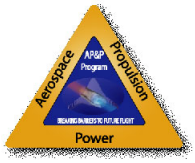
The Computing & Interdisciplinary Systems Office

Annual Review and Planning Meeting
October 9-10, 2002

Combustor Simulation



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Combustor Simulation

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

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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.

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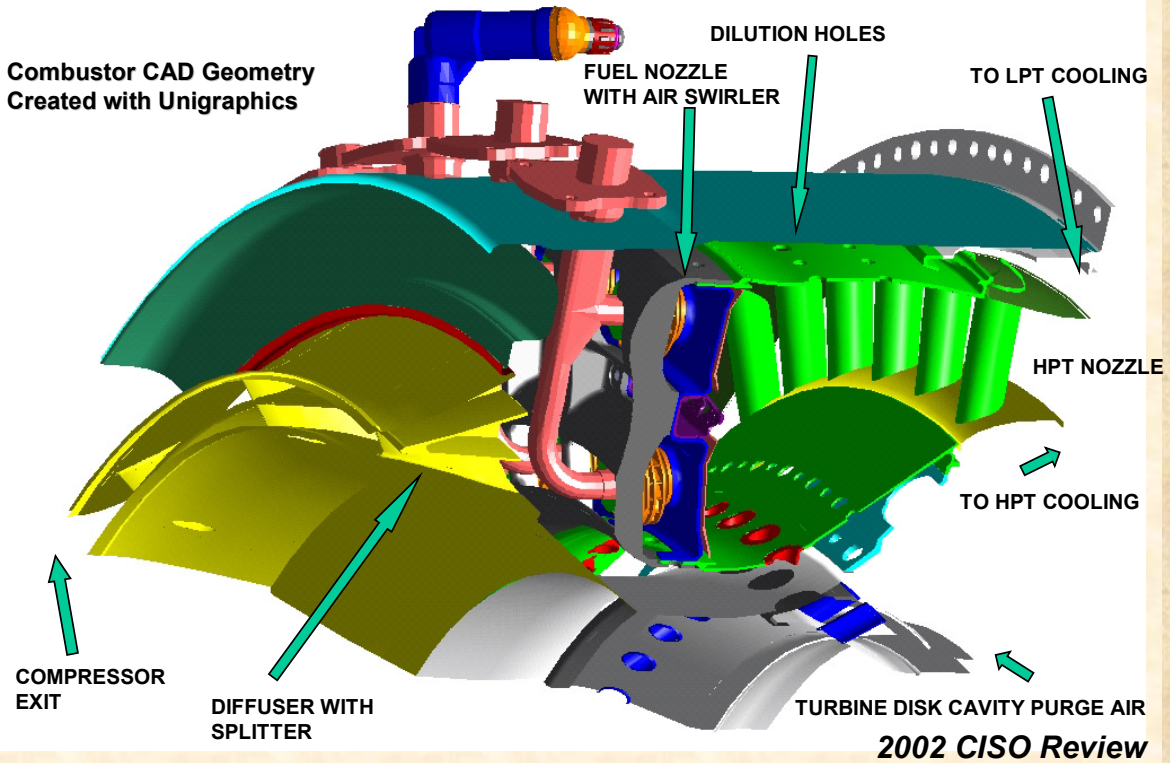
Detailed Simulation of Aircraft Turbofan Engine



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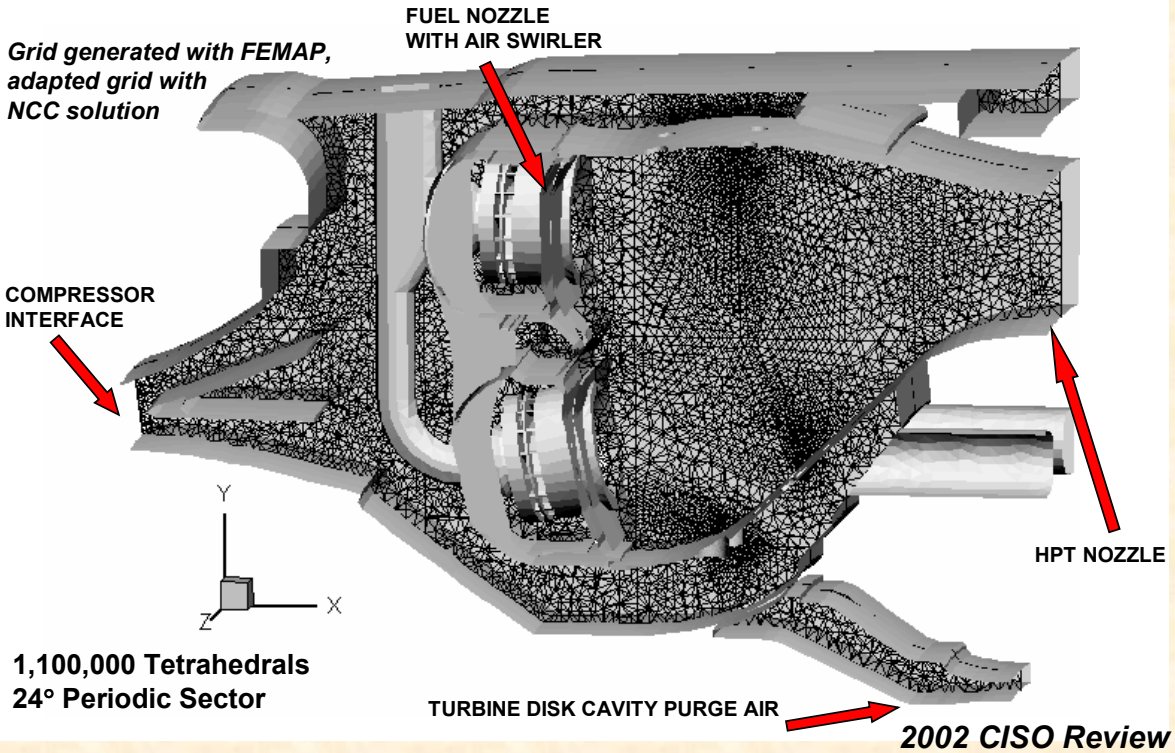
Detailed Simulation of Aircraft Turbofan Engine

Combustor Grid with Adaptation



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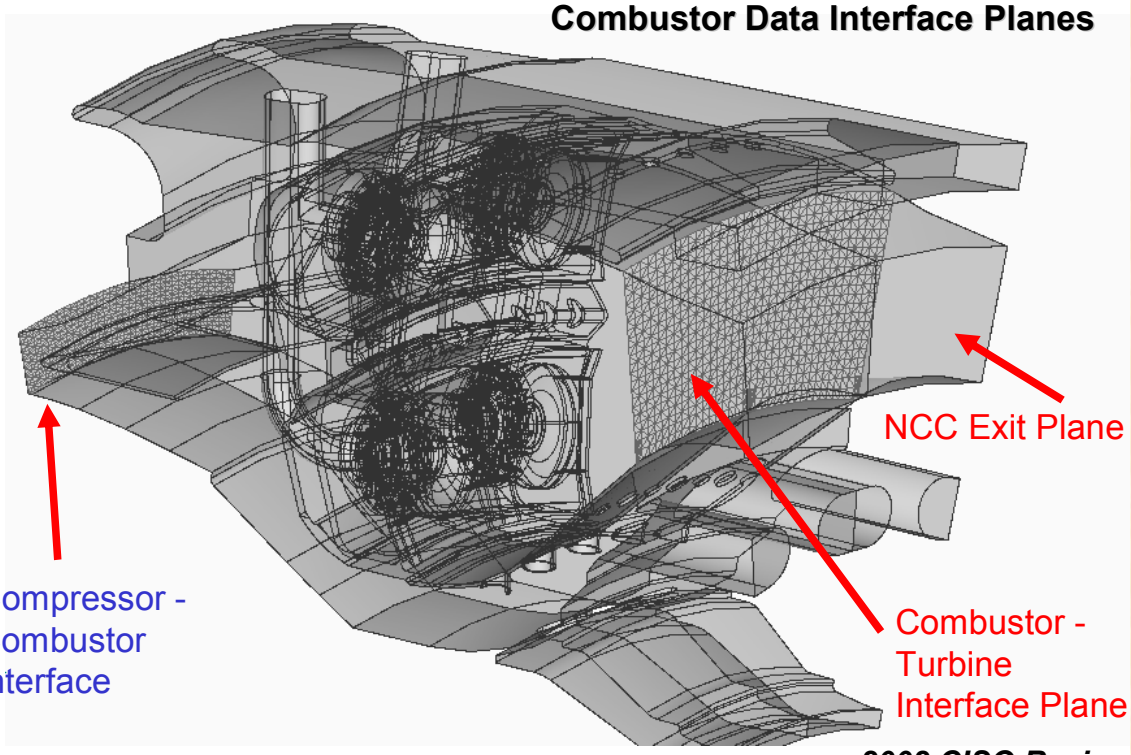
Combustor Data Interface Planes



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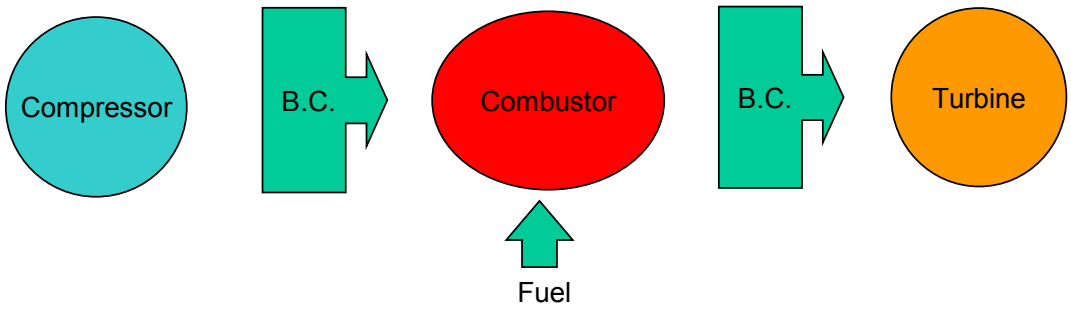
Boundary Condition Transfer



- 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.

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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.

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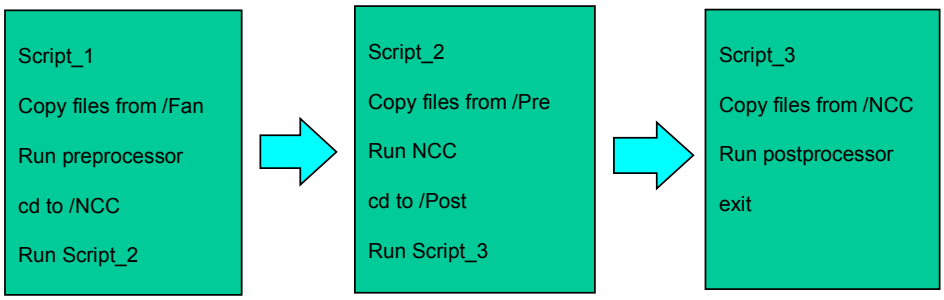
Run-time Scripts



- **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.**

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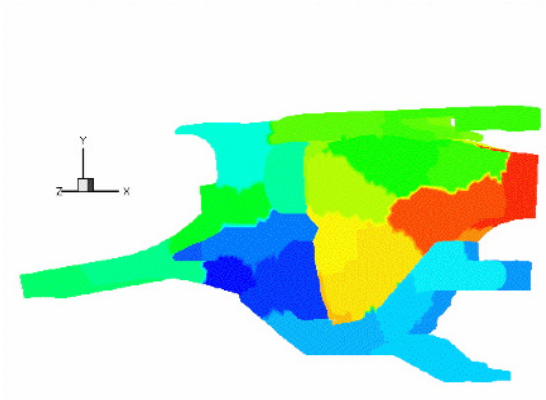
Combustor Simulation on Multiple Processors



- **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.**

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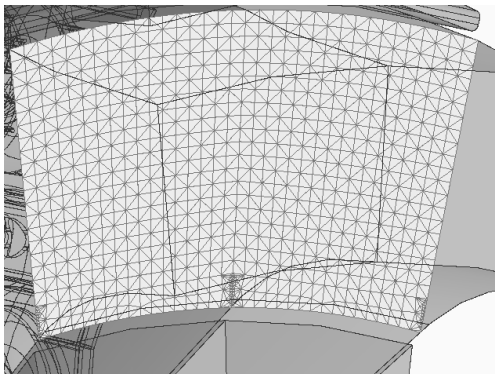
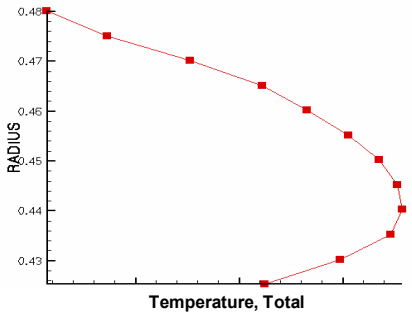
Detailed Simulation of Aircraft Turbofan Engine



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.

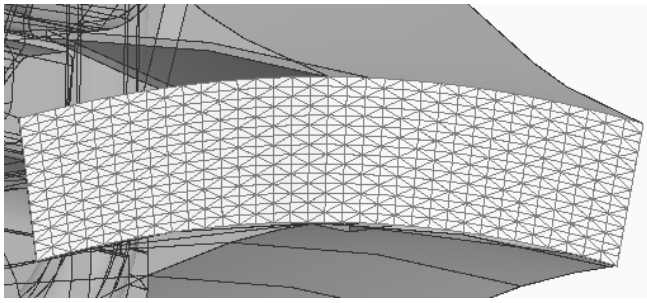


Mass averaged profiles for **velocities** were transferred at the combustor-turbine interface plane.

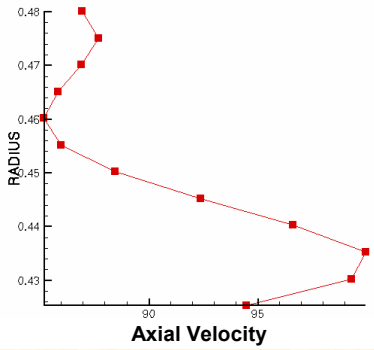
Mass averaged profile for **temperature** was transferred at the combustor exit plane.

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.



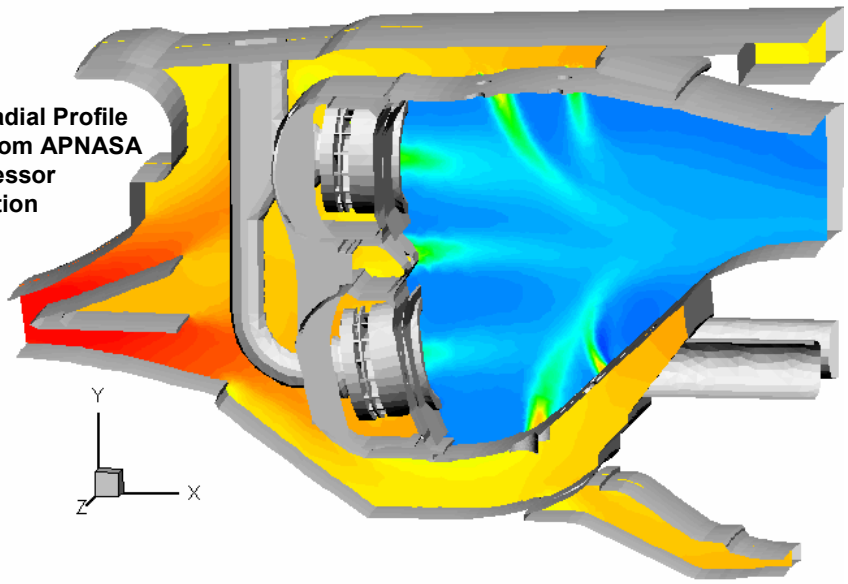
At this interface, the mass flow is preserved between the APNASA mesh and the NCC mesh by maintaining the shape of the circumferentially mass averaged profiles for velocities, while scaling the magnitudes of the velocities.

Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Pressure

National Combustion Code

Inlet Radial Profile BC's from APNASA compressor simulation



Radial Profiles at the Combustor Exit and Turbine Interface Plane.

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

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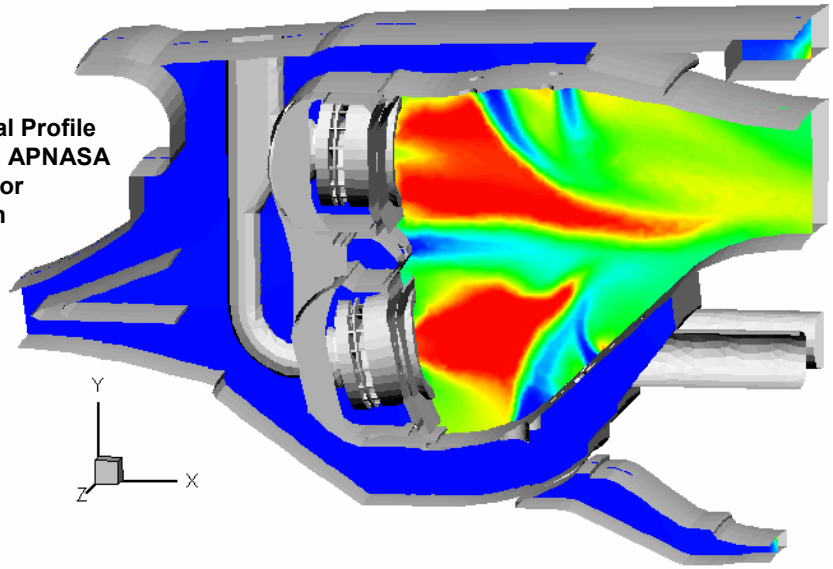
Detailed Simulation of Aircraft Turbofan Engine

Combustor Simulation Total Temperature

National Combustion Code

Inlet Radial Profile BC's from APNASA compressor simulation



Radial Profiles at the Combustor Exit and Turbine Interface Plane

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

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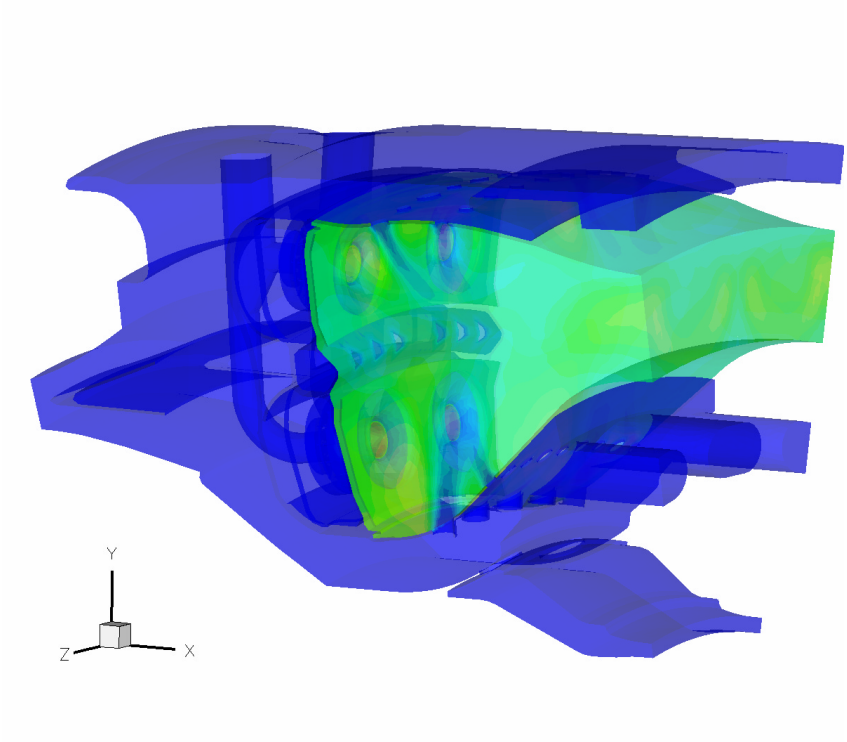
Total Temperature For GE90 Combustor



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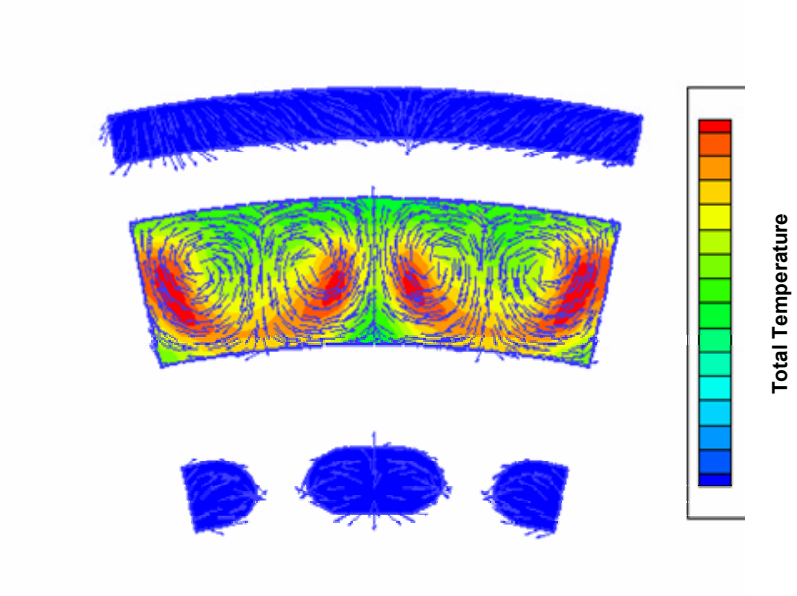
Combustor Exit Plane Vector Plot



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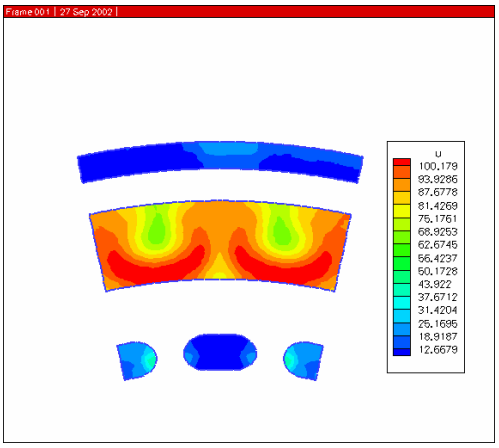
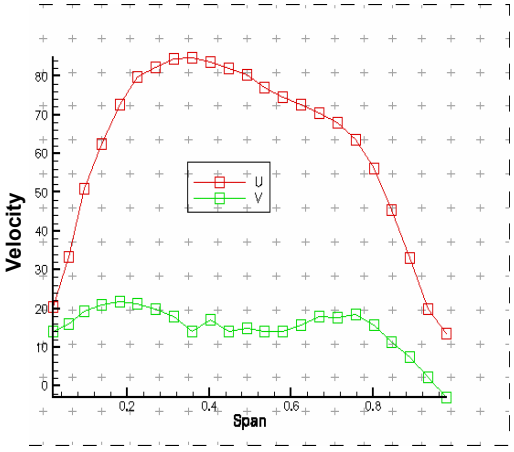
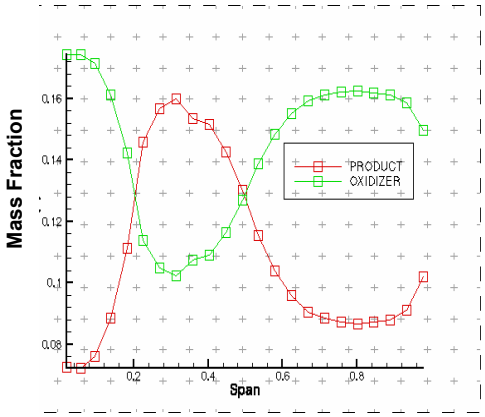
Combustor Velocity Exit Profile Data

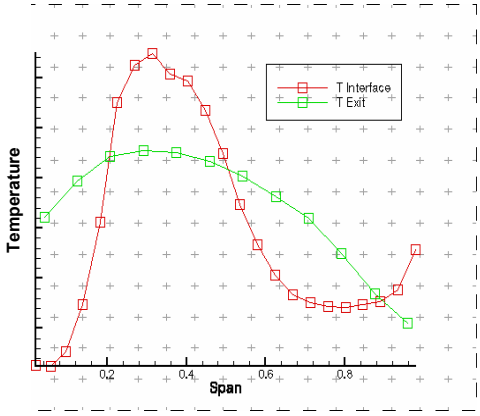




U - Axial Velocity
V - Radial Velocity

Species and Temperature Exit Profile Data





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

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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.

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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.**

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