// p22

2000 NPSS Review

NASA Glenn Research Center
October 4-5, 1999

Aircraft Engine Systems

Joseph P. Veres

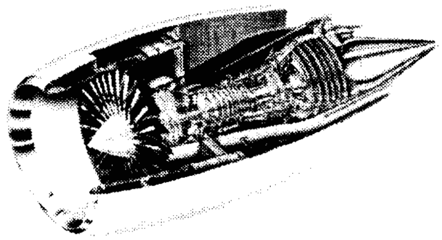
Detailed Simulation of Aircraft Turbofan Engine

Objective

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

Approach

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



Significance/Metrics

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

Point of Contact

Joseph Veres
tel.: (216) 433-2436
fax: (216) 433-5188
e-mail: jveres@grc.nasa.gov

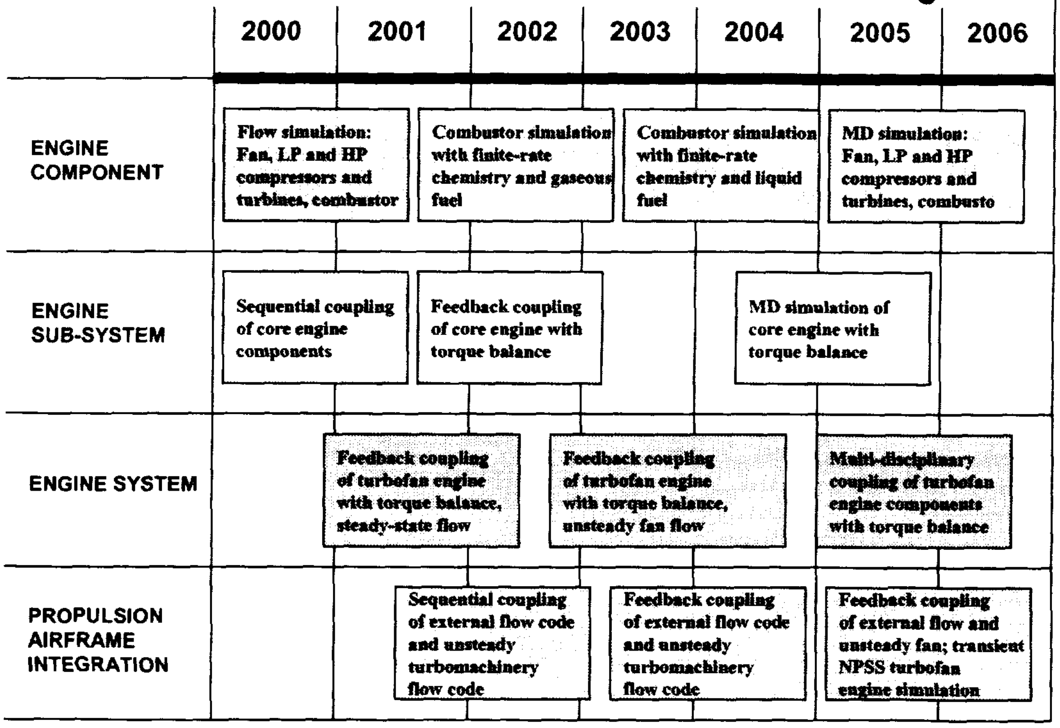
Detailed Simulation of Aircraft Turbofan Engine

Contributors:

GE Aircraft Engines:	
Lyle D. Dailey	Technical Manager, compressor and booster simulations
George Liu	Provided information on GE90 compression system
Bryan Doloresco	Provided 2-D Euler (CAFMIXII) solution for PIP+ compressor
Kevin Kirtley	(GE Corporate Research) Fan simulation with APNASA Version 5
Rolls Royce / Allison	
Edward J. Hall	Manager and principal investigator
ASE Technologies:	
Paul Vitt	Project Manager
Jason Smith	Performed booster, HPC, and turbine simulations
AP Solutions:	
Tim Beach	Provided radial multiblock gridding support (APG)
Mark G. Turner	Consultant on compression and turbine simulations
AYT:	
Rob Ryder	Consultant on combustion simulations
NASA Glenn Research Center:	
John Adamczyk	APNASA turbomachinery flow code
Nan-Suey Liu	National Combustion Code (NCC)
Jeff Moder	NCC and APNASA code coupling
Le Tran	NCC and APNASA code coupling
John Gallagher	Combustor CAD geometry to grid generator interface
Don VanDrei	Task Manager
Joseph P. Veres	Manager Aircraft Engine Systems

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine



2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006

ENGINE COMPONENT

Flow simulation: Fan, LP and HP compressors and turbines, combustor

Combustor simulation with finite-rate chemistry and gaseous fuel

Combustor simulation with finite-rate chemistry and liquid fuel

MD simulation: Fan, LP and HP compressors and turbines, combusto

ENGINE SUB-SYSTEM

Sequential coupling of core engine components

Feedback coupling of core engine with torque balance

MD simulation of core engine with torque balance

ENGINE SYSTEM

Feedback coupling of turbofan engine with torque balance, steady-state flow

Feedback coupling of turbofan engine with torque balance, unsteady fan flow

Multi-disciplinary coupling of turbofan engine components with torque balance

PROPULSION AIRFRAME INTEGRATION

Sequential coupling of external flow code and unsteady turbomachinery flow code

Feedback coupling of external flow code and unsteady turbomachinery flow code

Feedback coupling of external flow and unsteady fan; transient NPSS turbofan engine simulation

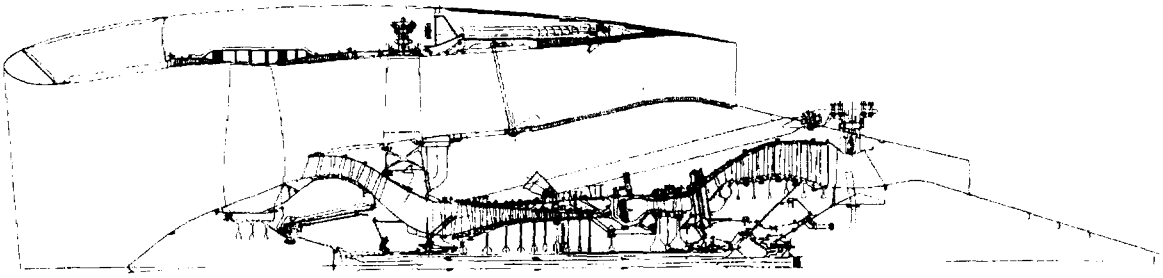
2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

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

2000 NPSS Review

Detailed Flow Simulation of Aircraft Turbofan Engine



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

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

2000 NPSS Review

Detailed Flow Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

NASA and GEAE Developed APNASA Version 5 Featuring:

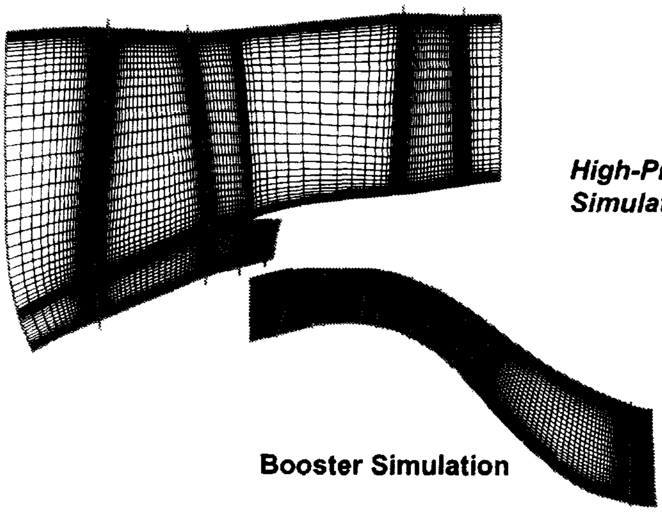
- 4-stage Runge-Kutta explicit Navier-Stokes solver
- Local time steps
- Implicit residual smoothing
- Implicit k-ε turbulence model
- Models multi-stage effects by calculating deterministic stresses with generalized closure
- Domain decomposition in axial direction
- Uses MPI message passing
- Radial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

2000 NPSS Review

Detailed Flow Simulation of Aircraft Turbofan Engine

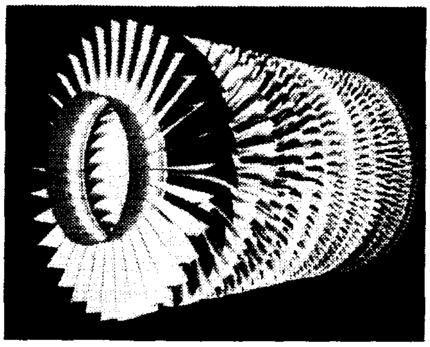
FY00 Accomplishments: Turbomachinery Flow Simulations with APNASA

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



Booster Simulation

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



2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Critical Computing Capability for High-Pressure Compressor Simulations

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

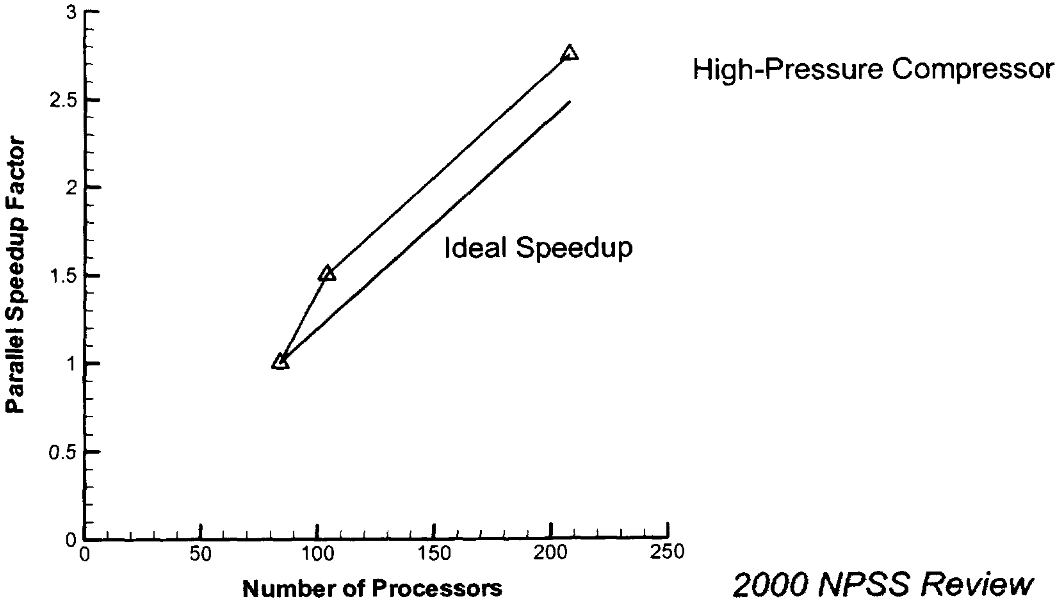
HPCCP resources allowed many trials to be completed
in a reasonable amount of time even for a large 21 blade row case --
CRITICAL IN DEBUGGING AND DEVELOPMENT

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Performance of APNASA on HPCC NAS Origin 2000 Machines



2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: HP-LP Turbine Flow Simulation

Aspects of Turbine Simulations

- Transonic aerodynamics

  High work HP turbines have strong shock systems.

- Embedded blade row operating conditions

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

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

- Turbine flight hardware is actively cooled

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

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

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

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

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

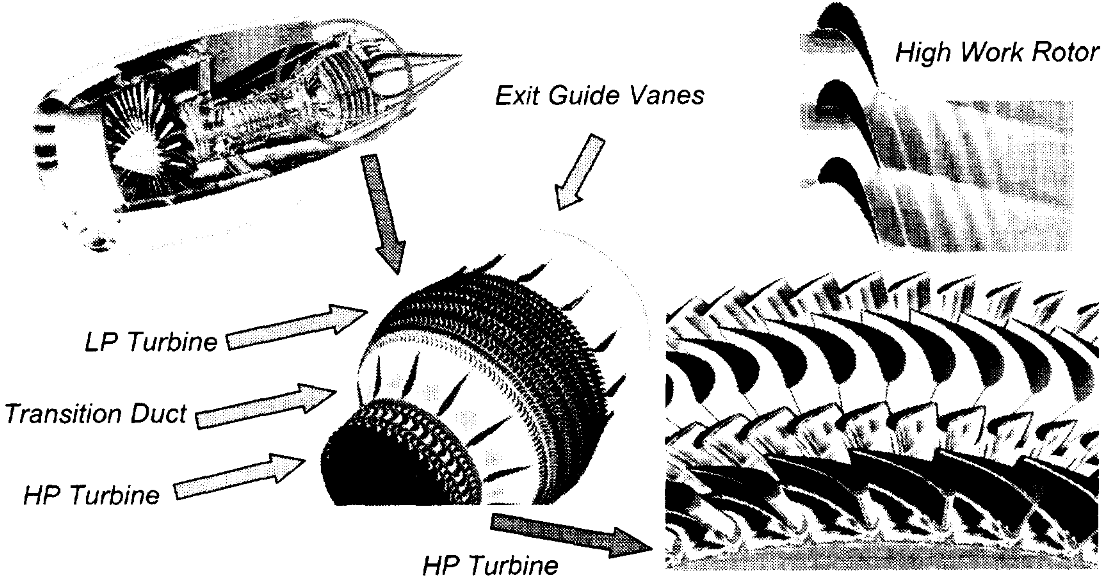
Analysis of the simulation has identified excessive turbine aerodynamic interaction losses that can be reduced by 50%. This 50% reduction in turbine interaction losses will result in a $3 million/year savings in fuel costs for a new fleet of aircraft. The parallel efficiency and accurate simulation with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

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery

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



2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Processing Requirement for HP-LP Turbine Simulation

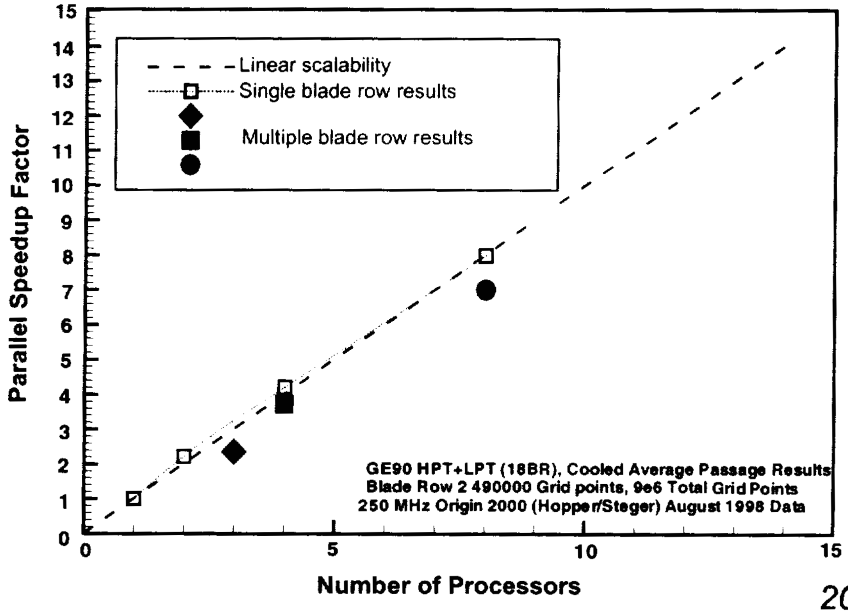
- Typical average-passage analysis mesh size for a given blade row
  - 280x45x55 ~ 700,000 grid points
- 10-18 blade rows for a combined HP and LP turbine system
  - 7 to 12.6 million grid points
- Design cycle requirements are 24 to 48 hour turnaround time
- Requires 6,000 to 10,000 iterations for convergence,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

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: Turbomachinery Flow Simulations

Parallel Performance of APNASA on HPCC NAS Origin 2000 Machines



High-Pressure/
Low-Pressure Turbines

Detailed Simulation of Aircraft Turbofan Engine

GEAE Conclusions: Turbomachinery Simulation

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

Detailed Simulation of Aircraft Turbofan Engine

GEAE Recommendations for Future Direction

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

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

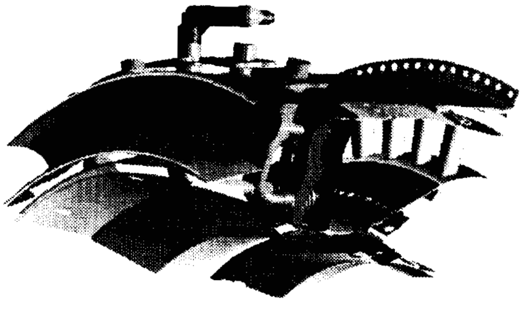
National Combustion Code (NCC)

Objective

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

Approach

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



Significance/Metrics

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

Point of Contact

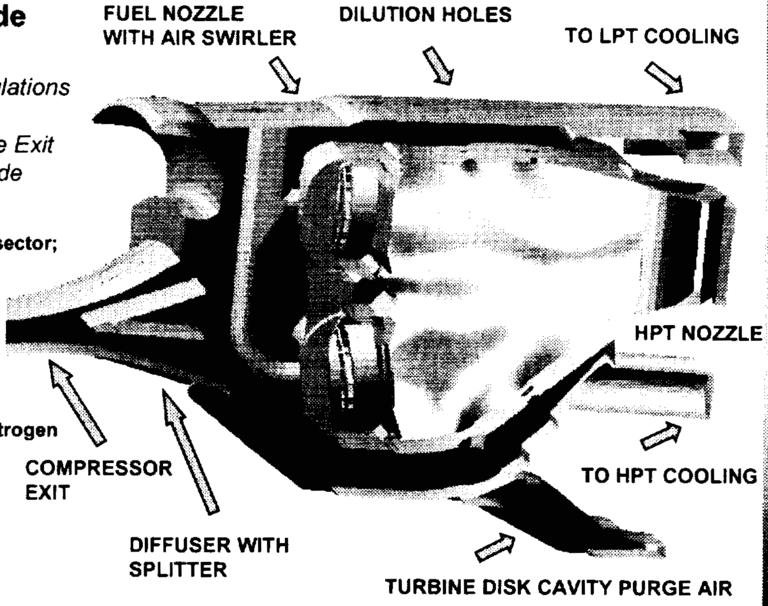
Dr. Nan-Suey Liu
tel.: (216) 433-8722
fax: (216) 433-5802
e-mail: fsliu@grc.nasa.gov

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

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



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

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

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

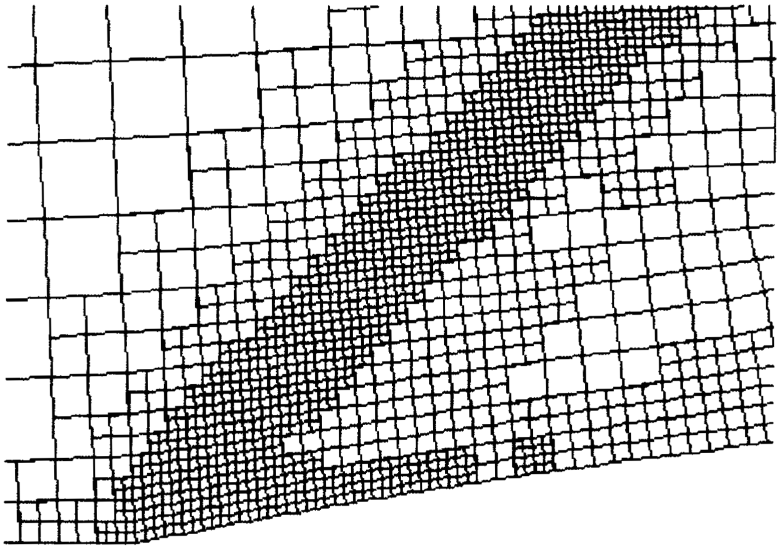
2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

NCC Exploring Mesh Adaptation for Improved Resolution

Four Levels of Adaptation

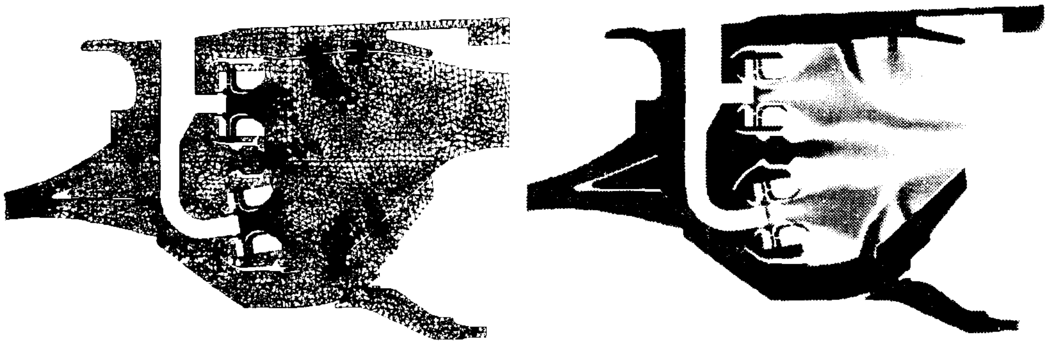


2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

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



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

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

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

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

1 Level Mesh Adaptation on Pressure, Temperature and Speed Gradients

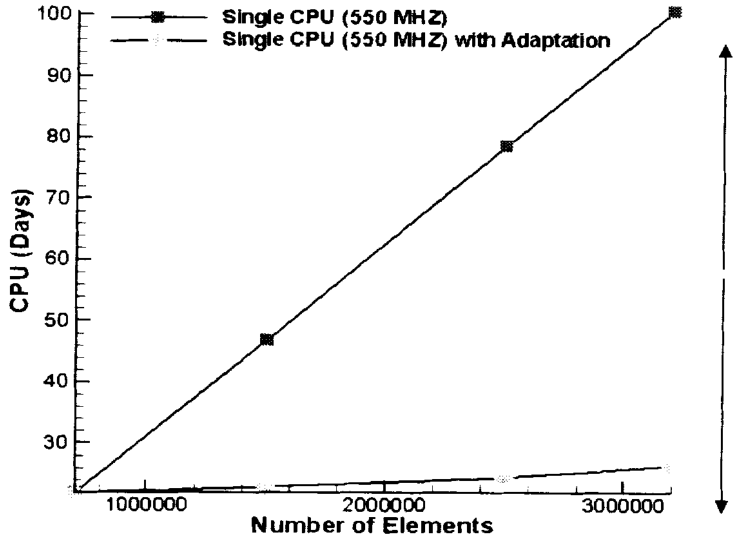
Base mesh: 720,000 tetrahedral elements
Adapted mesh: 1,760,000 tetrahedral elements

2000 NPSS Review

Detailed Simulation of Aircraft Turbofan Engine

FY00 Accomplishments: National Combustion Code

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

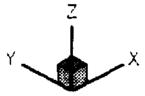


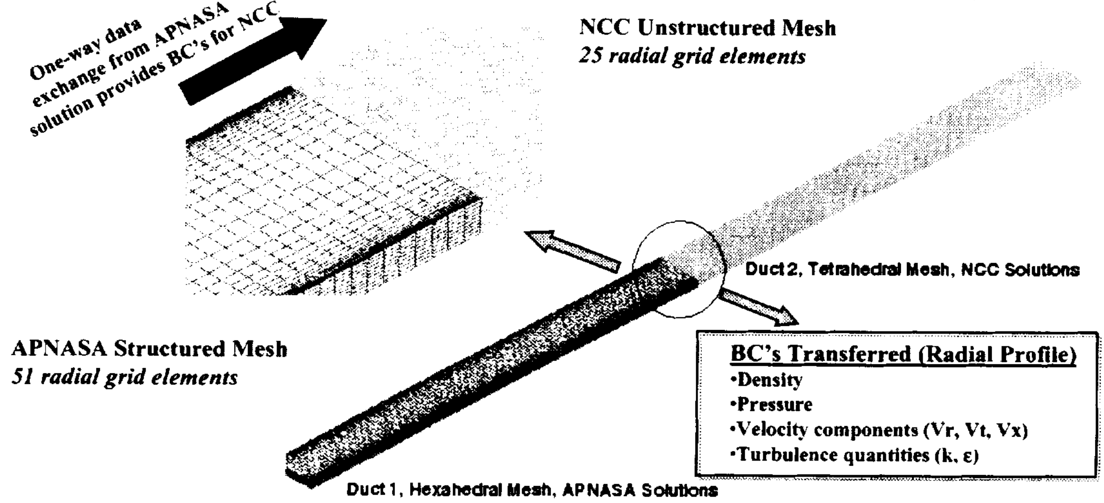
4 CPU Equivalency

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

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





NCC Unstructured Mesh
25 radial grid elements

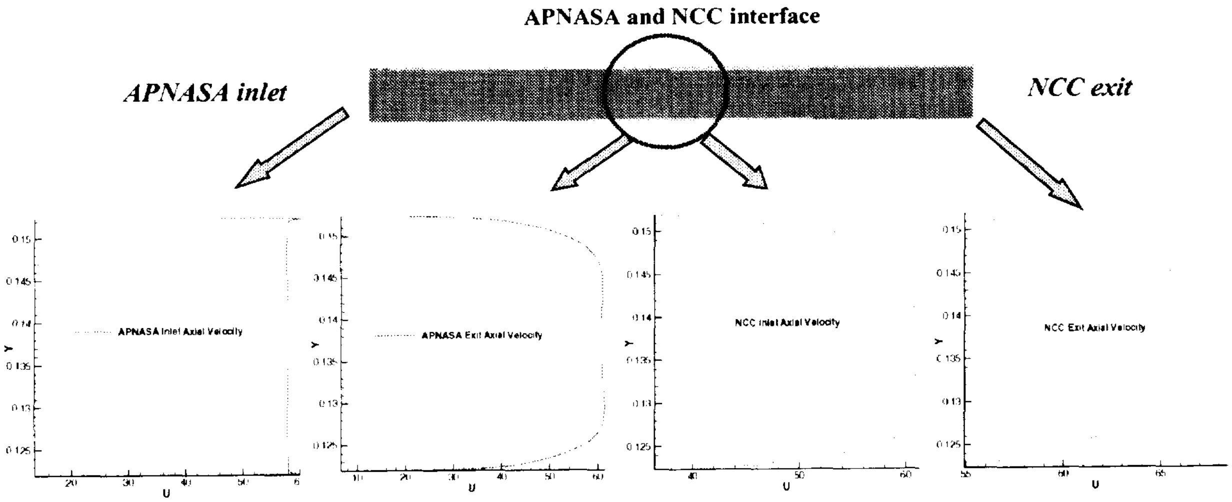
APNASA Structured Mesh
51 radial grid elements

BC's Transferred (Radial Profile)
- **Density**
- **Pressure**
- **Velocity components (Vr, Vt, Vx)**
- **Turbulence quantities (k, ε)**

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

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



2000 NPSS Review

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Developed Standard Data Exchange Coupling Methodology

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

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

File Names:

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

2000 NPSS Review

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

The velocity components are the cylindrical coordinates components

Vr = radial
Vt = azimuthal
Vx = axial

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

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

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

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

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

Tref_AP = reference temperature in units of R {Rankine}

Lref_AP = reference length in units of in {inches}

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

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

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

Convert to desired units:

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

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

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

(For APNASA, Pfac = Tfac = Lfac = Gfac = 1)

Xhub_dim = dimensional Hub axial location
= Xhub * Lref

Rhub_dim = dimensional Hub radius
= Rhub * Lref

Xtip_dim = dimensional tip axial location
= Xtip * Lref

Rtip_dim = dimensional tip radius
= Rtip * Lref

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

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

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

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

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

Rhoref = reference density
= Pref/(Gasc_Tref)

Vref = reference speed
= sqrt(Gasc_Tref)

Kref = reference turbulent kinetic energy
= Vref*Vref

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

2000 NPSS Review

Detailed Simulation of Aircraft Engine

FY00 Accomplishments: Coupling of APNASA and NCC

Standard Data Exchange Coupling Methodology (continued)

p_dim = dimensional static pressure
= p * Pref

rho_dim = dimensional mass density
= rho * Rhoref

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

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

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

k_dim = dimensional turbulent kinetic energy
= k * Kref

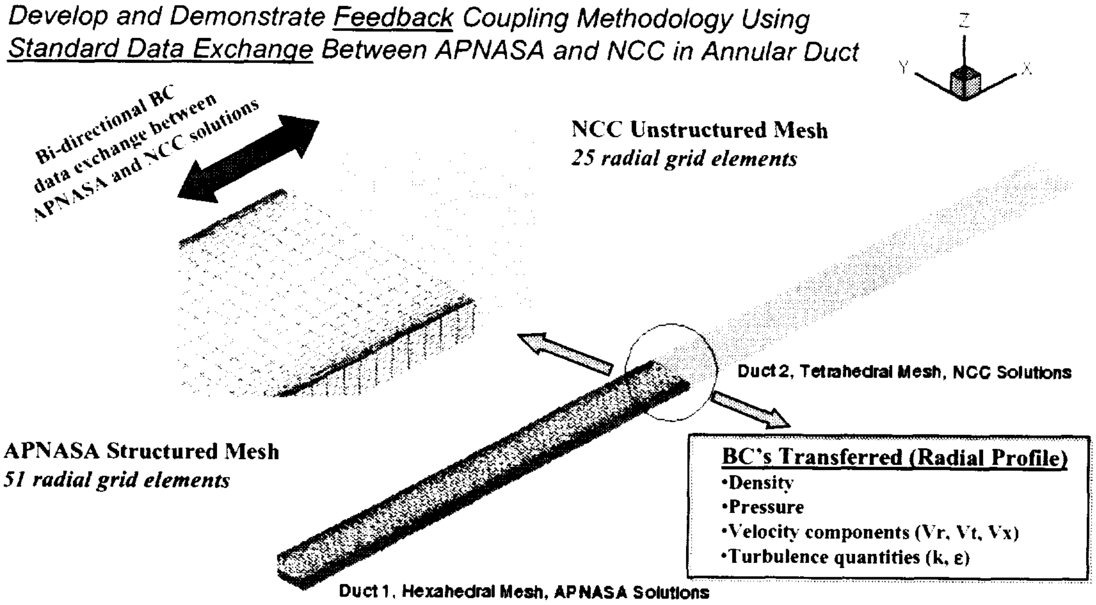
ep_dim = dimensional turbulent specific dissipation
= ep * Epref

2000 NPSS Review

Detailed Simulation of Aircraft Engine

FY01 Plans: Coupling of APNASA and NCC

Develop and Demonstrate *__Feedback__* *Coupling Methodology Using* *__Standard Data Exchange__* *Between APNASA and NCC in Annular Duct*



Bi-directional BC data exchange between APNASA and NCC solutions

NCC Unstructured Mesh
25 radial grid elements

Duct 2, Tetrahedral Mesh, NCC Solutions

APNASA Structured Mesh
51 radial grid elements

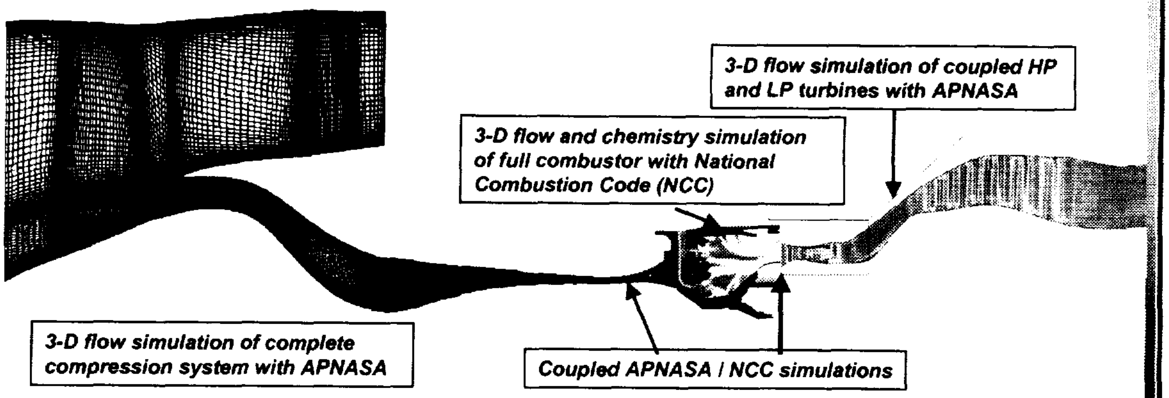
BC's Transferred (Radial Profile)
- **Density**
- **Pressure**
- **Velocity components (Vr, Vt, Vx)**
- **Turbulence quantities (k, ε)**

Duct 1, Hexahedral Mesh, APNASA Solutions

Detailed Simulation of Aircraft Turbofan Engine

FY01 Plans: Coupling of APNASA and NCC

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



3-D flow simulation of coupled HP and LP turbines with APNASA

3-D flow and chemistry simulation of full combustor with National Combustion Code (NCC)

3-D flow simulation of complete compression system with APNASA

Coupled APNASA / NCC simulations

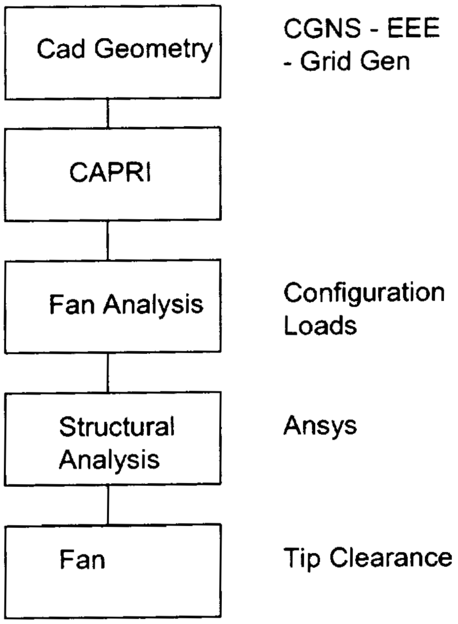
NPSS Multidisciplinary Integration and Analysis

NASA Contract NAS3-98003
Task Order #5

NPSS Review 2000
NASA Glenn Research Center
October 4, 2000

Initial Task Discussions

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



Cad Geometry — CGNS - EEE - Grid Gen

CAPRI

Fan Analysis — Configuration Loads

Structural Analysis — Ansys

Fan — Tip Clearance

EEE - Energy Efficient Engine
MD - Multidisciplinary

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)

2000 NPSS Review

Participants in Prototype

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

ADPAC - Advanced Ducted Propfan Analysis Code
NESSUS - Numerical Evaluation Stochastic Structure Under Stress

2000 NPSS Review

Program Technical Elements

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

HPCC - High Performance Computing and Communication

2000 NPSS Review

Development Milestones

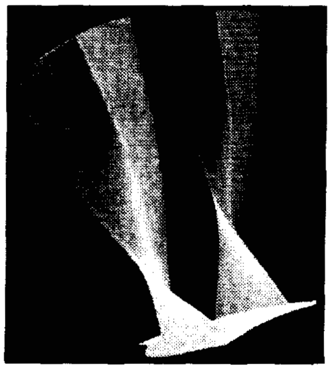
- Hot to Cold Coordinate Conversion
  - Extract cold manufacturing coordinate database based on desired hot running design shape.
- Cold to Warm Coordinate Conversion
  - Develop automated off-design airfoil shape based on off-design speed and aero loads.
- Incorporate Probabilistic Method
  - Produce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

2000 NPSS Review

Developmental Notes

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

Aero/Structural Coupling



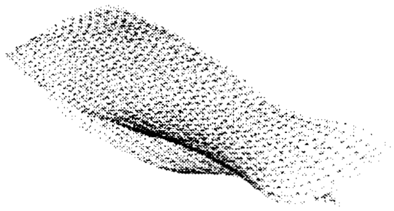
ADPAC CFD Analysis

Input

Geometry, operating conditions

Output

Pressure, temperature



ANSYS Structural Analysis

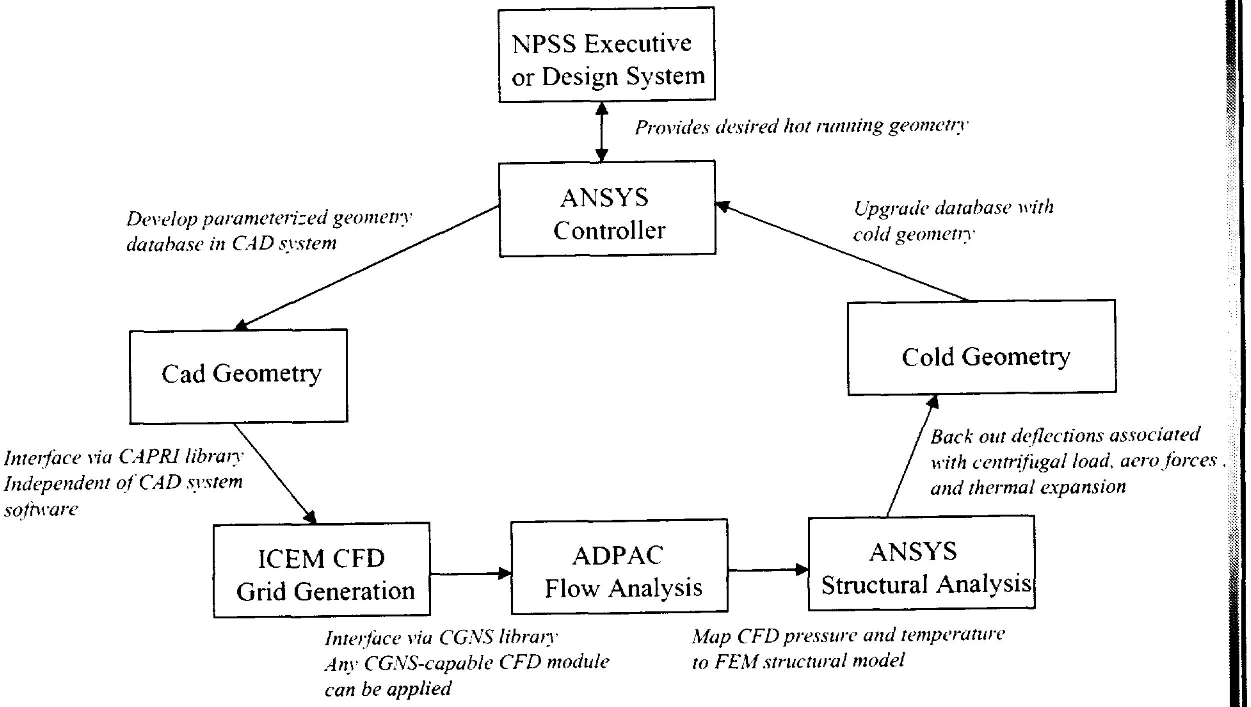
Input

Geometry, operating conditions, pressure, temperature

Output

Deformations, stress

Hot to Cold Conversion



NPSS Executive or Design System

Provides desired hot running geometry

ANSYS Controller

Develop parameterized geometry database in CAD system

Upgrade database with cold geometry

Cad Geometry

Cold Geometry

Interface via CAPRI library Independent of CAD system software

Back out deflections associated with centrifugal load, aero forces, and thermal expansion

ICEM CFD Grid Generation

ADPAC Flow Analysis

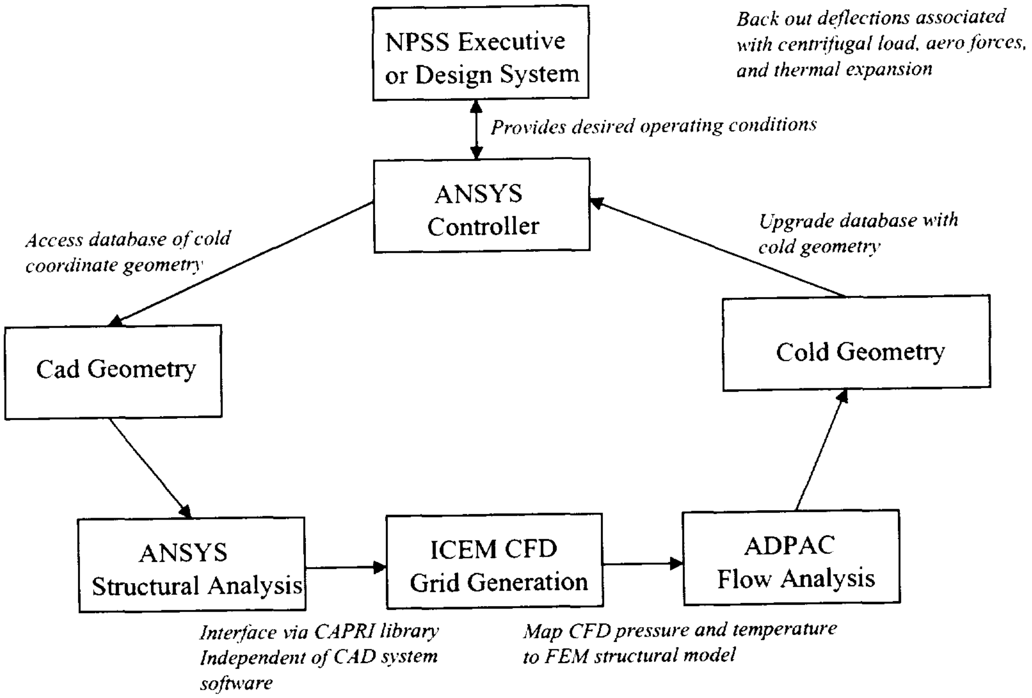
ANSYS Structural Analysis

Interface via CGNS library Any CGNS-capable CFD module can be applied

Map CFD pressure and temperature to FEM structural model

2000 NPSS Review

Cold to Lukewarm Conversion



NPSS Executive or Design System

Back out deflections associated with centrifugal load, aero forces, and thermal expansion

Provides desired operating conditions

ANSYS Controller

Access database of cold coordinate geometry

Upgrade database with cold geometry

Cad Geometry

Cold Geometry

ANSYS Structural Analysis

ICEM CFD Grid Generation

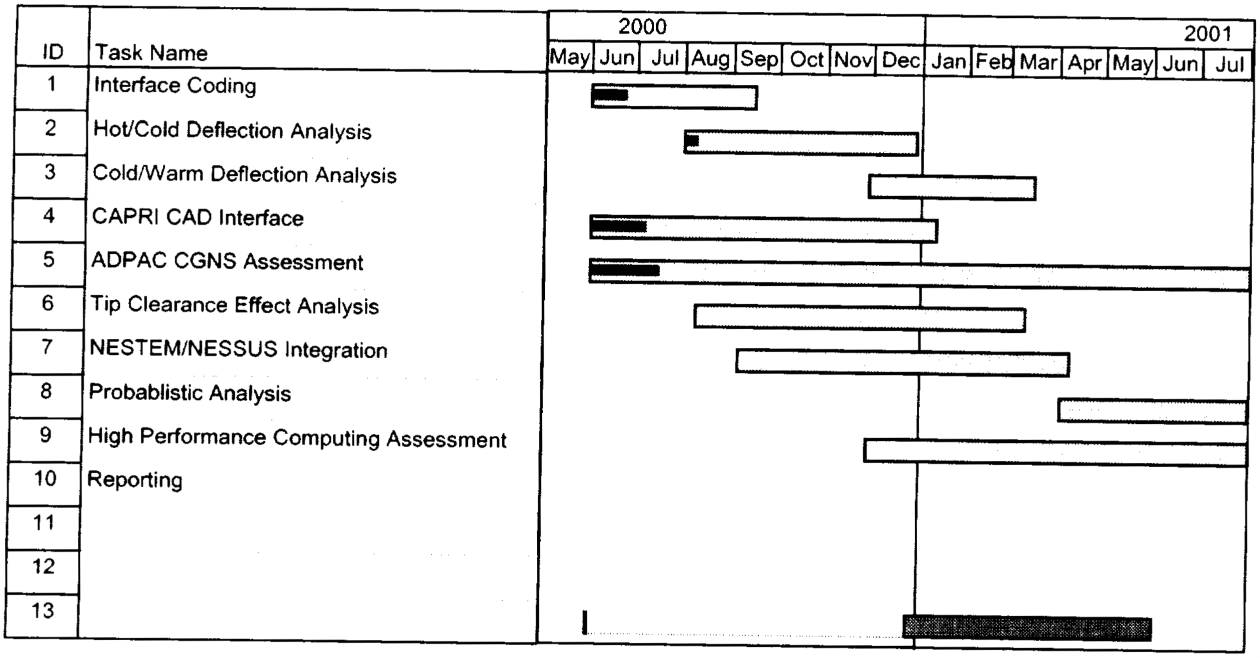
ADPAC Flow Analysis

Interface via CAPRI library Independent of CAD system software

Map CFD pressure and temperature to FEM structural model

2000 NPSS Review

Schedule



2000 NPSS Review