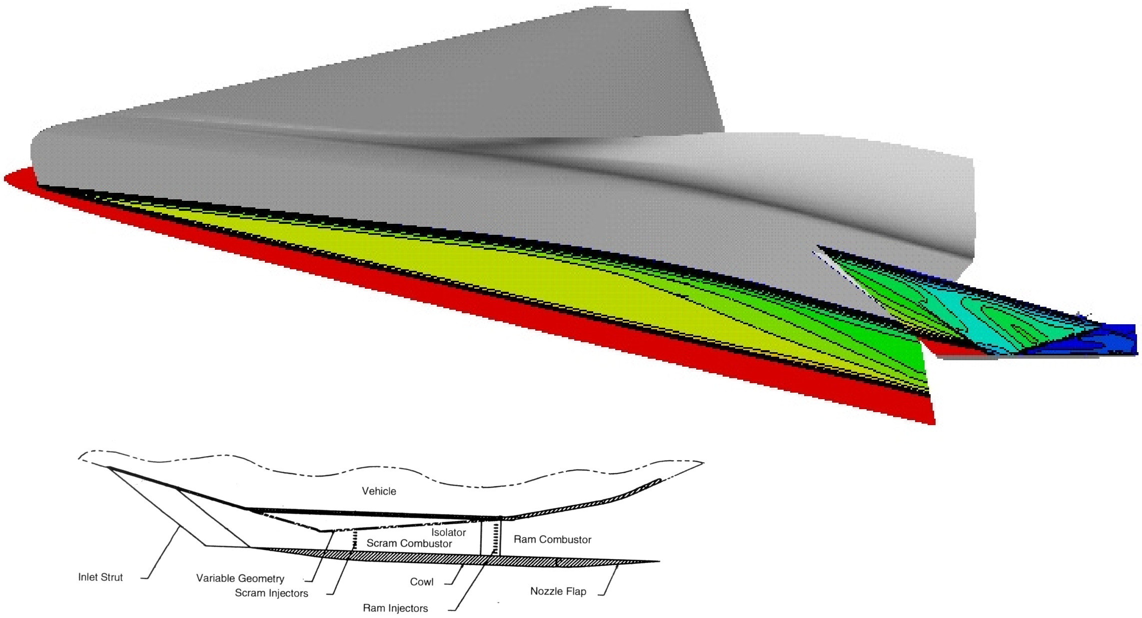
ISTAR Multidisciplinary Simulation: Objectives

- **Develop high fidelity tools that can influence ISTAR design**
- **In particular, tools for coupling Fluid-Thermal-Structural simulations**
- **RBCC/TBCC designers carefully balance aerodynamic, thermal, weight, & structural considerations; consistent multidisciplinary solutions reveal details (at modest cost)**
- **At Scram mode design point, simulations give details of inlet & combustor performance, thermal loads, structural deflections**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Approach Flow: Mach Contours



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Approach Solution

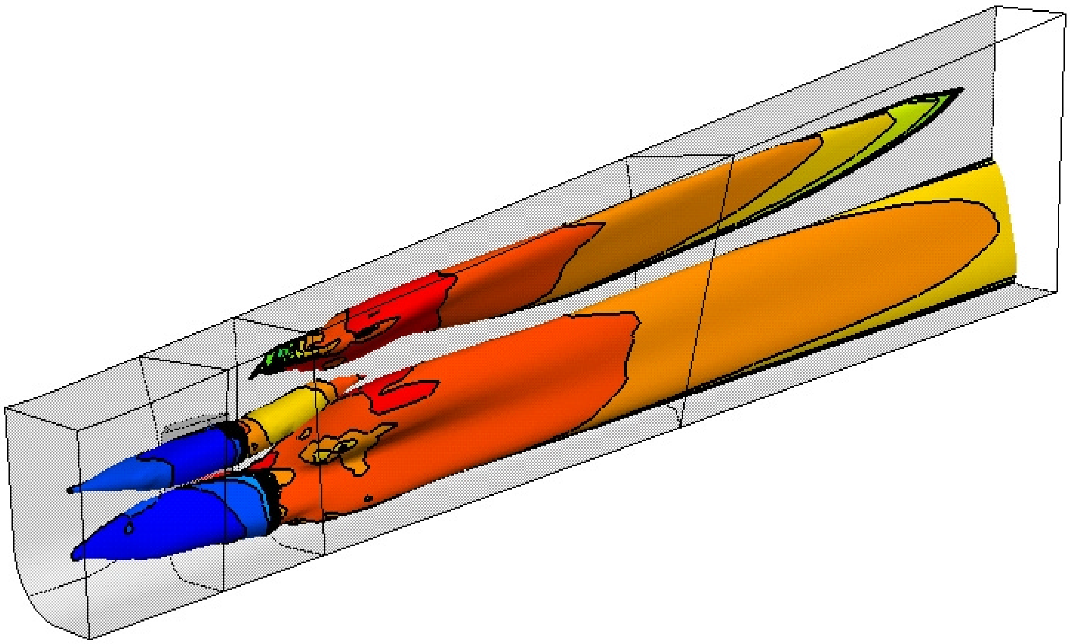
- **Full Navier-Stokes solution using *Overflow*.**
- **Simulation includes forebody, canard, & engine inlet—only forebody geometry that influences engine inflow**
- **Chimera five block structured grid with 9×10^5 cells.**
- **k-ω turbulence model with low-Reynolds number form—no compressibility correction**
- **Equilibrium chemistry**
- **Sets Combustor inflow**
- **Yields heat & pressure loads for thermal & structural analysis**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Combustor Solution:

Fuel mass fraction iso-surface colored by temperature



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

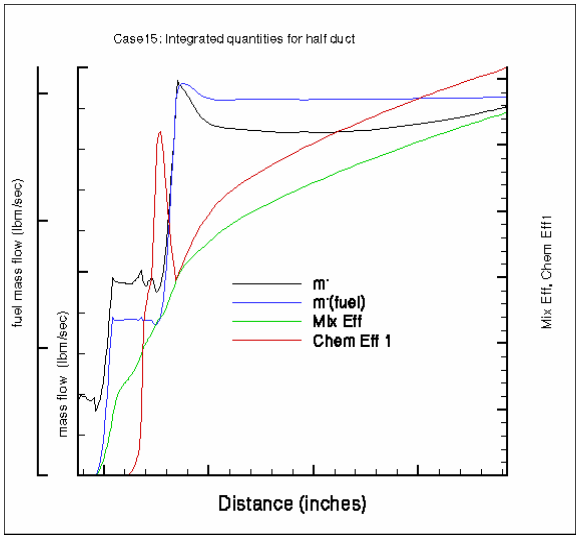
Combustor Solution

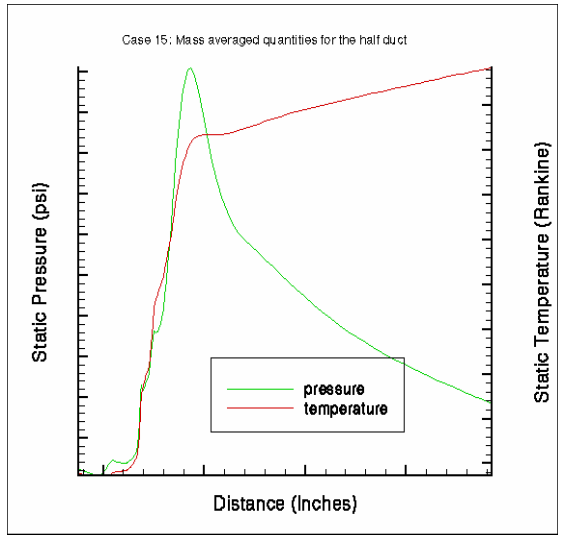
- Full Navier-Stokes plus finite-rate chemistry solution using *Vulcan*.
- Composite five block grid with 1.9×10^5 cells.
- 6-species 3-step finite-rate gaseous Ethylene model
- Inflow profile from Approach solution.
- k-ω turbulence model with wall functions; Compressibility correction
- Each injector modeled as a single triangular slot with equivalent area, massflow, and momentum. (normal injection).
- Flame holding cavity included.
- Yields heat & pressure loads for thermal & structural analysis

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

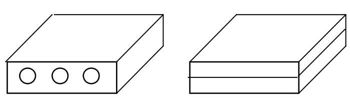
Combustor Solution:
1-D Averaged Quantities





Thermal and Structural Solutions

- ANSYS—commercial finite element solver.
- 3-D unstructured grid with $1.3\text{x}10^5$ nodes and $8.6\text{x}10^4$ tetrahedra
- Temperature dependent material properties for Inconel 625, Titanium β21S
- Coolant passages modeled as a bi-layer material



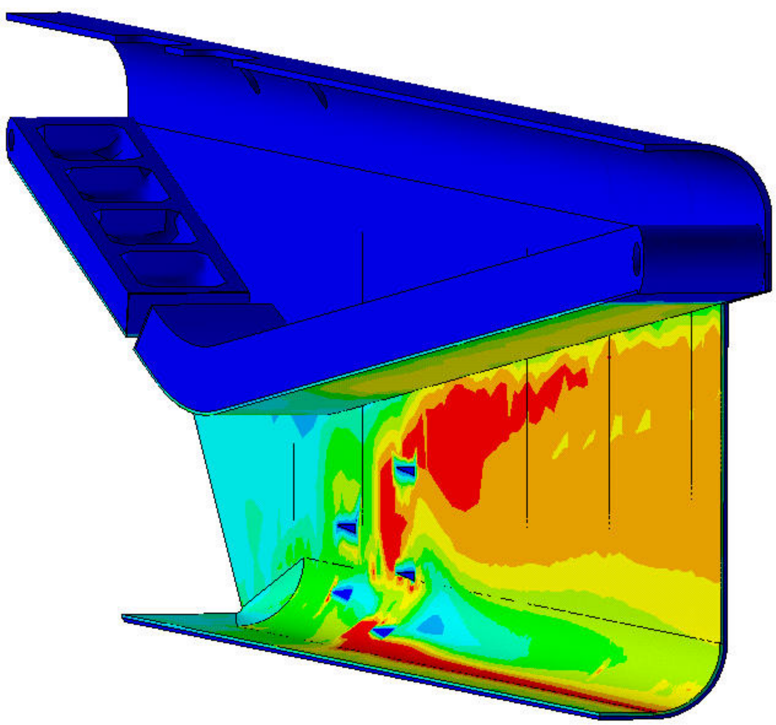
- Neglects details of heat conduction around coolant passages, plus structural effects
- Some modeling of coolant circuit.
- Thermal model yields temperatures from heat loads, coolant system, and material properties
- Structural model yields deflections & stresses from pressure & temperature loads

Ansys Thermal/Structural Grid

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

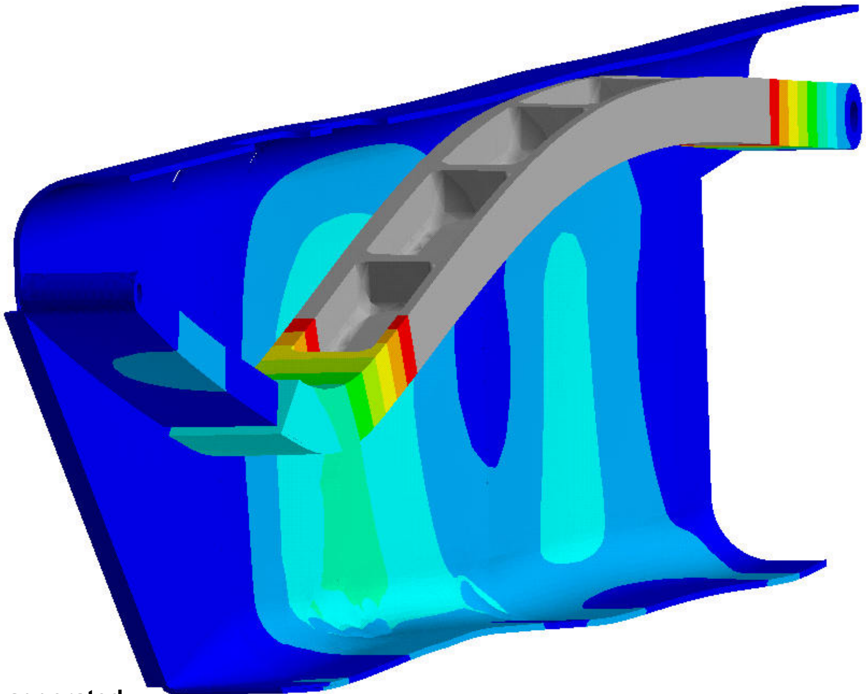
Coupled Thermal Solution



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Structural Solution

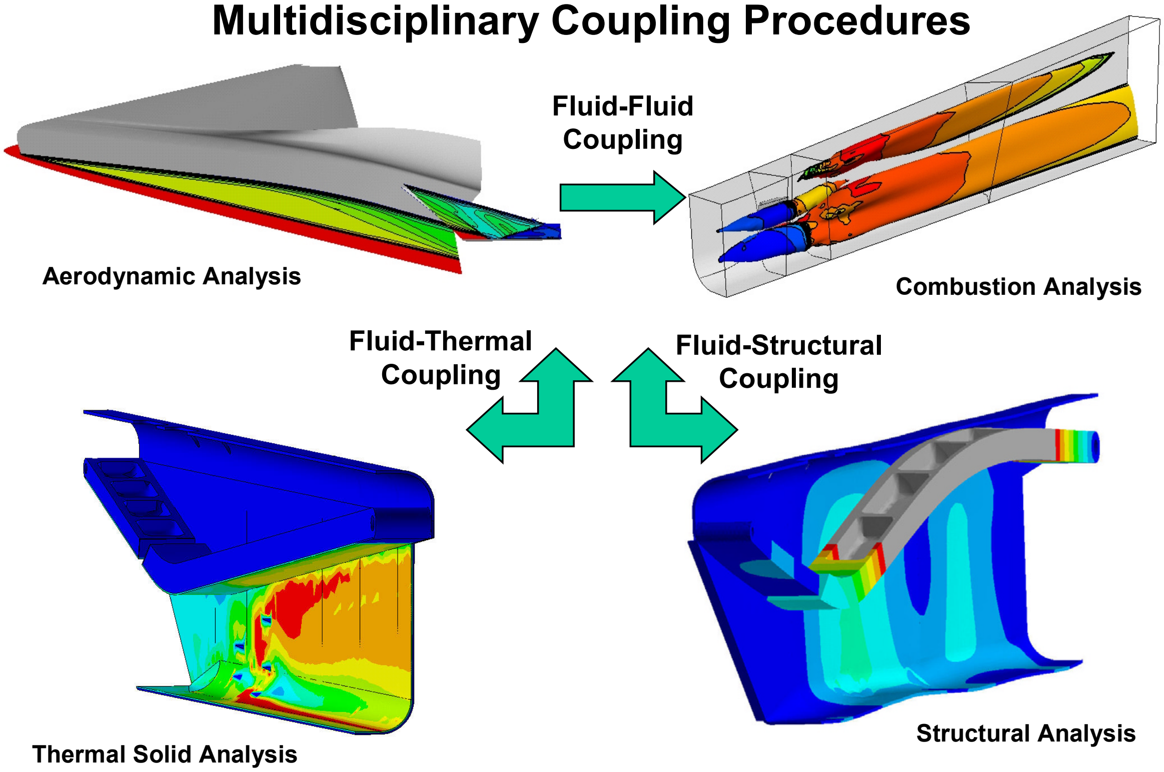


Deflections Exaggerated

COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

Multidisciplinary Coupling Procedures



COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

Consistent Multidisciplinary Solutions

- **Fluid-Fluid Coupling:** Flow quantities are the same where the Fluid codes meet
- **Fluid-Thermal Coupling:** Heat fluxes & Temperatures are the same where Fluid & Thermal codes meet
- **Fluid-Structural Coupling:** Deflected walls are the same as the Fluid boundaries

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

ISTAR Multidisciplinary Simulation: Interpolation & Consistency

- Interpolation transfers inflow profiles, thermal & pressure loads, displacements from code-to-code.
- One-pass:

  (Fluid $\Rightarrow$ Thermal $\Rightarrow$ Structural)

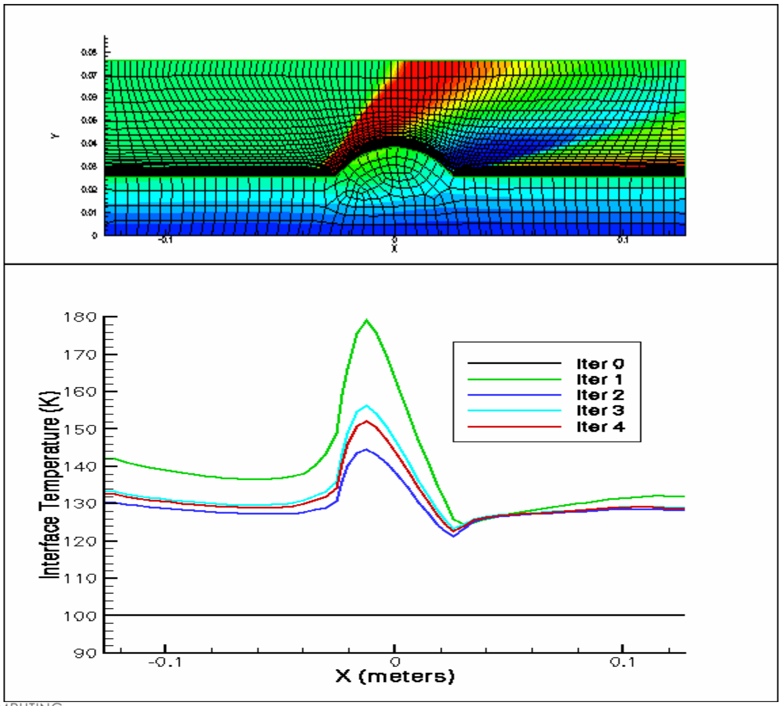
  Boundary conditions often inconsistent.
- Consistency achieved with multiple passes:

  (Fluid $\Leftrightarrow$ Thermal $\Leftrightarrow$ Structural)

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Fluid-Thermal Iteration



In engine case,
L2 Norm of:

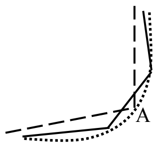
$\Delta T = 500\ ^oR$.

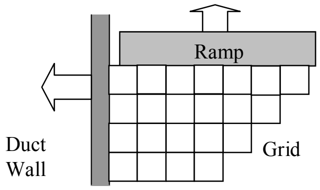
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Challenging Issues in Coupling: Toolkit Specific

- **Robust interpolation between codes on wetted surface**
  - Accept all types of grids and formats.
  - Some tolerance for out of plane target points.
  - Subsetting of source grids.
  - Extrapolation at boundaries.





- **Update fluid grids to include surface deflections**
  - Difficult when deformations, particularly shear deformations, exceed the grid spacing.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

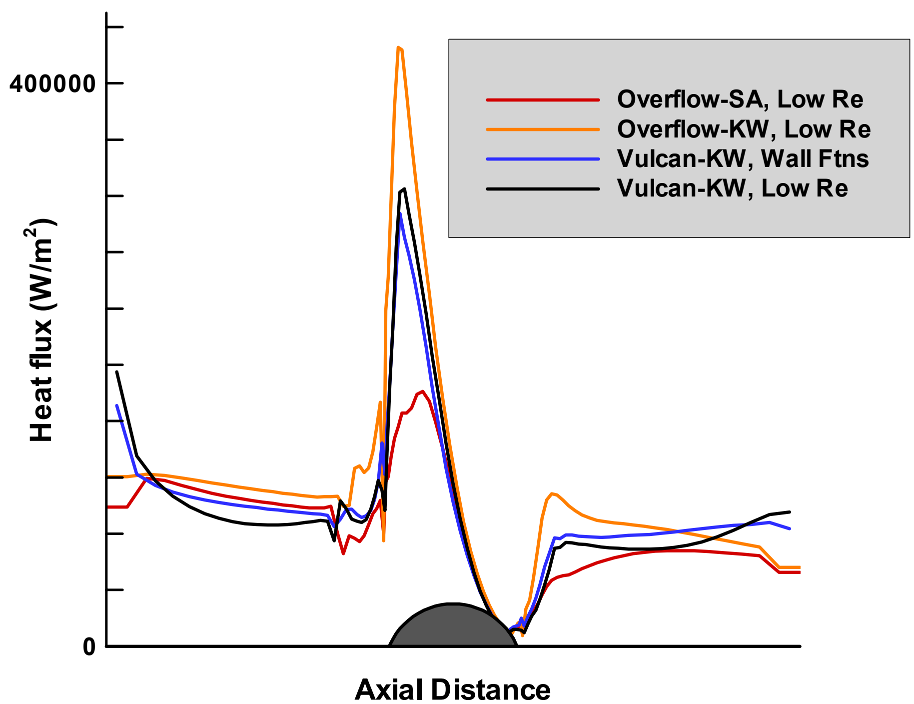
Challenging Issues in Coupling: Code Specific

- **Noisy heat fluxes from fluid codes**
- **Code compatibility w.r.t coupling (turbulence models, wall functions?)**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Calculation of Accurate Heat Fluxes



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Benefits & Costs

(Single Discipline vs. Multidisciplinary)

- **Cooling system design potentially aided by thermal/fluid calc.**
- **Computational cost: MD adds 100% of single discipline**
- **Cost of Setting up MD problem: a toolkit would help (Interpolation++)**
- **Disparate turn around times:**
  thermal & structural time is <1% of fluid & combustion

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Summary

- **Single discipline simulations coupled into Multidisciplinary simulation.**
- **Application is Scram design point of ISTAR concept vehicle**
- **Reveal some code coupling issues and obstacles, costs and benefits**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Cost Effective Testbeds and Code Parallelization Efforts

Annual Review and Planning Meeting
October 9-10, 2002

Isaac López

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Cost-effective Testbeds

- **Vision**
  - To integrated cost-effective high-performance systems into NASA Information Power Grid (IPG) and to show the US aerospace industry the capabilities of Grid Computing.
- **Objective**
  - To develop in cooperation with other NASA centers a distributed computational environment capable of executing full 3-D aerospace propulsion applications.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Cost-effective Testbeds

- This Cost-effective Testbeds task provides for the operation, maintenance, and support of the local GRC systems. It also provides initial user support. As part of providing the IPG testbed, the task provides local support for the Globus software and other grid services. A related effort is the evaluation of CORBA as the application interface to grid systems, including the provision of CORBA security services. In addition the computing testbeds are to provide a development environment for the grand challenge application.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

FY02 Accomplishments

- A compressible Lattice Boltzmann (LB) model has been successfully developed for turbomachinery simulations. Successful simulation of cascades has been carried out and it is the first successful turbomachinery simulation by a LB model. The parallel performance of the simulation was also outstanding, a 400:1 speedup was archived using 500 CPUs.
- A new upgrade to the Aeroshark cluster was procured and delivered to GRC. This upgrade focuses on faster CPUs and better interprocessor communications.
- Demonstrated a 3D simulation using CORBA over the Information Power Grid. VULCAN (Viscous Upwind ALgorithm for Complex Flow ANalysis) Code was used for this simulation.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

FY02 Accomplishments

- **The IPG tem at GRC had a major contribution to the completion of a PCA milestone for CICT/CNIS project. The team worked for months with ARC researchers to get their applications running on our clusters.**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Milestones

- **FY03**
  - Test and document the use of high performance interconnects on Commodity Based Cluster (4th Qt.).
  - Demonstrate coupling of high fidelity aerospace propulsion codes using CORBA on the Information Power Grid. (4th Qt.)
- **FY04**
  - Demonstrate and document the use of alternative schedulers capable of integrating seamless into the grid. (2nd Qt.)
  - Demonstrate a cost performance ratio of at least 15:1 on commodity based cluster vs. traditional UNIX clusters using an aerospace propulsion application. (3rd Qt.)
- **FY05**
  - Demonstrate hybrid network communication tool for applications utilizing the mobile and terrestrial grid (2nd Qt.)
  - Provide Seamless and Autonomous Information Power Grid Support to CORBA-Enabled Applications (2nd Qt.)
  - Upgrade commodity based cluster to 512 64bits CPUs (3rd Qt.) (Over guideline funds required for this milestone)

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Technical talks

- **Aeroshark Cluster Upgrade**
- **CORBA highlights**
- **A LATTICE BOLTZMANN METHOD FOR TURBOMACHINERY SIMULATIONS**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Commodity Based Cluster "Aeroshark"

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Why Commodity Based Clusters?

- Provide a cost-effective platform for running aerospace application.
- Introduce a heterogeneous component to NASA Power Grid

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

CBC upgrade
Why it was needed?

- In order to better impact more advanced simulations
- To make available a larger number of processors to a single simulation
  - Faster interconnects
- To bring cluster technology to current state of the art

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

CBC upgrade

Old cluster numbers:

- Processor speed: 600 MHz
- Memory speed: 100 MHz
- Memory/node: 512 MB
- Memory total: 32 GB
- Network bandwidth: 100 Mbps
- Network latency: 0.1 ms (1 x 10^-4 s)
- PCI bus peak performance: 132 MByte/s

New cluster numbers:

- Processor speed: 1667 MHz
- Memory speed: 266 MHz
- Memory/node: 1024 MB
- Memory total: 64 GB
- Network bandwidth: 2,000 Mbps
- Network latency: 7 ns (7 x 10^-9 s)
- PCI bus peak performance: 528 MByte/s

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

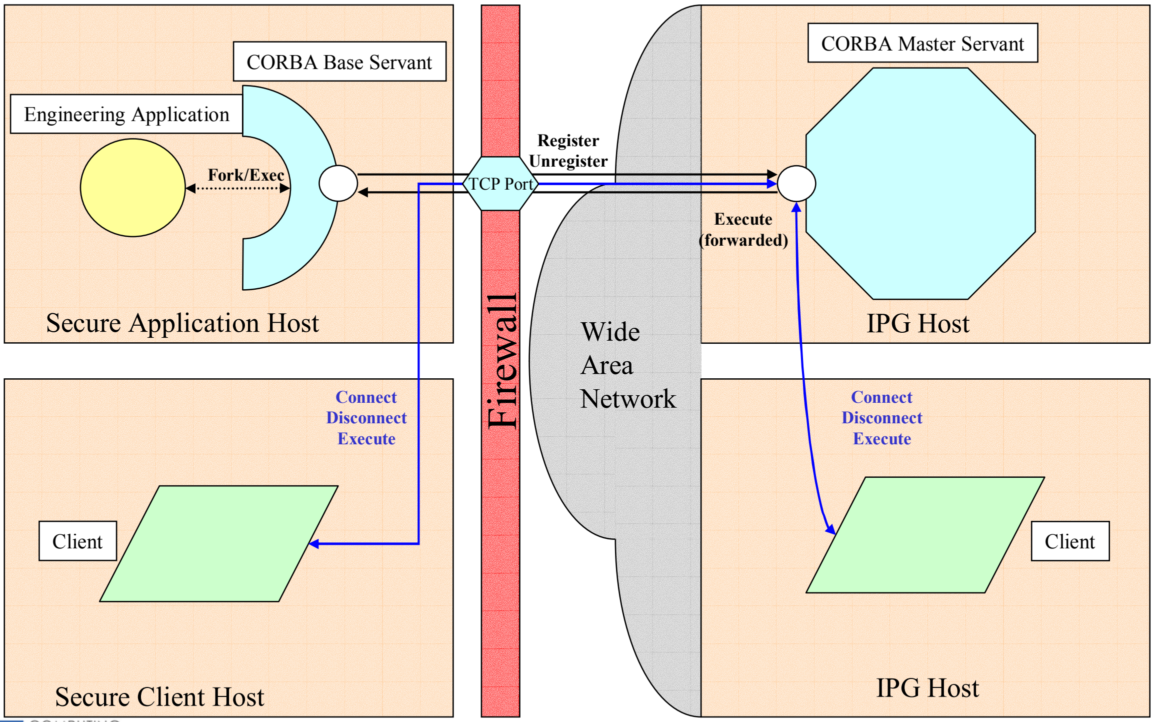
2002 CISO Review

CORBA Highlights

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

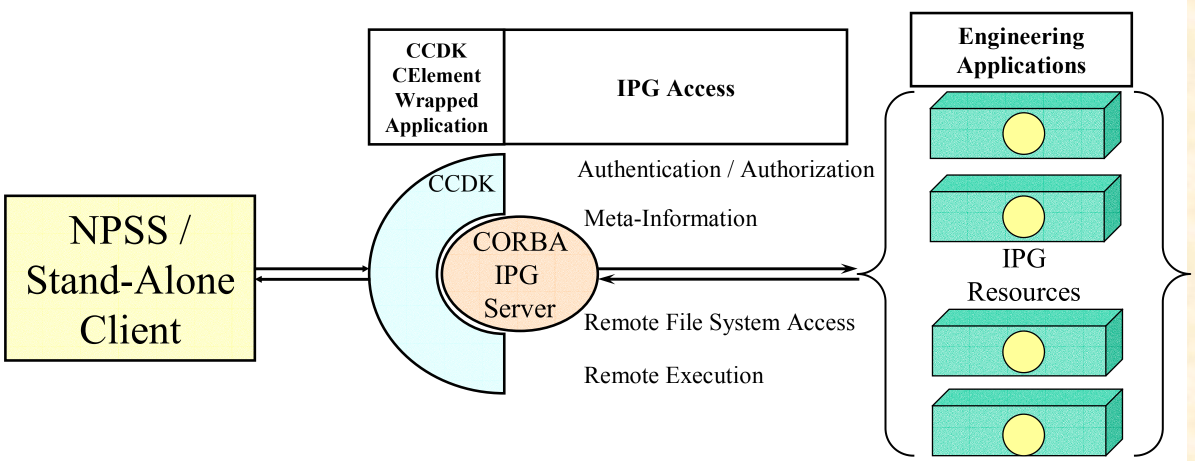
Bi-Directional IIOP Enables Cross-Firewall Interactions for Secure, Grid-Enabled Engineering Applications



COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 C

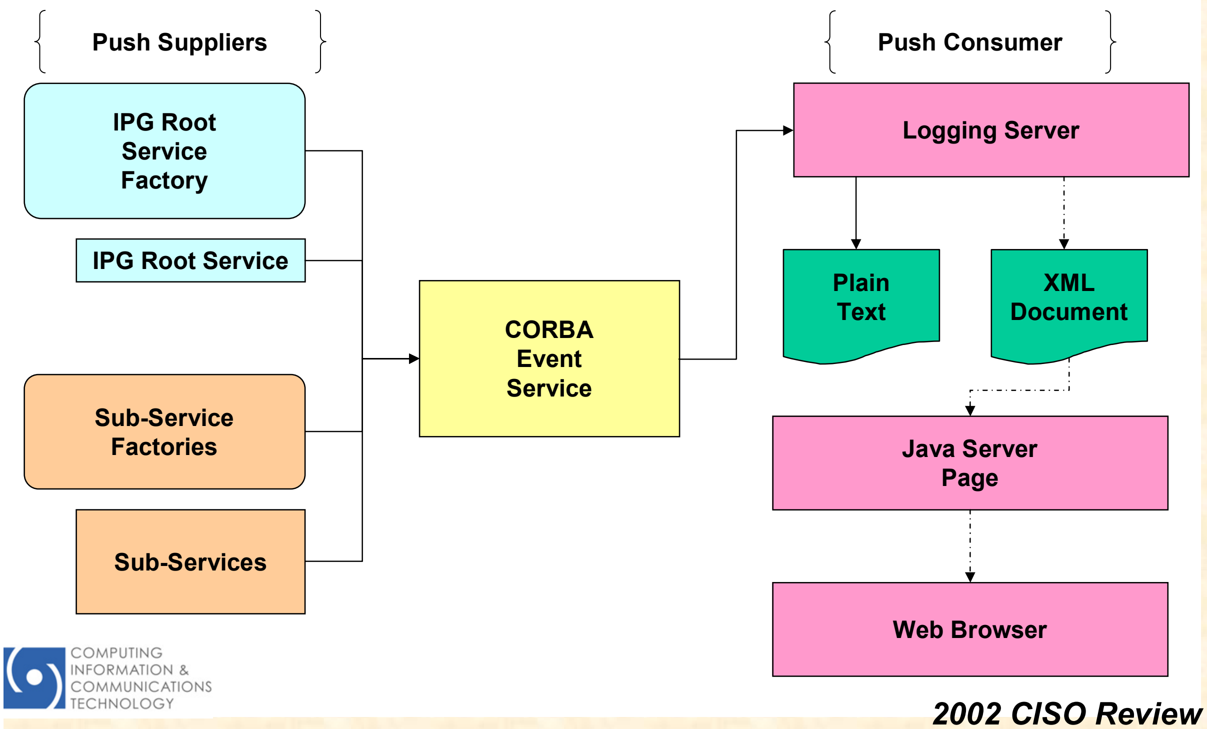
Integration of IPG with the NPSS CORBA Component Developers Kit



COMPUTING
INFORMATION &
COMMUNICATIONS
TECHNOLOGY

2002 CISO Review

CORBA-IPG Event Logging Service Architecture



A LATTICE BOLTZMANN METHOD FOR TURBOMACHINERY SIMULATIONS

A.T. Hsu[a], and I. Lopez[b]

[a]Department of Mechanical Engineering
Indiana University Purdue University Indianapolis
[b]NASA Glenn Research Center

October 2002

Computing and Interdisciplinary Systems Office
Glenn Research Center

2002 CISO Review

Outline

- Lattice Boltzmann Method
- Objectives
- Current LB model
- Simulation of cascades and result
- Parallel computing and result
- Conclusion remarks

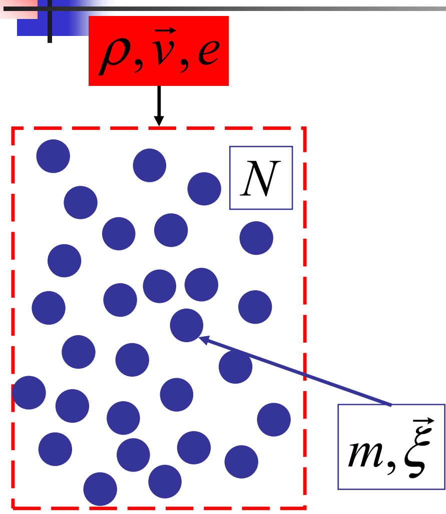
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Introduction

- Lattice Boltzmann (LB) Method is a relatively new method for flow simulations.
- The start point of LB method is statistic mechanics and Boltzmann equation.
- The LB method tries to set up its model at molecular scale and simulate the flow at macroscopic scale
- LBM has been applied to mostly incompressible flows and simple geometry

Statistic Mechanics

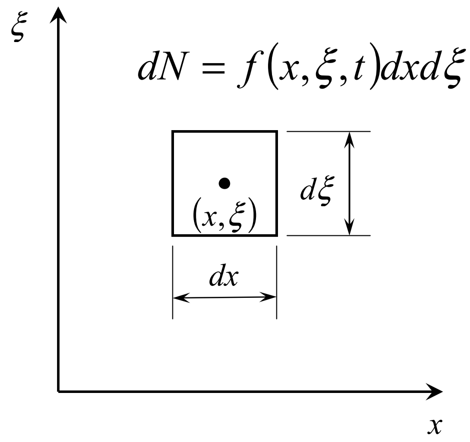


A small domain near point x

- Statistic mechanics views fluid as a collection of particles.
- The properties of the fluid are determined by the average properties of the particles in the collection

Boltzmann Equation
1) Distribution Function

$$dN = f(x,\xi,t)\,dx\,d\xi$$



Phase space for 1D problem

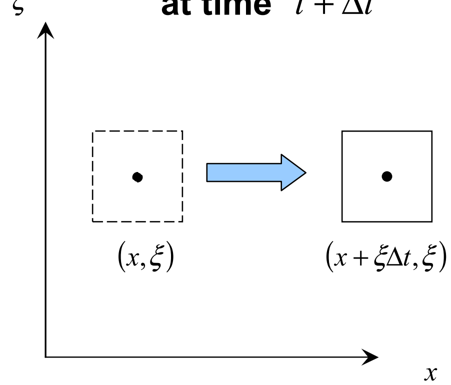
- A phase space consists of both location and velocity of particles is introduced.
- The distribution function is defined as the density of the number of particles at point (x,ξ)

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Boltzmann Equation
2) Time Evolution Of Distribution Function

at time $t+\Delta t$



- Assume that there is no external force and no collision between the particles, the velocity of the particles will not change

The two domain have the same number of particles

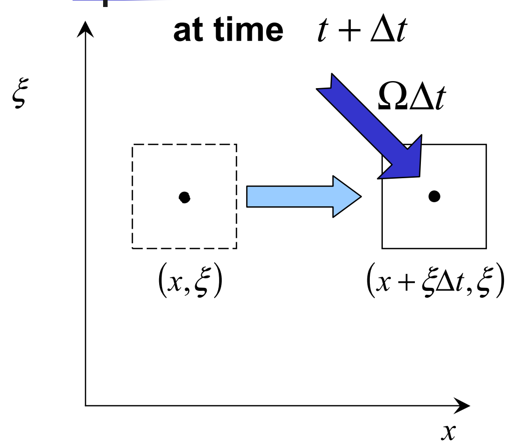
$$f(x+\xi\Delta t,\xi,t+\Delta t)\,dx\,d\xi = f(x,\xi,t)\,dx\,d\xi$$

$$f(x+\xi\Delta t,\xi,t+\Delta t) = f(x,\xi,t)$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Boltzmann Equation
3) Collision Term



- **Collisions between particles change their velocities, and make them move in and out of the domain**
- **A collision term describes the net increase of the density of the number of particles in the domain due to the collision**

$$f(x+\xi\Delta t,\xi,t+\Delta t)=f(x,\xi,t)+\Omega\Delta t$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Boltzmann Equation
4) BGK Collision Term

- **One of the simplest collision models is the Bhatnagar, Gross and Krook (BGK) simplified collision model**

$$\Omega=-\frac{1}{\tau}\left(f-f^{(eq)}\right)$$

- **The BGK model is widely used in LB models**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Boltzmann Equation

5) Boltzmann Equation

- **The Boltzmann equation in finite difference form:**

$$f\left(\vec{x}+\vec{\xi}\Delta t,\vec{\xi},t+\Delta t\right)=f\left(\vec{x},\vec{\xi},t\right)+\Omega\Delta t$$

- **By Taylor expansion, the above equation can be written in the differential form**

$$\frac{\partial f}{\partial t}+\vec{\xi}\cdot\vec{\nabla}f=\Omega$$

This is the Boltzmann Equation

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Macroscopic Properties

$$Y\left(\vec{x},t\right)=\frac{\int\eta\left(\vec{\xi}\right)f\left(\vec{x},\vec{\xi},t\right)d^3\xi}{\int f\left(\vec{x},\vec{\xi},t\right)d^3\xi}$$

- **The Macroscopic properties are determined by the average value of properties of the particles**

density $$\rho=m\int f(\vec{x},\vec{\xi},t)d^3\xi$$

momentum $$\rho\vec{v}=m\int\vec{\xi}f\left(\vec{x},\vec{\xi},t\right)d^3\xi$$

thermal energy $$\rho\varepsilon=\frac{m}{2}\frac{D_f}{D}\int\left|\vec{\xi}-\vec{v}\right|^2 f\left(\vec{x},\vec{\xi},t\right)d^3\xi$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Enskog-Chapman Expansion

- It has been shown that the Euler equation and Navier-Stokes equation are the zeroth-order and first order approximations of the Boltzmann equation, respectively.,
- That is to say, the Boltzmann equation describes the fluid phenomena in a more accurate way than tradition fluid dynamics does

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Lattice Boltzmann Method

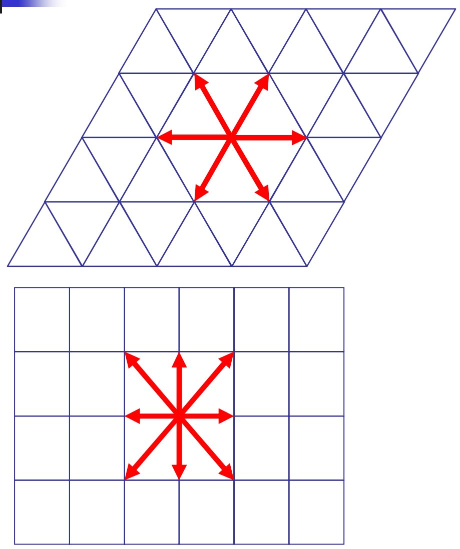
- Lattice Boltzmann Method can be reviewed as a numerical method to solve the Boltzmann equation
- In LB method, the phase space is discretized.
- In a LB model, the velocity of a particle can only be chosen from a velocity set, which has only a finite number of velocities

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Lattice Boltzmann Method

1) Velocity Set and Grid



- **For the convenience of computation, the position space is discretized in such a way that the particles travel with one of the velocity in the velocity set will arrive at a correspondent node at next time step.**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Lattice Boltzmann Method

2) Macroscopic Properties

- **In the LB method, the macroscopic properties are evaluated through the weight summation**

$$Y = \int \eta(\vec{\xi}) f^{(eq)}(\vec{x}, \vec{\xi}, t) d\vec{\xi} = \sum_{\alpha} W_{\alpha} \eta(\vec{\xi}_{\alpha}) f^{(eq)}(\vec{x}, \vec{\xi}_{\alpha}, t)$$

$$\rho = m \sum_{\alpha} f_{\alpha}^{(eq)} \qquad \rho\vec{v} = m \sum_{\alpha} \vec{\xi}_{\alpha} f_{\alpha}^{(eq)} \qquad \rho\varepsilon = \frac{m}{2} \sum_{\alpha} \left|\vec{\xi}_{\alpha} - \vec{v}\right|^2 f_{\alpha}^{(eq)}$$

where $f_{\alpha}^{(eq)}(\vec{x}, \vec{\xi}_{\alpha}, t) = W_{\alpha} f^{(eq)}(\vec{x}, \vec{\xi}_{\alpha}, t)$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Lattice Boltzmann Method

3) Time Evolution Equation

- Boltzmann equation in finite difference form with the BGK collision term

$$f\left(\vec{x}+\vec{\xi}_{\alpha}\Delta t,\vec{\xi}_{\alpha},t+\Delta t\right)=f\left(\vec{x},\vec{\xi}_{\alpha},t\right)-\frac{\Delta t}{\tau}\left(f\left(\vec{x},\vec{\xi}_{\alpha},t\right)-f^{(eq)}\left(\vec{x},\vec{\xi}_{\alpha},t\right)\right)$$

where $\vec{\xi}_{\alpha}$ is one of velocities in the velocity set

  - Set $\Delta t=\tau$

$$f\left(\vec{x}+\vec{\xi}_{\alpha}\Delta t,\vec{\xi}_{\alpha},t+\Delta t\right)=f^{(eq)}\left(\vec{x},\vec{\xi}_{\alpha},t\right)$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Lattice Boltzmann Method

4) The Calculation

$$Y(\vec{x},t)=\sum_{\alpha}\eta\left(\vec{\xi}_{\alpha}\right)f_{\alpha}^{(eq)}\left(\vec{x}-\vec{\xi}_{\alpha}\Delta t,\vec{\xi}_{\alpha},t-\Delta t\right)=\sum_{\alpha}Y_{\alpha}\left(\vec{x}-\vec{\xi}_{\alpha}\Delta t,t-\Delta t\right)$$

- The calculation of LB method can be viewed as following steps

  1) a node dividing its macroscopic quantities into parts

  2) the node sending parts of the macroscopic quantities to corresponding nodes

  3) a node receiving the parts of the macroscopic quantities sent by nearby nodes, adding them together and obtaining the macroscopic quantities for next time step

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Advantages of LB method

- Start from a clear and direct physical picture at molecular level;
- Algorithm is simple and straightforward;
- Natural parallel scheme;
- Easy to incorporate the physical phenomena at molecular level, possible of modeling fluid phenomena that can not be modeled with the traditional fluid mechanics.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Motivation

- There are very few reports about the successful LB simulations of the real life problems
- Successful extension of LB method to the simulation of turbomachinery can show the maturity of LB method and the promise of this method in the simulation of real life problem
- The parallel nature of LB method make it a possible high performance solver for turbomachine simulations

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Challenges

1. Most of LB models can only simulate the flow with a small Mach number
2. Most of past LB simulations are laboratory type simulations with simple computational domain and boundary
3. The proper LB model for simulation should be developed and necessary techniques should be developed

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Current Work

- Develop a compressible LB model.
- Introduce a boundary condition that allows accurate turbine blade simulation
- Develop mesh treatment for the irregular computational domain

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Current Work

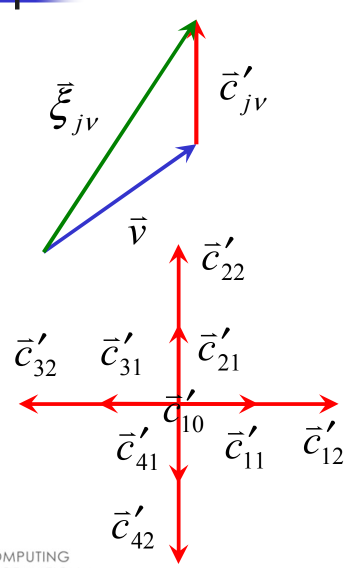
- **Simulations carried out for three different cascades. It is the first time that turbomachines have been simulated by a LB model.**
- **The parallel performance of the LB model has been tested**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model

1) The Velocity Set

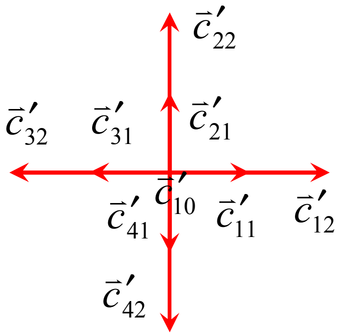


- **A velocity in the velocity set consists of three parts.**
- **First the macroscopic velocity has been included explicitly into the microscopic velocity.**
- **Second, there is a set of diffusion velocity**

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model
2) The Diffusion Velocity



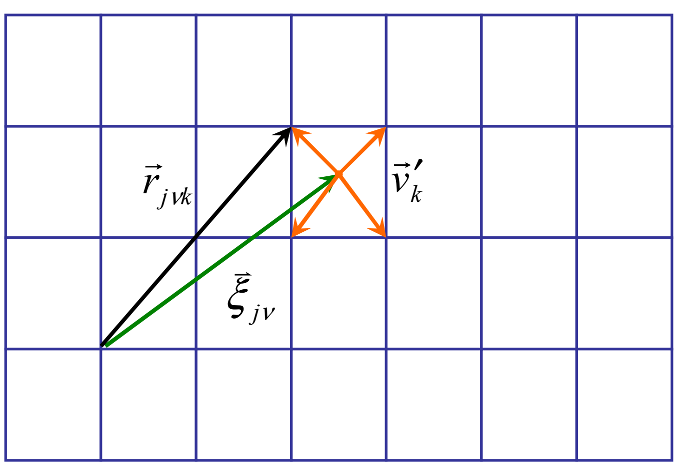
- There are 3 levels of diffusion velocity in current model
- The module of the diffusion velocities are determined by macroscopic quantities

$$c'_\nu = \begin{cases} 0 & for \quad \nu = 0 \\ \mathrm{int}\left(\sqrt{D(\gamma-1)\rho e/(\rho - b_0 d_0)}\right) & for \quad \nu = 1 \\ \mathrm{int}\left(\sqrt{D(\gamma-1)\rho e/(\rho - b_0 d_0)}\right) + 1 & for \quad \nu = 2 \end{cases}$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model
3) The Velocity Set



- A third set of velocities $\vec{v}'_k$ is introduced to carry the particles to the nearest vertex nodes

$$\vec{r}_{j\nu k} = \vec{v} + \vec{c}'_{j\nu} + \vec{v}'_k$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model
4) The Microscopic Quantities

- Mass, only one species is considered, is a constant

$$m = 1$$

- Velocity, consists of macroscopic velocity and a diffusion velocity

$$\vec{\xi}_{j\nu} = \vec{v} + \vec{c}'_{j\nu}$$

- Total energy is the same for all particles

$$\zeta = \frac{1}{2}v^2 + e$$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model
4) Modification of Microscopic Quantities

- For the purpose of recovering the correct Navier-Stokes equation, a correction term has been introduced

$$\chi_{j\nu k} = \frac{\rho}{\rho - b_0 d_0} \frac{D}{2c'^2_v} \left(\vec{c}'_{j\nu} \cdot \vec{v}'_k\right)$$

  - Mass $m_{j\nu k} = 1 - \lambda_{j\nu k}$
  - Velocity $\vec{\xi}_{j\nu k} = \vec{v} + \vec{c}'_{j\nu} - \lambda_{j\nu k}\vec{v}$
  - Total energy $\zeta_{j\nu k} = \left(1 - \lambda_{j\nu k}\right)\left(\frac{1}{2}v^2 + e\right)$

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Current Model

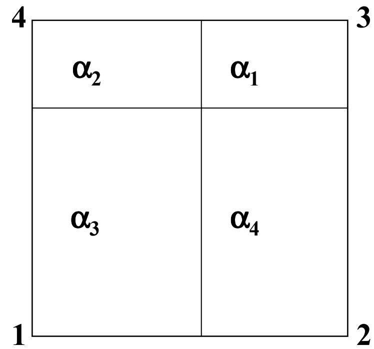
5) The Equilibrium Distribution Function

$$f_{j\nu k}^{(eq)} = f_{\nu k}^{(eq)}$$

$$f_{\nu k}^{(eq)} = \alpha_k d_\nu$$

$$d_1 = \frac{(\rho - b_0 d_0)c_2'^2 - D(\gamma - 1)\rho e}{b_1\left(c_2'^2 - c_1'^2\right)}$$

$$d_2 = \frac{D(\gamma - 1)\rho e - (\rho - b_0 d_0)c_1'^2}{b_2\left(c_2'^2 - c_1'^2\right)}$$



$$\alpha_1 = |u_3' v_3'| \qquad \alpha_2 = |u_4' v_4'|$$

$$\alpha_3 = |u_1' v_1'| \qquad \alpha_4 = |u_2' v_2'|$$

The Flow Chart Of Computation

Macroscopic properties

↓

Calculate the equilibrium distribution function | Calculate the microscopic velocities

↓

The destination of particles | Calculate the macroscopic properties to be sent

↓

Send

↓

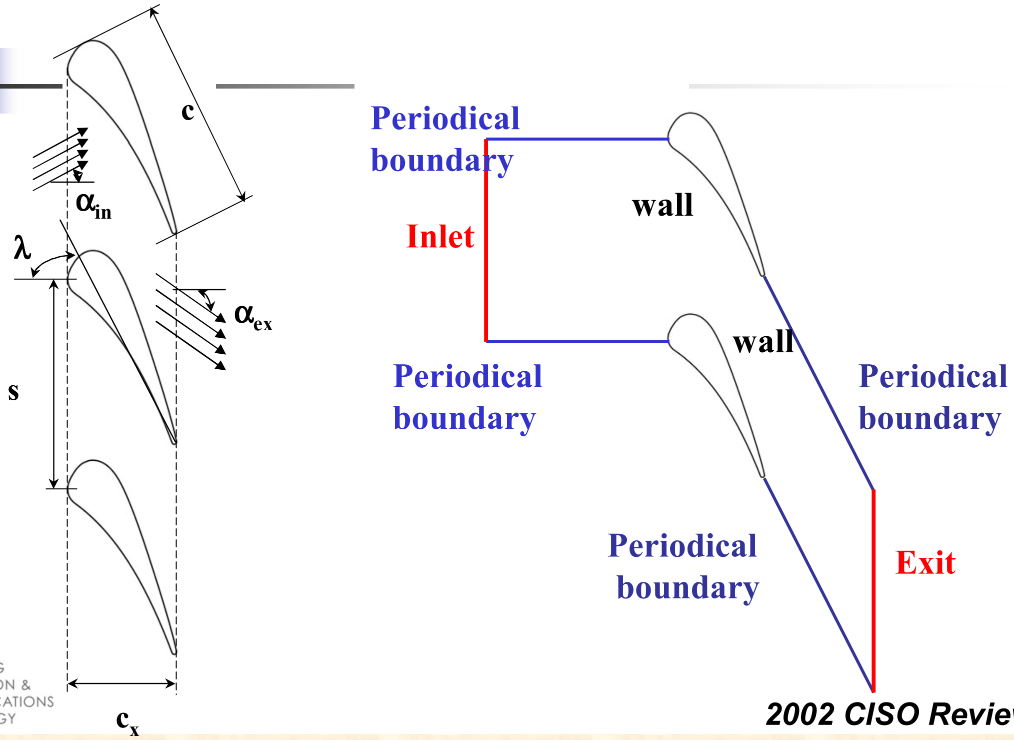
Receive

↓

Calculate the macroscopic properties of new time step

(→ back to Macroscopic properties)

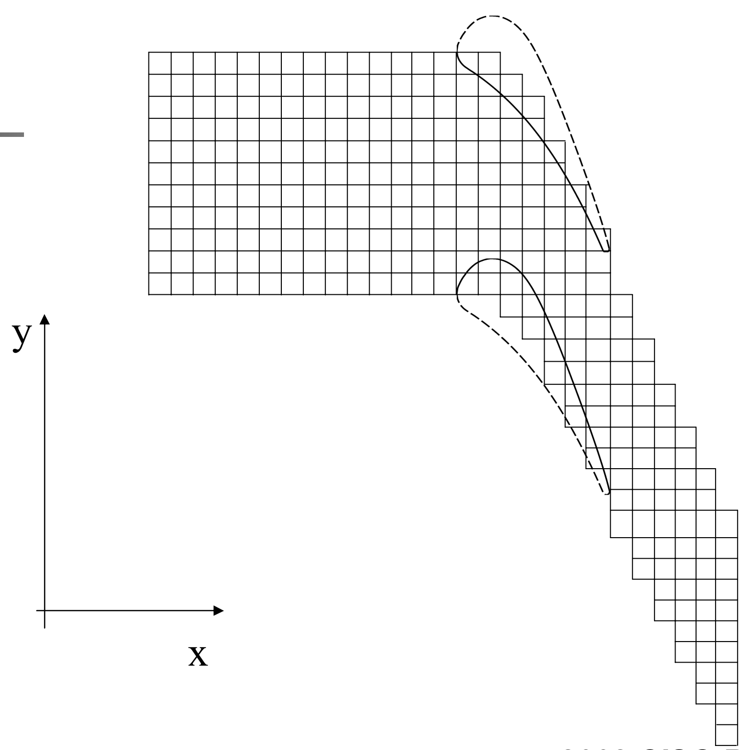
Geometry of Cascade and Simulation Domain



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

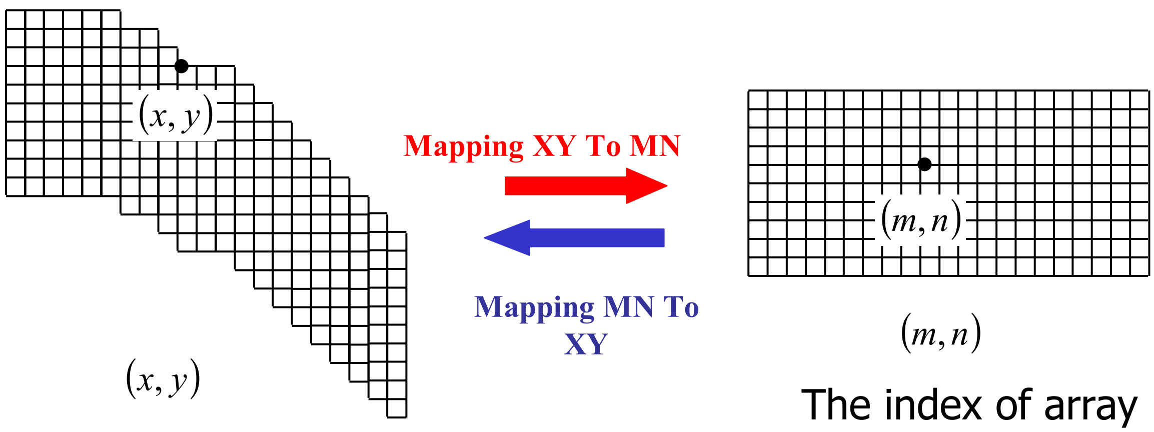
Mesh



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

The Mapping Between Coordinates and Indexes



The coordinate of nodes

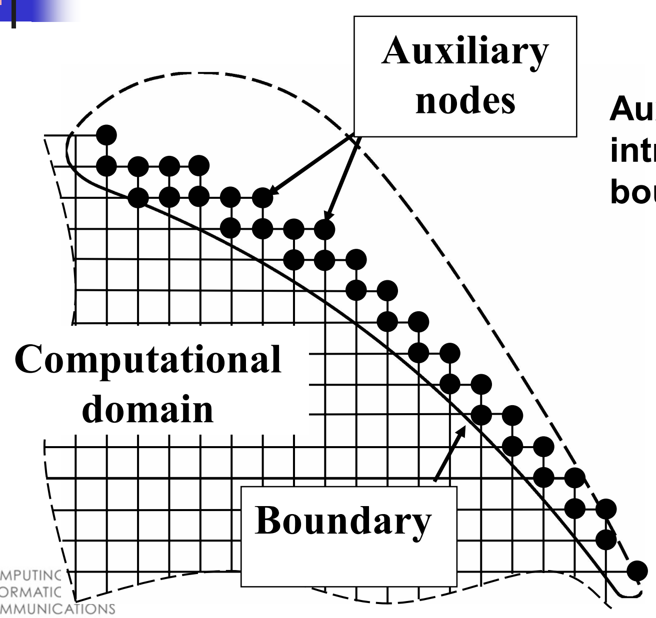
The index of array

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Implement of Boundary Condition

1) Wall Boundary - Auxiliary Nodes

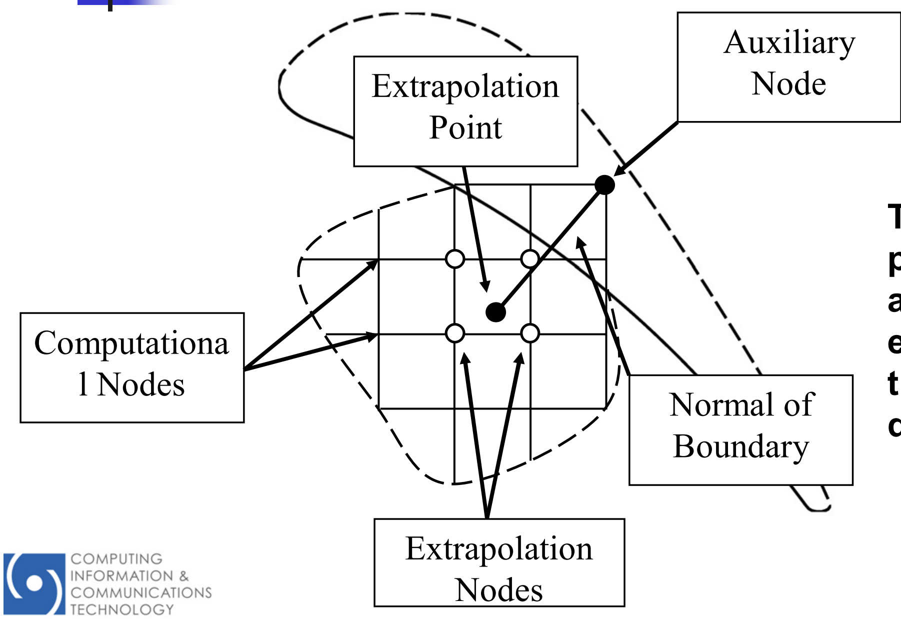


Auxiliary nodes were introduced to implement wall boundary conditions

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Implement of Boundary Condition
2) Wall Boundary - Extrapolation

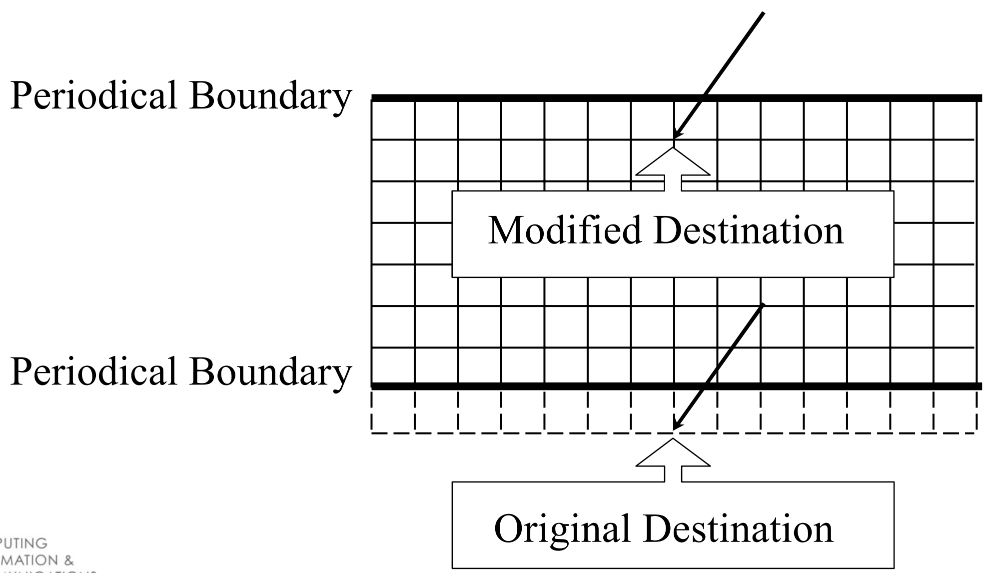


The macroscopic properties of auxiliary nodes are extrapolated from the computational domain.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

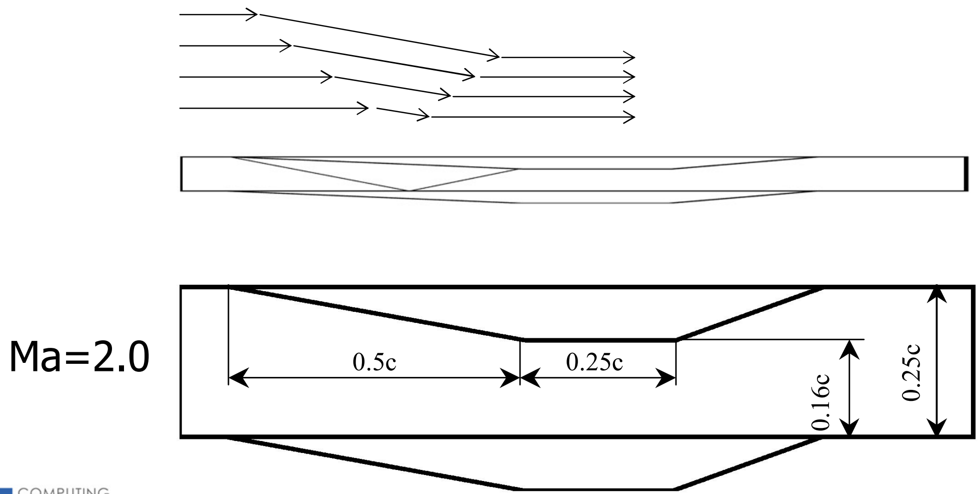
Implement of Boundary Condition
3) Periodical Boundary



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

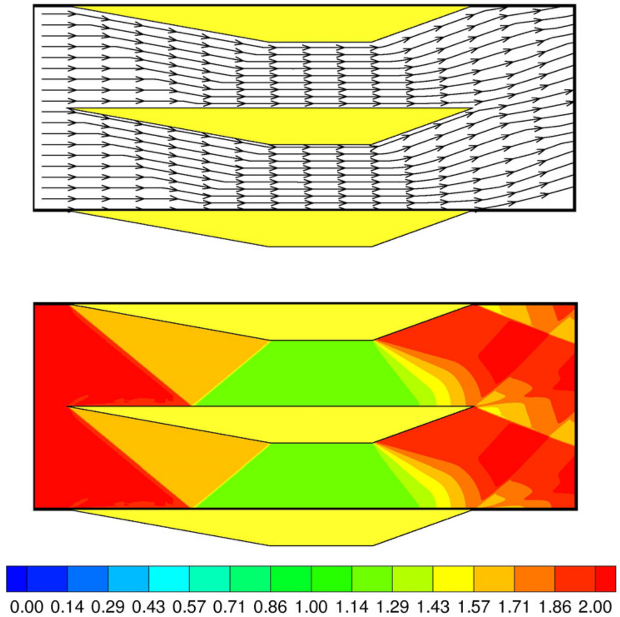
Wedge Cascade
Geometry



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

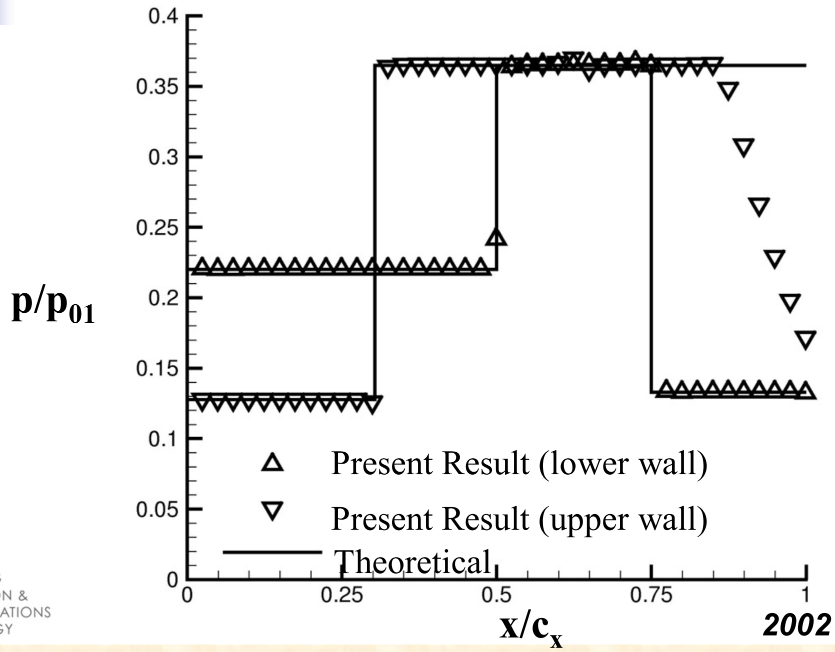
Wedge Cascade
Result: Stream Line and Ma Contour



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

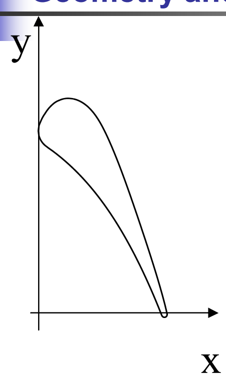
Wedge Cascade
Result: Static Pressure at Walls



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade
Geometry and Inlet and Outlet Parameters



Stagger Angle	**59.89°**
Chord	**14.49cm**
Spacing	**11.77cm**
Solidity	**1.23**
Axial Chord	**7.82cm**

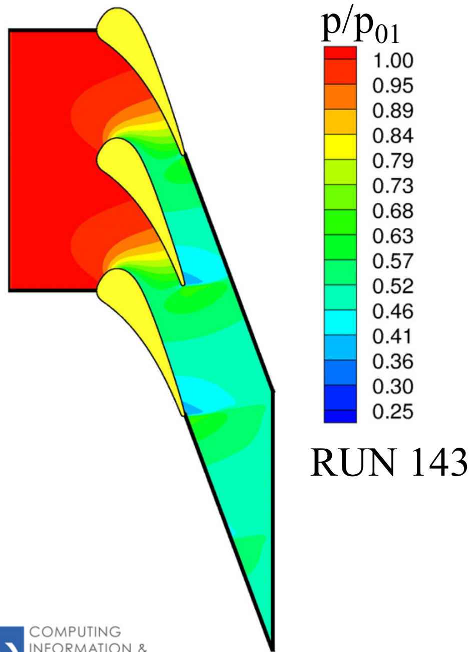
Run Number	α_{in}	p_{t1} (Pa)	T_{t1} (K)	Ma_1	Re_1	p_2/p_{t1}
RUN 143	0	7755	811	0.17	0.63×10^6	0.50
RUN 144	0	7889	815	0.16	0.63×10^6	0.59

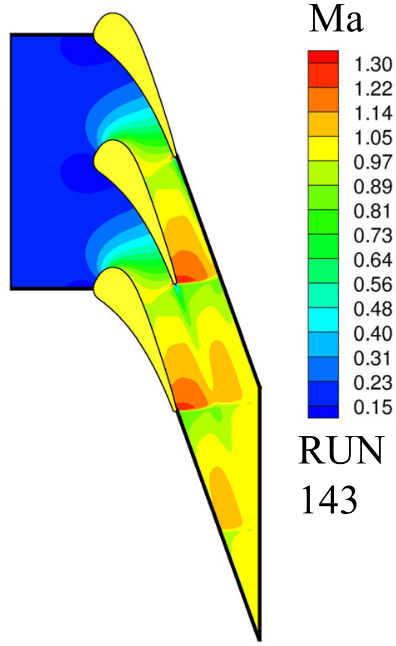
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade RUN 143

esults



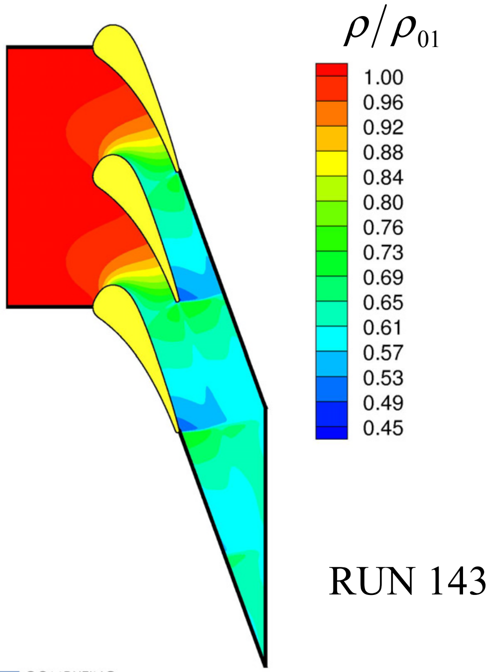


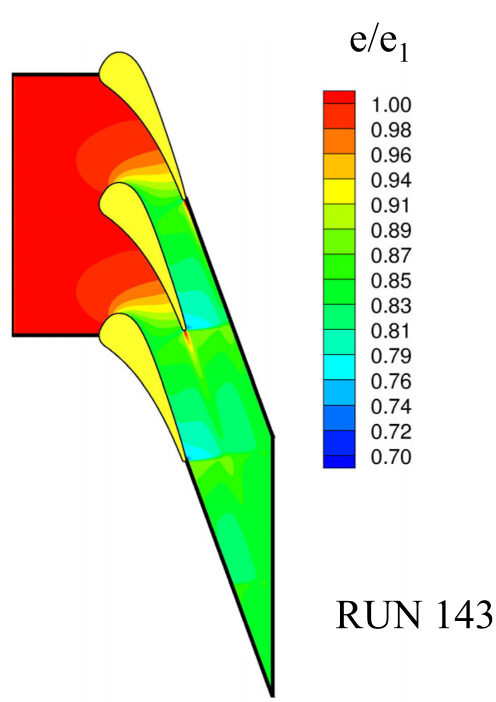
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade RUN 143

Results

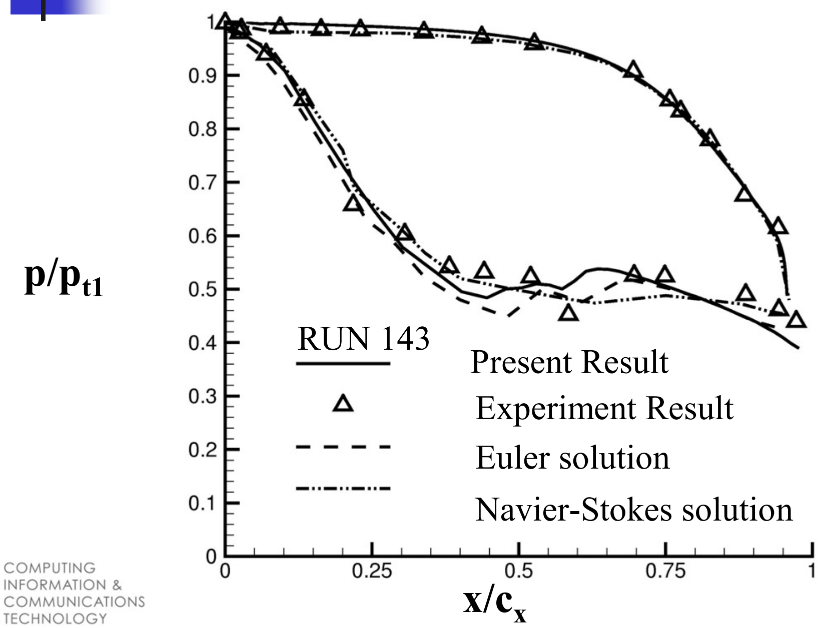




COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

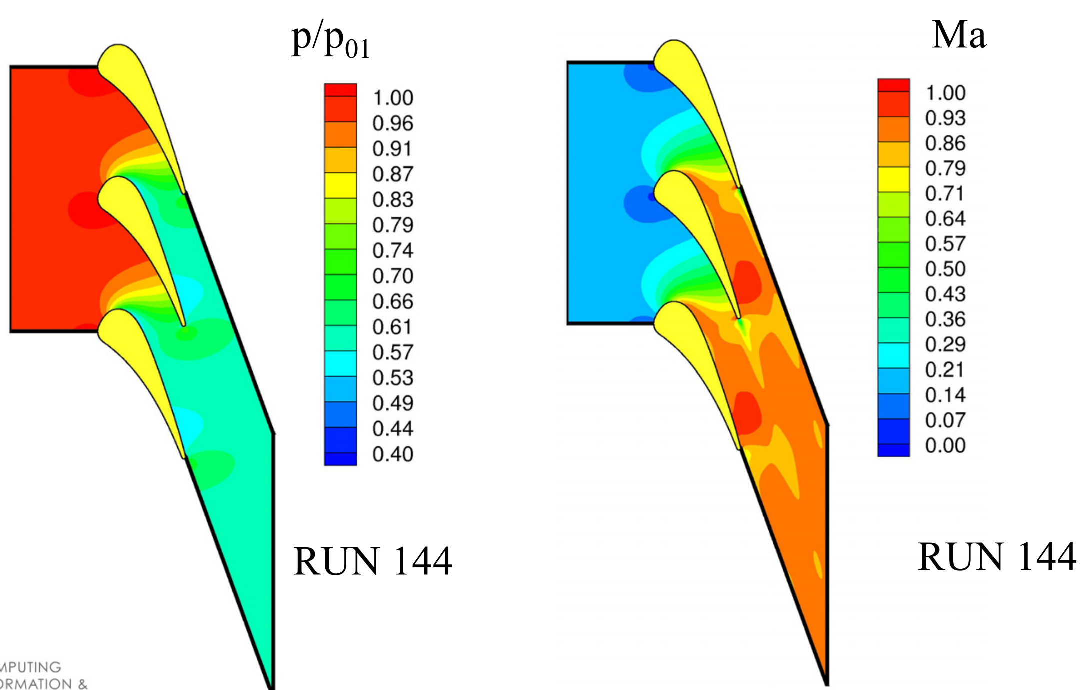
C3X Cascade RUN 143
Results



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade RUN 144
Results

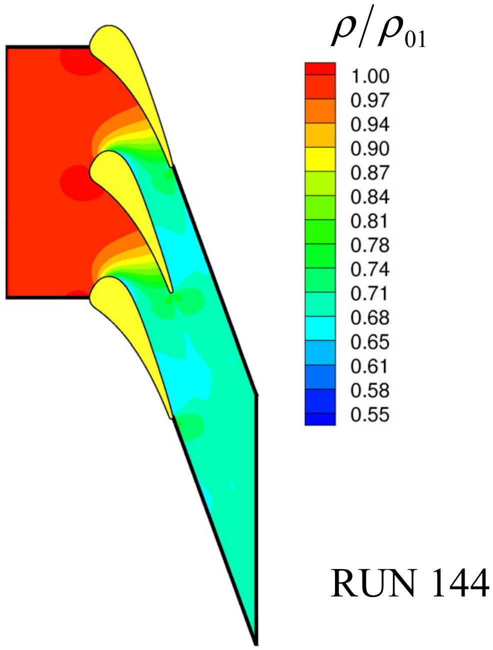


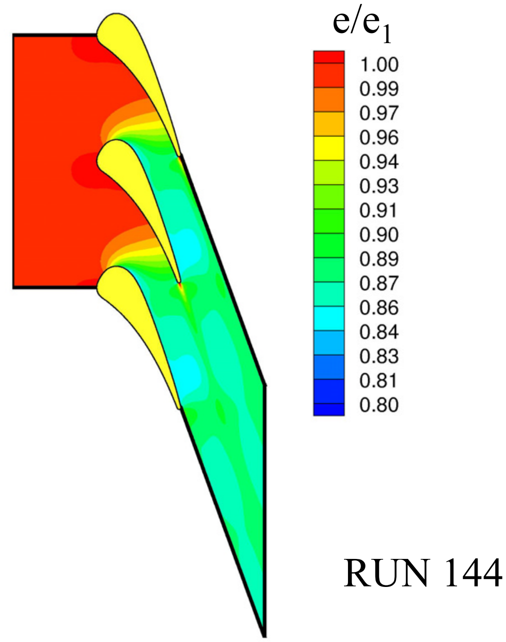
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade RUN 144

Results



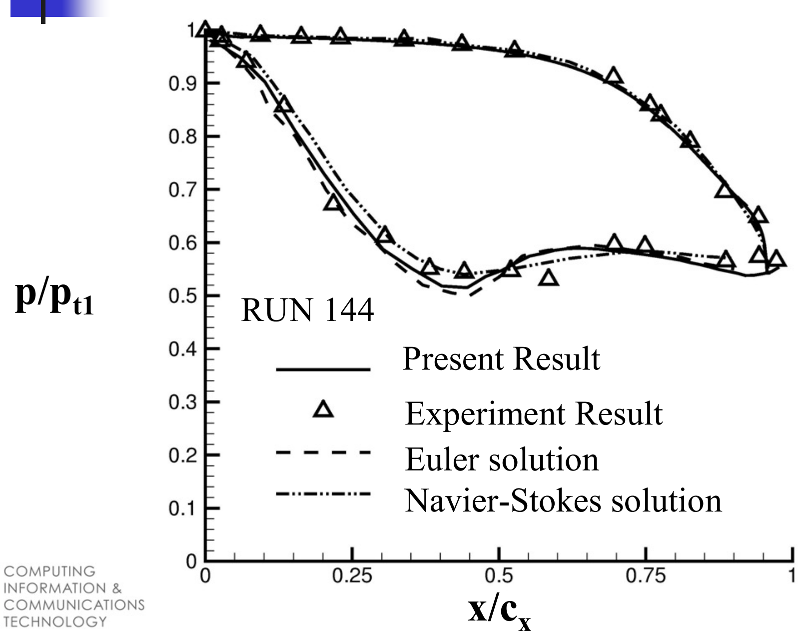


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

C3X Cascade RUN 144

Results

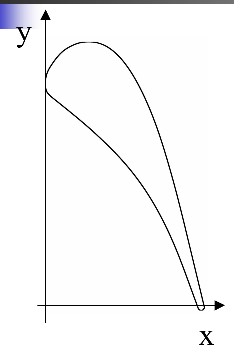


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

VKI Cascade

Geometry and Inlet and Outlet Parameters



Stagger Angle	**55.0°**
Chord	**67.646 mm**
Spacing	**57.50 mm**
Solidity	**1.1765**
Axial Chord	**36.98 mm**

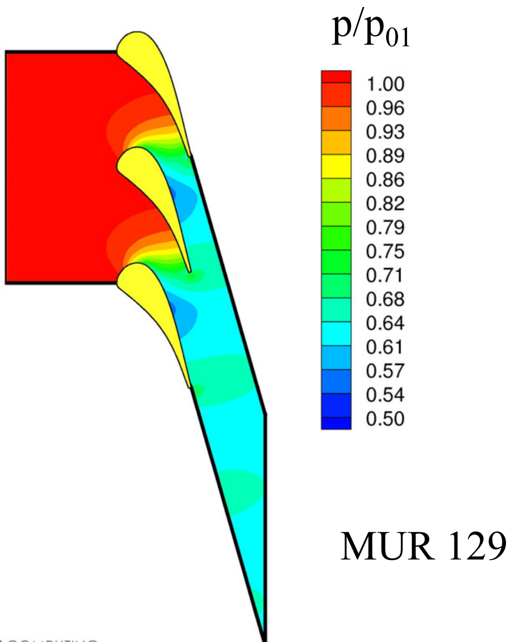
Run Number	α_{in}	p_{t1} (Pa)	T_{t1} (K)	Ma_1	Re_1	Ma_2
MUR 129	0	18200	409.20	0.15	0.27×10^6	0.84

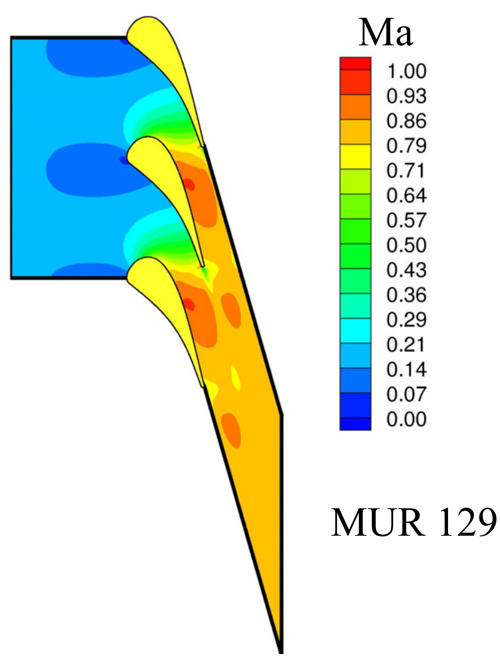
COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

VKI Cascade MUR 129

Results

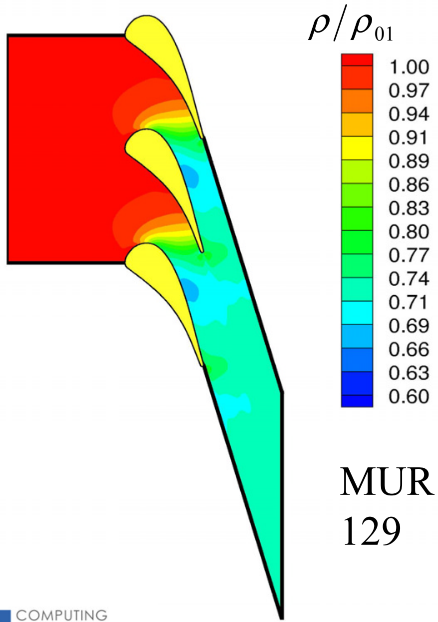


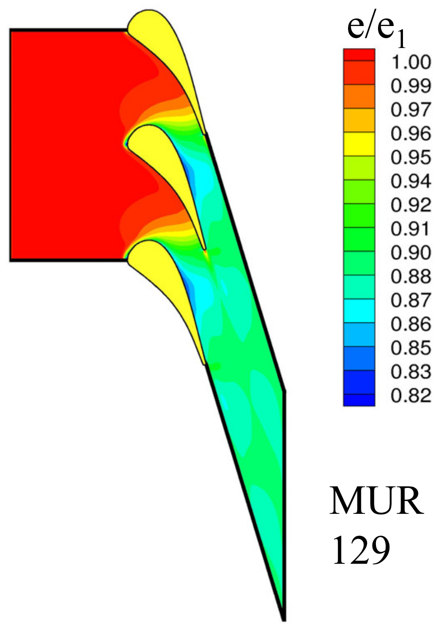


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

VKI Cascade MUR 129



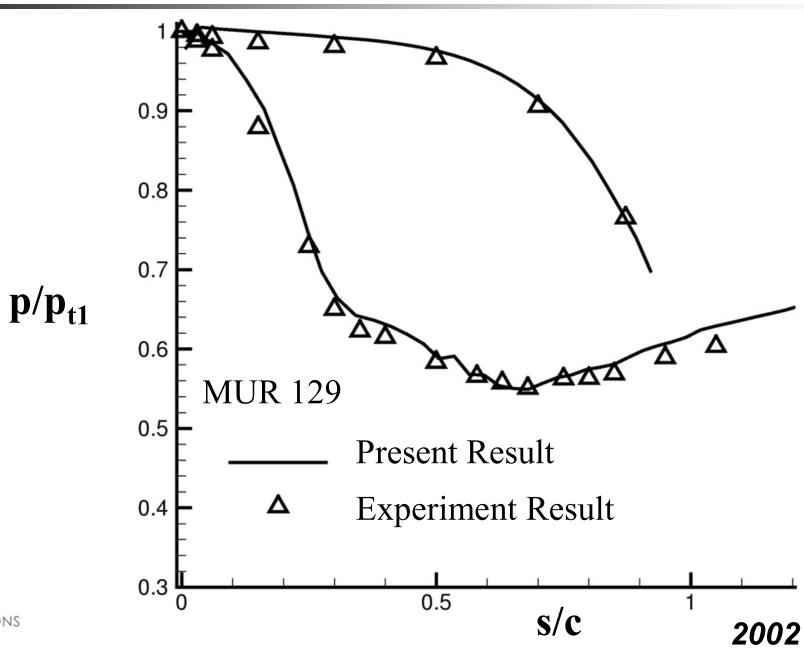


COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

VKI Cascade MUR 129

Results



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Parallel Computing

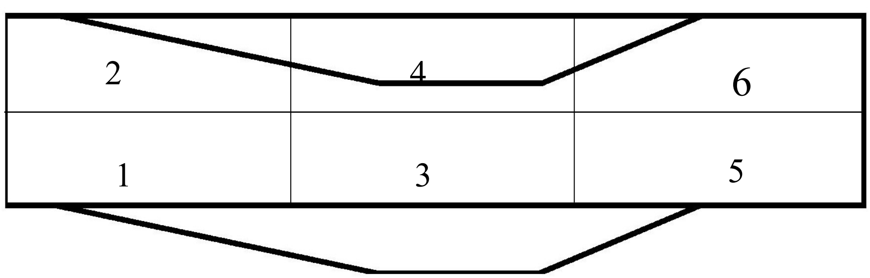
- The LB method is a natural parallel method;
- The LB model is explicit in time;
- The area of dependent domain of a node is determined by the magnitude of velocity set, which is usually a small number.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Parallel Computing
1) Division of Blocks

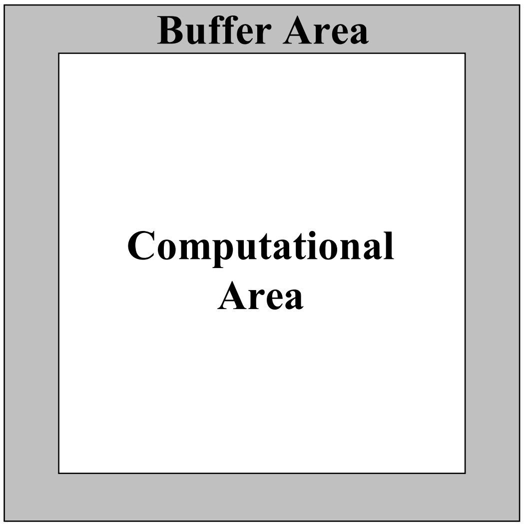
- The simulation of wedge cascade was parallelized to test the parallel performance of current LB model

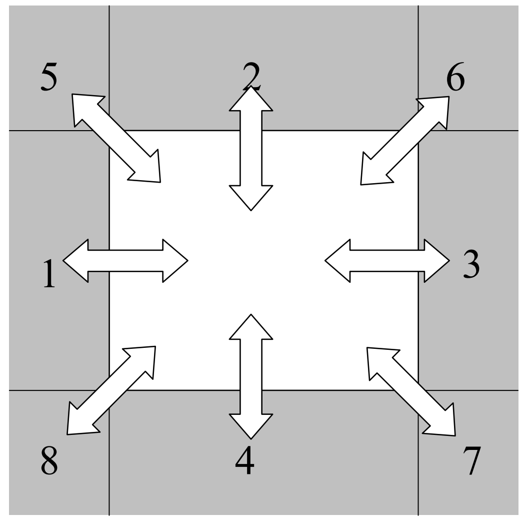


COMPUTING INFORMATIOI COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Parallel Computing
2) Information Exchange

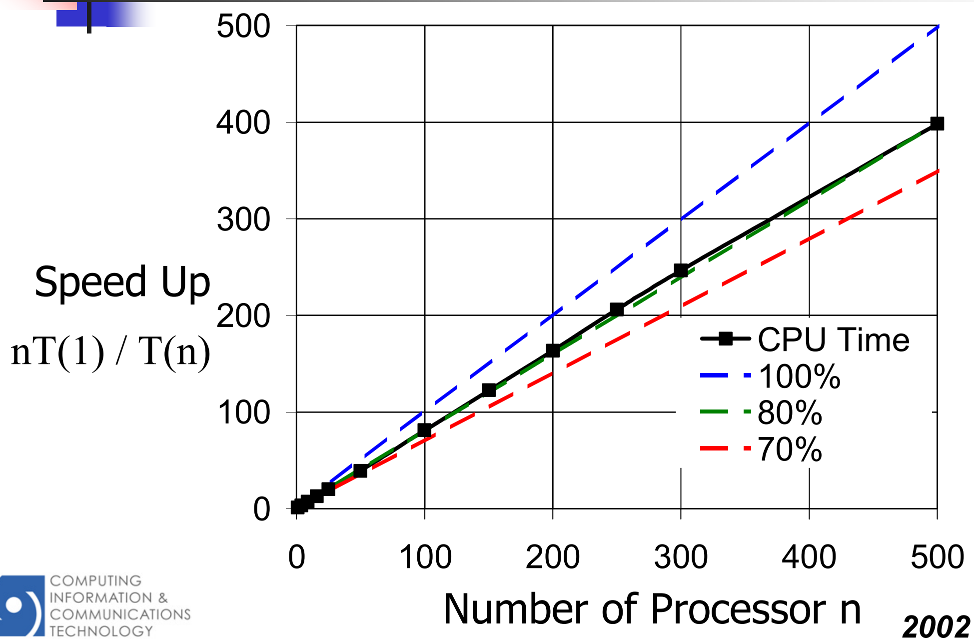




COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Parallel computing
3) Result



COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Conclusion

1) A compressible LB model has been successfully developed for turbomachinery simulations.

2) Successful simulation of cascades has been carried out and it is the first successful turbomachinery simulation by a LB model.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Conclusion

3) A treatment of boundary condition in LB method has been introduced to the current compressible LB model.

4) A new mesh treatment method has been devised in order to use regular mesh on a irregular geometry.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Conclusion

5) The parallel efficiency of the new compressible LB model is studied. A linear efficiency has been demonstrated.

6) The theoretical basis of the current model is analyzed in detailed.

COMPUTING INFORMATION & COMMUNICATIONS TECHNOLOGY

2002 CISO Review

Acronym List

0–D	0–Dimensional
1–D	1–Dimensional
2–D	2–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
APP	Aero Power and Propulsion
APU	Auxiliary Power Unit
ASME	American Society of Mechanical Engineers
Autodoc	Auto Documentation
BC	Boundary Condition
CAD	Computer Aided Design
CAPRI	Computational Analysis Programming Interface
CBC	Commodity Based Cluster
CIAPP	Computational Intelligence for Aerospace Power and Propulsion
CICT	Computing, Information & Communication Technology
CNIS	Computing, Networking & Information Systems
CCDK	CORBA Component Development Kit
CFD	Computational Fluid Dynamics
CORBA	Common Object Request Broker Architecture
CPU	Central Processing Unit
CSPAN	Compressor Conceptual Design Code
Dev Kit	NPSS Development Kit
DLM	Dynamically Loadable Module
DOCSec	Distributed Object Computing Security
DOE	Department of Energy
ECS	Engineering for Complex Systems
FPI	Fast Probabilistic Integration
FTT	Florida Turbine Technology
GCA	Grand Challenge Applications
GEAE	General Electric Aircraft Engines
GRC	Glenn Research Center
HP	Hewlett Packard
HLTM	Highly Loaded Turbo Machinery
HPC	High Pressure Compressor
HPT	High Pressure Turbine
Ht	Total Enthalpy
IE	Information Environments
IGTI	International Gas Turbine Institute
IGV	Inlet Guide Vane
IPG	Information Power Grid
ISTAR	Third generation launch vehicle design

JANNAF	Joint Army Navy NASA Air Force
JSF	Joint Strike Fighter
KBE	Knowledge Based Engineering
LB	Lattice Boltzmann
LPC	Low Pressure Compressor
LPT	Low Pressure Turbine
LSF	Load Sharing Facility
MD	Multi-Disciplinary (Fluid-Thermal-Structural)
MHz	Mega Hertz
MPI	Message Passing Interface
NICE	NASA Industry Cooperative Effort
NCC	National Combustion Code
NOZ	Nozzle
NPSS	Numerical Propulsion System Simulation
OGV	Outlet Guide Vane
OMG	Object Management Group
ORB	Object Request Broker
PBS	Portable Batch System
PD	Preliminary Design
PDM	Product Data Manager
PED	Preliminary Engine Design
PSAO	Propulsion Systems Analysis Office
Pt	Total Pressure
PUMPA	One-Dimensional Pump Analysis Code
P&W	Pratt & Whitney
r Cu	Radius times Tangential Velocity
RBCC	Rocket Based Combined Cycle
RLV	Reusable Launch Vehicle
RFP	Request For Proposal
RRC	Rolls-Royce Corporation
SAE	Society of Automotive Engineers
SGI	Silicon Graphics, Inc.
SIP	Strategic Implementation Plan (at NASA Glenn Research Center)
SOAPP	State of the Art Propulsion Program
SSL	Secure Socket Layer
TBCC	Turbine Based Combined Cycle
TGIR	Turning Goals Into Reality
TRL	Technology Readiness Level
u	Axial Component of Velocity
UEET	Ultra-Efficient Engine Technology
V	Version
v	Radial Component of Velocity
VBS	Visual-Based Syntax
WAVE	What-if Value Added Engineering
WI	Williams International
WPAFB	Wright Patterson Air Force Base

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY (*Leave blank*)

2. REPORT DATE
August 2003

3. REPORT TYPE AND DATES COVERED
Technical Memorandum

4. TITLE AND SUBTITLE
2002 Computing and Interdisciplinary Systems Office
Review and Planning Meeting

5. FUNDING NUMBERS
WBS–22–704–40–01

6. AUTHOR(S)
John Lytle, Gregory Follen, Isaac Lopez, Joseph Veres, Thomas Lavelle, Arun Sehra, Josh Freeh, and Chunill Hah

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
John H. Glenn Research Center at Lewis Field
Cleveland, Ohio 44135–3191

8. PERFORMING ORGANIZATION REPORT NUMBER
E–13578

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
National Aeronautics and Space Administration
Washington, DC 20546–0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
NASA TM—2003-211896

11. SUPPLEMENTARY NOTES
Viewgraphs from the 2002 CISO Review and Planning Meeting sponsored by the NASA Glenn Research Center, Middleburg Heights, Ohio, October 9–10, 2002. John Lytle, Gregory Follen, Joseph Veres, Thomas Lavelle, Arun Sehra, Josh Freeh, and Chunill Hah, NASA Glenn Research Center; and Isaac Lopez, U.S. Army Research Laboratory, NASA Glenn Research Center. Responsible person, Gregory Follen, organization code 2900, 216–433–5193.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Unclassified - Unlimited
Subject Category: 01 Distribution: Nonstandard

Available electronically at http://gltrs.grc.nasa.gov

This publication is available from the NASA Center for AeroSpace Information, 301–621–0390.

12b. DISTRIBUTION CODE

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 NASA Glenn's Propulsion program, NASA Ames, 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 year's review meeting describes the current status of the NPSS and the Object Oriented Development Kit with specific emphasis on the progress made over the past year on air breathing propulsion applications for aeronautics and space transportation applications. Major accomplishments include the first 3–D simulation of the primary flow path of a large turbofan engine in less than 15 hours, and the formal release of the NPSS Version 1.5 that includes elements of rocket engine systems and a visual based syntax layer. NPSS and the Development Kit are managed by the Computing and Interdisciplinary Systems Office (CISO) at the NASA Glenn Research Center and financially supported in fiscal year 2002 by the Computing, Networking and Information Systems (CNIS) project managed at NASA Ames, the Glenn Aerospace Propulsion and Power Program and the Advanced Space Transportation Program.

14. SUBJECT TERMS
Aerodynamics; Engineering; Space transportation; Mathematics and computer science

15. NUMBER OF PAGES
188

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	