

TURBOFAN ENGINE CORE COMPARTMENT VENT AERODYNAMIC CONFIGURATION
DEVELOPMENT METHODOLOGY

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ABSTRACT

This paper presents an overview of the design methodology used in the development of the aerodynamic configuration of the nacelle core compartment vent for a typical Boeing commercial airplane together with design challenges and recommended process improvements for future design efforts.

Core compartment vents exhaust engine subsystem flows from the space contained between the engine case and the nacelle of an airplane propulsion system. These subsystem flows typically consist of precooler, oil cooler, turbine case cooling, component cooling and nacelle leakage air.

The design of core compartment vents is challenging due to stringent design requirements, mass flow sensitivity of the system to small changes in vent exit pressure ratio, and the need to maximize overall exhaust system performance at cruise conditions. Typically, the vent is located on the core cowl afterbody and is sized for maximum flow rate which occurs at an icing heavy hold condition. This condition differs considerably from cruise - where thrust recovery is the objective. The afterbody pressure distribution and vent back pressure vary widely between these two conditions and must be well understood to develop a good integrated core compartment vent design.

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**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

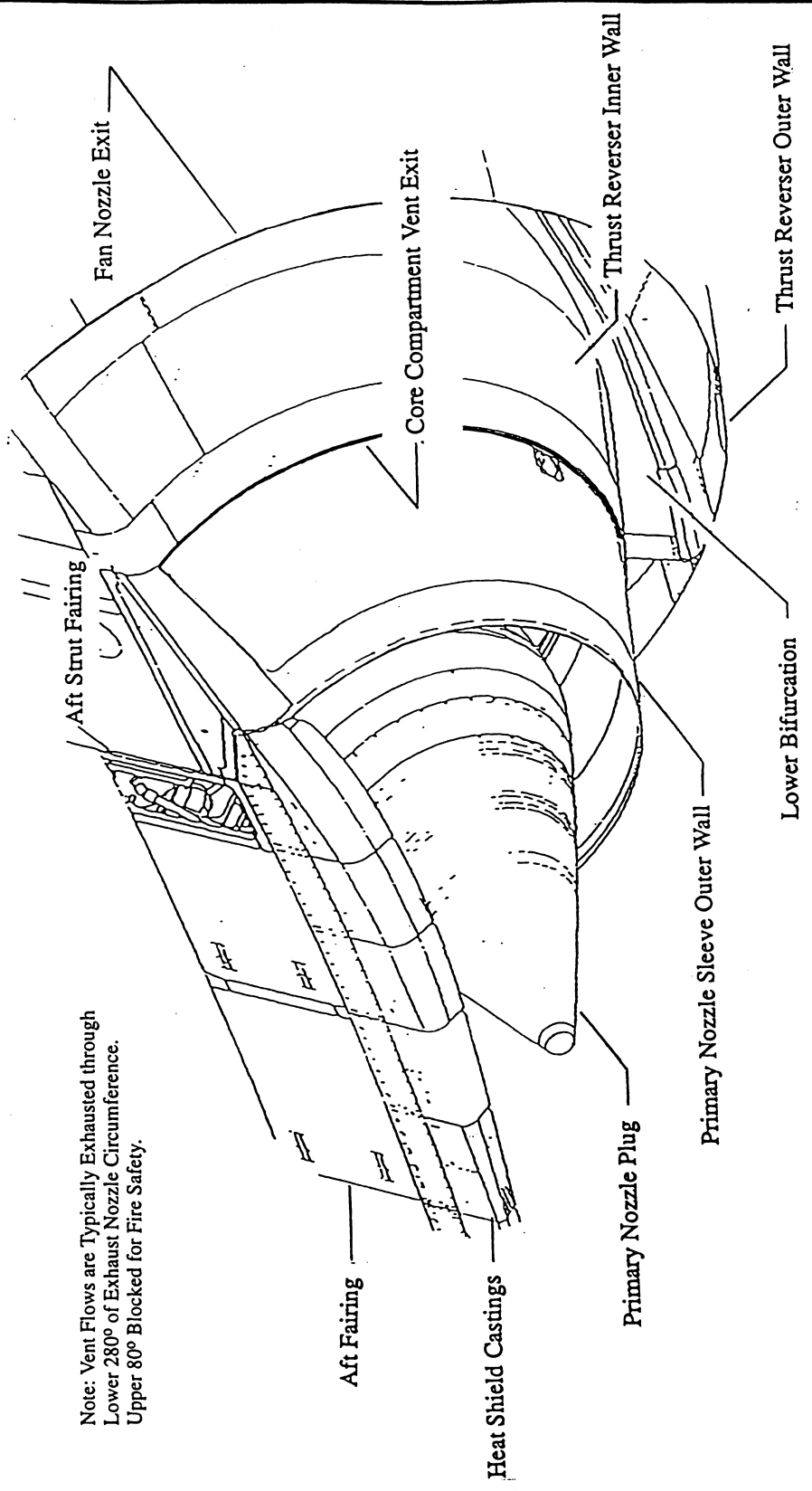
Presentation Topics

- Typical Core Compartment Vent Geometry / Purpose.
- Core Compartment Vent Design Requirements / Objectives.
- Core Compartment Vent Design Methodology.
- Conclusions.

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**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

**Typical Exhaust Nozzle / Core Compartment
Vent Geometry**



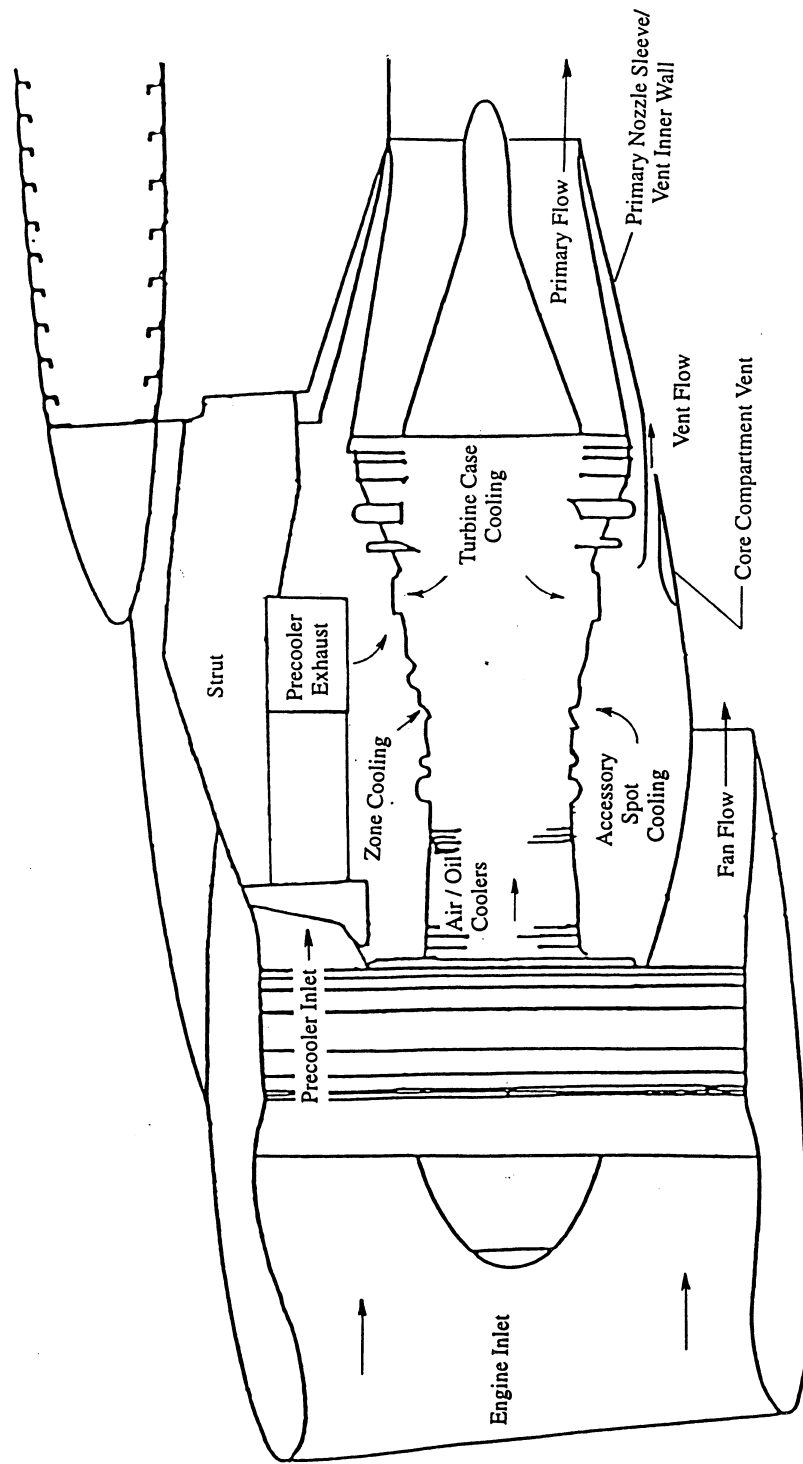
Note: Vent Flows are Typically Exhausted through Lower 280° of Exhaust Nozzle Circumference. Upper 80° Blocked for Fire Safety.



Purpose of Core Compartment Vent

- The Core Compartment Vent Exhausts Engine Subsystem Flows.
- Precooler Exhaust.
- Turbine Case Cooling.
- Engine External Component Cooling.
- General Zone Cooling.
- Engine and Gearbox Oil Cooling.

Typical Engine Subsystem Flows



Design Requirements and Objectives
(Vent Sizing Condition)

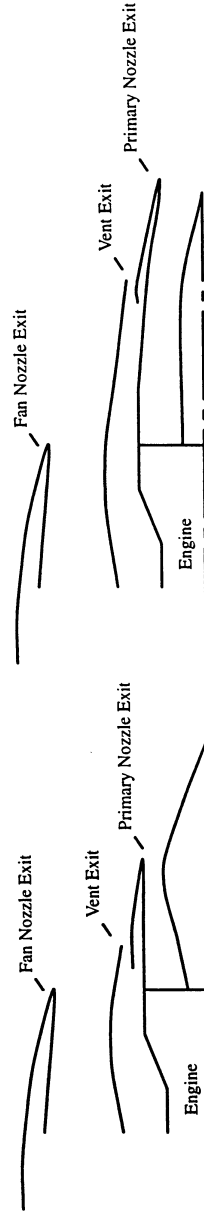
- The Core Compartment Vent is Designed in Collaboration with the Engine Company.
- The Core Compartment Vent is Sized for the Airplane Operating Condition with the Greatest Single Engine Bleed Demand / Vent Exhaust Flow.
- Typically a Single Engine Bleed, Hot Day Icing Heavy Hold Condition.
 - 22,000 Feet Altitude, ISA+15 °F, 0.6+ Mach, Engine Part Power.
 - Fan Flow is Subsonic.
- Maximize Core Compartment Total Pressure – Typical Limit ~ 1.3 psig.
 - Results in Smallest Vent Area.

Design Requirements and Objectives, Continued
(Airplane Cruise Condition)

- The Core Compartment Vent is Designed to Maximize Exhaust System Cruise Performance.
- Cruise Altitude, 0.8+ Mach, Cruise Engine Power.
- Fan Flow Supersonic with Expansion / Compression Waves.
- Two to Three Times Less Corrected Vent Flow Rate than Sizing Condition.
- Maximize Core Compartment Total Pressure – Typical Limit ~ 0.8 psig.
- Maximize Vent Thrust.

Design Requirements and Objectives, Continued
(Vent Exit Location Window)

- Core Compartment Vent Exit Location Window:
- Function of Engine / Nacelle Geometry.
- Distance Between Fan Nozzle and Primary Nozzle Exits and Turbine Exit Flange Location Relative to Primary Nozzle Exit.



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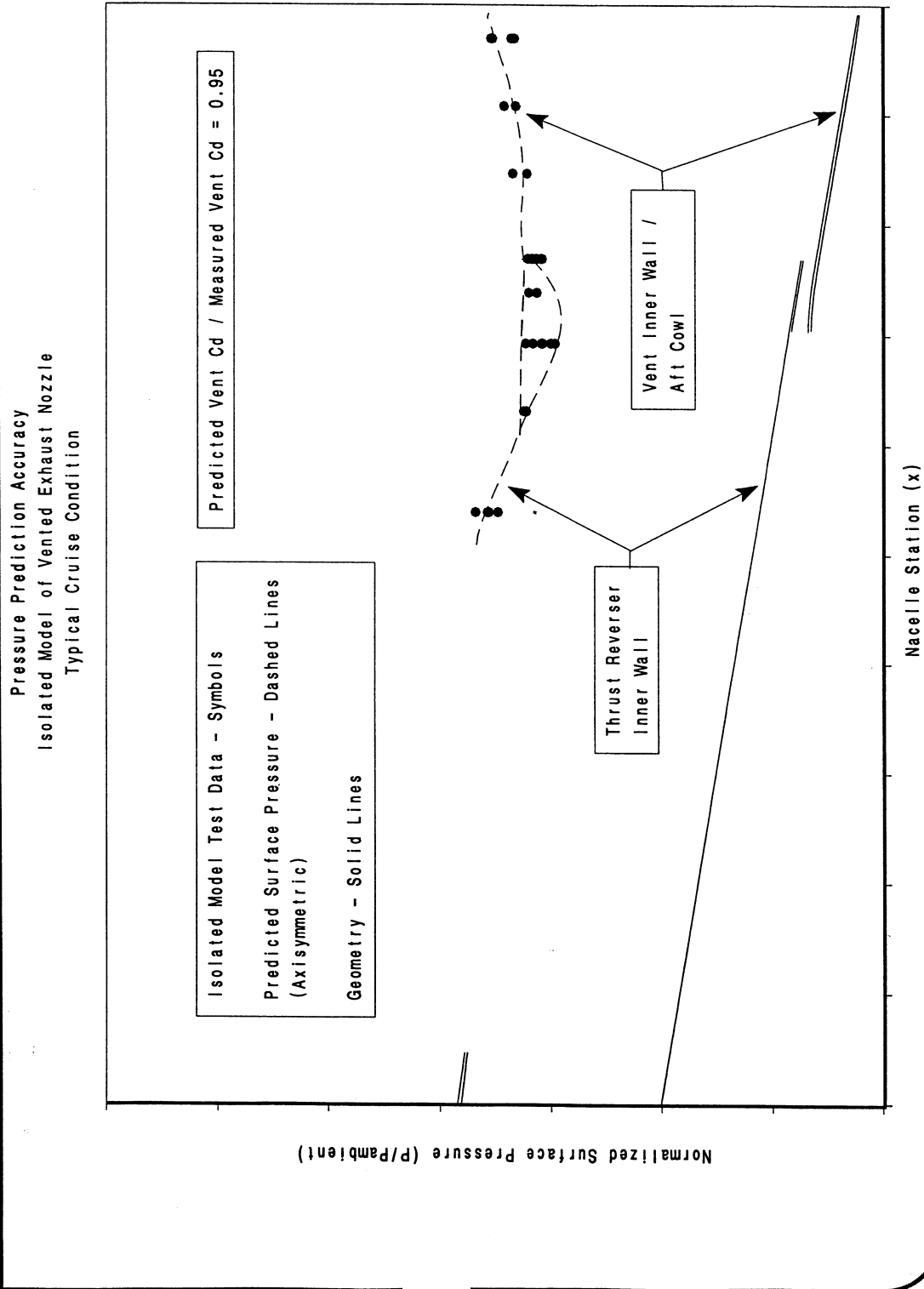
**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

Core Compartment Vent Design Methodology
(Analytical Tool Accuracy Requirements)

- Computational Fluid Dynamics used to Configure the Core Compartment Vent.
- Good Pressure Prediction Accuracy Required for Vent Mass Flow Prediction Accuracy.
- Vents Operate at Low Pressure Ratios – Mass Flow Sensitive to Variations in Local Pressure Ratio (Influence Factor up to 40:1).
- Local Vent Pressure Ratio is a Function of Fan Nozzle Pressure Ratio, Vent Pressure, Airplane Mach Number and External Pressure Influences of the Wing / Strut.

Core Compartment Vent Design Methodology
(Analysis Tool / Modeling / Accuracy)

- Navier–Stokes Code PARC2D used Primarily.
- Analyze / Design Isolated Axisymmetric Vent Geometry.
- Most Accurate / Time Effective Technology Available.
- Vent Exit Comprises ~ 280° of Exhaust Nozzle Circumference.
- Good Agreement with Isolated Model Test Pressure / Vent Mass Flow.
- Configurations Produce Positive Thrust at Cruise.

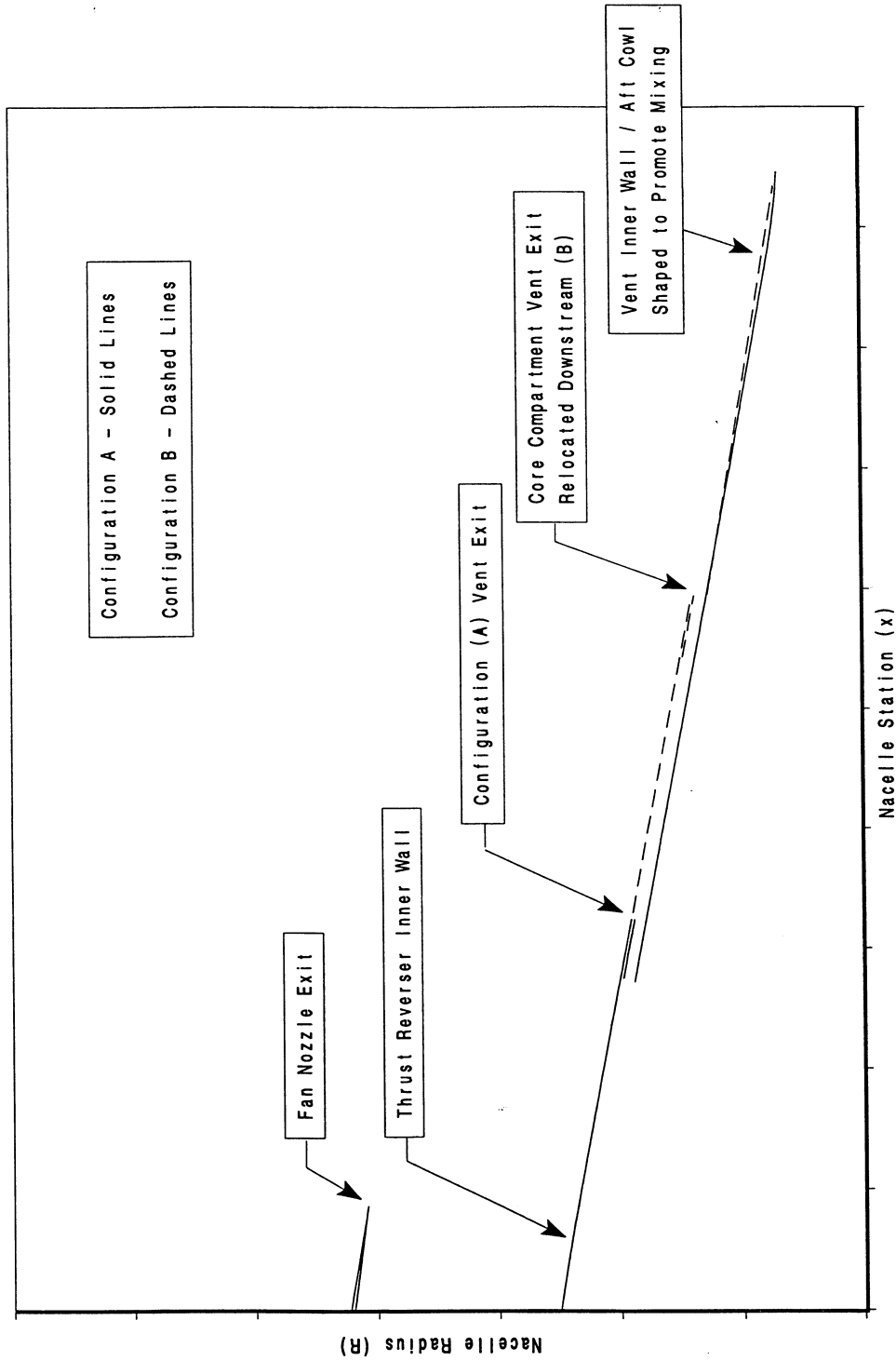


Core Compartment Vent Design Methodology
(Vent Exit Position Objectives)

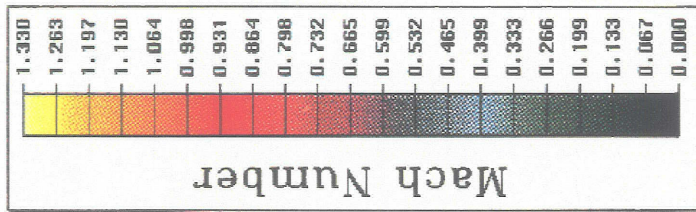
- Position Vent Exit in Cruise High Pressure Region on Thrust Reverser Inner Wall.
- Maximize Vent Flow Momentum.
- Favorable Cruise Pressure Gradient Downstream of Vent Exit.
- Maximize Nozzle Surface Pressure Recovery / Avoid Vent Flow Separation.

Turbofan Engine Core Compartment Vent Aerodynamic Configuration Development Methodology

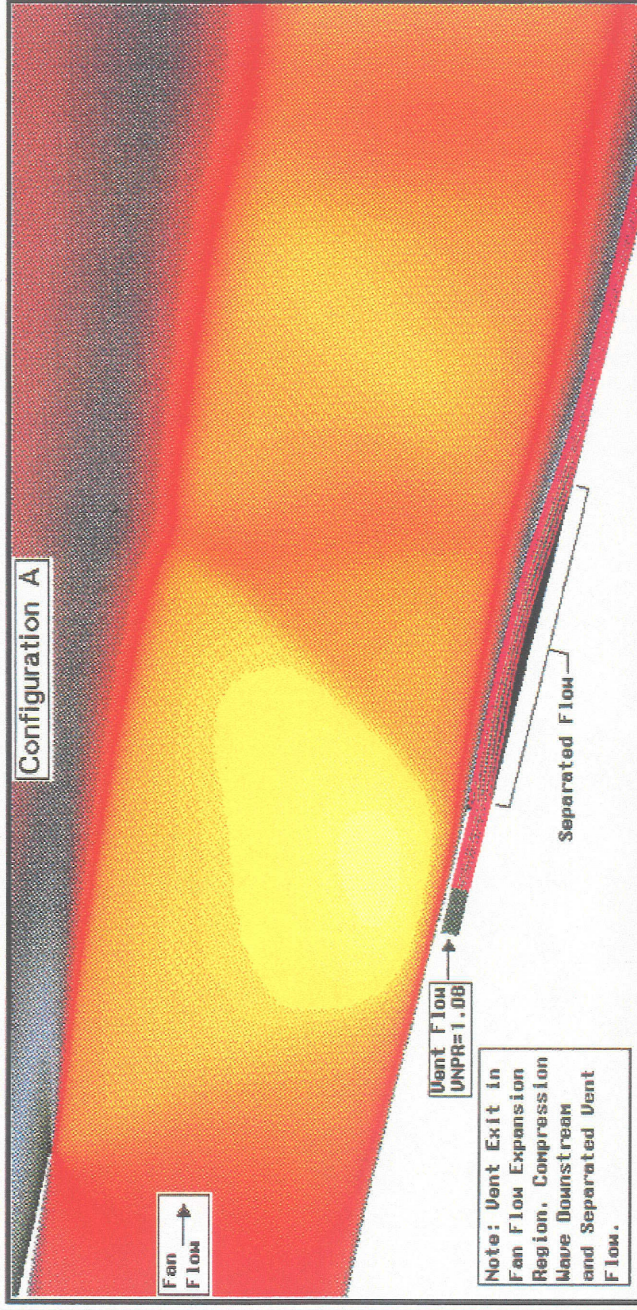
Effect of Vent Exit Location on
Exhaust Nozzle Flowfield / Performance
Comparison of Configuration A and B Geometries



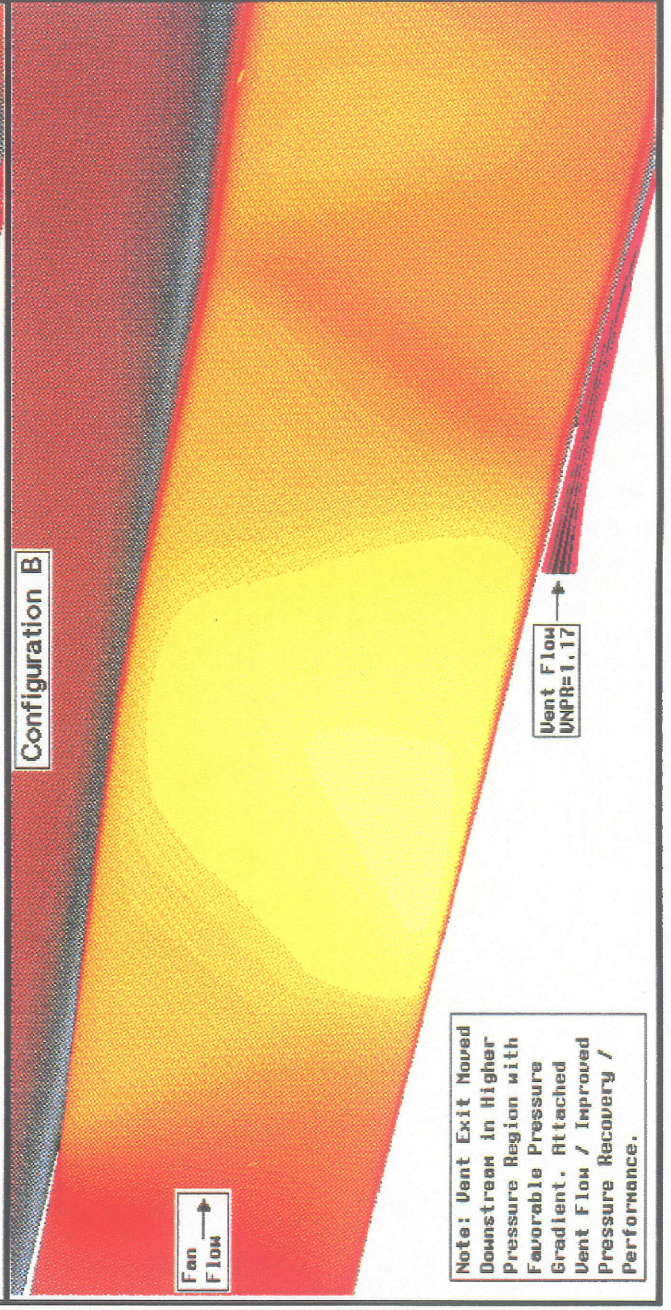
Effect of Vent Exit Location on Vent Flow Separation at Cruise Conditions.



Configuration A

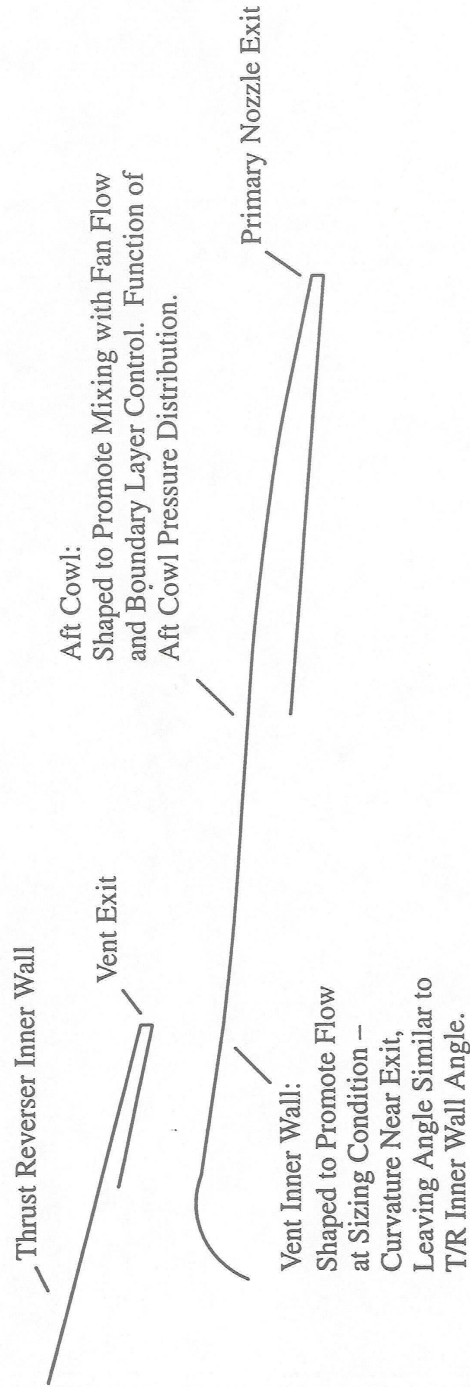


Configuration B



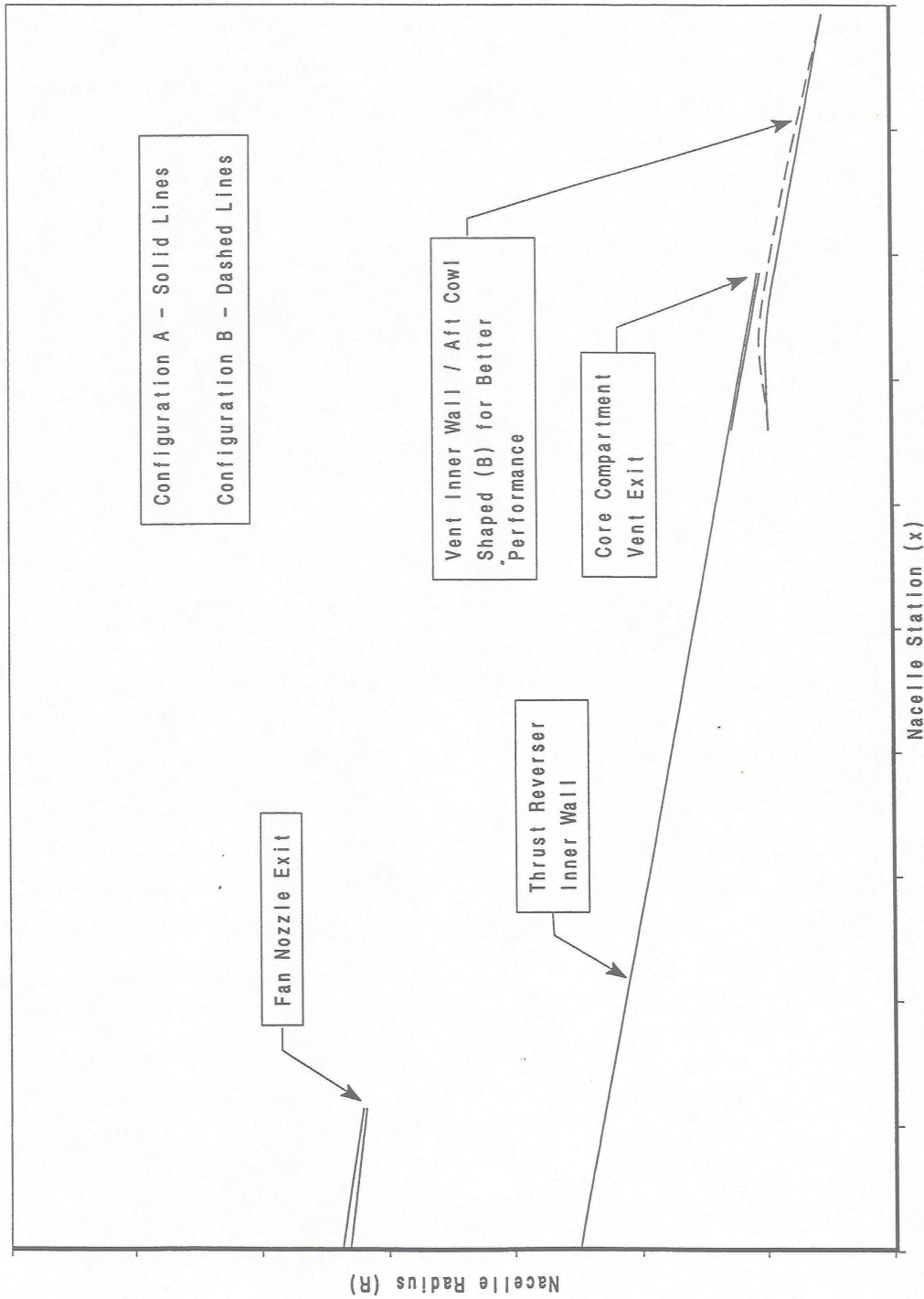
Core Compartment Vent Design Methodology
(Vent Sizing / Wall Shape Objectives)

- **Size Flow Area / Shape Vent Inner Wall and Aft Cowl Wall to Accommodate Flow at Sizing Condition and Maximize Pressure Recovery at Cruise.**

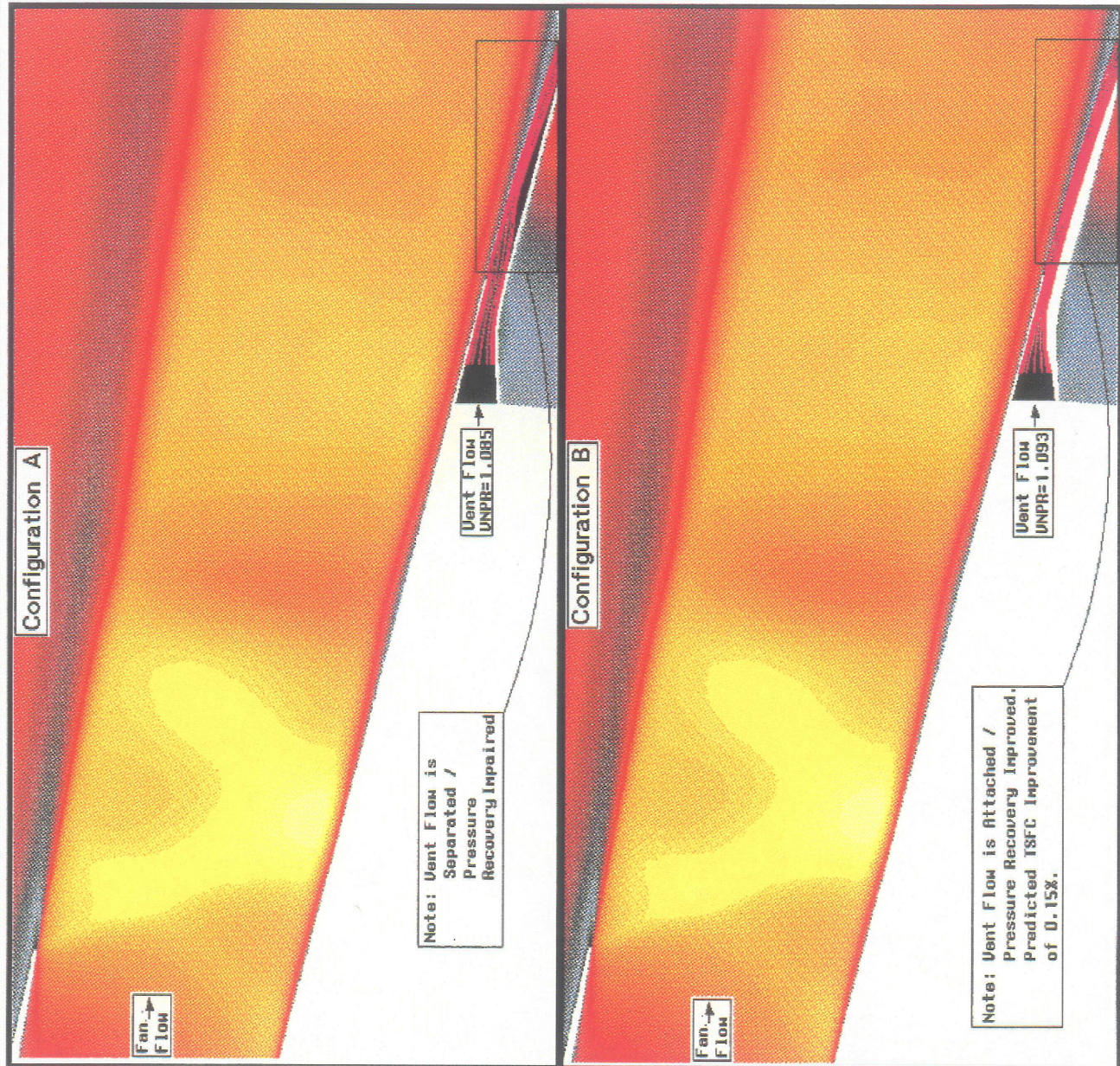
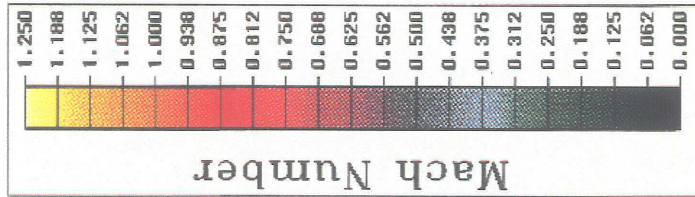


Turbofan Engine Core Compartment Vent Aerodynamic Configuration Development Methodology

Effect of Vent Inner Wall Modification on
Exhaust Nozzle Flowfield / Performance
Comparison of Configuration A and B Geometries



Effect of Vent Inner Wall Shape on Vent Flow Separation and Cruise Performance



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**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

**Core Compartment Vent Design Methodology
(Effectiveness)**

- Flight Test Data Confirm the Effectiveness of the Designs.
- Sizing Flow Requirements Achieved.
- Positive Vent Thrust at Cruise.

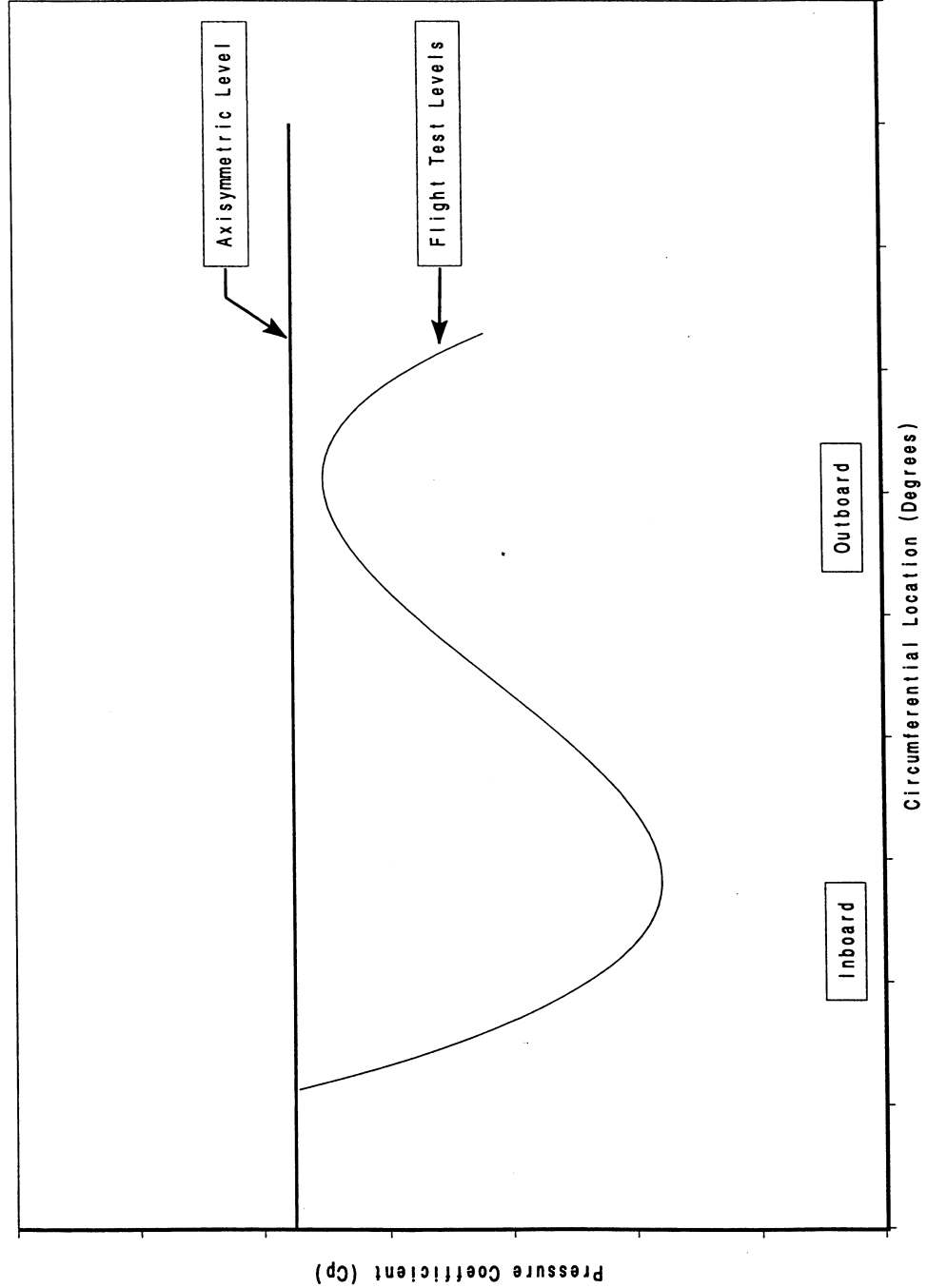
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**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

**Core Compartment Vent Design Methodology
(Installation Effects)**

- Vent Mass Flow is a Strong Function of Vent Exit Pressure Ratio (P_{TV} / P_{local}).
- Affected by Wing / Strut / Engine Installation.
- Vent Exit / Aft Cowl Pressure Magnitude and Circumferential Distribution.

Example of Predicted and Flight Test
Vent Exit Static Pressure Levels



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**Turbofan Engine Core Compartment Vent
Aerodynamic Configuration Development Methodology**

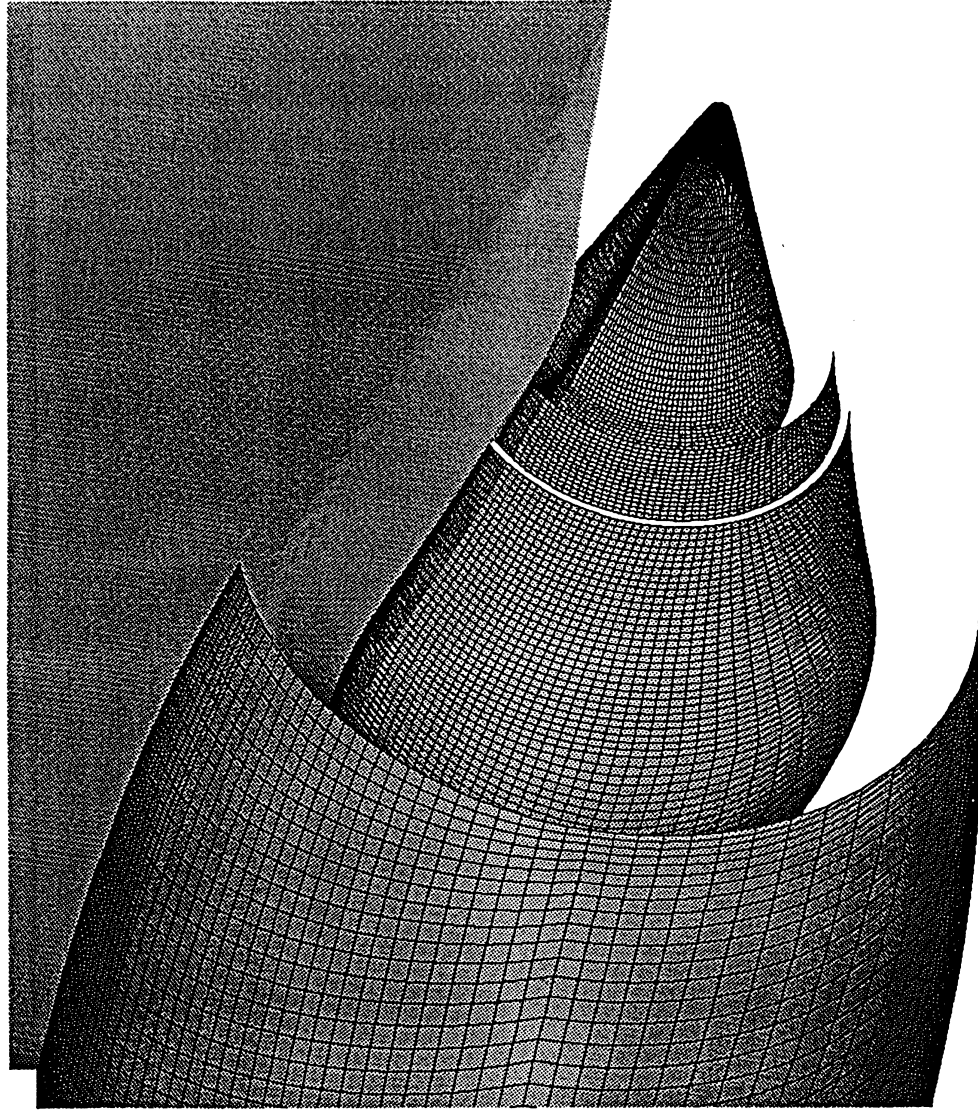
**Core Compartment Vent Design Methodology
(Improvements)**

- Three Dimensional Navier–Stokes Analysis of the Installed Nozzle could Aid the Design of Core Compartment Vent Configurations:
- Account for Installation Effects – Reduced Vent Area, Increased Vent Pressure, Greater Vent Thrust Recovery.
- Now Possible due to Improvements in:
 - Grid Generator, Flow Solver, Computer Technology.
- Pursuing 3D Technology for Future Efforts.

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**Turbofan Engine Core Compartment Vent
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**Core Compartment Vent Design Methodology
(3D Grid Example)**



Conclusions

- Core Compartment Vent Design Methodology Yields Configurations that:
 - Effectively Exhaust Engine Subsystem Flows.
 - Contribute Positive Thrust at Cruise.
- Three Dimensional Viscous CFD Technology could be useful in better Designing Core Compartment Vent Configurations.
 - Account for Installation Effects.
 - Pursuing for Future Efforts.