NPSS Overview to TAFW Multidisciplinary Simulation Capabilities

September 12, 2001

Presented by
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for the
NPSS Development Team

Computing and Interdisciplinary Systems Office
Glenn Research Center

Presentation Outline

- Definition of NPSS
- Current Status of NPSS
  - NPSSv1 Capabilities
  - Engineering Demonstrations
  - Planned Capabilities

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- ***Definition of NPSS***
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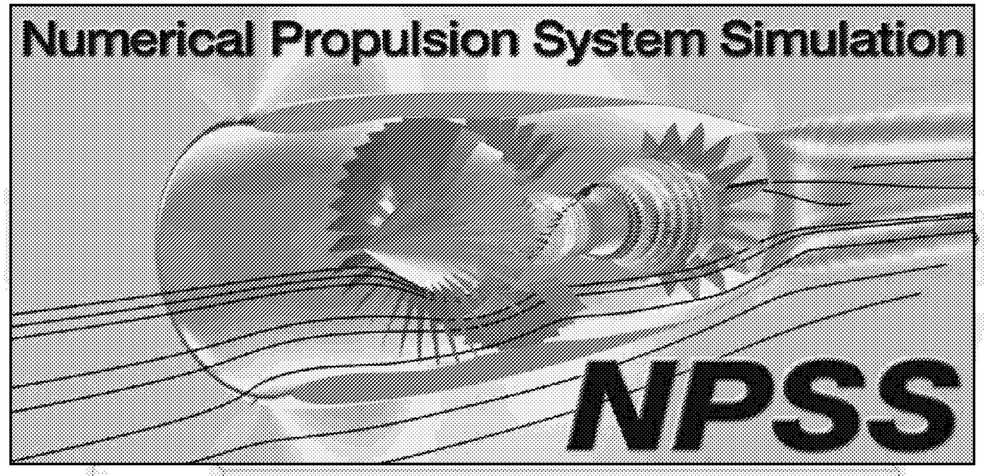
Definition of NPSS - the Numerical Propulsion System Simulation

NPSS is a concerted effort by NASA Glenn Research Center, the aerospace industry, and academia to develop an advanced engineering environment – or integrated collection of software programs - for the analysis and design of aircraft engines and, eventually, space transportation components.

NOTE: NPSS is now being applied by GE ground power to ground power generation with the view of expanding the capability to non-traditional power plant applications (example: fuel cells) and NPSS has an interest in in-space power and will be developing those simulation capabilities



Validated Models

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

Integrated Interdisciplinary Analysis and Design of Propulsion Systems

High-Performance Computing

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

Rapid Affordable Computation of

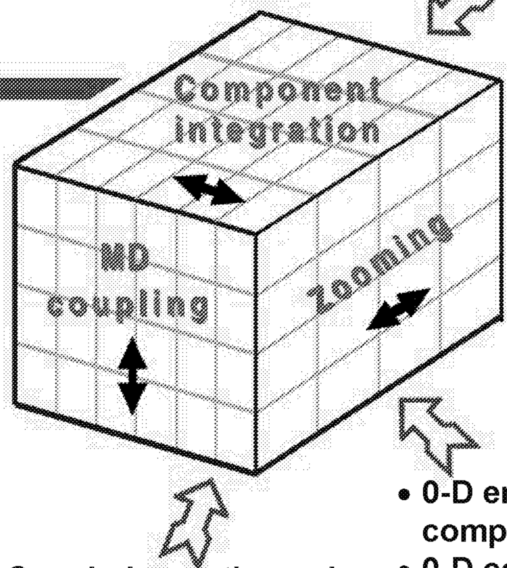
- Performance
- Stability
- Cost
- Life
- Certification requirements

A Numerical Test Cell for Aerospace Propulsion Systems

HPCCP/NPSS
Work Breakdown Structure

Engineering Applications

- Code Parallelization
- 3–D Subsystems/System



Simulation Environment

- Gov't/industry collaborative effort
- Object-oriented programming
- CAD geometry interface

Seamless integration of people, data, analysis tools, and computing resources

- Coupled aero-thermal-structural analysis
- Hierarchical methods

- 0-D engine/1-D compressor
- 0-D core/3-D LP subsystem

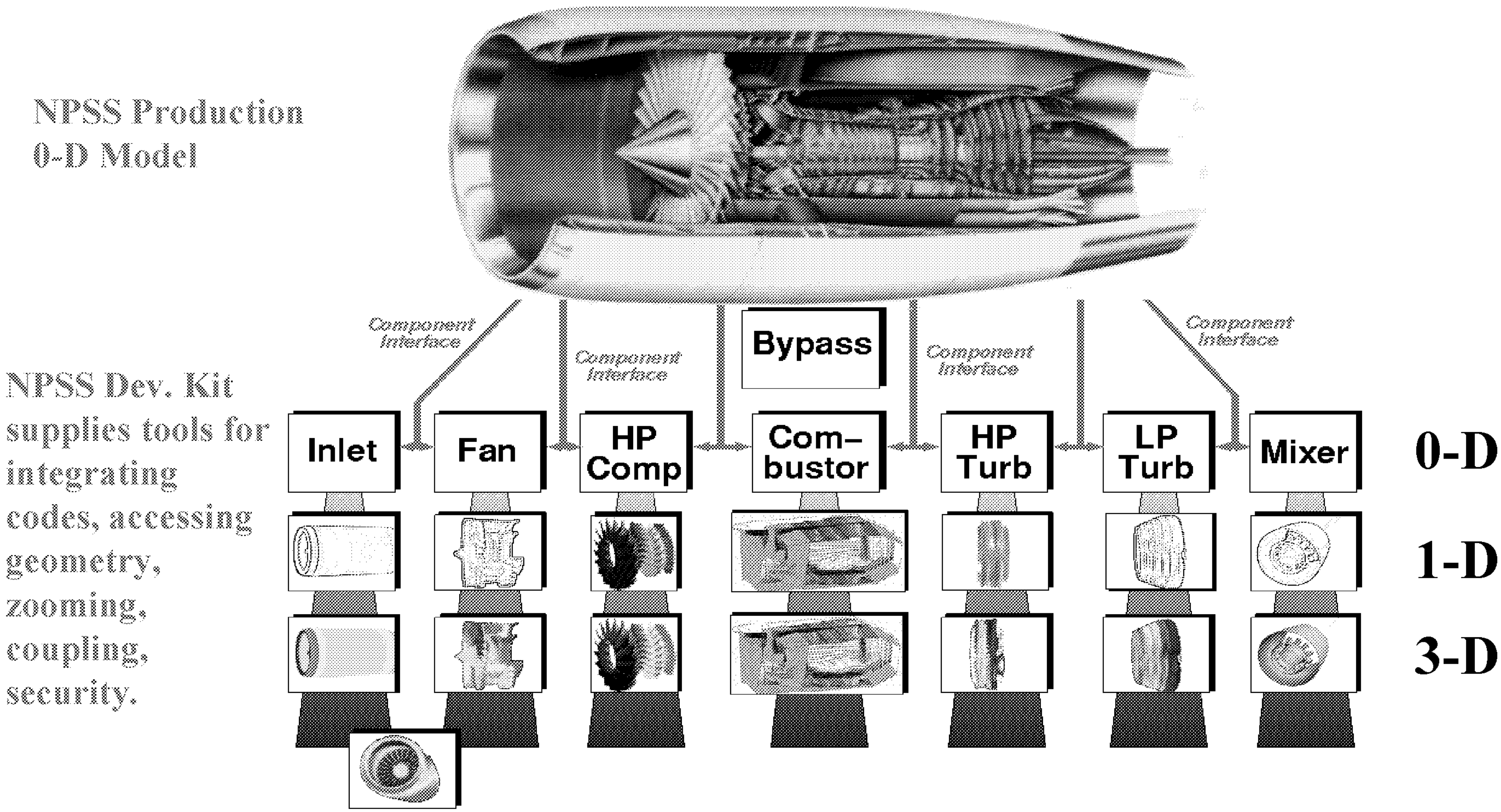
High-fidelity, large-scale simulations

Computing Testbeds

- High-speed networks
- PC cluster
- Distributed computing

Low-cost, distributed parallel computing

NPSS Production and Simulation Architecture



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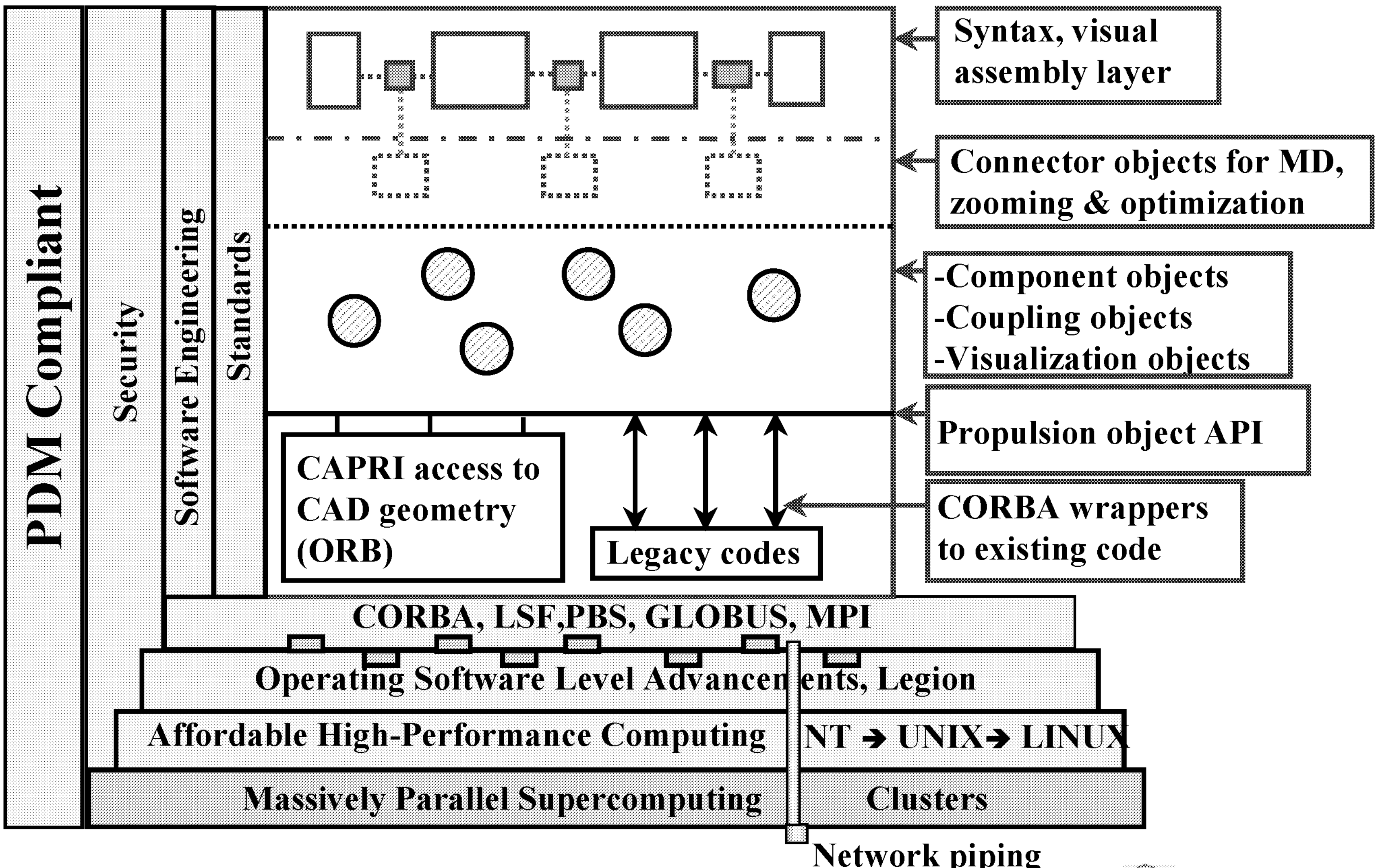
NPSS Object-Oriented Architecture



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NPSS Version 1.0.0 Capabilities

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

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

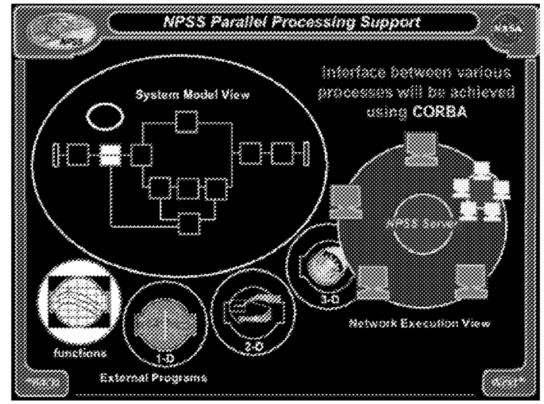
Selected FY00 Highlights

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

NPSS Development Kit

FY00 Accomplishments

Integrating Codes Through CORBA Wrapping



- **Direct FORTRAN support**

  Allows converting FORTRAN code to a CORBA object without reverting to file I/O & attendant startup/shutdown overheads.

- **Single-precision floating-point variables**
- **'Meta' variables**

  i.e., Shaft, Nmech mapped to multiple boundary conditions.

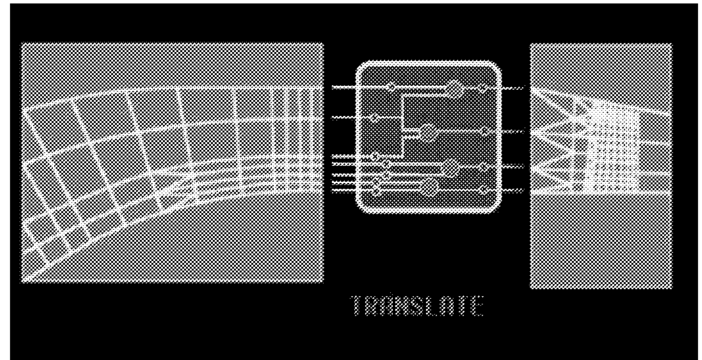
- **Variable access via functions**

  For parallel codes where the CORBA process doesn't own storage of referenced data.

- **Circumferential averaging**
- **1-D array support**

NPSS Development Kit

FY00 Accomplishments

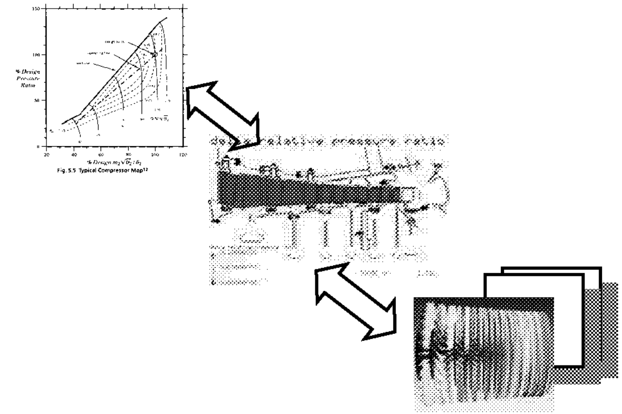


Coupling

- 2-D/3-D/Axi-symmetric mismatched grids, with cell or node centered data
- Interpolation method is internally unstructured, currently the only API uses structured grids
- Rolls-Royce ADPAC-NPSS-ANSYS sensitivity project
  - Will likely require unstructured support. Current interpolator has this, but API and messaging formats need to be defined
  - Likely wrap ANSYS via Java using file I/O
  - ANSYS optimizer loop to be emulated by Java client application
- Examining "best practices in coupling" for recovery into Dev. Kit
  - ASCI project coupling
  - Overflow-Vulcan-ANSYS
  - Haha3d-ANSYS
  - APNASA-TFLOW

NPSS Development Kit

FY00 Accomplishments



Zooming

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

NPSS Development Kit

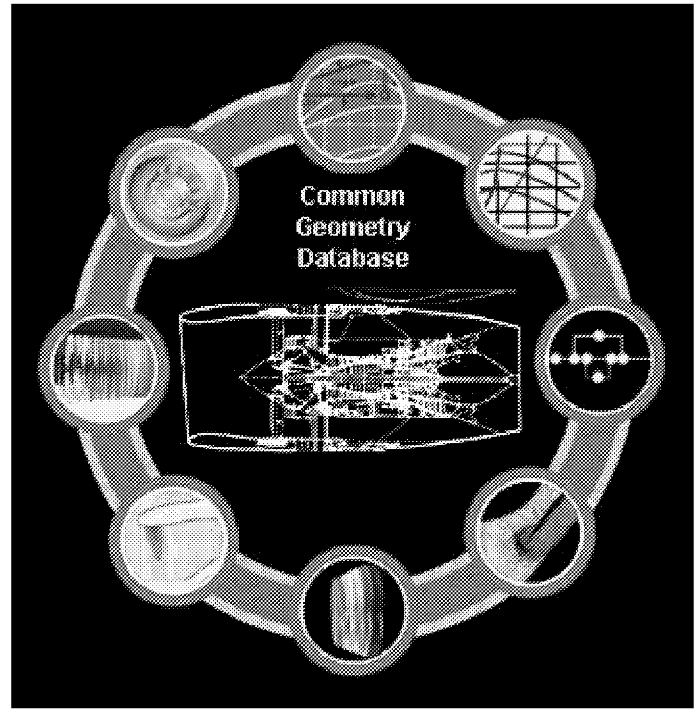
FY00 Accomplishments

CORBA Security

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

NPSS Development Kit

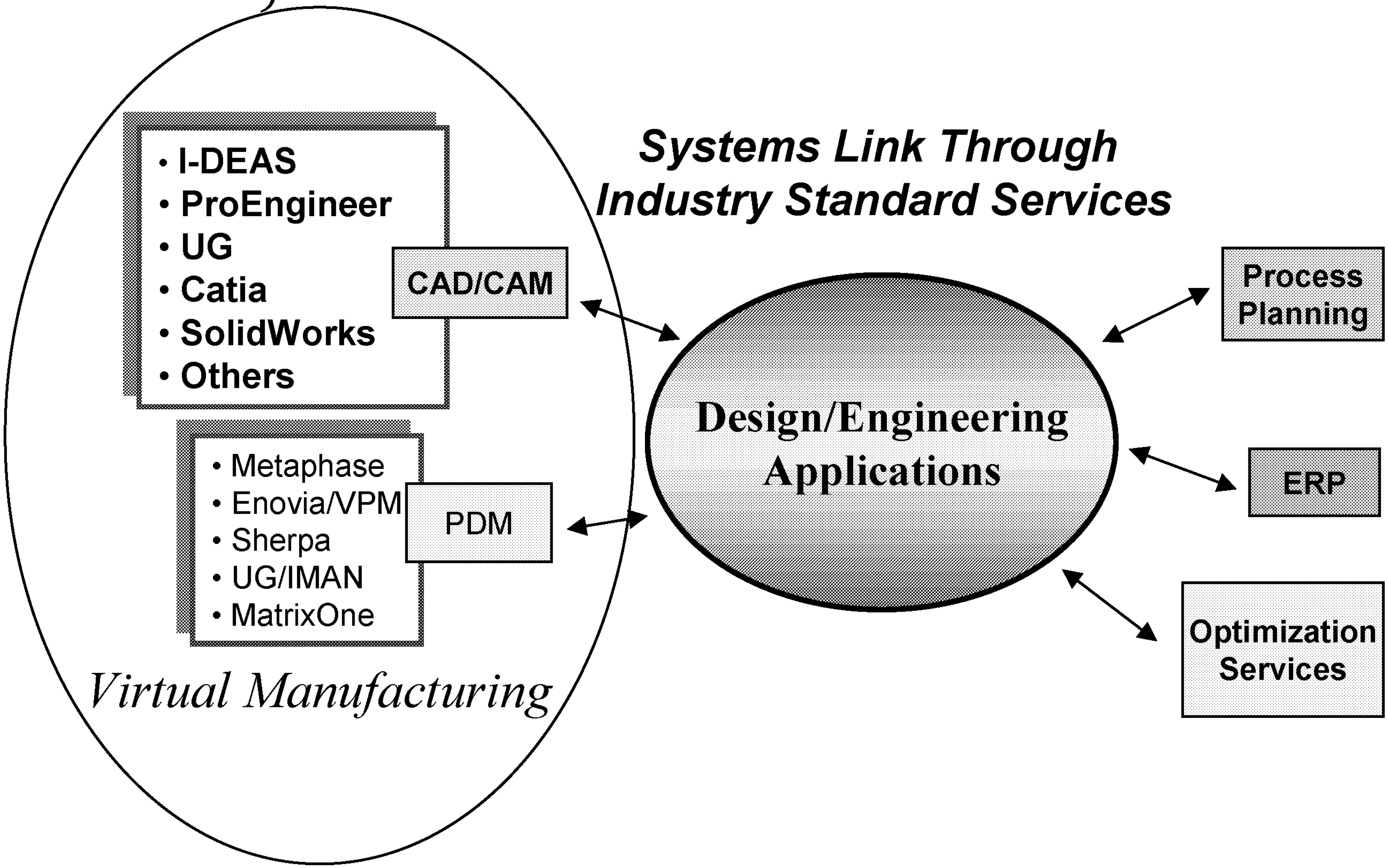
FY00 Accomplishments



CAD Access & Interoperability Through Common Interface

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

NPSS, OMG Shared Vision



CAPRI FY00:

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

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

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

CAPRI FY01: Geometry Creation

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

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

FY01 Major Milestones

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

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NPSS Multidisciplinary Integration and Analysis

NASA Contract NAS3-98003
Task 5

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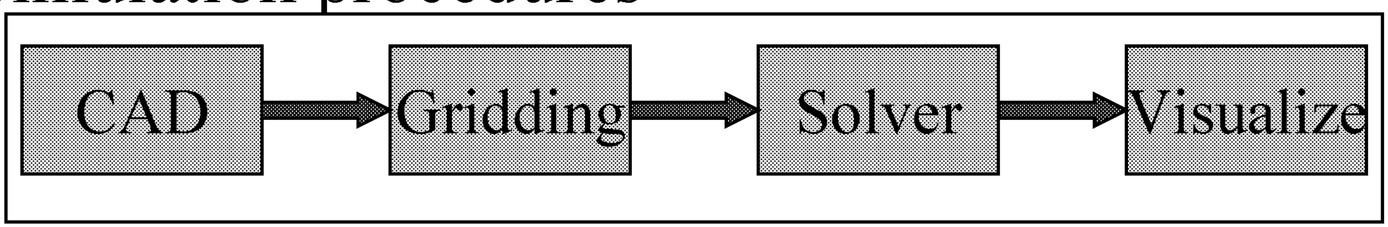
Rolls-Royce, Indianapolis, IN

NPSS On-Site Review
March 21-22, 2001

Geometry Challenges

- Industry interacting with multiple CAD systems
- Need to produce CAD data from within non CAD-based design systems
- Access to geometry required by multiple disciplines (aero/heat transfer/stress/dynamics/acoustics)
- Simulation procedures



  - File based
  - Requires “good geometry”
  - One way communication
  - Difficult to introduce reverse engineering

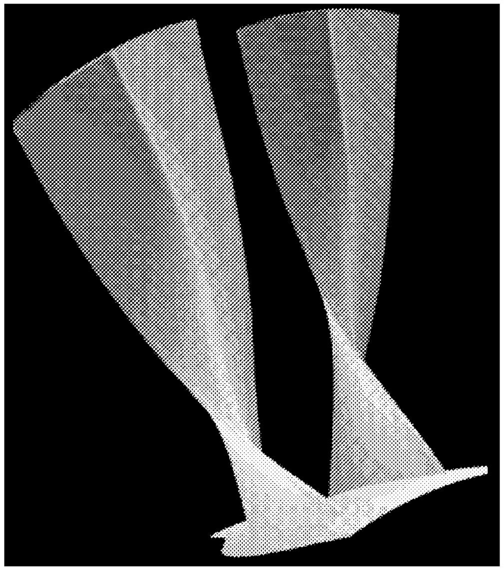
CAPRI

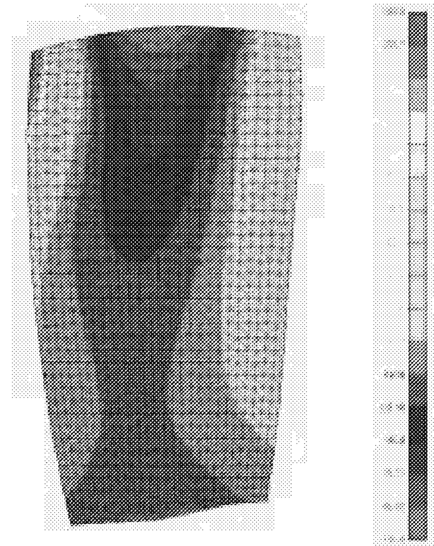
- CAD vendor neutral application programming interface
- Allow access to geometry from within all modules of an analysis system
- Reliance on standards is minimized
- Modular system
- Multiple languages
- Transient solutions
- Allow multi-disciplinary coupling and zooming
- CAPRI combines geometry and topology

Multidisciplinary Integration and Analysis

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

Aero/Structural Coupling





ADPAC CFD Analysis

Input:
geometry, operating conditions

Output:
pressure, temperature

ANSYS Structural Analysis

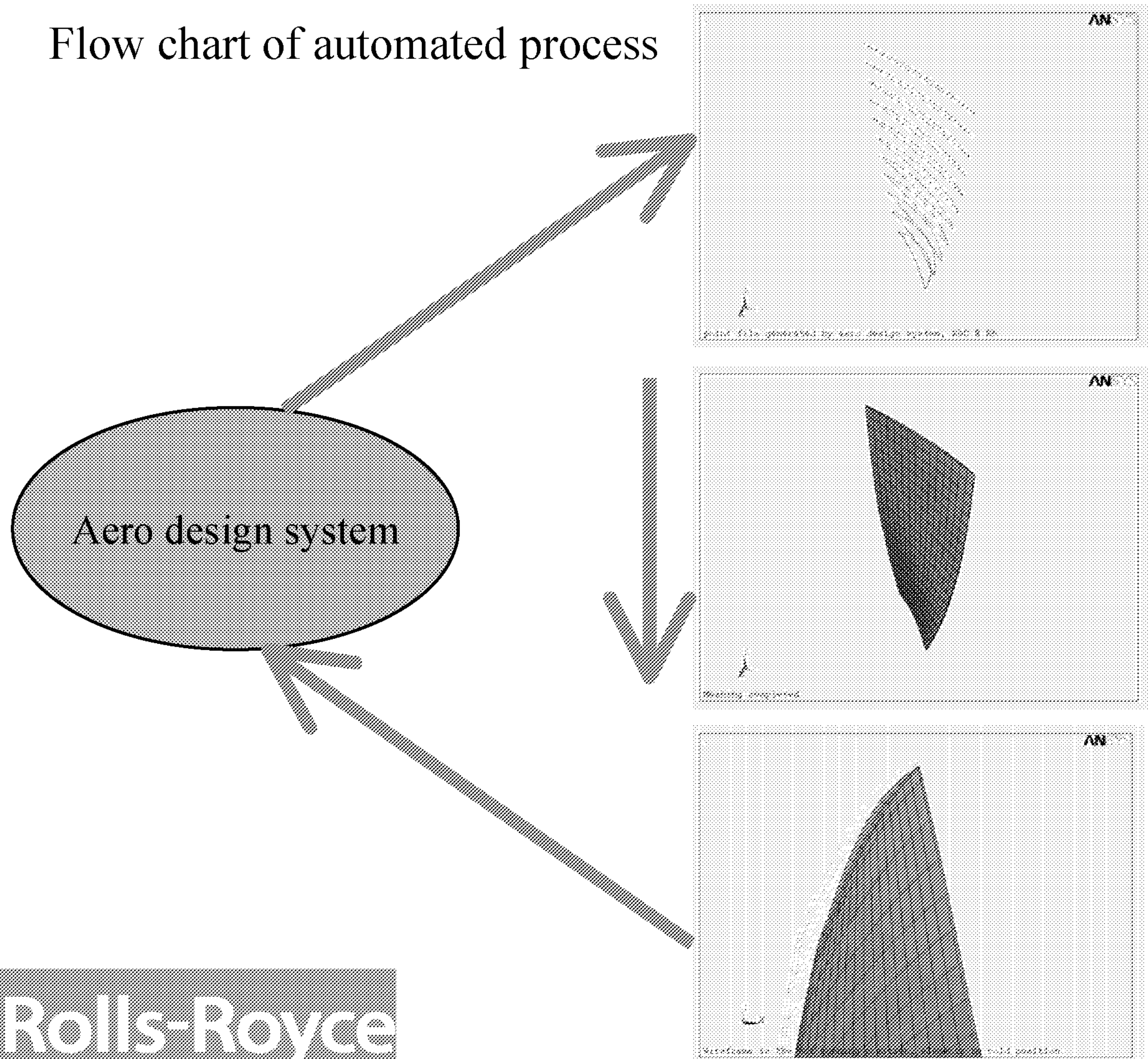
Input:
geometry, operating condition,
pressure, temperature

Output:
deformations, stress

Rolls-Royce

ANSYS Multidisciplinary Implementation

- Flow chart of automated process



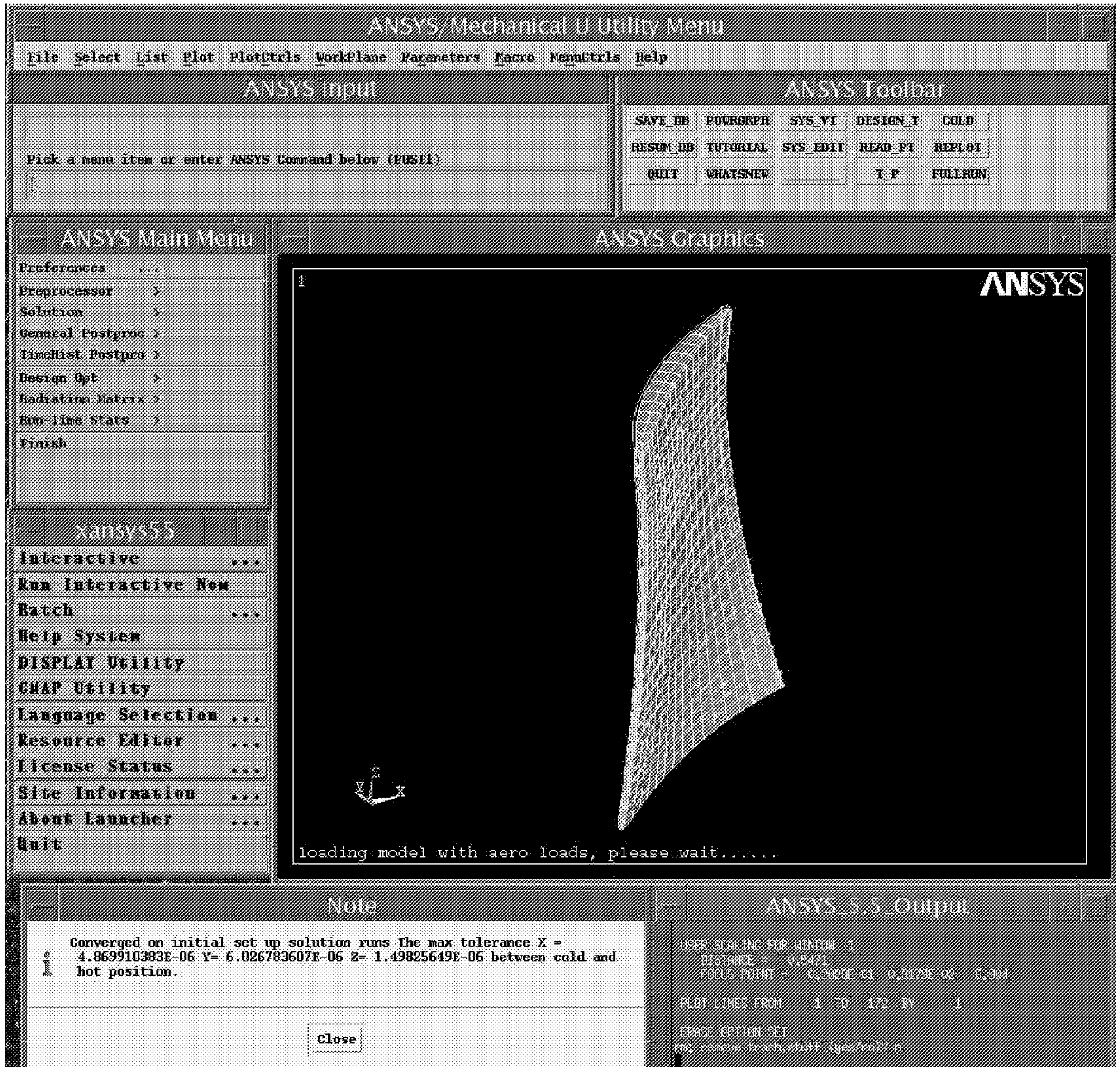
•Point file is created by Aero design system, read into 3D CAD or ANSYS
•History file is kept for re-runs of different designs of the airfoil
•The number of points and stream sections must be kept constant, location of points can change.

•ADPAC results are mapped onto mesh
• structural analysis is run for first guess on un-wrap of blade. Deflected shape is used to calculate the initial guess on cold geometry. The mesh is morphed using an iterative process to get the cold mesh geometry.

•The cold mesh node locations and the original nodal locations are used to generate a deflection file.
•Deflection file is used to generate new Aero data input which is used to analyze off design point configurations

Multidisciplinary Demo

- Hot to cold coordinate conversion via ANSYS
- Point-based airfoil definition input
- Fully automated (based on existing hot aero CFD data)
- Demo system delivered to NASA
- Expanding system for automated cold to warm conversion including CFD meshing/solution operations



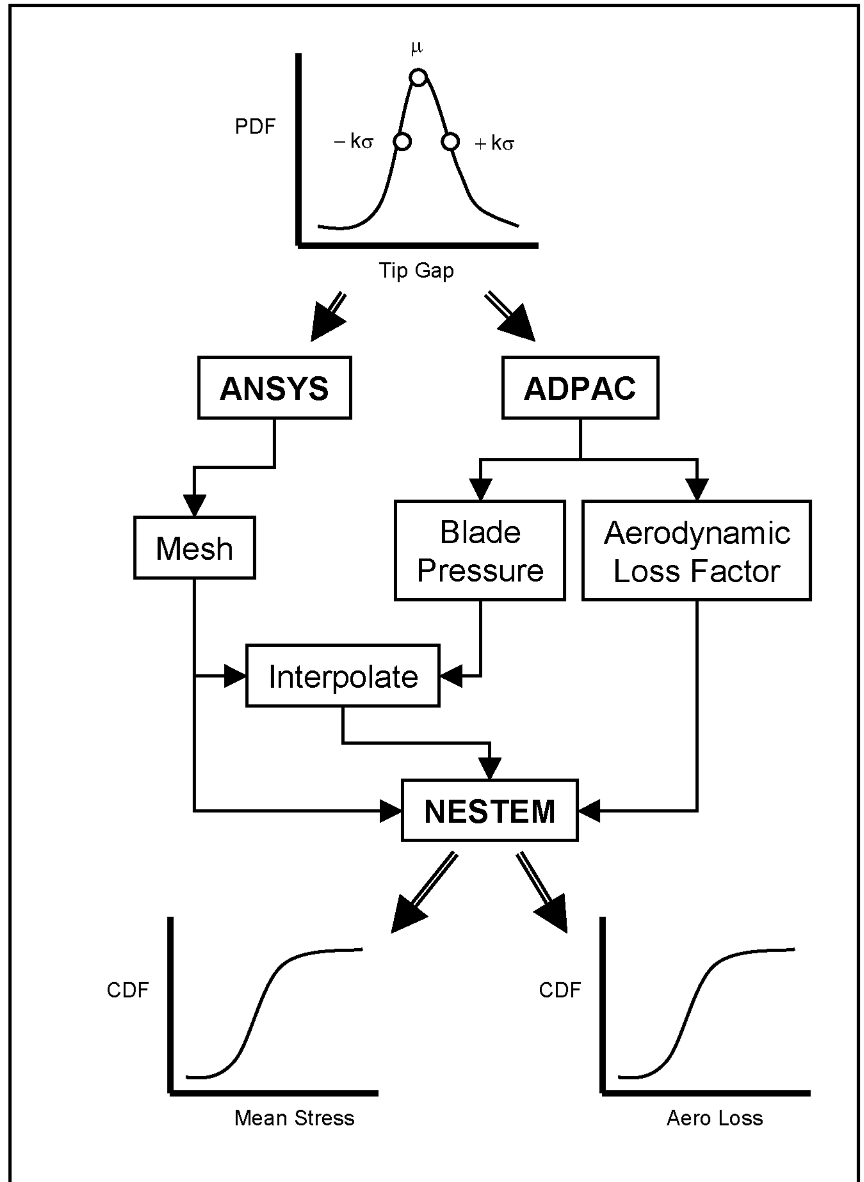
Probabilistic Tip-Gap Study

Objective

- Determine Effect Of Tip Gap Variability On Aerodynamic Loss Factor And Mean Stress Distribution

Approach

- Select PDF for tip gap
- Perform ADPAC analysis for three values of tip gap (μ, $+k\sigma$, $-k\sigma$)
- Develop ANSYS FE Mesh
- Input , FE Mesh, Blade Pressure, Aero Loss Factor into NESTEM
- Predict Cumulative Distribution Function for Mean Stress and Aero Loss Factor



Rolls-Royce

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MultiDisciplinary Pump Development

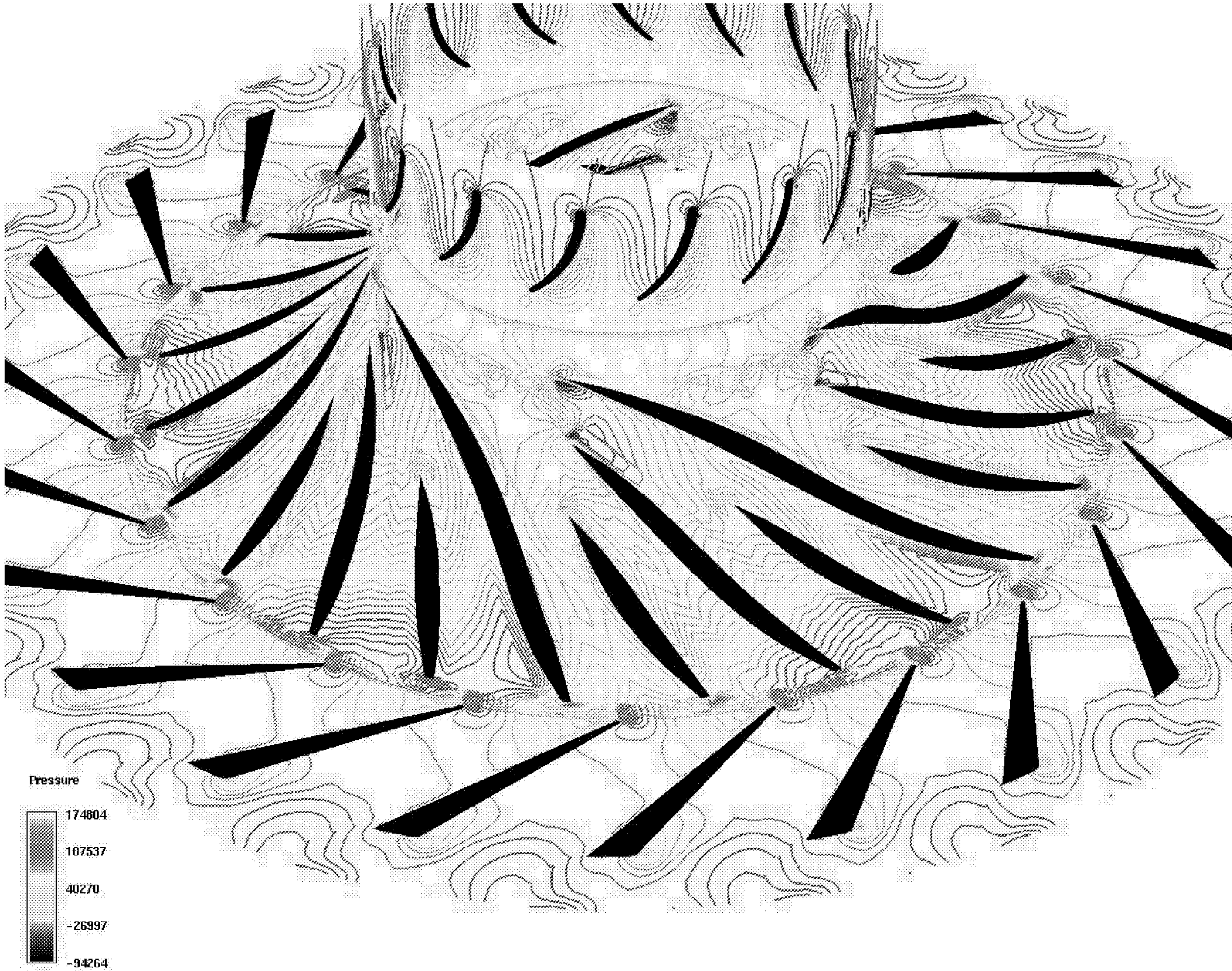
- Unsteady 3D Fluid (NS) Structural Simulation
- Uses Hah3D and Ansys
- Designed to Mature Code Coupling Developers Kit (CCDK) Tool

Computational Grid

- 160x34x265 for single-passage IGV-impeller-diffuser.
- Simplified analysis:
  - 5 IGV passages
  - 2 impeller passages
  - 8 diffuser passages
- Final analysis:
  - 15 IGV passages
  - 6 impeller passages
  - 23 diffuser passages
- 7-10 cycles used for convergence.

Computational Grid

Initial Condition Pressure Contours at Midspan



Turbopump Model:

IGV blades: 5

Nodes 7200

Elements 3245

Impeller blades: 8

Nodes 12336

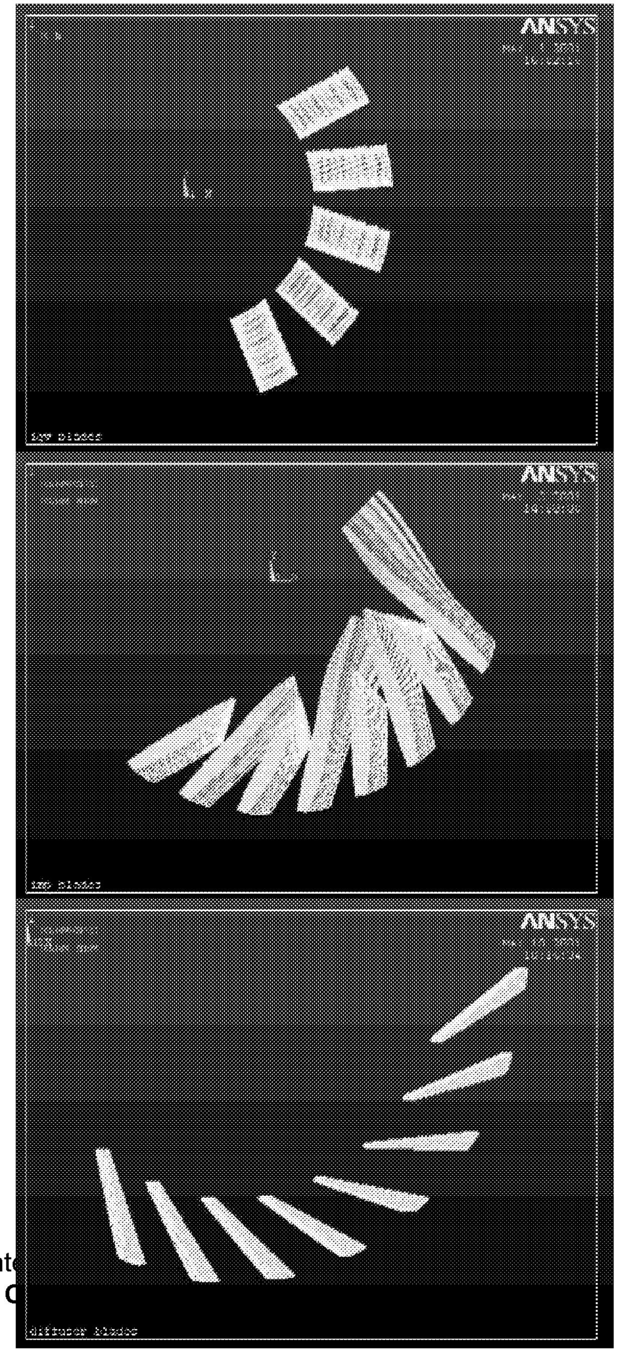
Elements 5566

Diffuser blades: 8

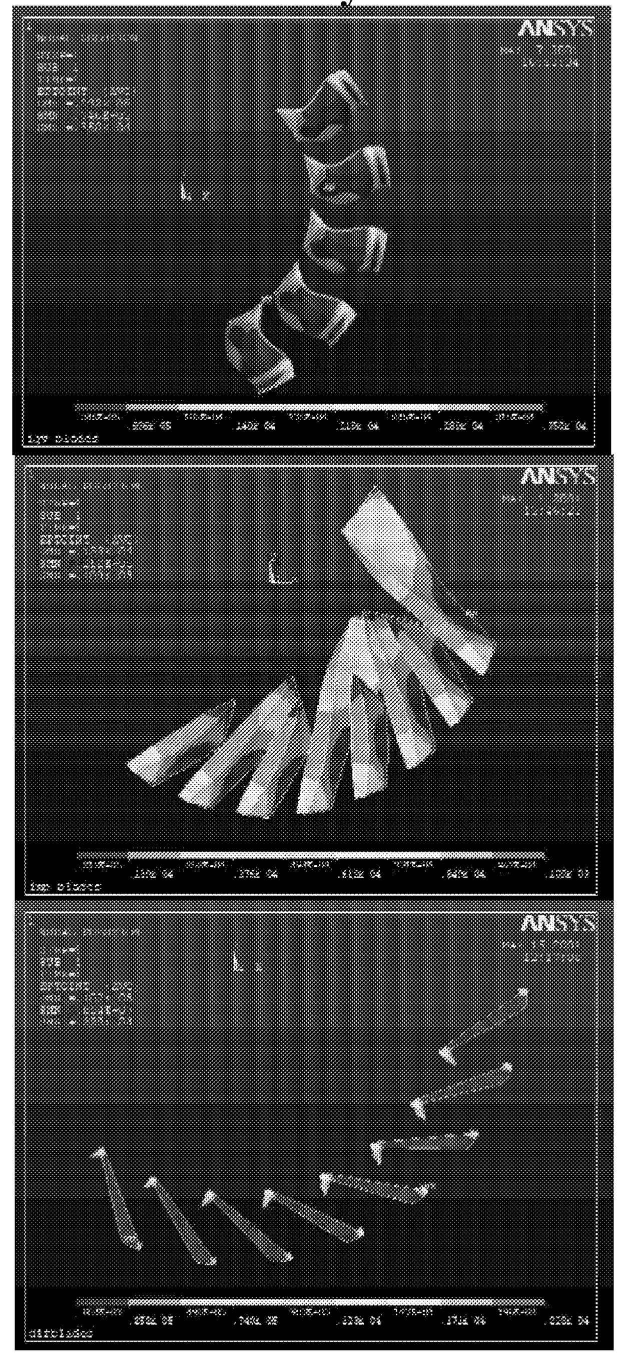
Nodes 8640

Elements 3872

FEA model: SOLID45



Total Intensity STRAIN



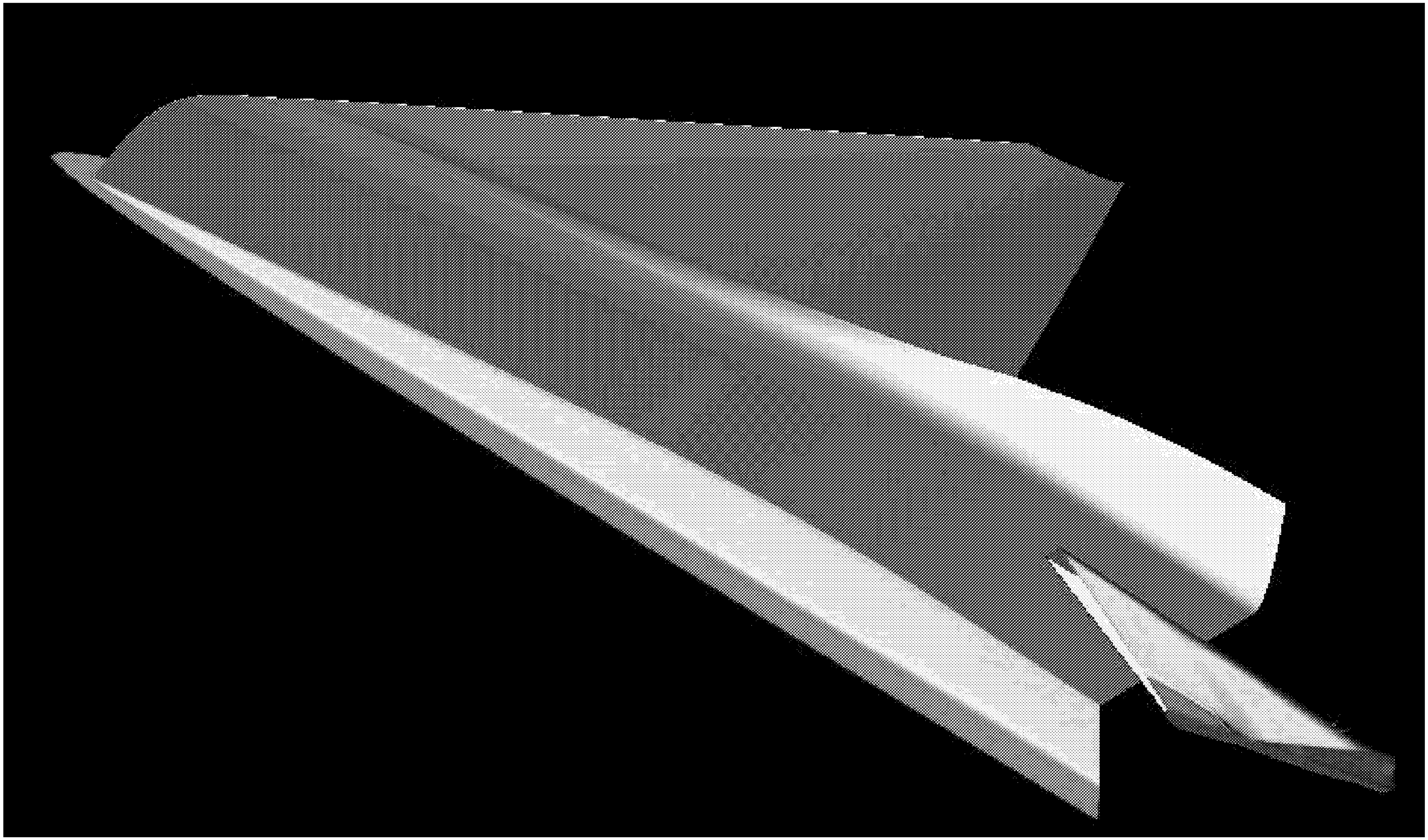
MultiDisciplinary ISTAR Simulation

- 3D Fluid (NS) Structural Simulation
- Uses Overflow, Vulcan, and Ansys
- Supports ISTAR Team and Oversight Team
- Designed to Mature Code Coupling Developers Kit (CCDK) Tool

ISTAR Engine Multidisciplinary Analysis

- Simulation of Approach Flow & Scram Flow for ISTAR Engine.
- Inflow Simulated with OVERFLOW; Scram Simulated with VULCAN. Structures with ANSYS
- Prelude to Aero/Thermal/Structural Simulation
- CFD Solution Delivered Aug. 2001
- Supports ISTAR Team and Oversight Team
- Designed to Mature Code Coupling Developers Kit (CCDK) Tool

Mach Distribution for ISTAR Engine Approach Flow



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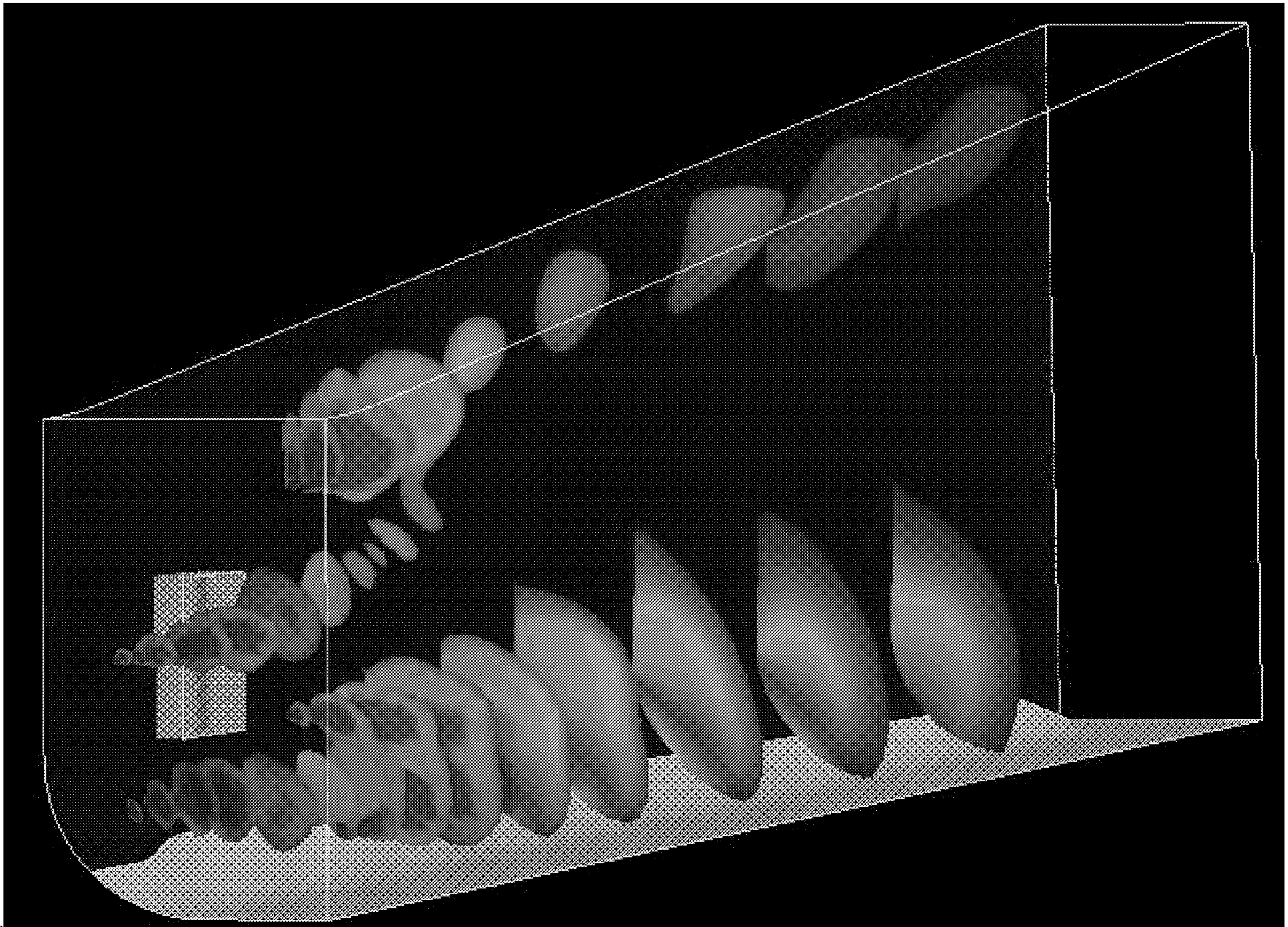
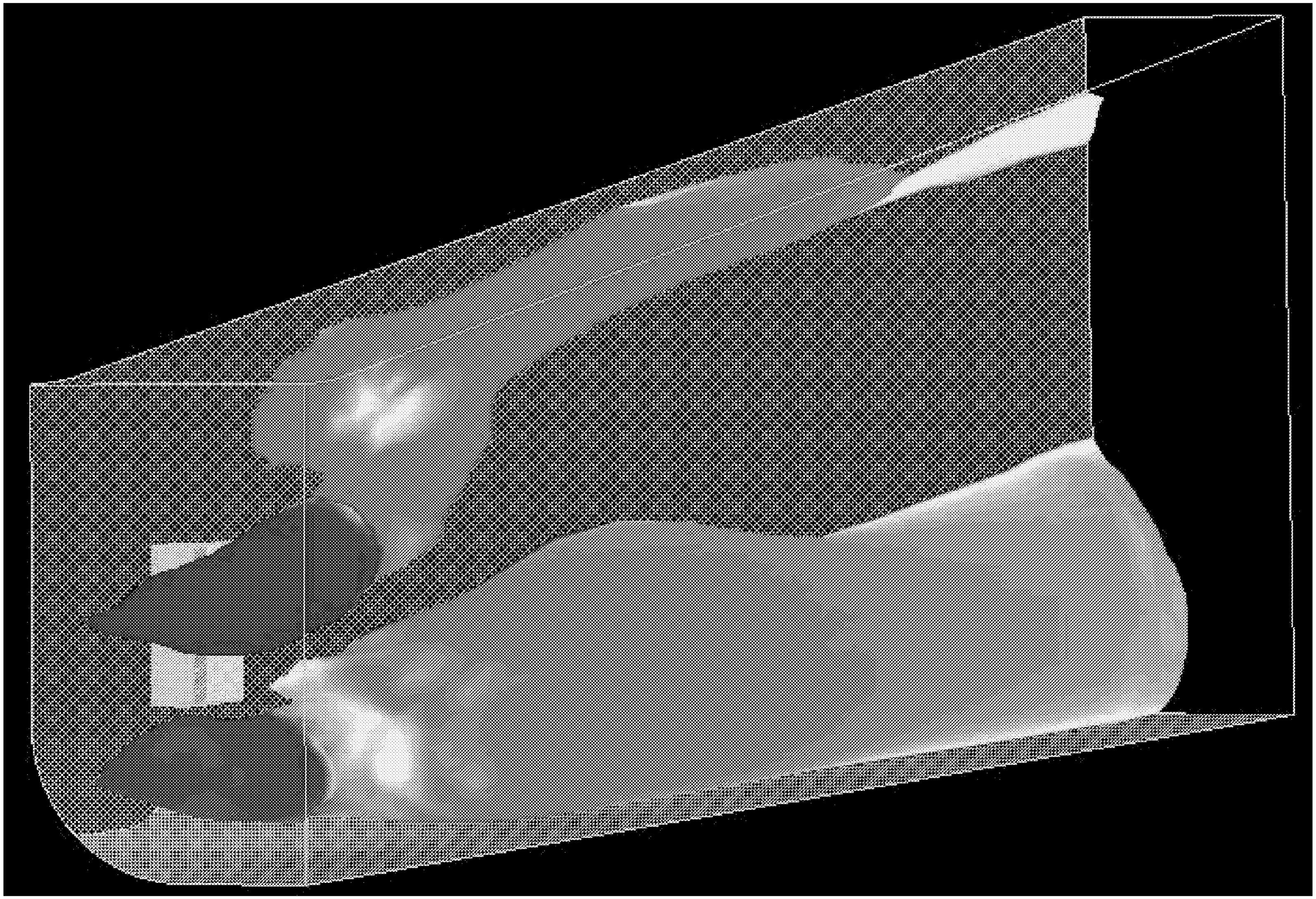
Fuel Mass Fraction in ISTAR Scram Combustor



Fuel Iso-Surfaces Colored by Temperature



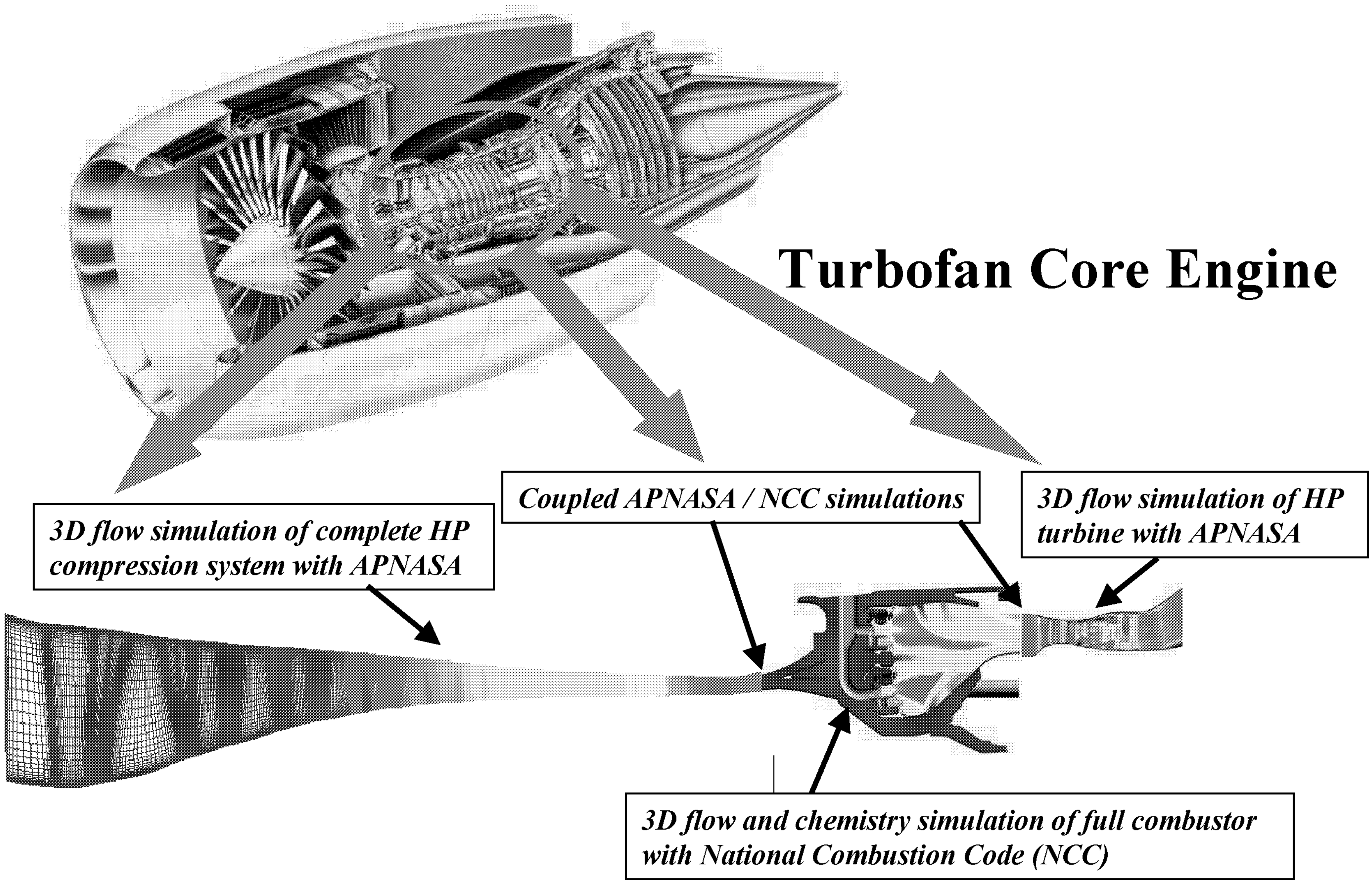
Future Work: Aero/Thermal/Structural Simulation

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

GE90 Engine Simulation

- Full Core 3D Simulation
- Uses APNASA and NCC
- Designed to Demonstrate Overnight Computation Capabilities
- Engineering Demonstration of 3D Code Coupling Capability

Turbofan Core Engine



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Numerical Propulsion System Simulation Roadmap

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

NPSS Version 2.0.0 Capabilities

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

NOTE:See NPSS SRS for detailed Version 2 requirements.

NPSS Architecture FY02 Milestones

- 3-D/3-D coupling of ANSYS and ADPAC wrappers incorporated into Development Kit.

- CORBA-based geometry services incorporated into Development Kit.

- CORBA Security services integrated with GLOBUS and incorporated into Development Kit.

- Fast probabilistic integration (FPI) deployed with Development Kit.

NPSS Wins 2001 NASA Software of the Year Award

NPSS Wins NASA 2001 Turning Goals Into Reality Award (TGIR)