NPSS ENGINE SYSTEMS SIMULATIONS

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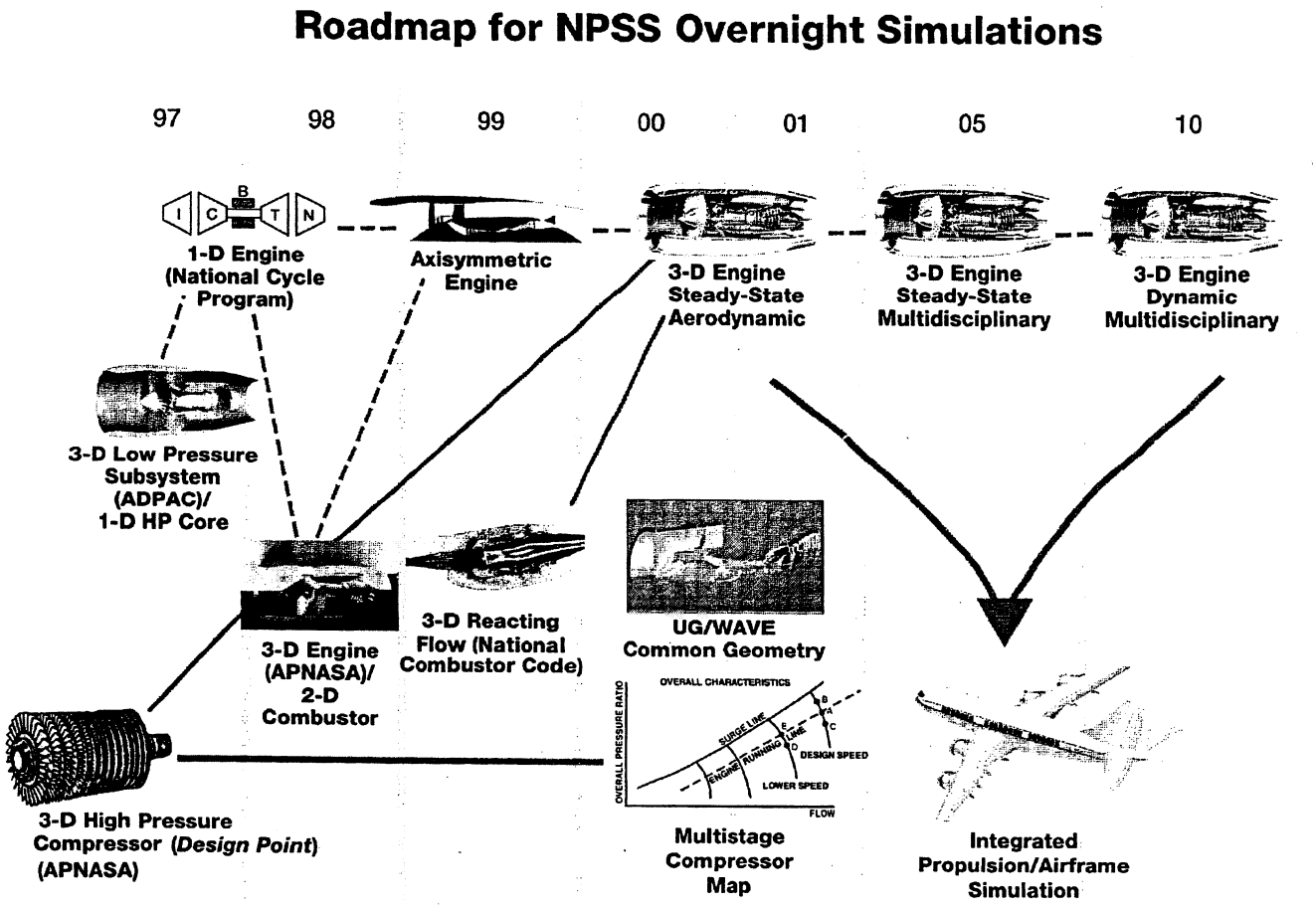


# Multidisciplinary Design Optimization Using UG/WAVE

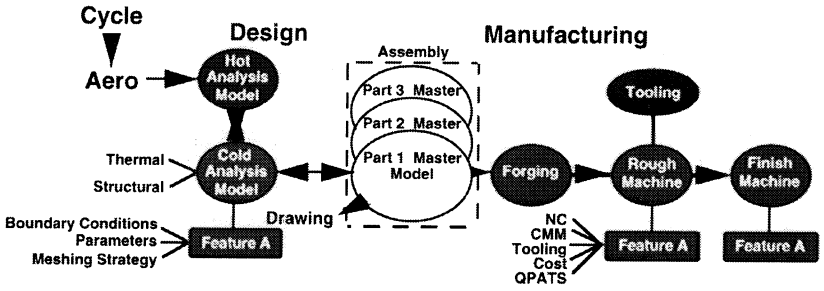
## Objective

To develop an associative control framework in a Unigraphics CAD environment enabling multidisciplinary design of propulsion systems

## Approach

To apply WAVE (What-if Alternative Valve Engineering) CAD design tool to control key design variables to create a complete gas turbine engine in a Unigraphics environment

**Common Geometry**




## Benefits

- The creation of a common geometry will encourage level concurrent engineering
- Supports concept to detailed design engineering and rapid optimization
- Standardization and automation of design practice and serves to capture the "corporate memory"
- Contract with GEAE NAS3-98004 Task Order #2

## Point of Contact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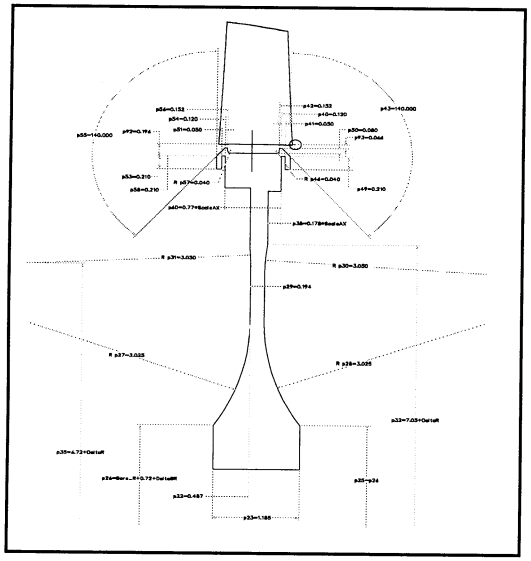
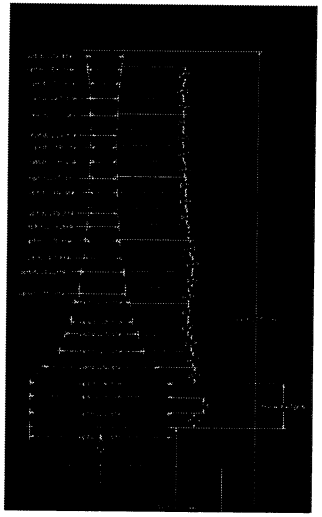
# Multidisciplinary Design Optimization Using UG / WAVE

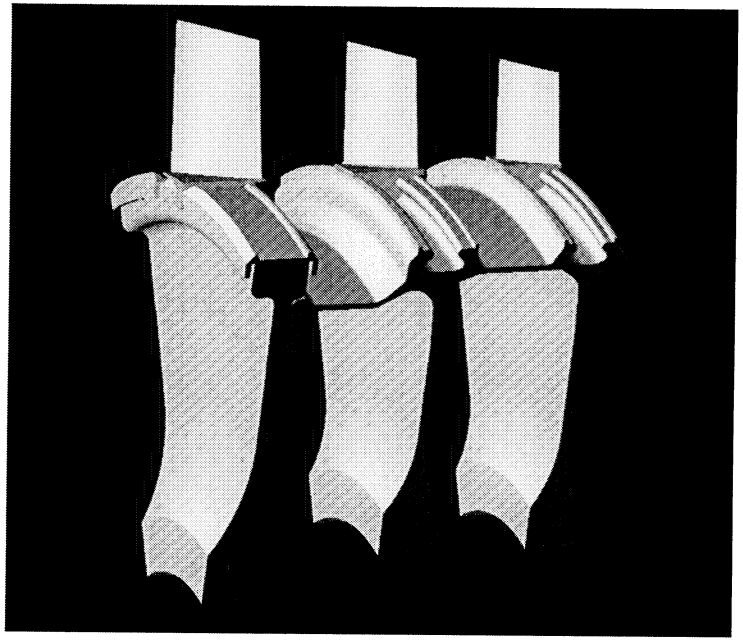
Design Rules Drive Knowledge based Unigraphics (UG) Sketch

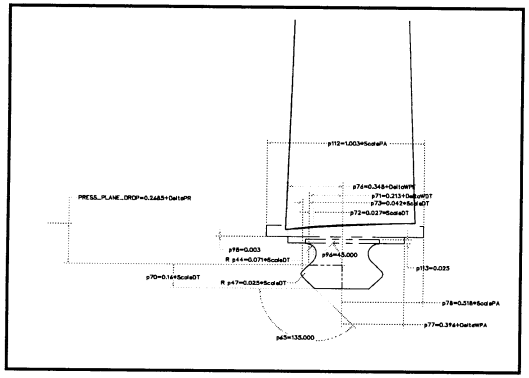


Disk 2D Profile, Calculated Blade and Post Loads

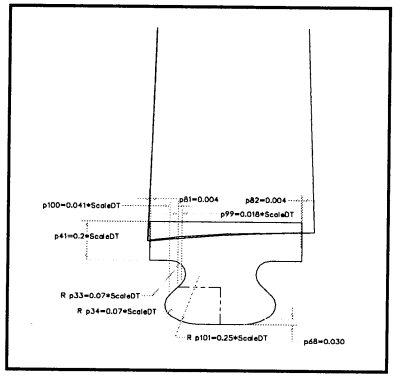


UG solid modeling feature is used to unite the base curves into one solid associative geometry of a complex object



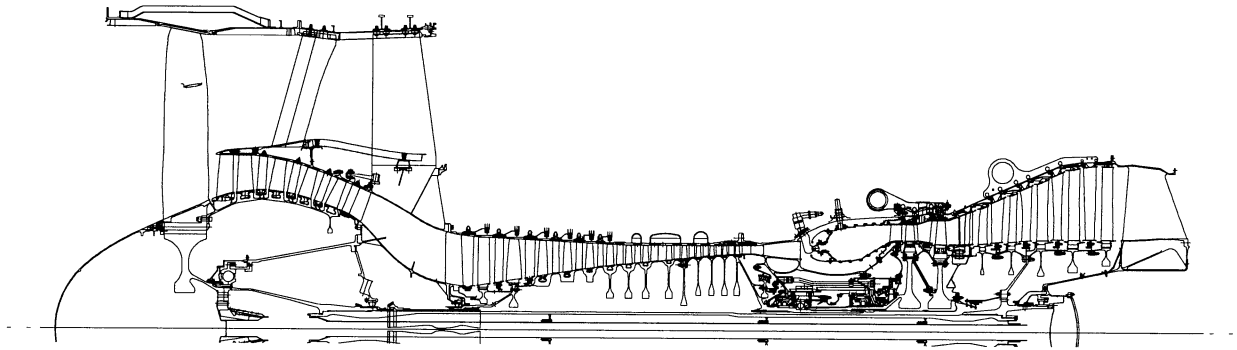


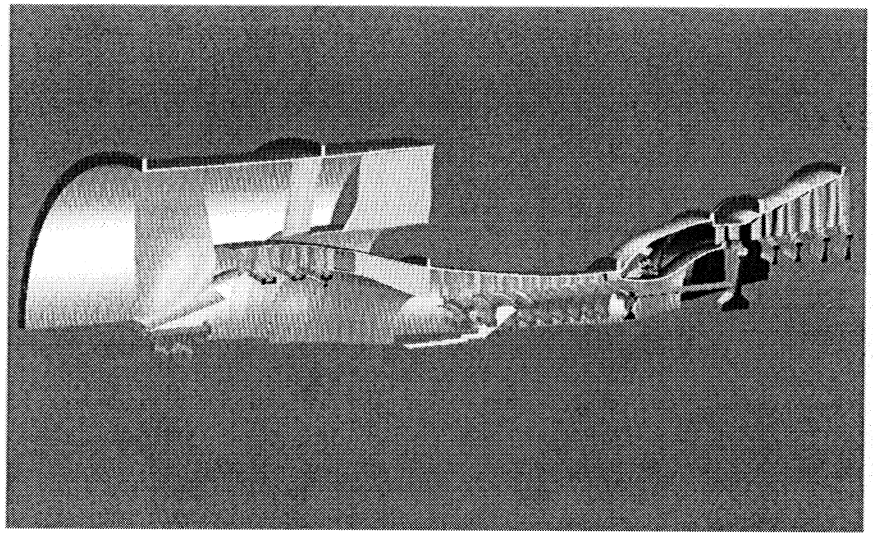
Disk Slot Sketch



Blade Dovetail

# Multidisciplinary Design Optimization Using UG / WAVE





- High-fidelity rapid creation of detailed geometry for system level concurrent engineering
- Controlled automation of design changes
- Links technical requirements with the creation of the base geometry at all levels
- Supports concept to detailed engineering
- Captures corporate knowledge

# Flow Solver for National Combustion Code

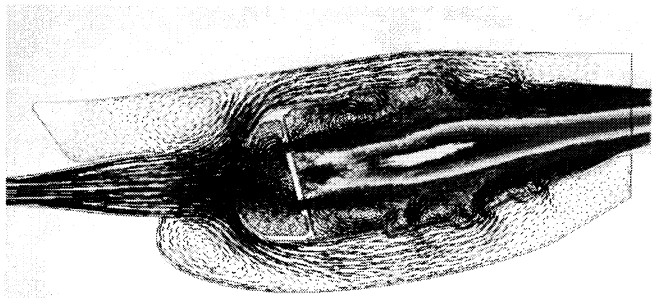
## Multidisciplinary Combustor Design and Analysis System with Emissions Modeling

### Objective

Develop an integrated system of codes for combustor design and analysis to enable a factor of 5 reduction in cost and analysis time

### Approach

- ✦ Develop a computational combustion dynamics capability (CCD)
- ✦ CORSAIR-CCD is a Navier-Stokes flow solver based on an explicit four-stage Runge-Kutta scheme
- ✦ Unstructured meshes
- ✦ Run on networked workstation clusters
- ✦ The solver can be linked to any CAD system via the Patran file system
- ✦ Contract with Pratt & Whitney NAS3-26618 Task Order #62
- ✦ Contract with CFD Research Corp. NAS3-97118



### Significance/Metrics

- ✦ The National Combustor Code is a system of codes that will enable the multidisciplinary analysis of the full combustor from compressor exit to turbine inlet
- ✦ The CORSAIR-CCD code is the baseline flow solver module

### Point of Contact

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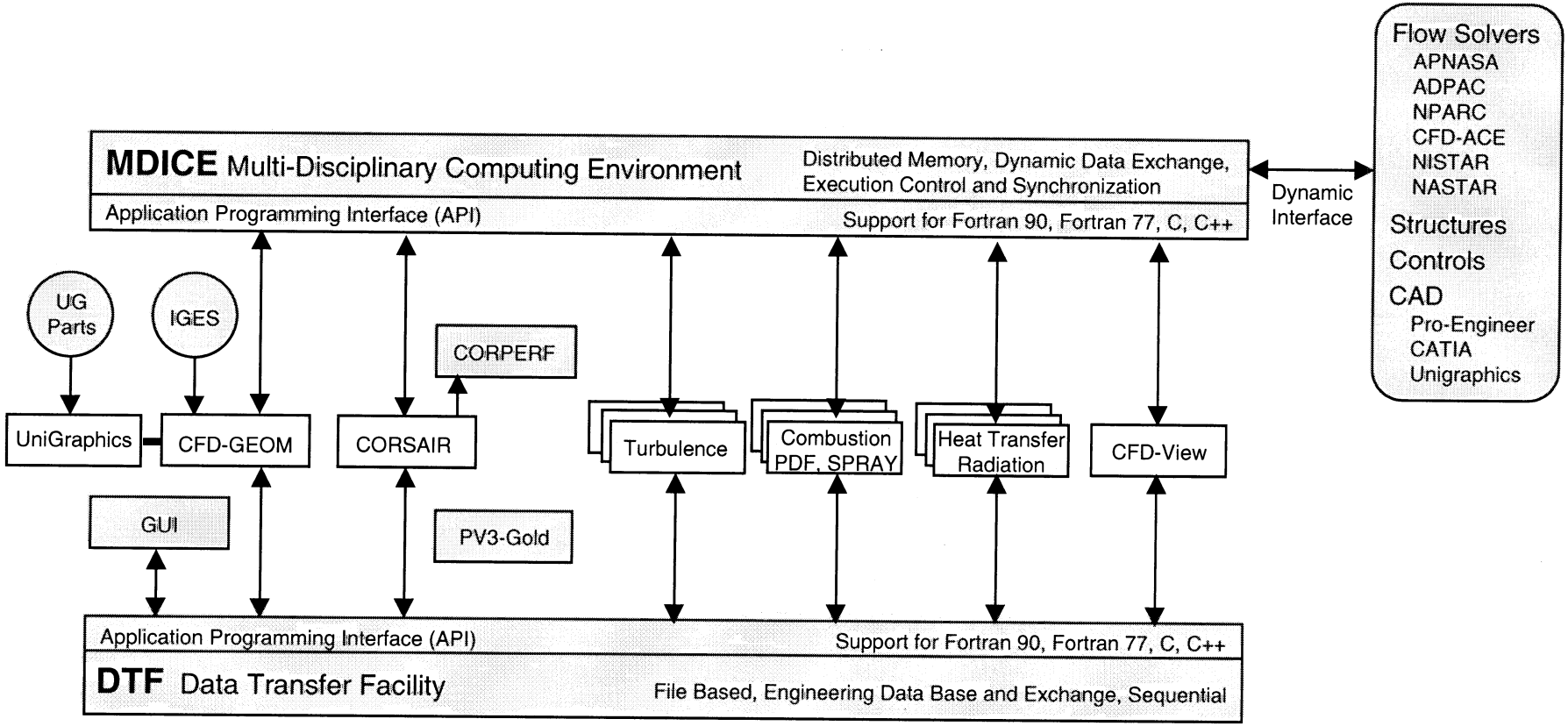
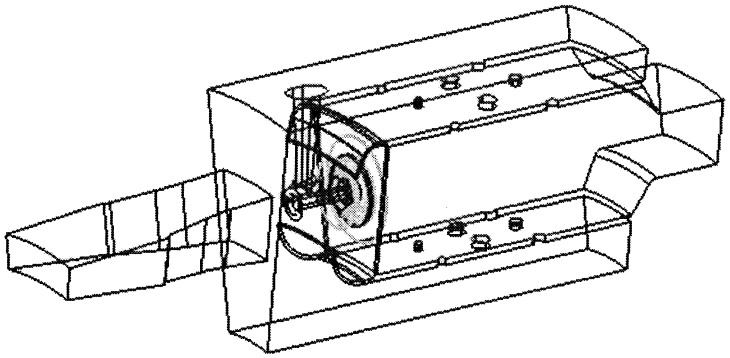
# National Combustion Code Computing Framework

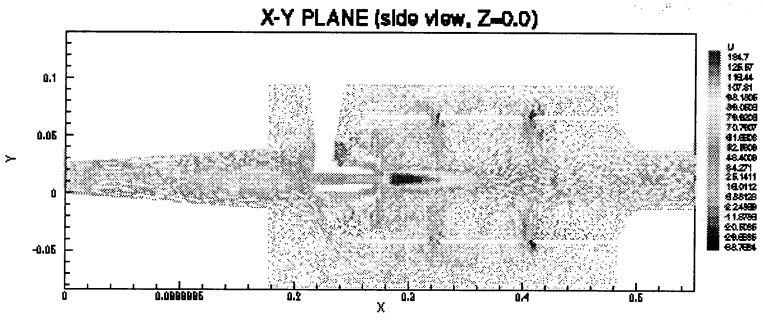
## *Conceptual Overview*



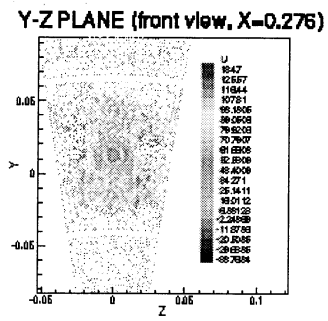
# National Combustion Code




Full Combustor Geometry Outline




Flow Simulation
(Absolute Velocities, Meridional View)




Flow Simulation
(Absolute Velocities, Axial View)

# Low Pressure Subsystem 3-D Model

## Objective

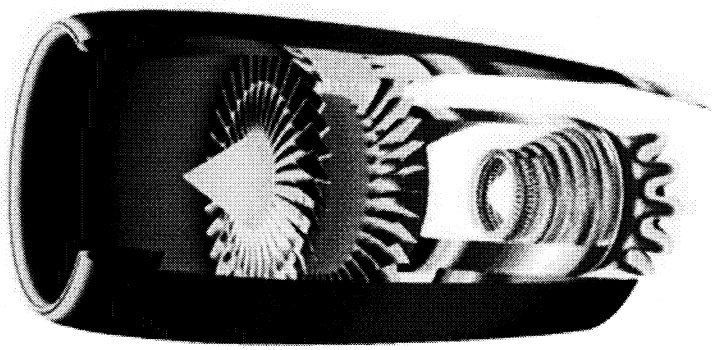
Develop a detailed flow simulation of the low pressure subsystem within a gas turbine engine using a simplified core engine model.

## Approach

- ✦ Apply the ADPAC 3-D Navier-Stokes flow code to the Energy Efficient Engine LP Subsystem consisting of: nacelle, inlet, fan, bypass duct, mixer, LP turbine and nozzle creating a 3-D flow model of LP Subsystem
- ✦ BC's at the core engine inlet and exit will be specified from thermodynamic cycle and data
- ✦ The simulation runs on parallel on distributed workstations
- ✦ Contract with Allison NAS3-27394 Task Orders #13, #17

## Impact/Metrics

- ✦ Evaluate the interaction effects between the LP subsystem components while considering the boundary conditions at the core engine
- ✦ The LPS model will reduce design/development time by enabling the designer to numerically investigate engine operability



## Applications

- ✦ HSR High Speed Civil Transport engine
- ✦ AST engines to assist in the development and certification of growth versions of existing engines
- ✦ Allison AE 3007 Engine

## Point of Contact

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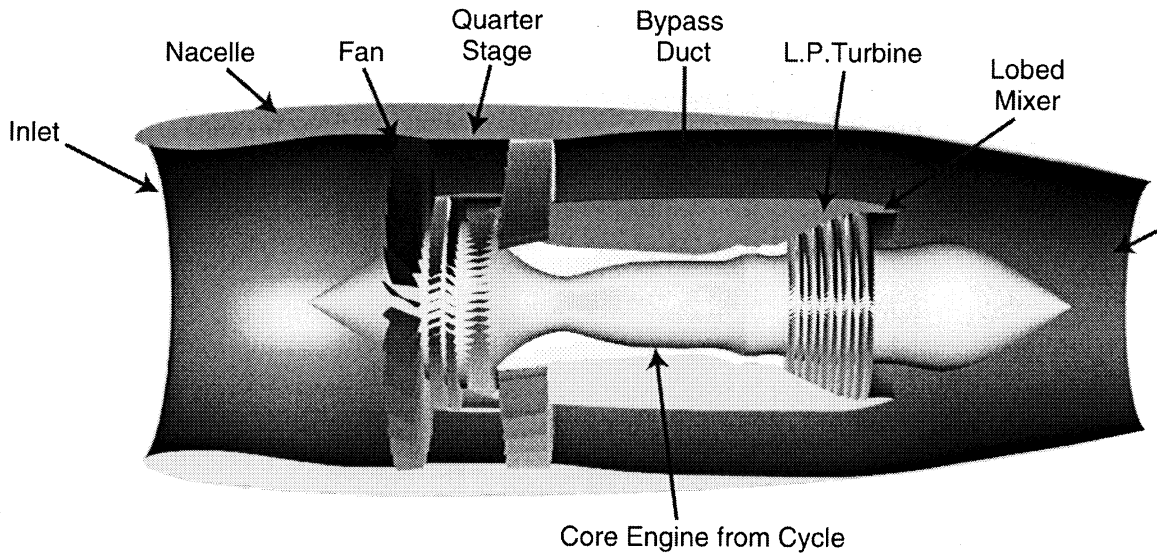
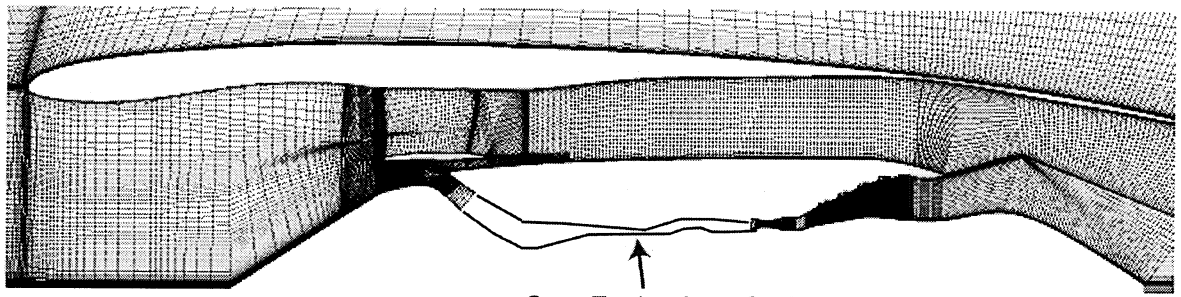
# Flow Simulation of the EEE Gas Turbine Low Pressure Subsystem



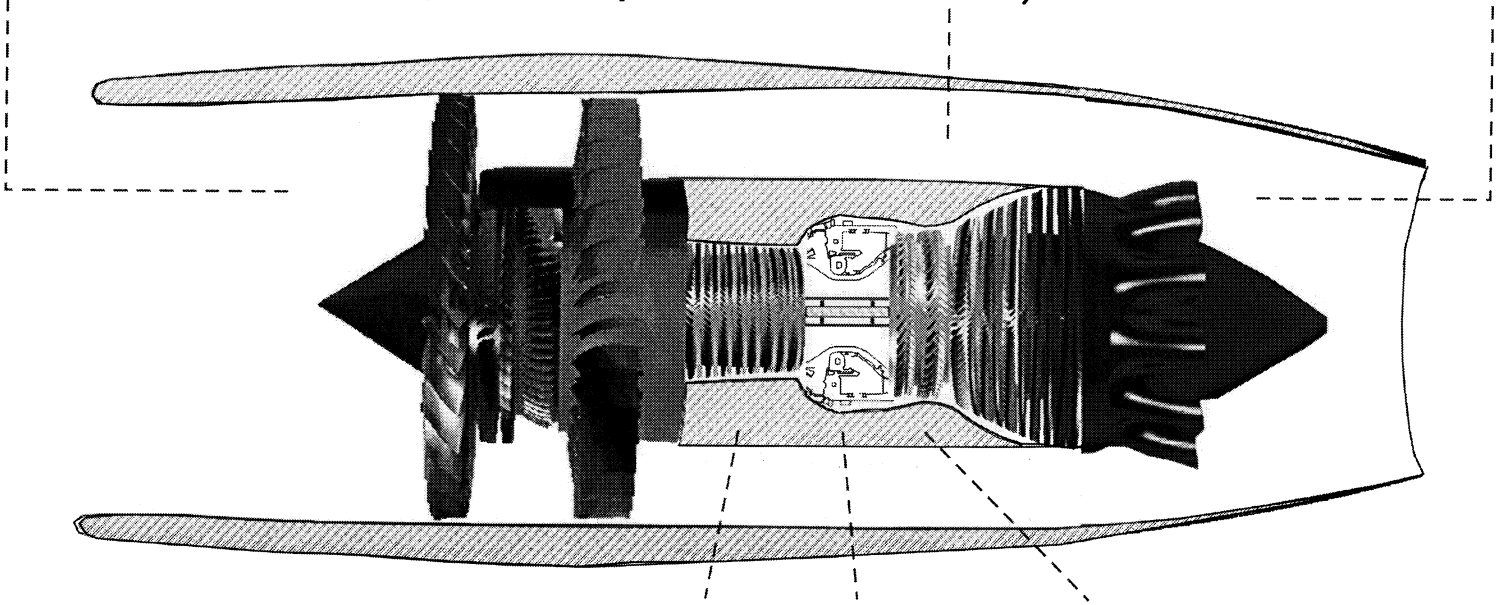

***Geometry***




***Grid***

# Flow Simulation of the EEE Gas Turbine Low Pressure Subsystem

**Low Pressure Subsystem Model — ADPAC CFD Analysis**
**(LP Subsystem Components / External Flow)**



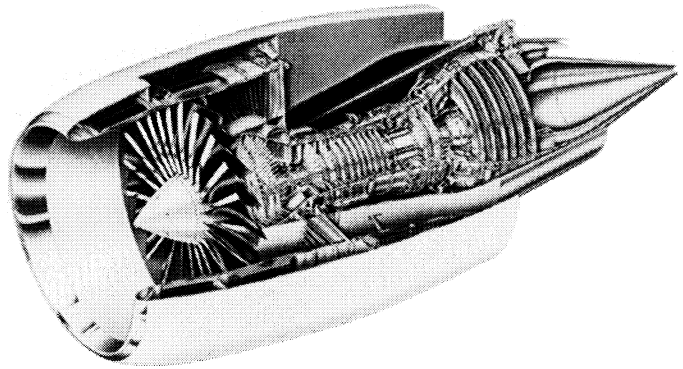
**Core Components: HP Compressor, Combustor, HP Turbine (Core Engine)**
**NEPP/NCP Thermodynamic Cycle Analysis**

*Energy Efficient Engine featuring Dual Spool Concentric Shaft Arrangement. Computer model of the Low Pressure Subsystem (spool) is with the ADPAC code, while the High Pressure (core engine) model is simulated with the NEPP/NCP thermodynamic cycle code.*

# HPCCP/NPSS Plan Detailed Flow Simulation of Modern Turbofan Engine

## Objective

Develop a detailed flow model of a full turbofan engine that runs on parallel workstation clusters overnight. The model will simulate the flow in the primary flowpath andwill have a simplified combustor model.



## Approach

- ✦ The 3-D flow analysis models the GE90 turbofan engine using APNASA (NASA's average passage flow code)
- ✦ The project leverages from current efforts between NASA and G.E. in developing the APNASA flow code and workstation clustering technology
- ✦ Contract with GEAE, NAS3-26617, Task Order #65

## Significance/Metrics

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

## Point of Contact

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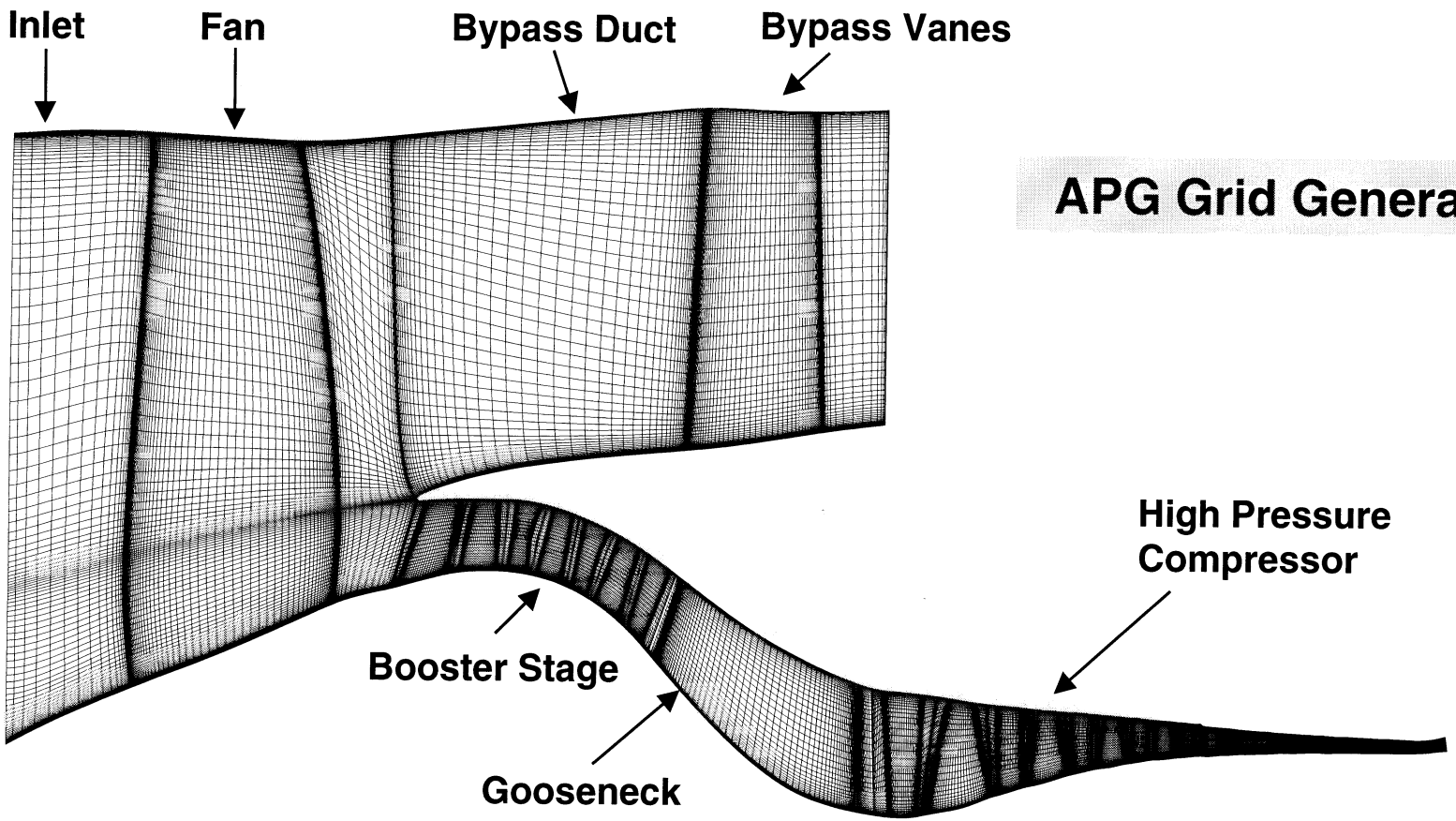
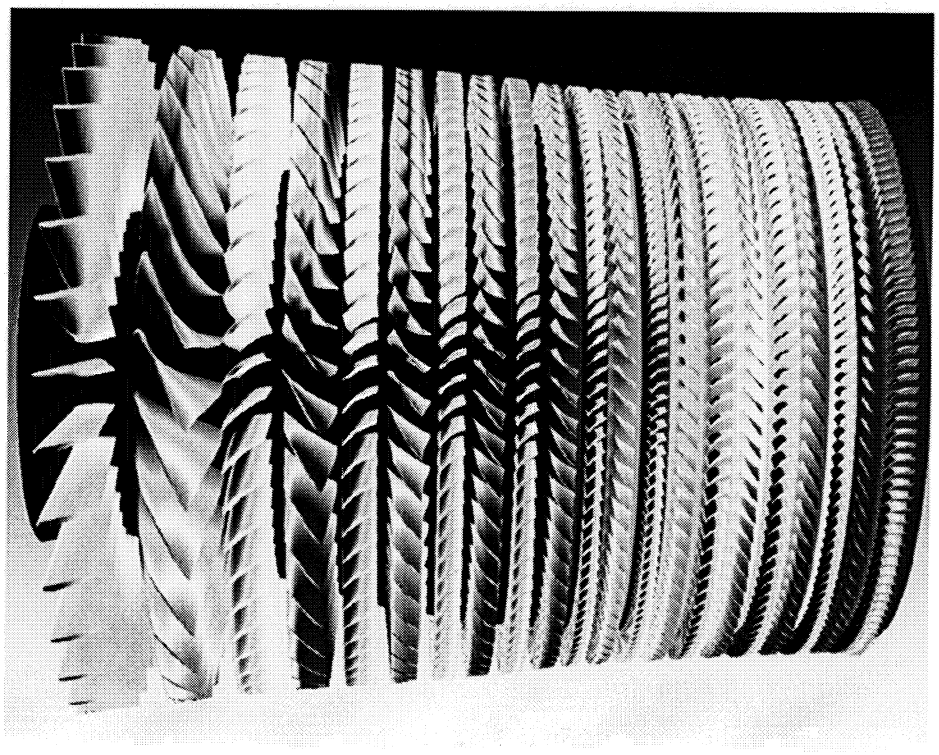
# Detailed Flow Simulation of Modern Turbofan Engine




**APG Grid Generator**

**Grid Generator for full GE90 compression system including fan, booster stage, high pressure compressor and bypass vanes**

# Detailed Flow Simulation of Modern Turbofan Engine



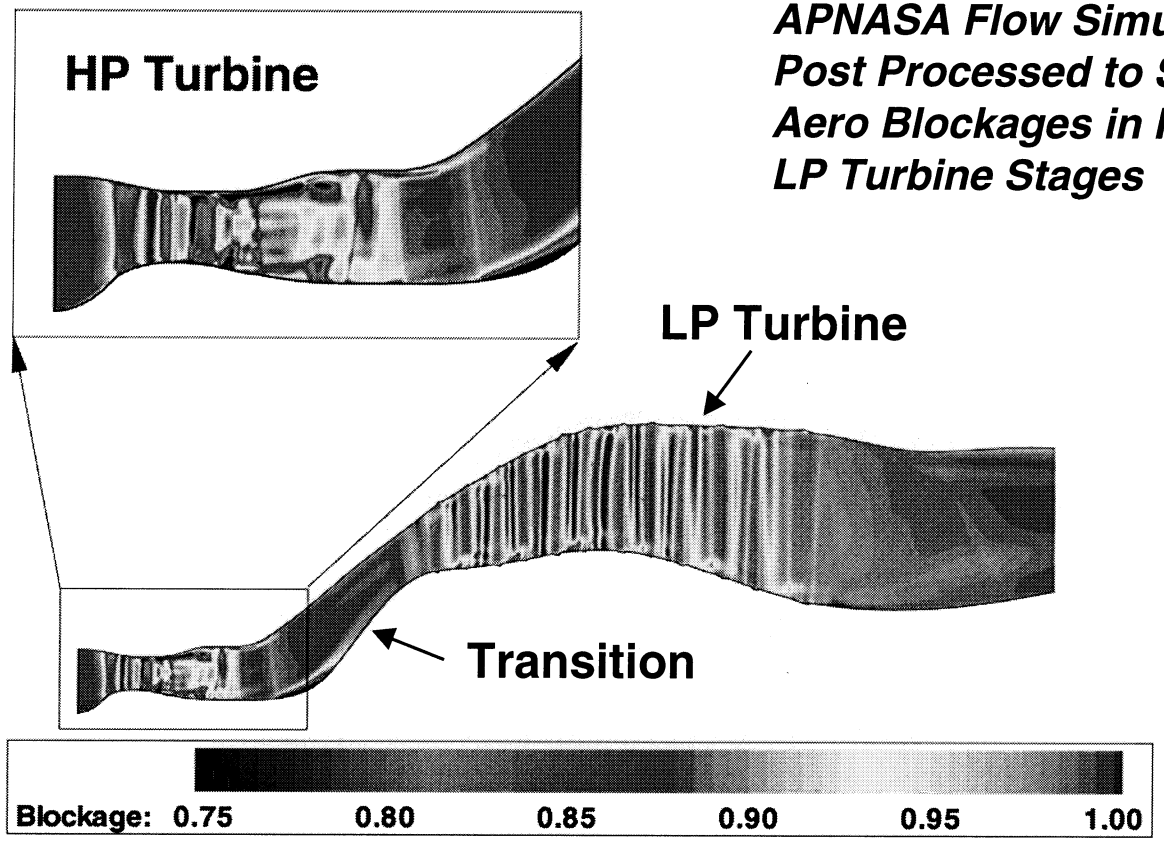
**APNASA multi-stage flow simulation of complete GE90 high pressure compressor, with excellent comparison between flow model and rig test data. Grid generation with APG, developed at NASA Lewis, and visualization is with APVIZ, developed at MIT. The simulation exploits two levels of parallelism with extremely high parallel efficiency.**

# Detailed Flow Simulation of Modern Turbofan Engine

***Engine Turbine Relative Mach Numbers***

- **Full HP and LP turbine coupled simulation with APNASA**
- **Cooling air included through source terms**
- **Leakage through seals and around blade and vane seals was modeled**

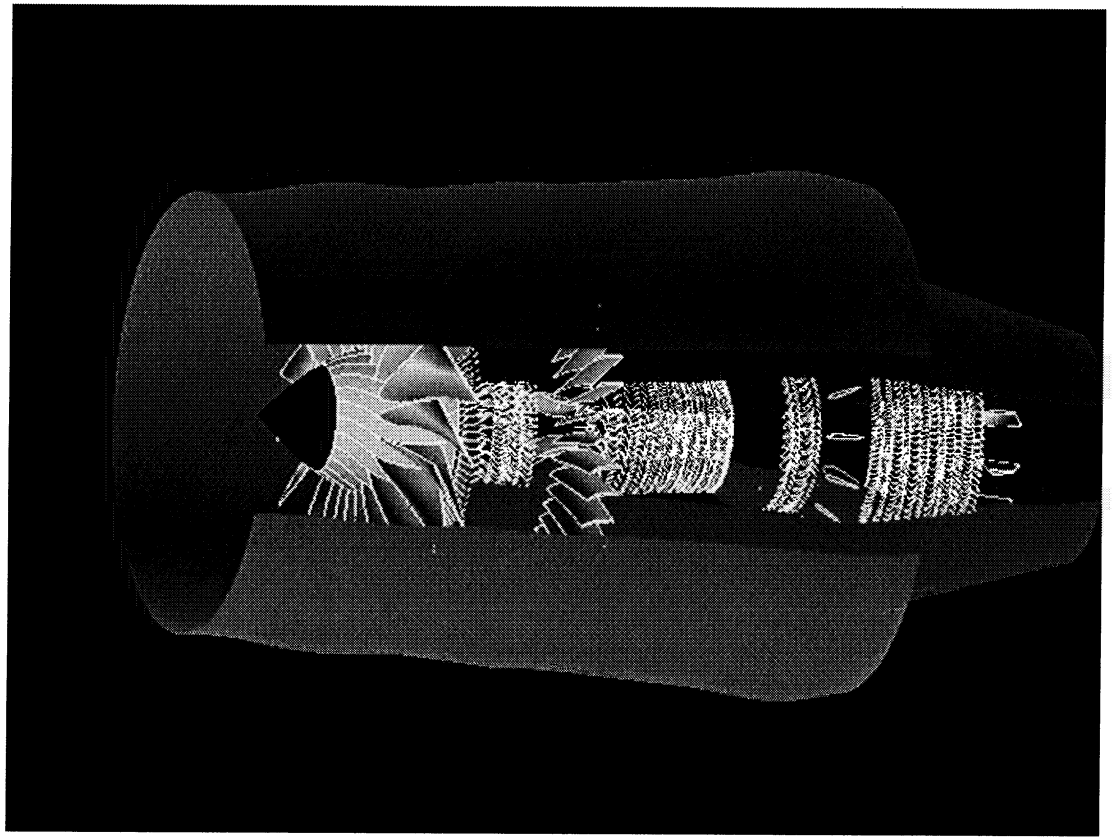
# Detailed Flow Simulation of Modern Turbofan Engine




*APNASA Flow Simulation Post Processed to Show Aero Blockages in HP and LP Turbine Stages*

**APNASA simulation of coupled high pressure and low pressure turbines of GE90 engine**

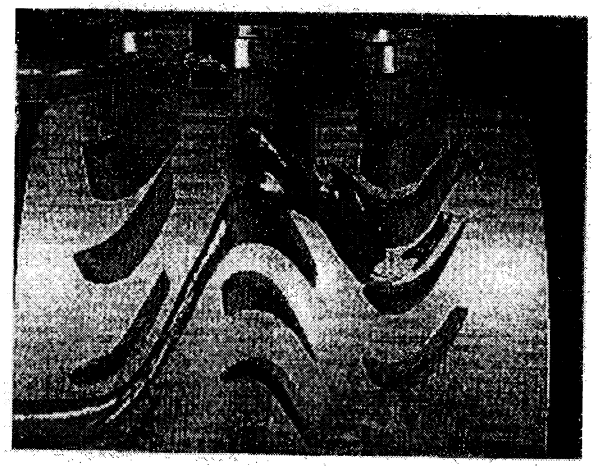
# Detailed Flow Simulation of Modern Turbofan Engine



- Full engine simulation visualization with FEVis
- Uses pV3 library from Bob Haimes (MIT)
- Optional MPEG output for animation

Navier-Stokes flow simulation of the GE90 engine primary flowpath using the APNASA average-passage code. Complete compression system and turbines were modeled as single simulations.

# Turbine Blade Tip and Outer Air Seal



## Objective

- Improve computer models for high pressure turbine rotor tip & outer air seal (OAS) heat loads using CFD as a close coupled tool.
- Use deterministic stresses to model the unsteady heat loads with steady CFD simulation

## Approach

- Contract with UTRC NAS3-26618, Task Order #28
- Unsteady analysis required to pass full burner pattern information to the rotor
- Establish unsteady numerical data base for multiple inlet temperature profiles from burner
- Apply 2D and 3D deterministic stresses from unsteady Euler to steady Navier-Stokes simulation

## Significance / Metrics

- Current steady CFD fails to capture hot gas distribution in rotor
- Inexpensive CFD analysis of full burner pattern effects on turbine rotor
- Hot streak migration through turbine blades can be simulated with steady flow code using deterministic stress data base

## Point of Contact:

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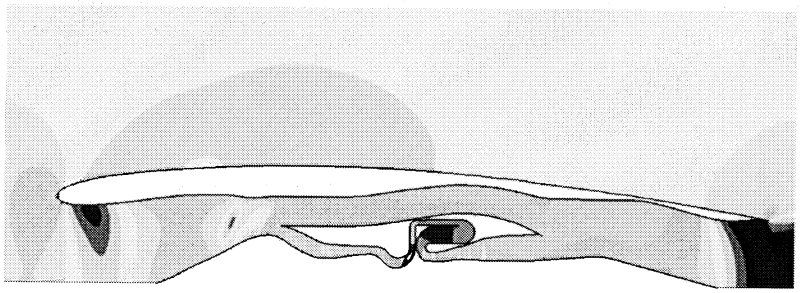
CD-97-75945

# ENG20 Simulation of Turbofan Engine

## Objective

Develop a US industry standard for an axisymmetric flow simulation environment of a full gas turbine engine. The model will computationally evaluate the interactions between components.



## Approach

To evaluate the capabilities of the ENG20 code using a test case (AlliedSignal 731-60 engine)

- Link AE's compressor and turbine axisymmetric streamline curvature codes UD0300M and TAPS with ENG20, to provide boundary conditions
- Evaluate GE's Global Data System, and convergence time
- Provide to NASA the developed interfaces which link the component codes to ENG20
- Contract with AlliedSignal Engine Co. NAS3-27483, Task Order #14

## Significance/Metric

The high fidelity full engine simulation can reduce the number of design and test iterations in an engine development program and lower acquisition cost

## Point of Contact

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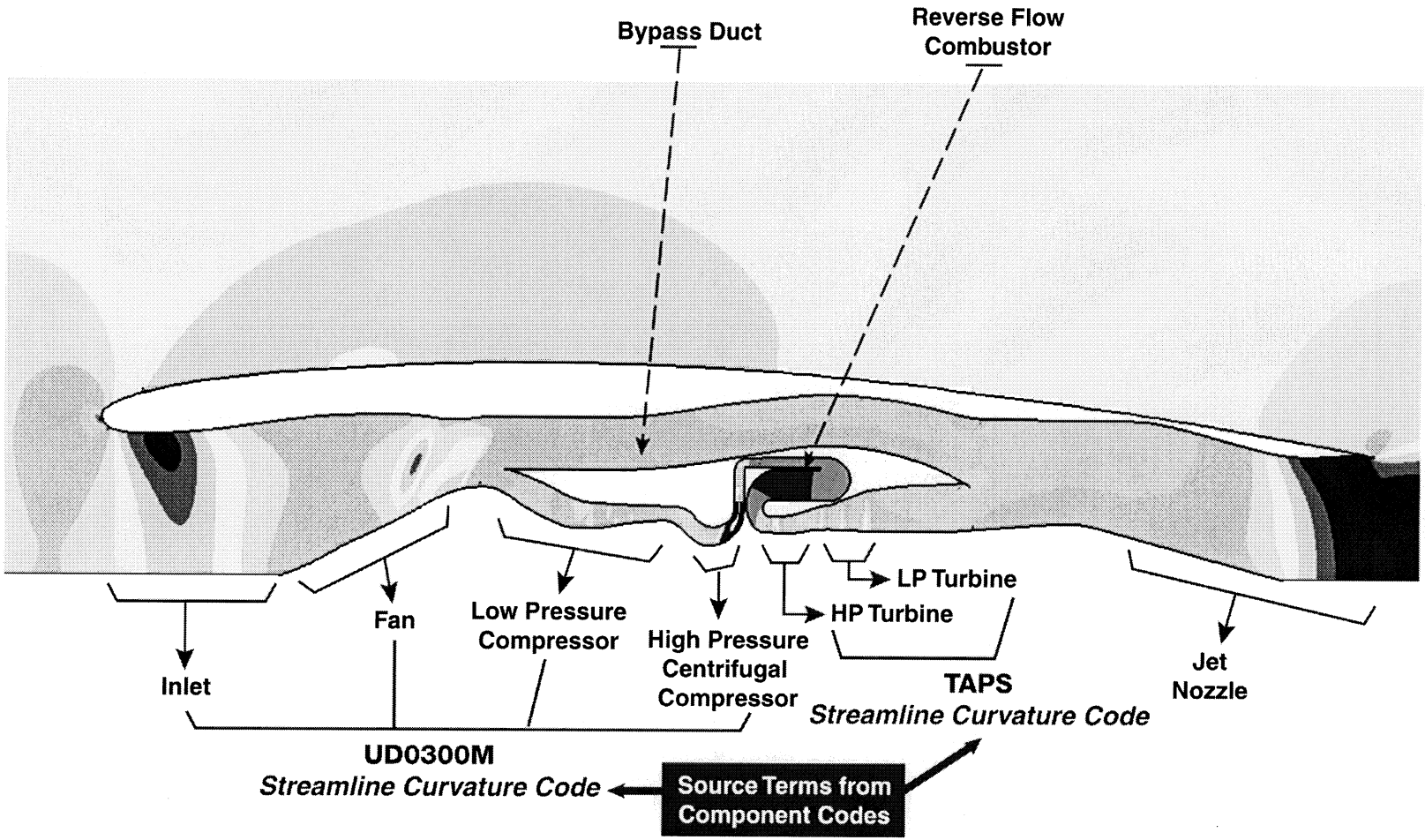
# ENG20 Simulation of AlliedSignal 731-60 Gas Turbine Engine