Technologies for Turbofan Noise Reduction

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Special thanks to Edmane Envia, James Bridges and Mike Jones

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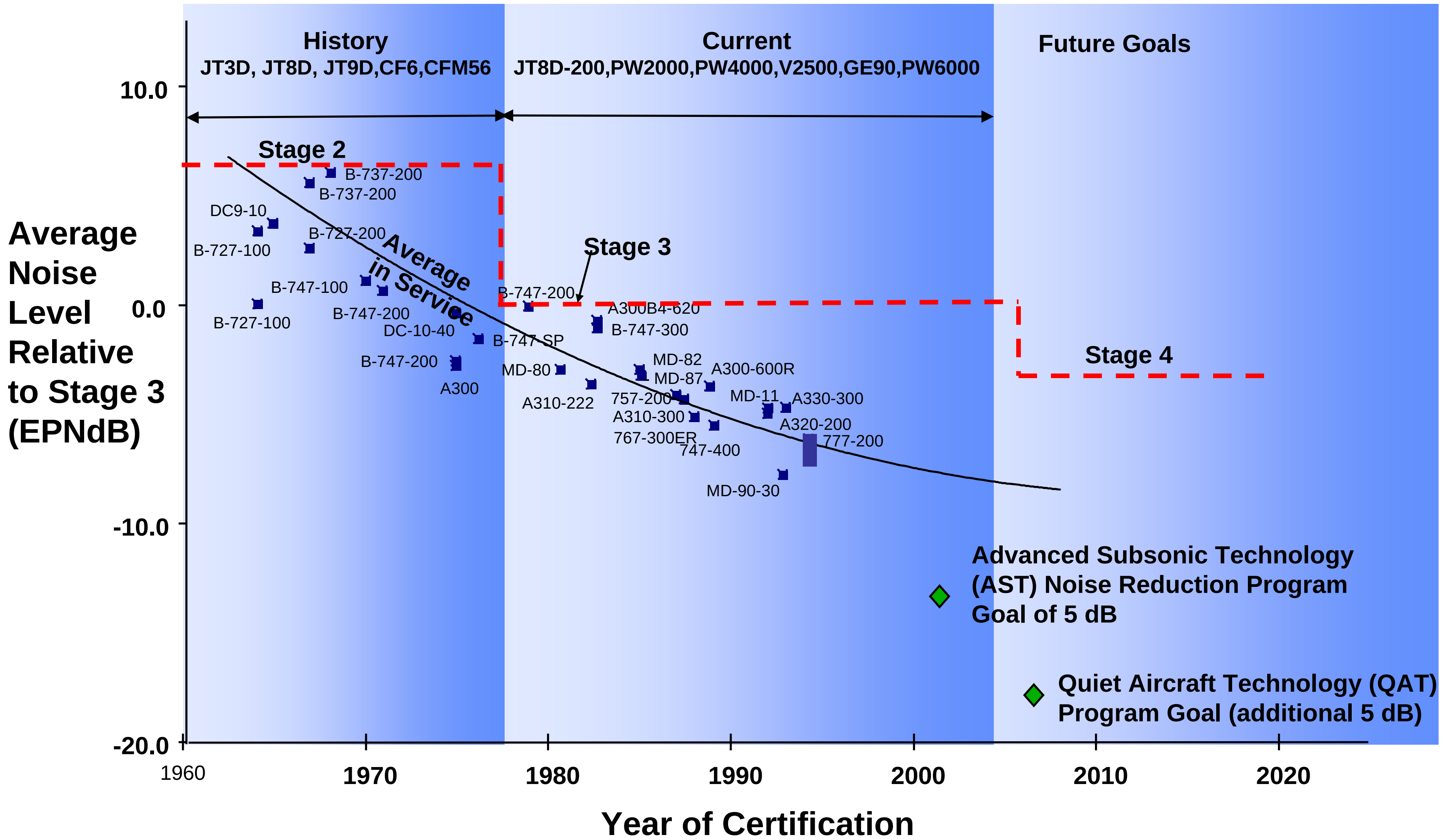
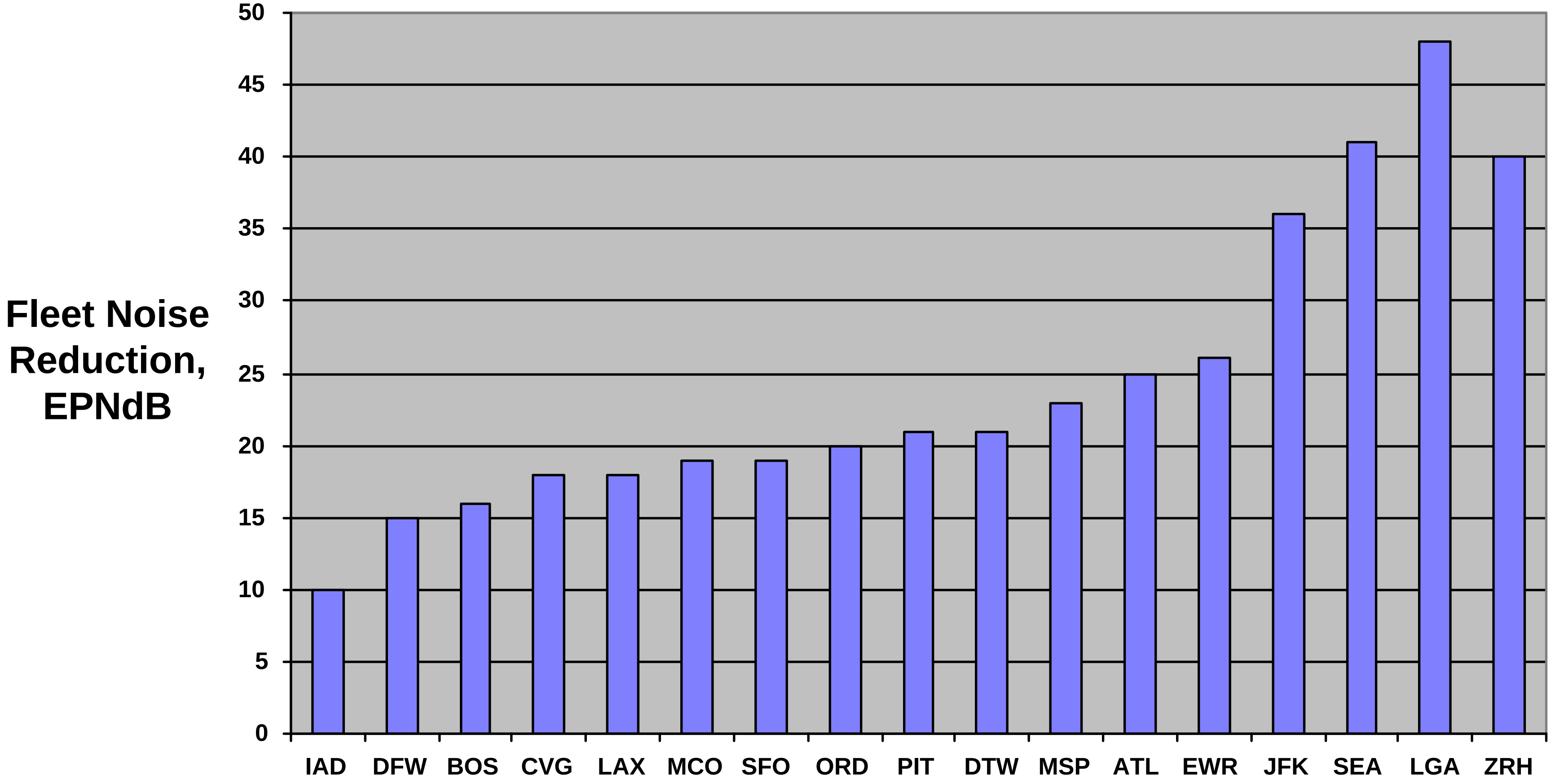
10th AIAA/CEAS Aeroacoustics Conference
Manchester, United Kingdom
May 11, 2004

New Technology Enables Aircraft To Meet Future Requirements



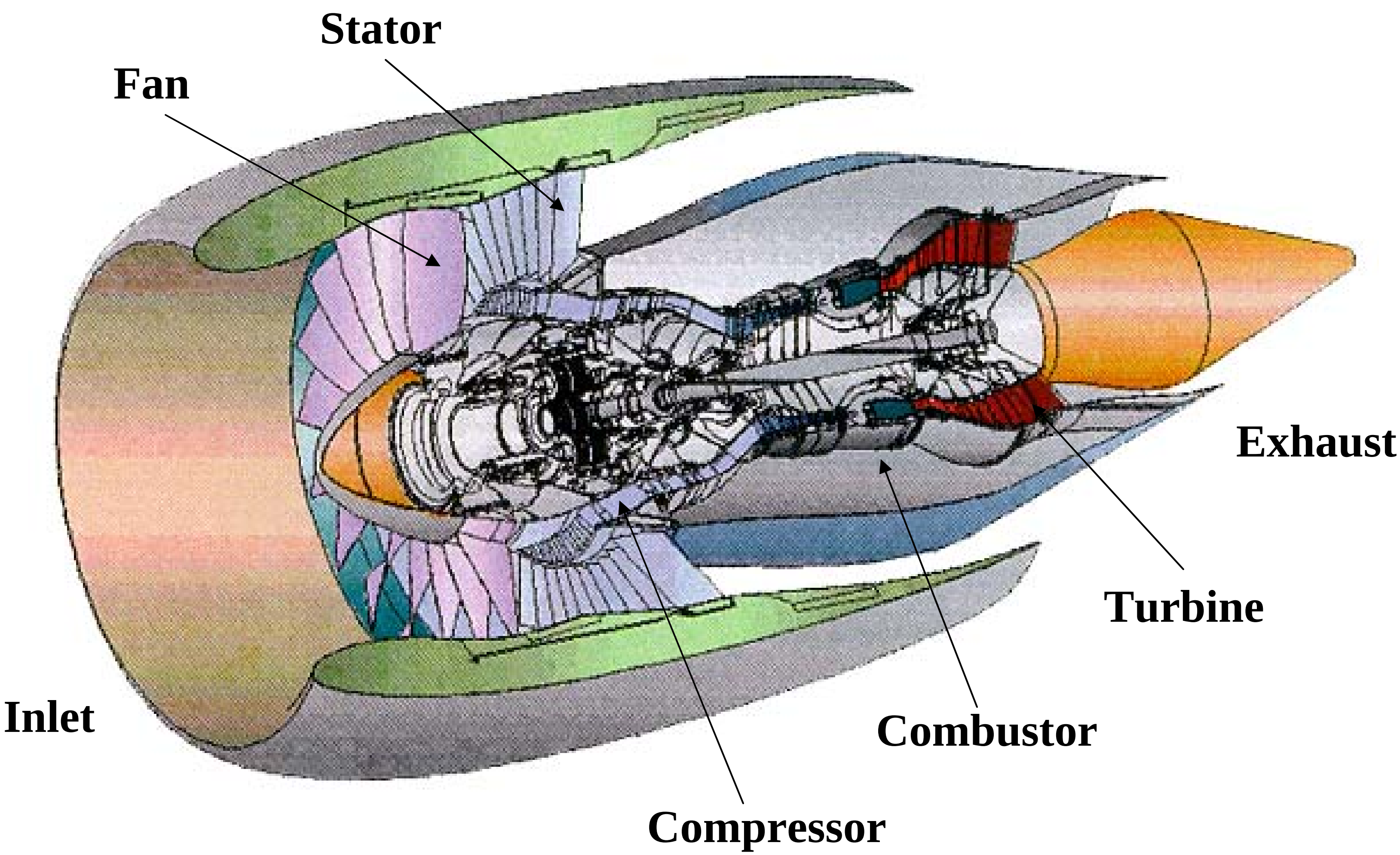
Aircraft Fleet Noise Reduction Needed For 55 LDN Noise Contours Within Airport Boundaries

According to a document from the U.S. Environmental Protection Agency (EPA) published in the 1970's, 55 LDN is the outdoor noise exposure level "requisite to protect the public health and welfare with an adequate margin of safety". The phrase "health and welfare" is defined as "complete physical, mental and social well-being and not merely the absence of disease and infirmity".



Analysis by Don Garber, NASA Langley, using NoiseMap

Pratt & Whitney's PW8000 Turbofan Engine (Conceptual)

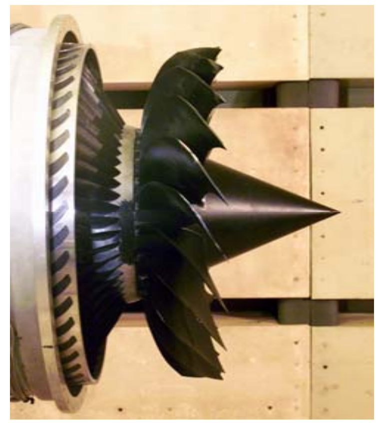


Engine Noise Reduction Technologies

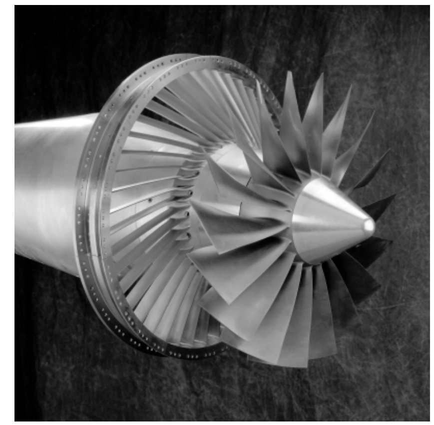
Higher Bypass Ratio

Scarf Inlets

Forward-Swept Fans

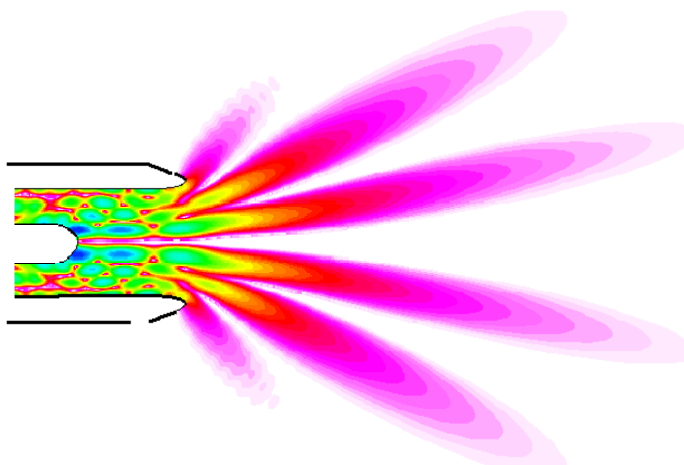


Swept/Leaned Stators

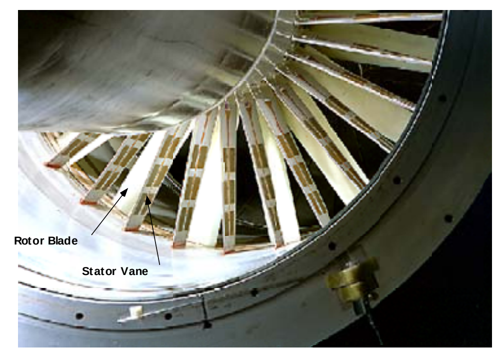


Chevron Nozzles

Noise Prediction



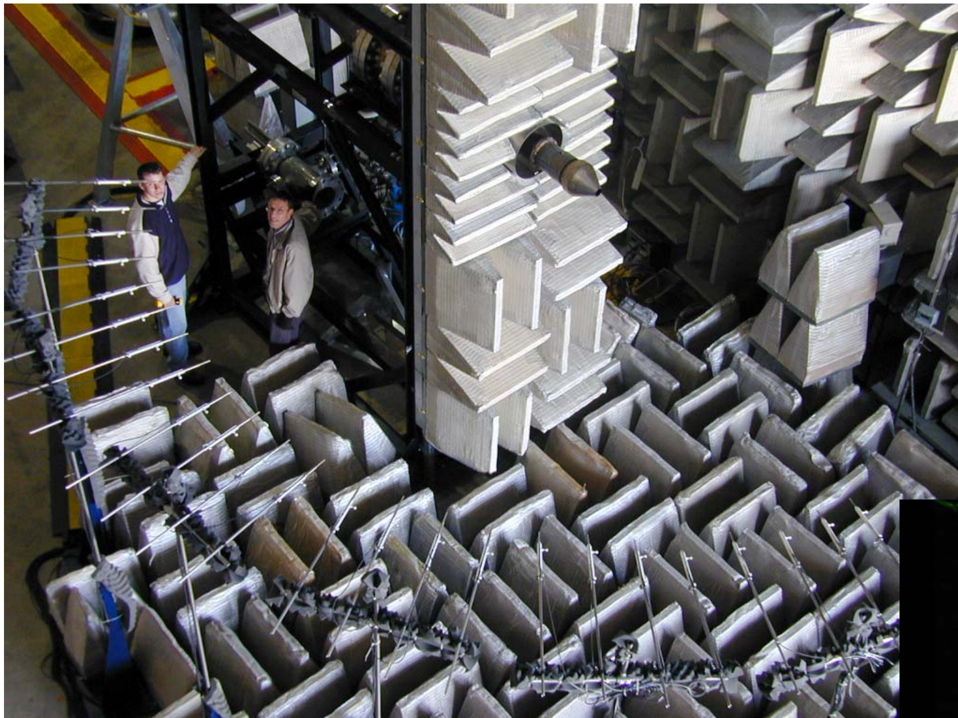
Active Noise Control



OUTLINE

- Source Diagnostics Tests
- Fan Noise
- Jet Noise
- Static Engine Tests & Flight Validation
- Future Directions

Small Hot Jet Acoustic Rig (SHJAR)

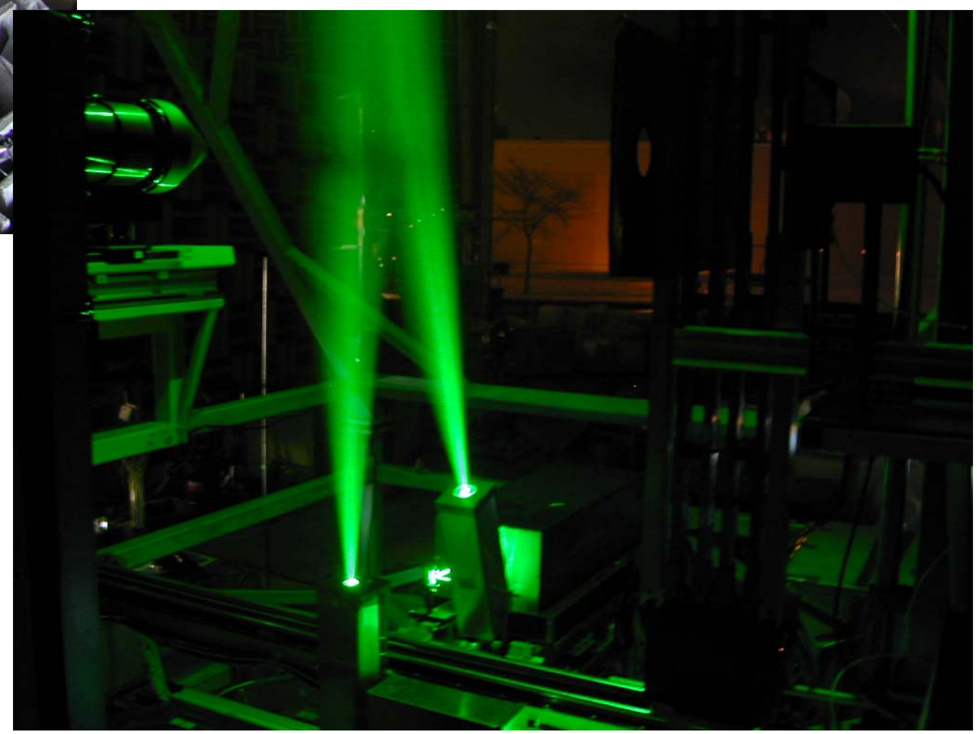


Far-field Acoustics

Koch, Bridges, Brown & Khavaran
(INCE NOISE-CON 2003)

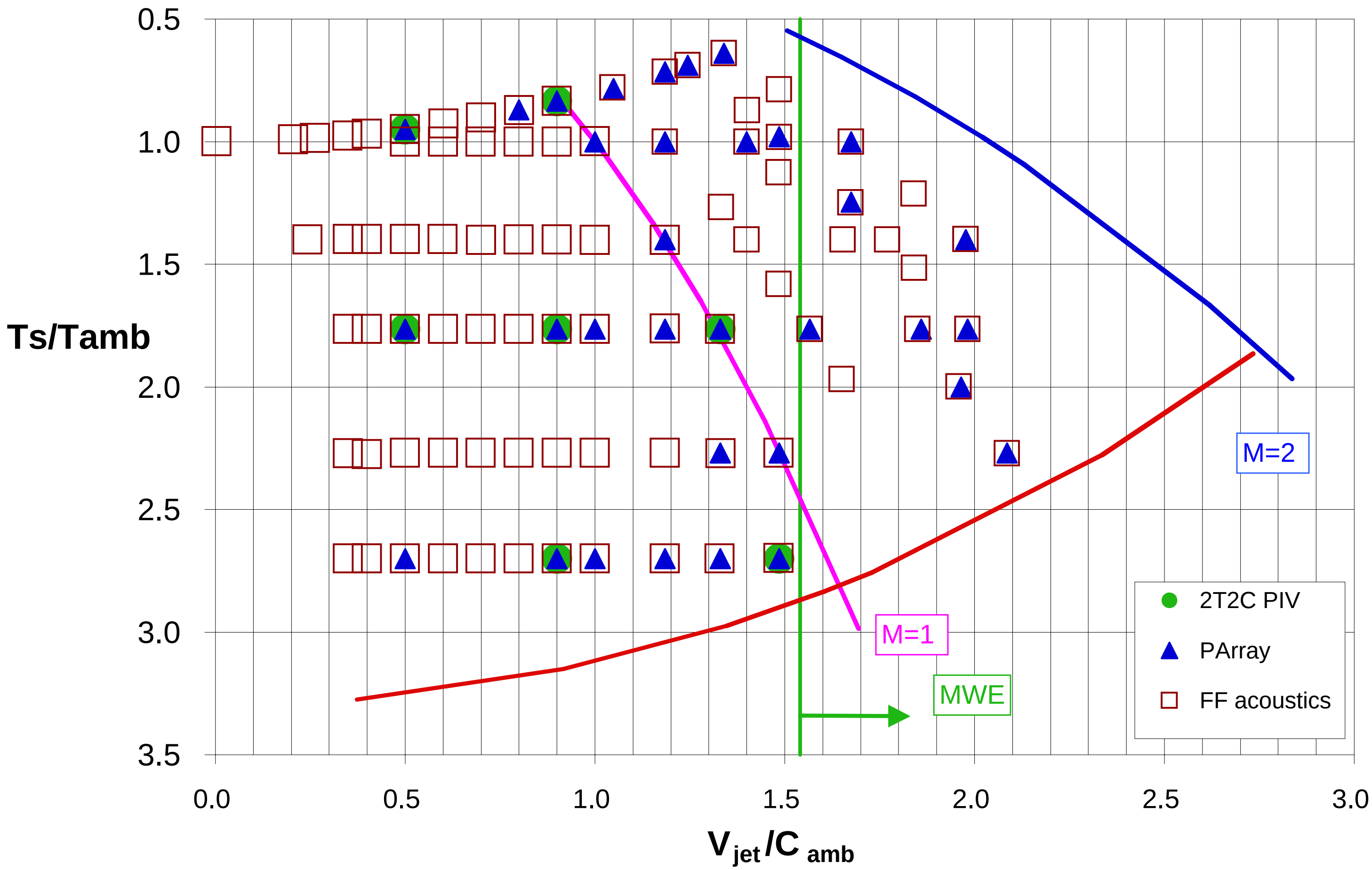
Bridges & Wernet (AIAA Paper 2003-3130)

Flow Diagnostics



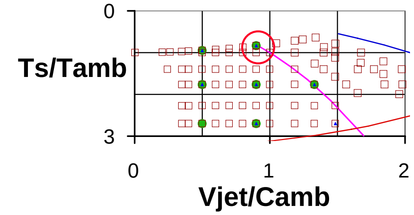
Jet Noise Baseline Data For CFD/CAA Validation

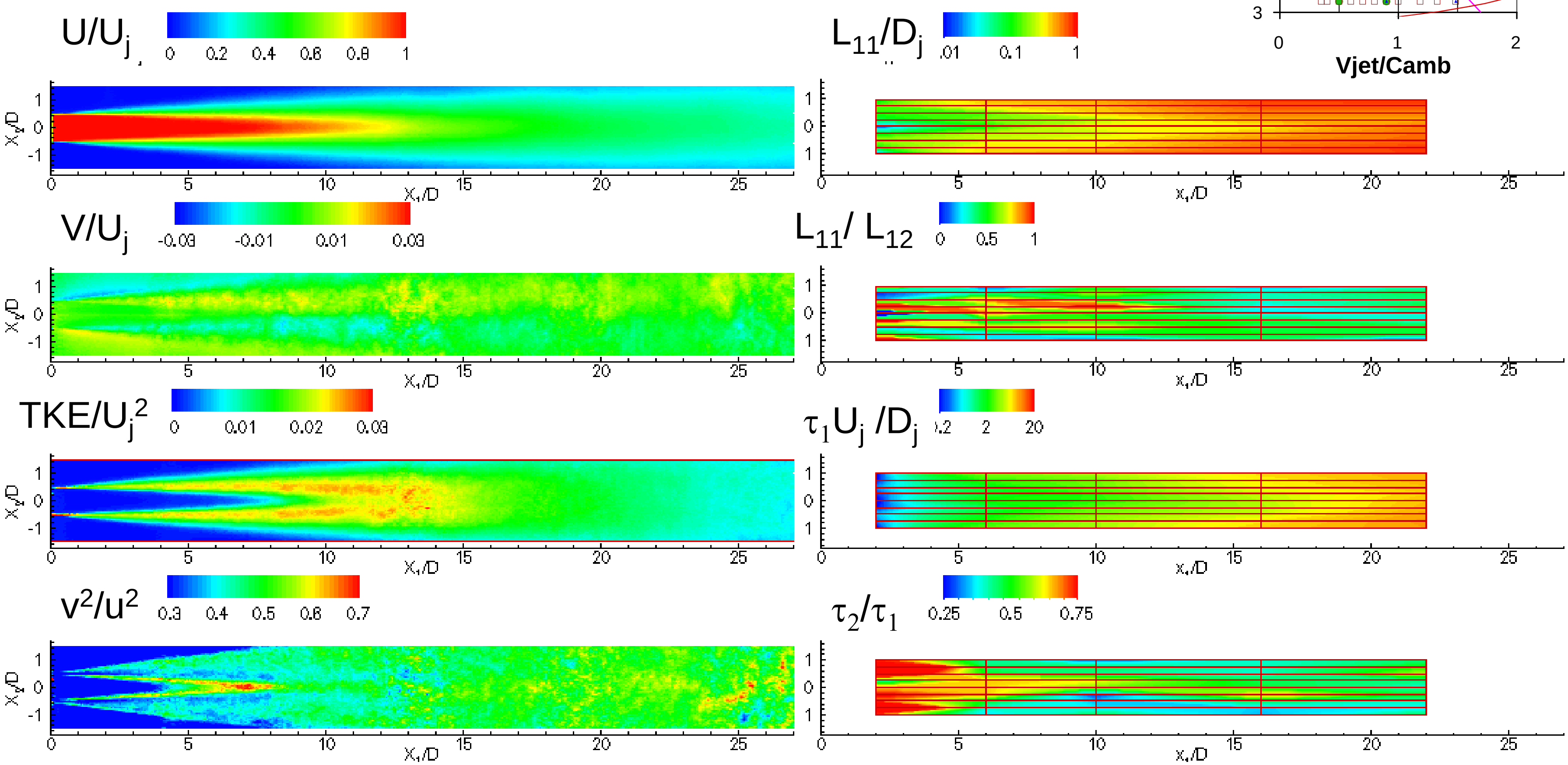
- Provide reliable data base for experimental and analytical comparisons
- Cover wide range of subsonic and supersonic conditions (Tanna data)



Jet Noise Baseline Data For CFD/CAA Validation

- **Objective: Turbulent flow statistics**



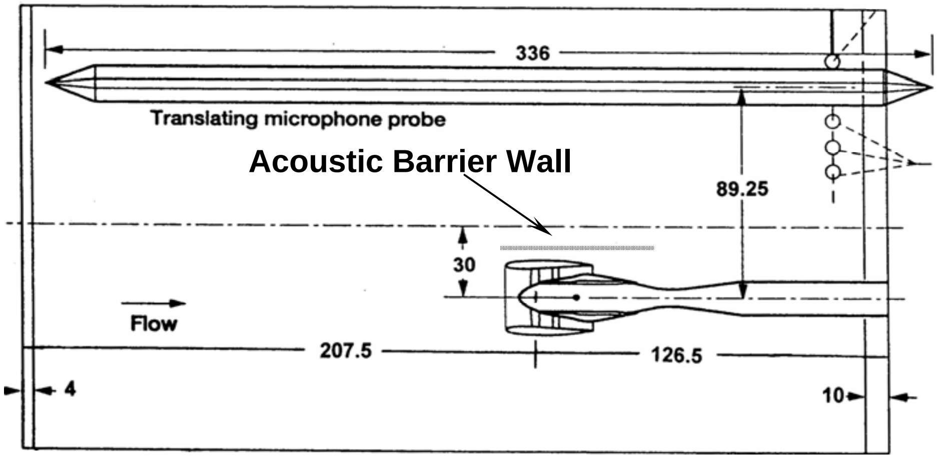


Bridges & Wernet (AIAA Paper 2002-2484)

Fan Source Diagnostics Test (SDT)

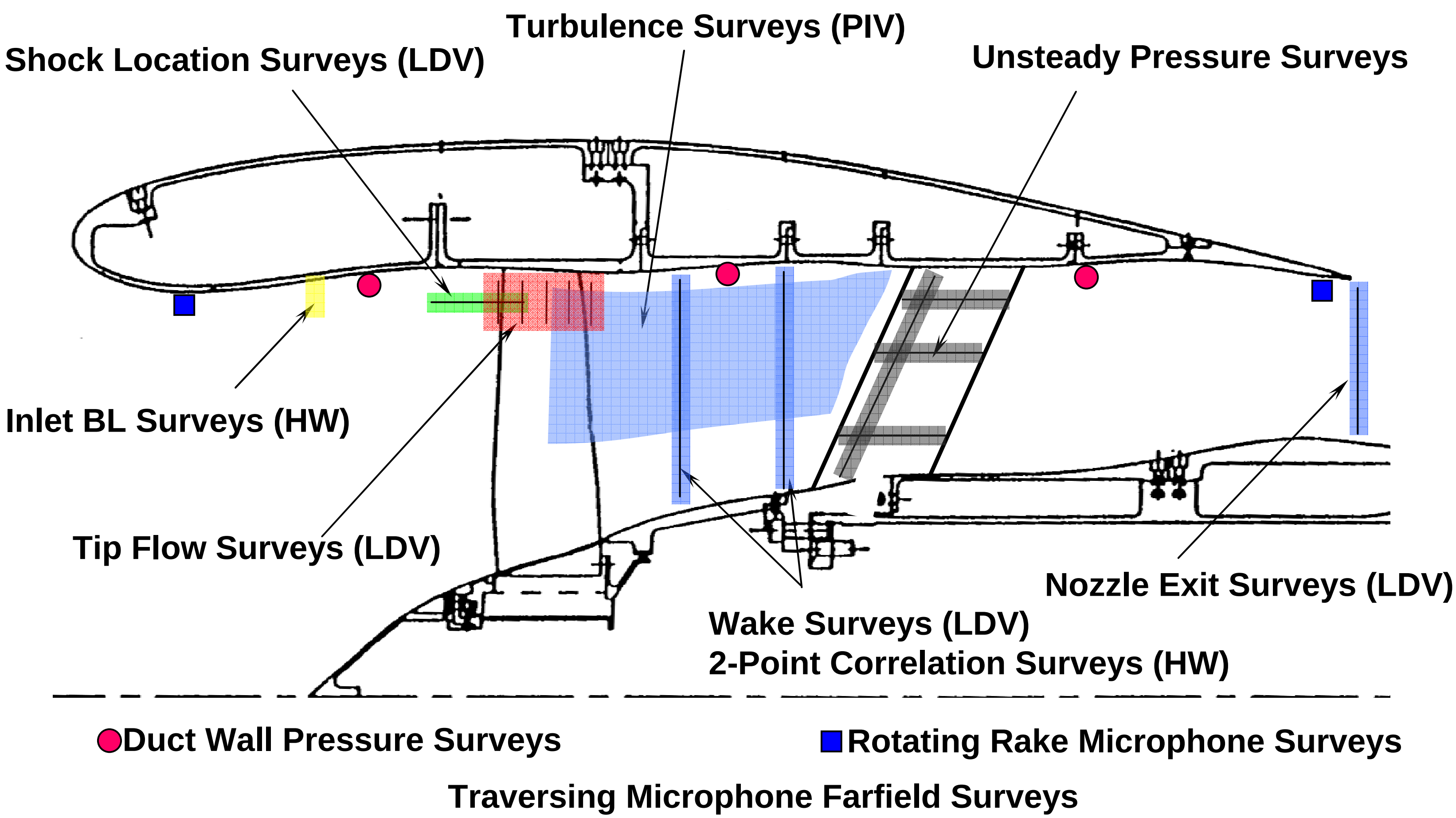
❑ Approach

- ➢ Comprehensive Aero-Acoustic Testing
- ➢ Advanced Diagnostics
- ➢ Source Separation
    - ➢ Inlet vs. exhaust
    - ➢ stage vs. rotor-alone



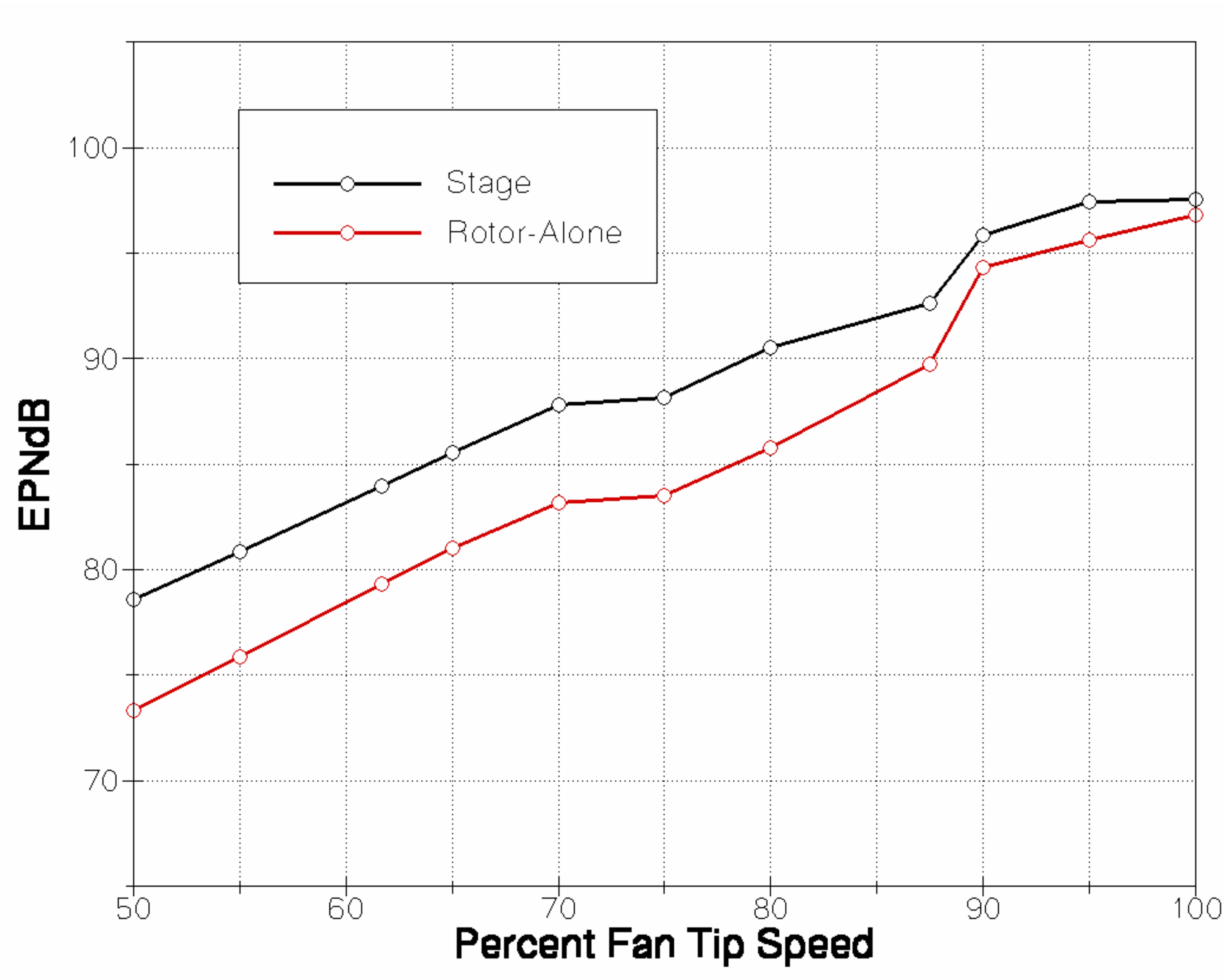
Top View Schematic of NASA's 9' x 15'
Low-Speed Wind Tunnel

Fan Source Diagnostics Test Summary



Tested 2 Fans, 3 Outlet Guide Vanes and Rotor-Alone Configurations at Multiple Fan Tip Speeds

Rotor-Alone Fan Noise



Fan Source Diagnostics Test - References

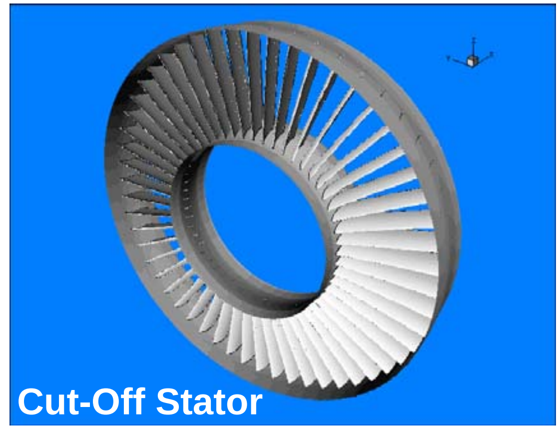
Rotor Alone Aerodynamic Performance Results
Hughes et. al (AIAA Paper 2002-2426)
Farfield Acoustic Results
Woodward et. al (AIAA Paper 2002-2427)
Tone Modal Structure Results
Heidelberg (AIAA Paper 2002-2428)
Wall Measured Circumferential Array Mode Results
Premo & Joppa (AIAA Paper 2002-2429)
Vane Unsteady Pressure Results
Envia (AIAA Paper 2002-2430)
LDV Measured Flow Field Results
Podboy et. al (AIAA Paper 2002-2431)
Computation of Rotor Wake Turbulence Noise
Nallasamy et. al (AIAA Paper 2002-2489)

Fan Tone Noise Prediction (Frequency Domain)

❑ Methodology

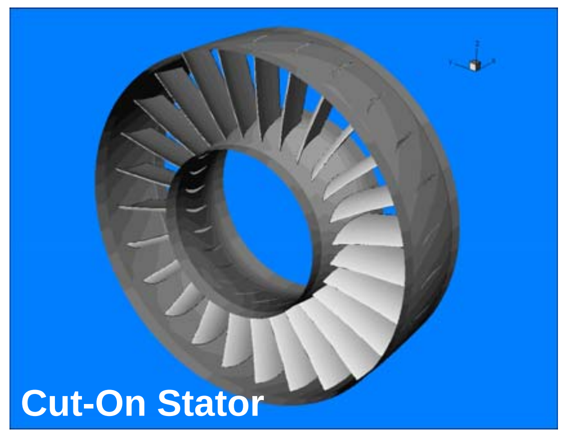
- ➢ **Fan Wake Description: Steady RANS**
- ➢ **OGV Acoustic Response: Linearized Euler**

Verdon et al. (NASA/CR-2001-210713)



Exhaust Tone Levels: Prediction Data*

Cut-Off Stator (2xBPF)			Cut-On Stator (1xBPF)		
Mode: (m,n)	**Power (dB)**		**Mode: (m,n)**	**Power (dB)**	
(-10,0)	113	111	(-4,0)	124	124
(-10,1)	100	97	(-4,1)	120	120
(-10,2)	101	103			
(-10,3)	102	98			
Total	**114**	**112**	**Total**	**125**	**125**



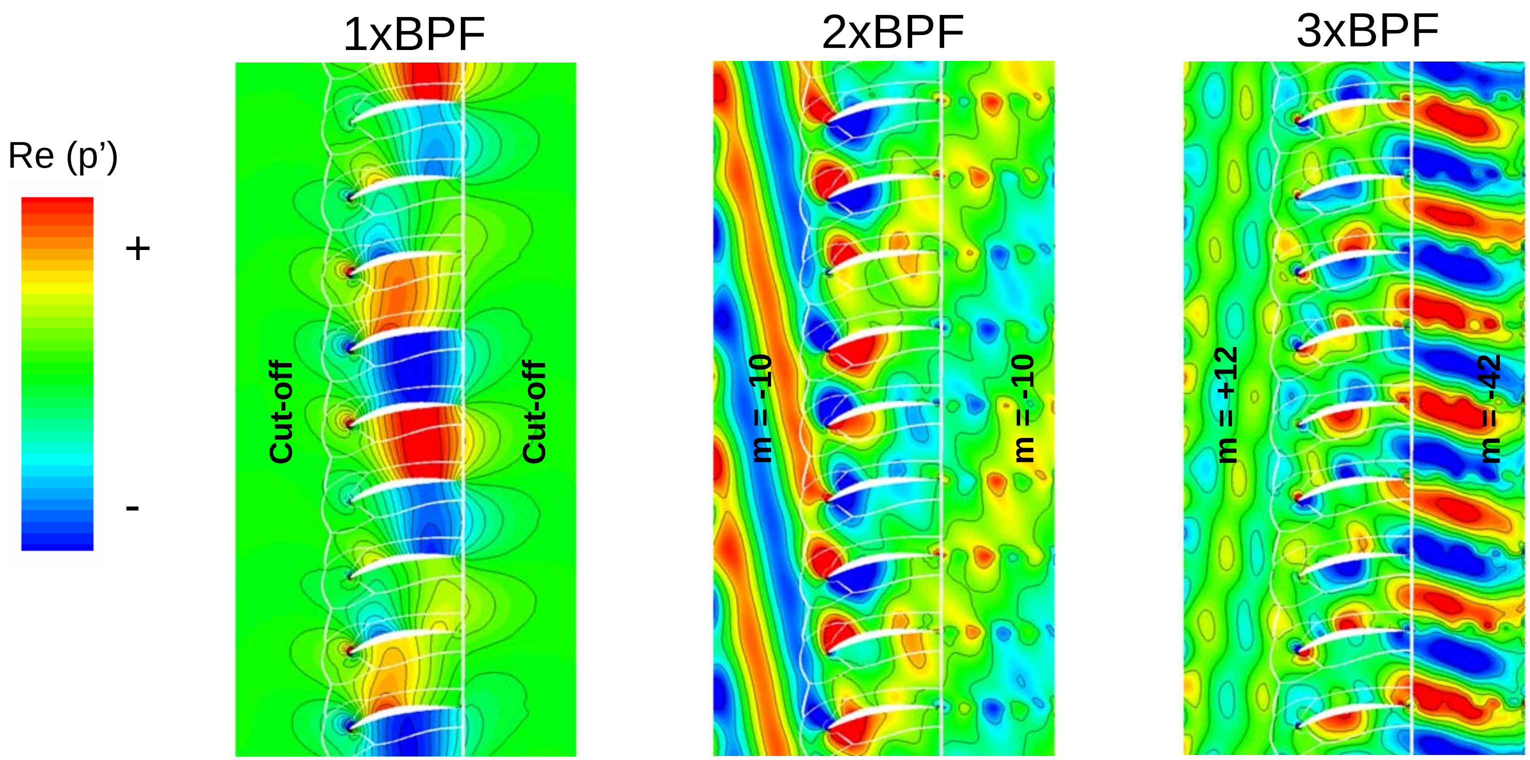
* **Data includes a recently discovered 3 dB correction**

Computational Aeroacoustics for Fan Noise Prediction (Time-Domain)

Nallasamy et al. (AIAA Paper 2003-3134)

❑ Methodology

- ➢ Time-Accurate, Non-linear & Inviscid Simulation
- ➢ Validated in 2D. Extension to 3D is Underway



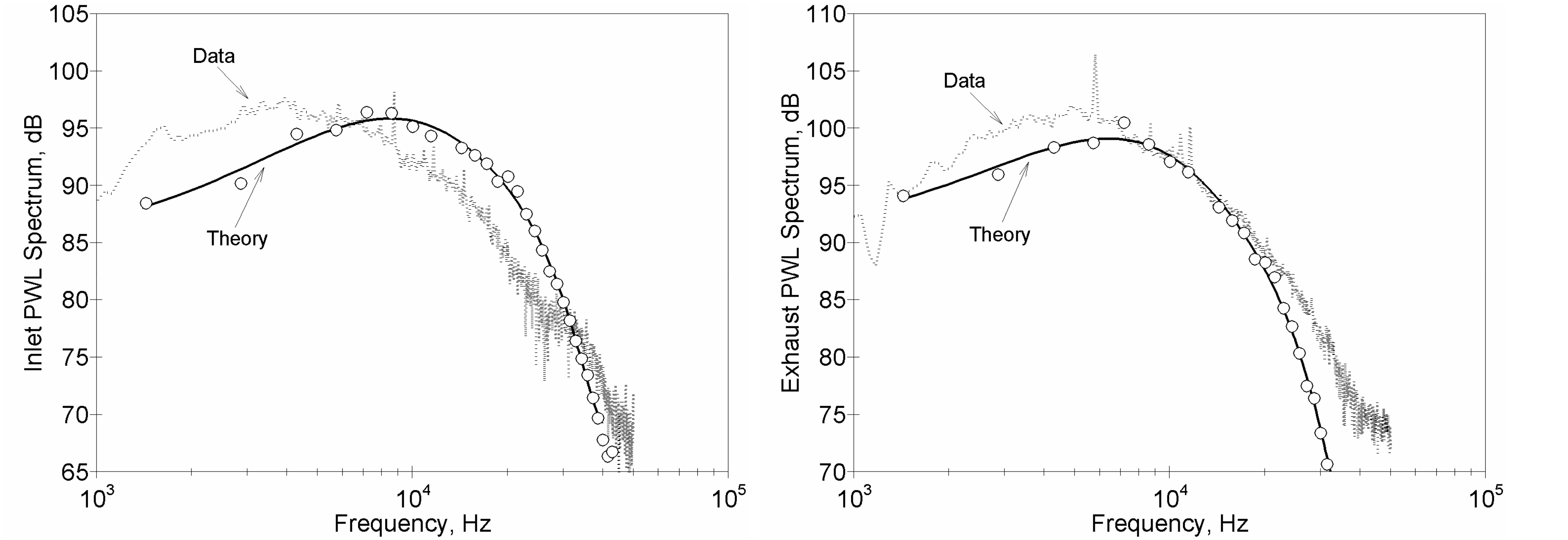
Harmonic content of unsteady pressure (only 9 passages shown)

Fan Broadband Noise Prediction

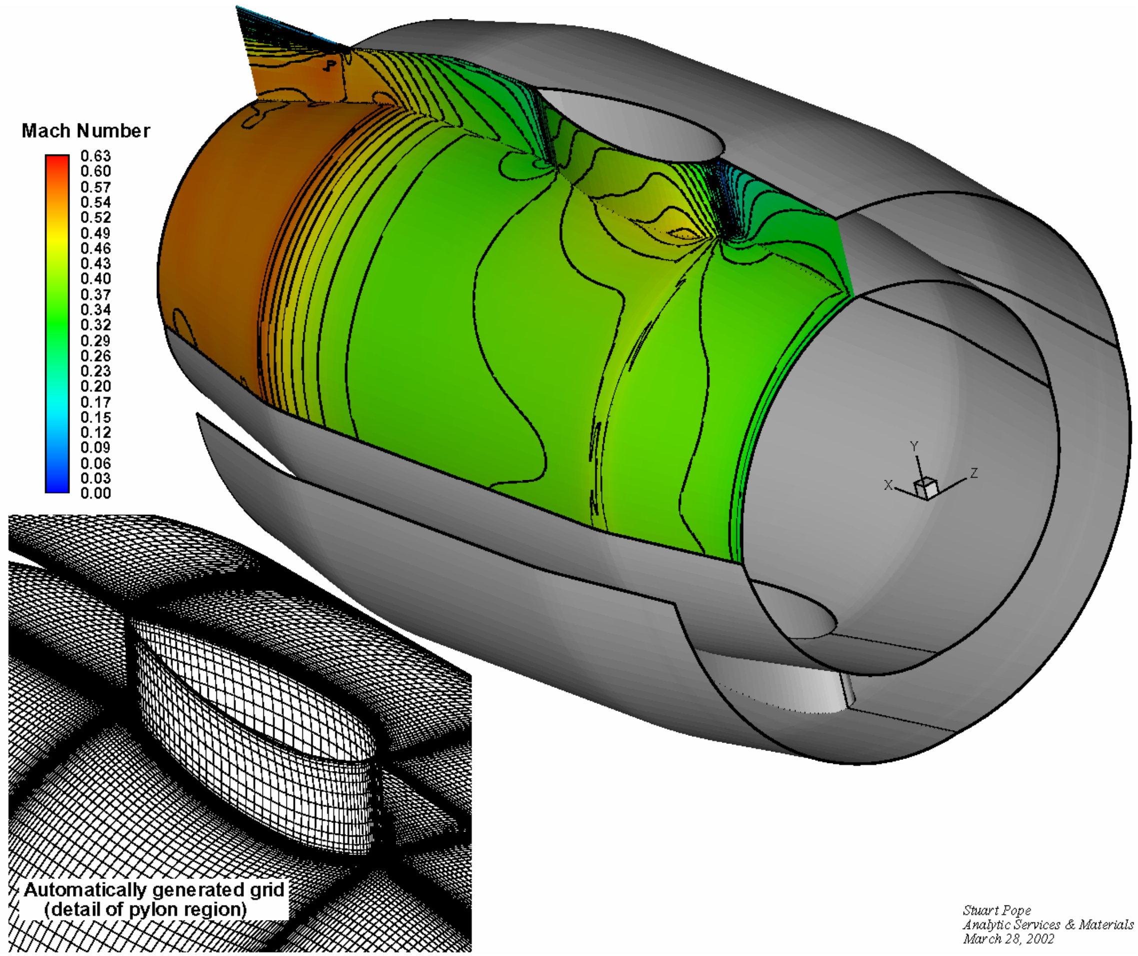
Nallasamy et al. (AIAA Paper 2002-2489)

- Methodology
  - **Fan Wake Turbulence Description: Steady RANS**
  - **OGV Acoustic Response: Strip-wise lift response (2D cascade)**
    Classical duct acoustics (3D)

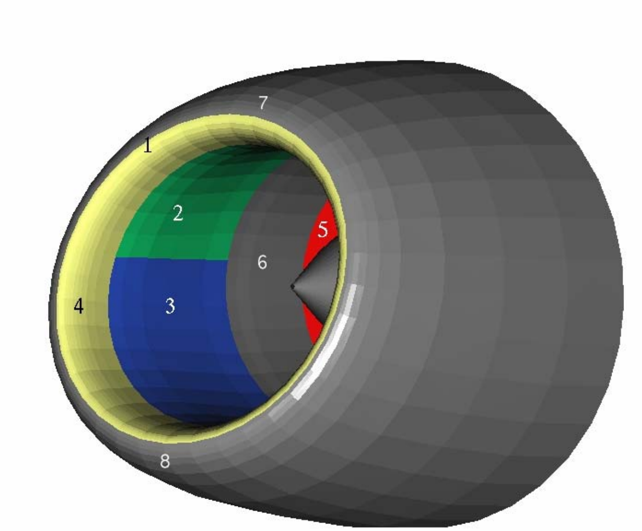
Inlet and Exhaust PWL at Approach Condition (Stator Contribution Only)
Data includes both coherent and broadband, theory only includes broadband



Fan Noise Duct Propagation
CDUCT-LaRC Code



- ✓ **Accounts for realistic geometries**
- ✓ **Uses CFD to achieve higher quality acoustic predictions**
- ✓ **Couples with source codes like LINFLUX or TFaNS**

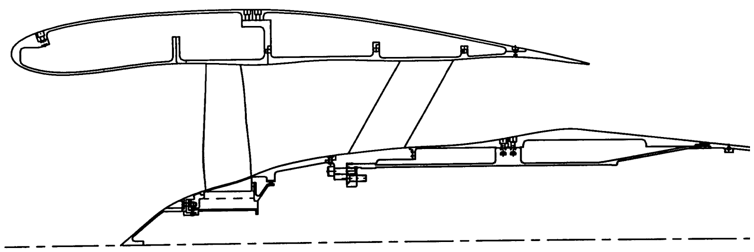


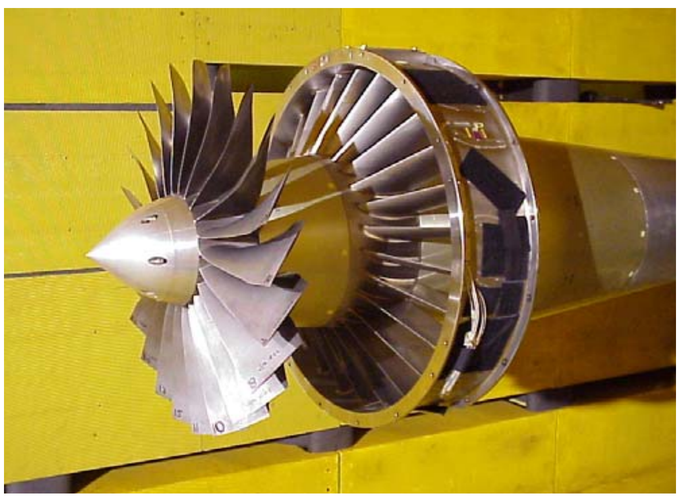
Scarf Inlets

Fan Noise Reduction

❑ Low-Count Swept OGV

- Low Count Reduces Broadband Noise
- Sweep Minimizes BPF Tone Penalty

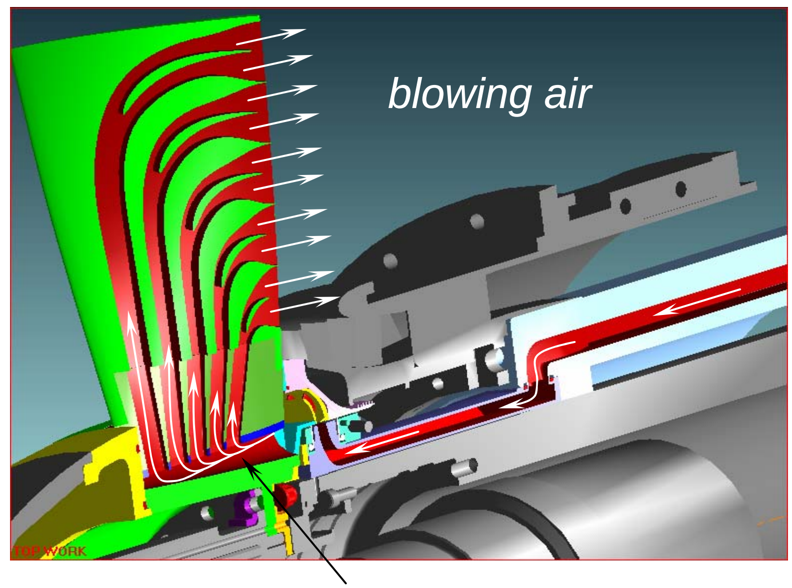




Woodward et al. (AIAA Paper 2002-2427)

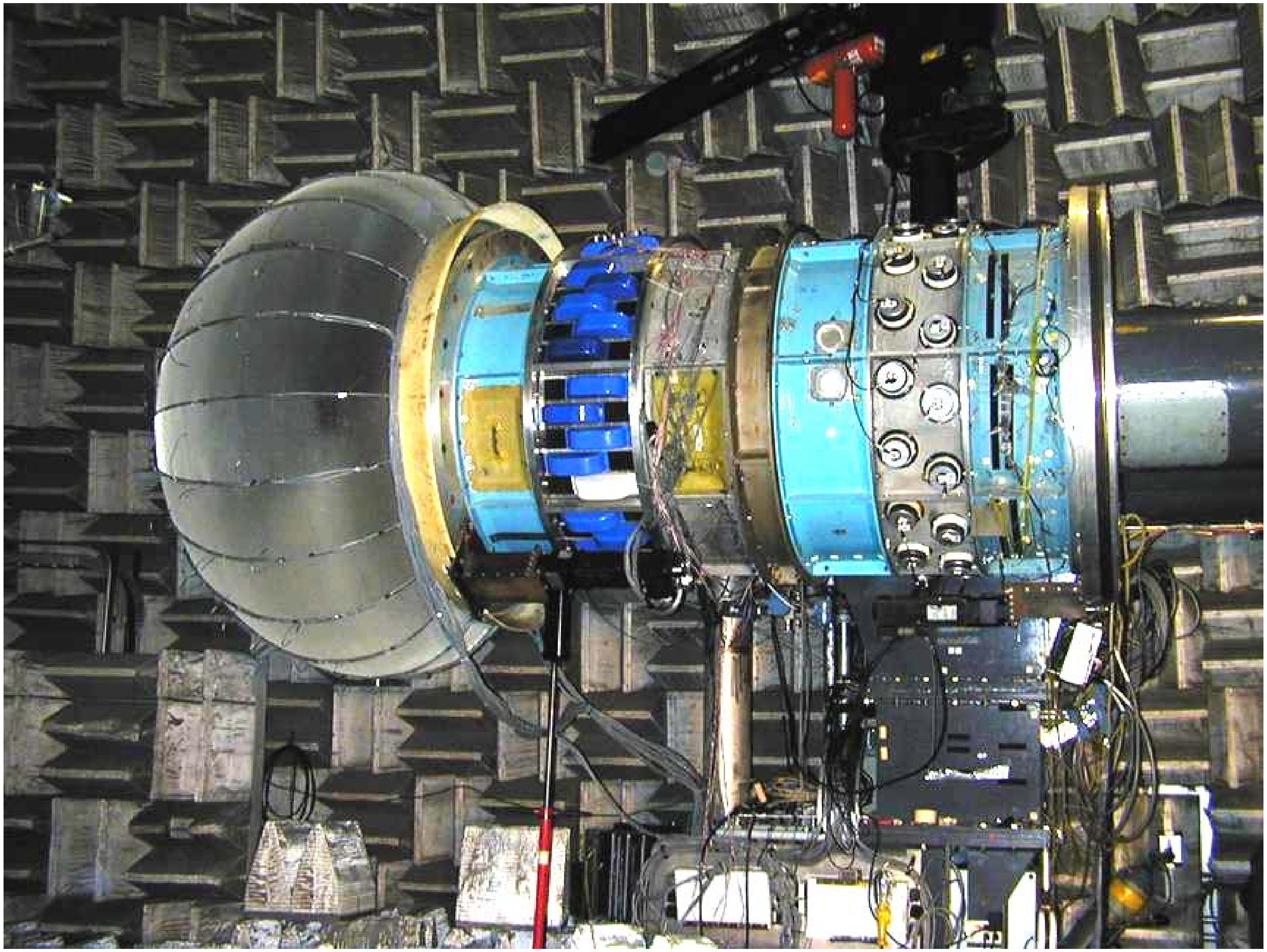
❑ Trailing Edge Blowing

- Fill-In the Rotor Wake
  - reduces tone noise
  - reduces broadband noise



Sutliff et al. (International J. of Aeroacoustics, Vol. 1, No. 3, 2002)

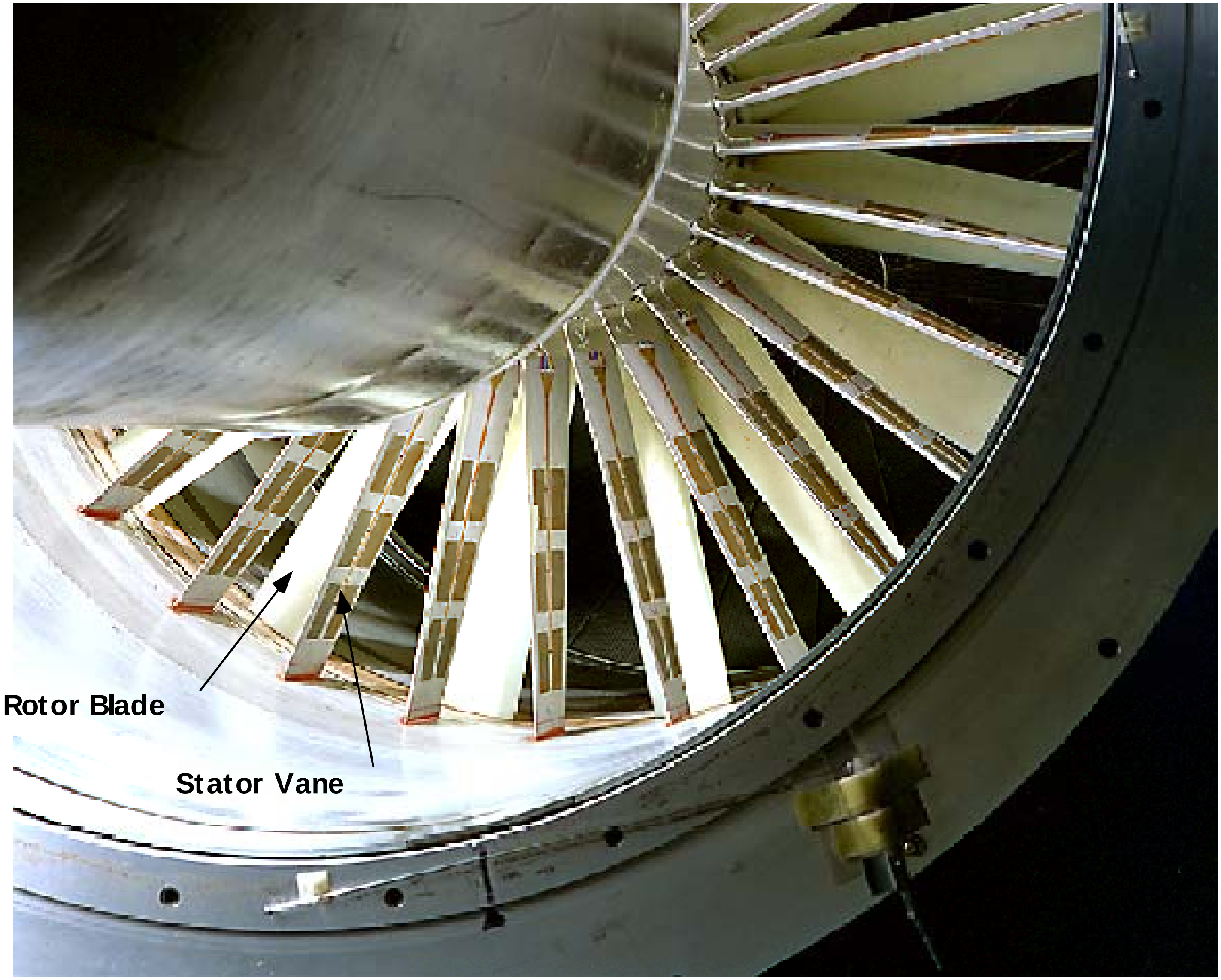
Fan Noise Reduction



Virginia Polytechnic Institute Herschel-Quincke (HQ) Tubes
NASA Advanced Noise Control Fan (ANCF)

Fan Noise Reduction

NASA/BBN Active Noise Control Fan Test

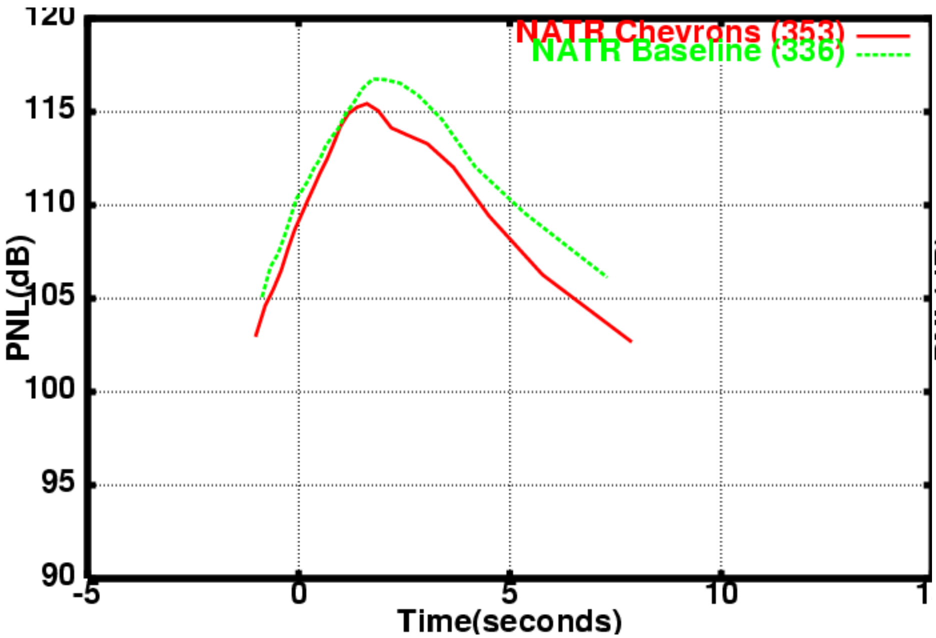


Jet Noise Reduction – Flight Tests

Model Scale Versus Flight Tests

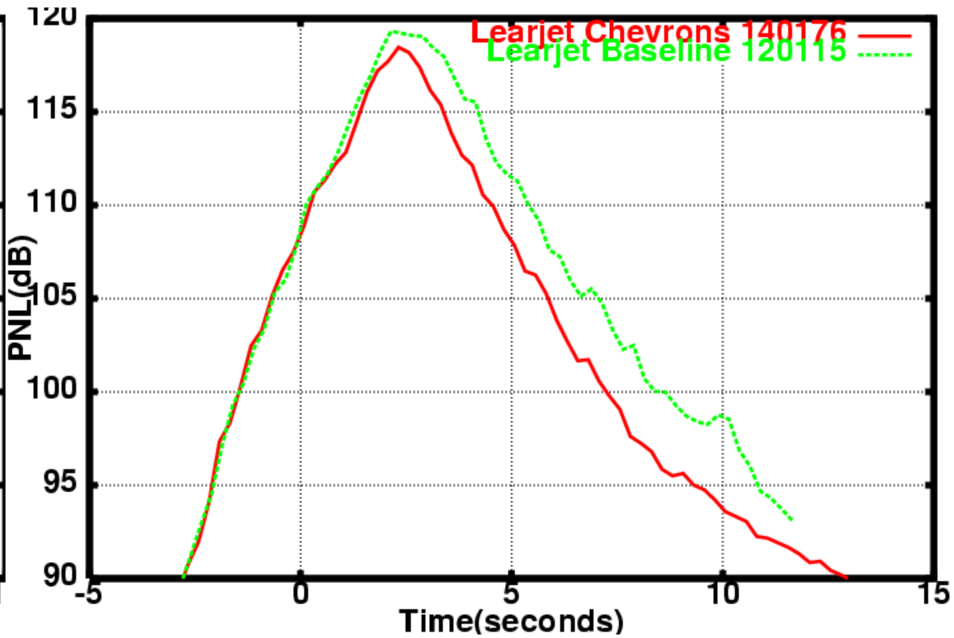
Chevron Benefit Comparison - Perceived Noise Level (PNL)

Model Scale Tests



Learjet Flight Data

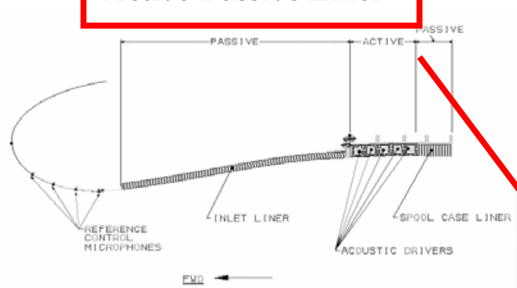
vs.



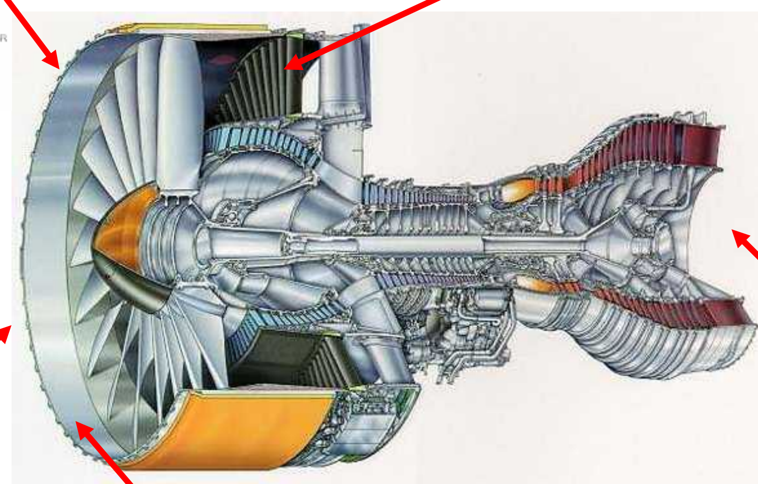
Brown & Bridges (*NASA TM 2003-212732)*

Pratt & Whitney PW4098 Engine Test

Active-Passive Liner

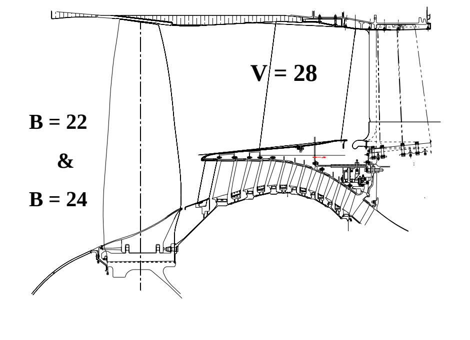


Scarf Inlet

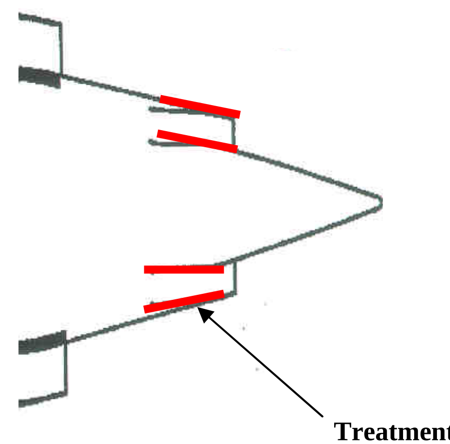


Advanced PW Fan Case Treatment

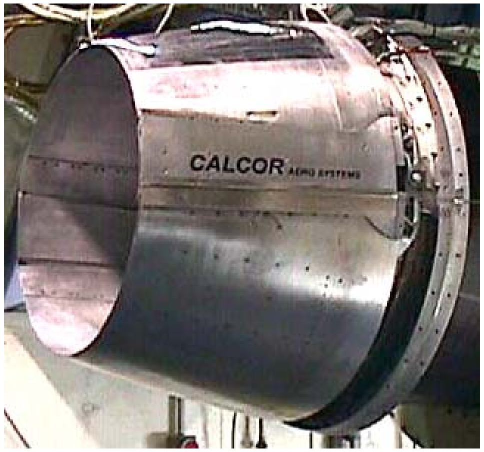
Fan Blade # Change and Low Number/Cuton FEGV



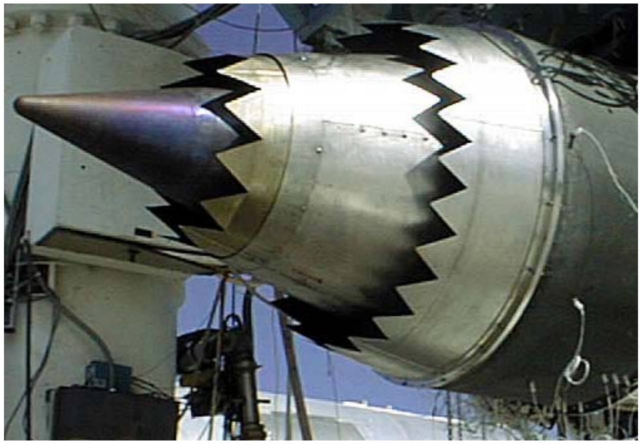
Treated Primary Nozzle



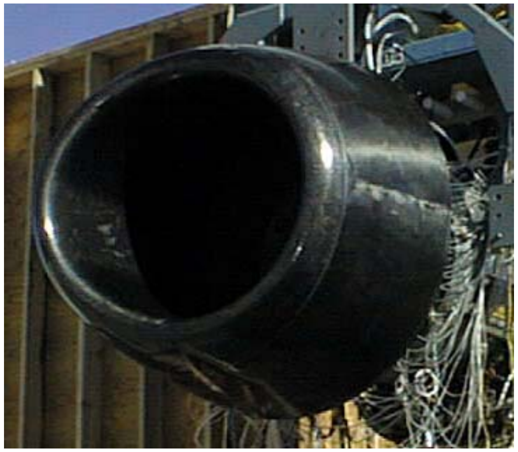
Honeywell Flight Demonstration of Noise Reduction Concepts



Variable Nozzle



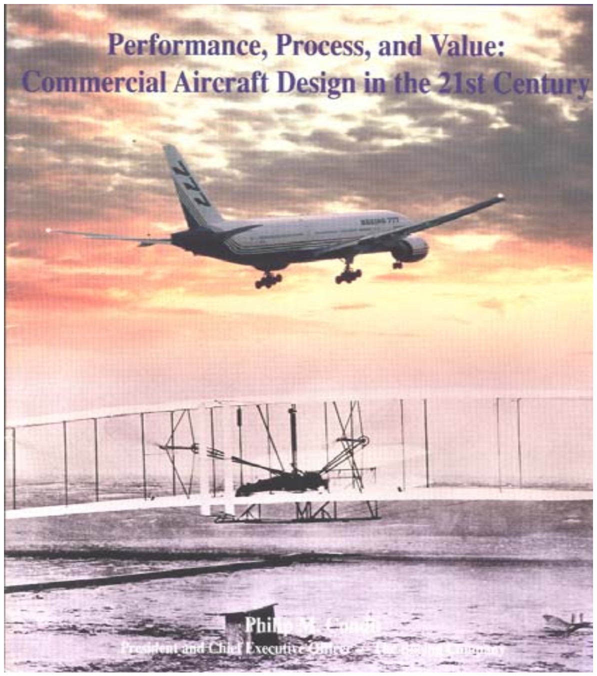
Chevron Nozzle



Scarf Inlet

1996 Wright Brothers Lectureship in Aeronautics

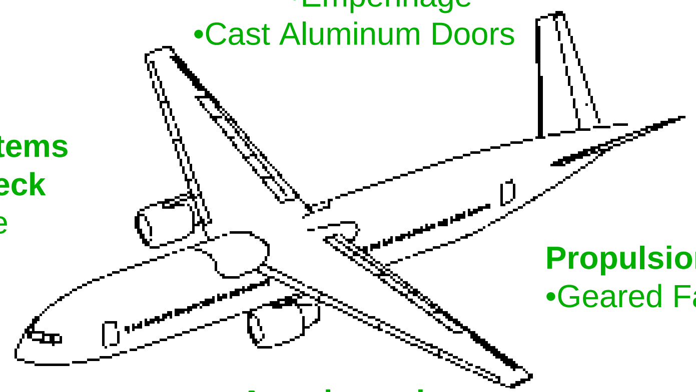
by Philip M. Condit, The Boeing Company, October 22, 1996



2016 Subsonic Airplane

Structure & Materials
- Low Temperature Graphite Composite:
  - Fuselage
  - Wing
  - Empennage
- Cast Aluminum Doors

Flight Systems & Flight Deck
- Fly-by-wire

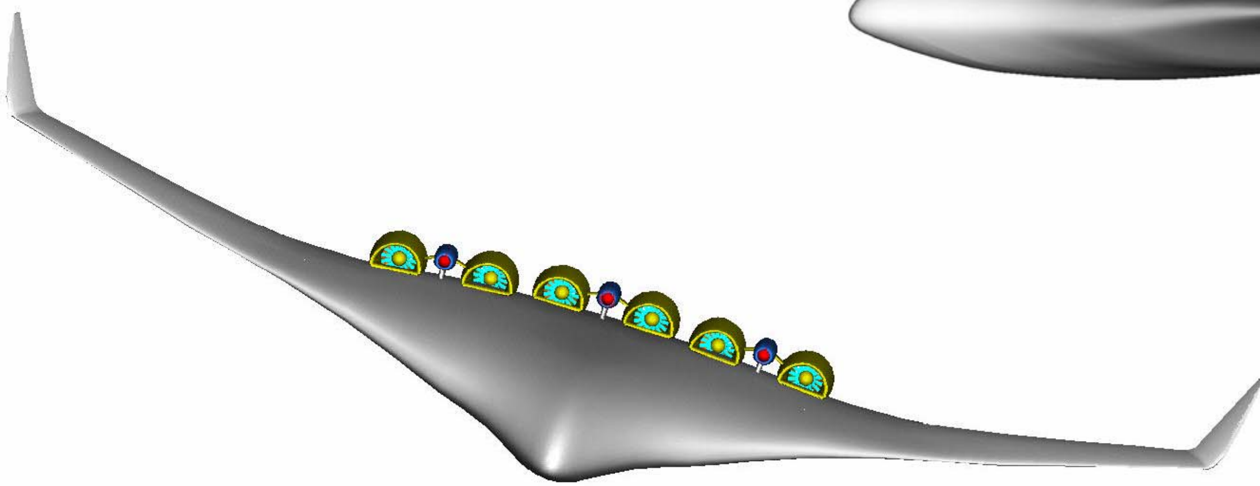


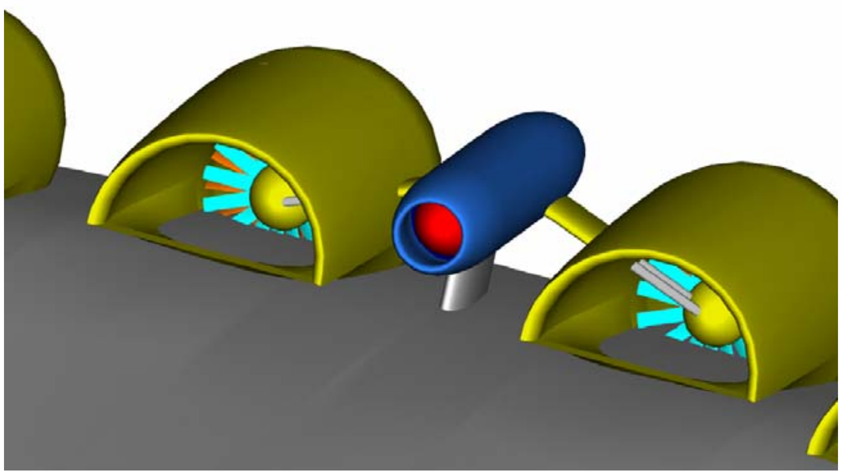
Propulsion System
- Geared Fan Engines

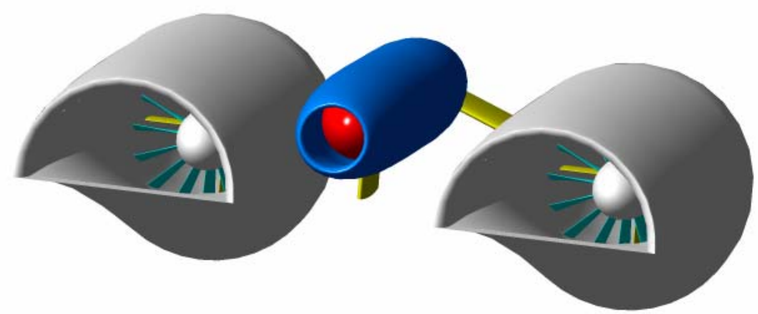
Aerodynamics
- Slotted Cruise Airfoil
- Natural Laminar Flow

"Ultra-high-bypass-ratio engines [to] reduce fuel consumption, engine maintenance, and community noise. It might be possible to reduce community noise by 10 dB, thus making airplane noise a non-issue at airports."

Dual-Fan Engine Concept On Blended Wing Body



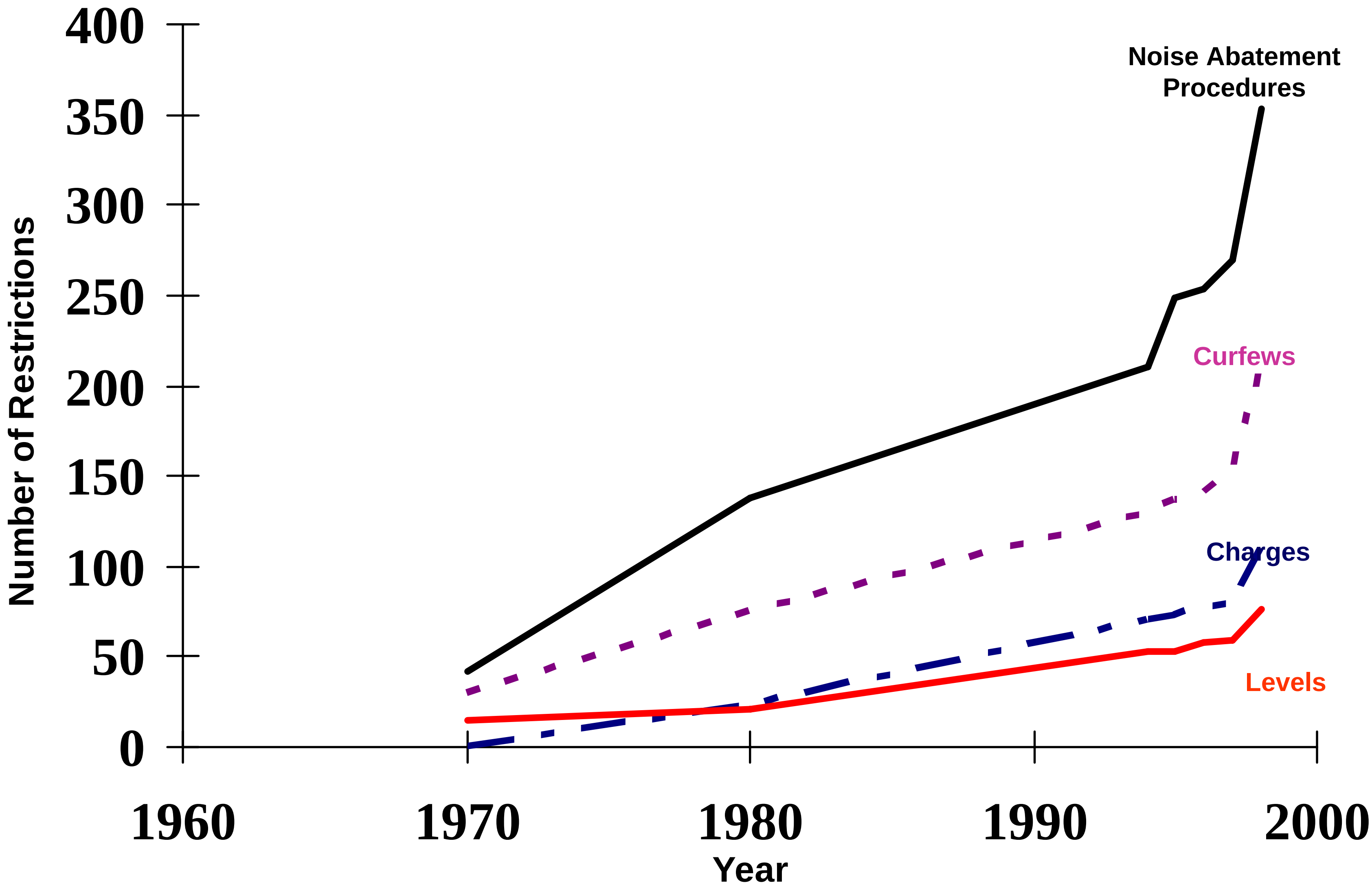




Backup Charts

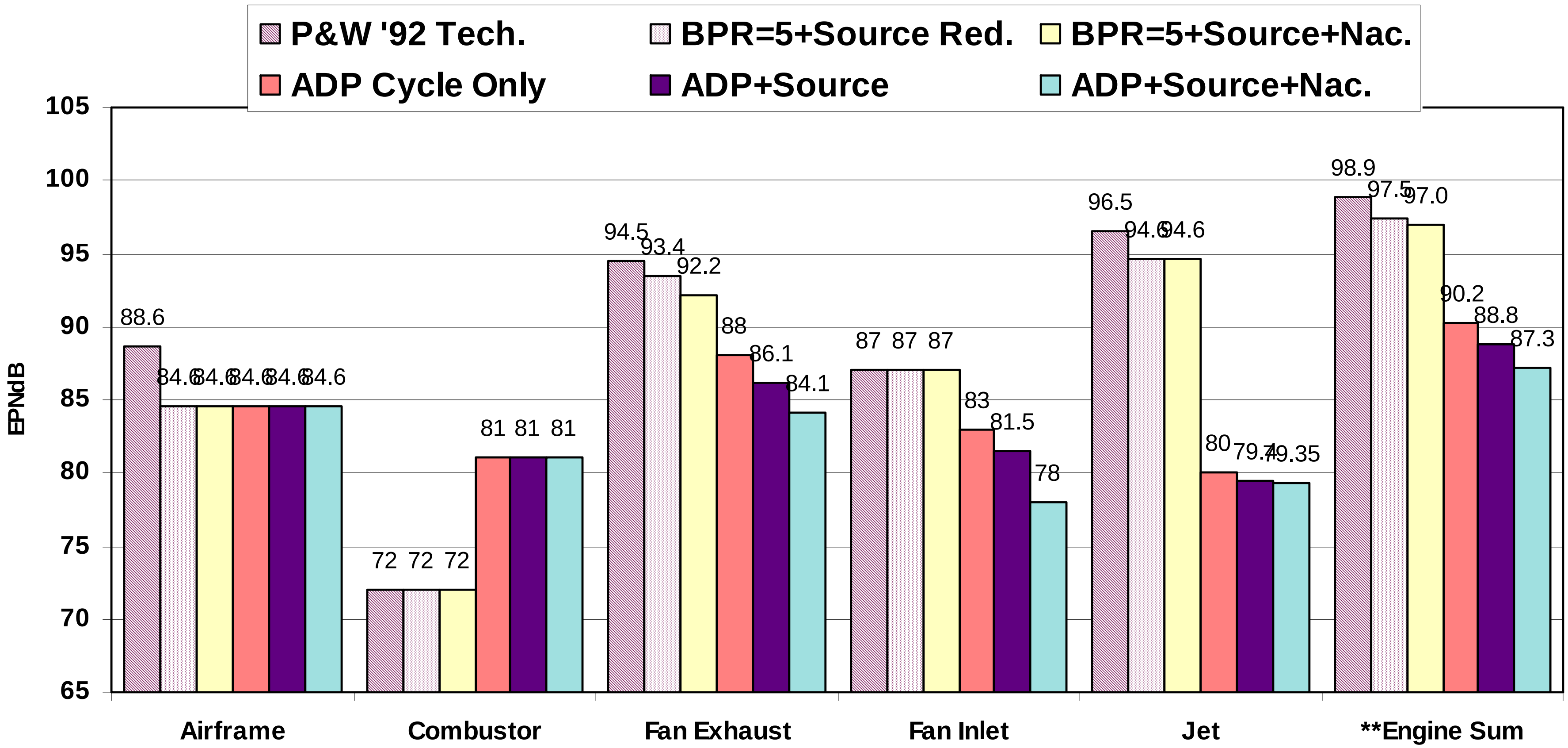
Noise Restrictions Continue to Grow

Number of Airports in Database: 591

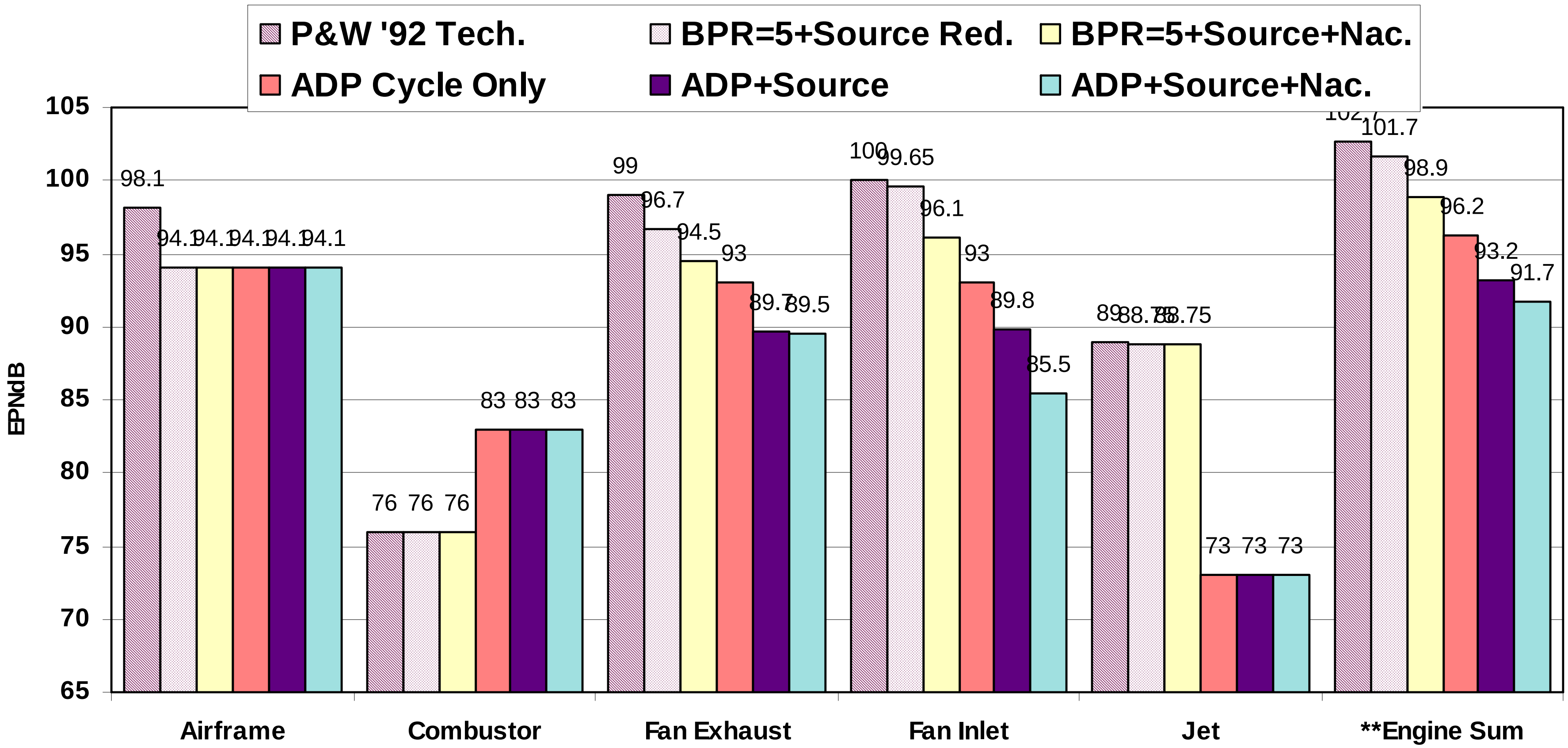


Source: David H. Reed, Manager of Noise Technology, Boeing Commercial Airplane, 1998

Engine Noise Reduction for a Large Quad Aircraft
Results From Pratt & Whitney Study
Approach Power

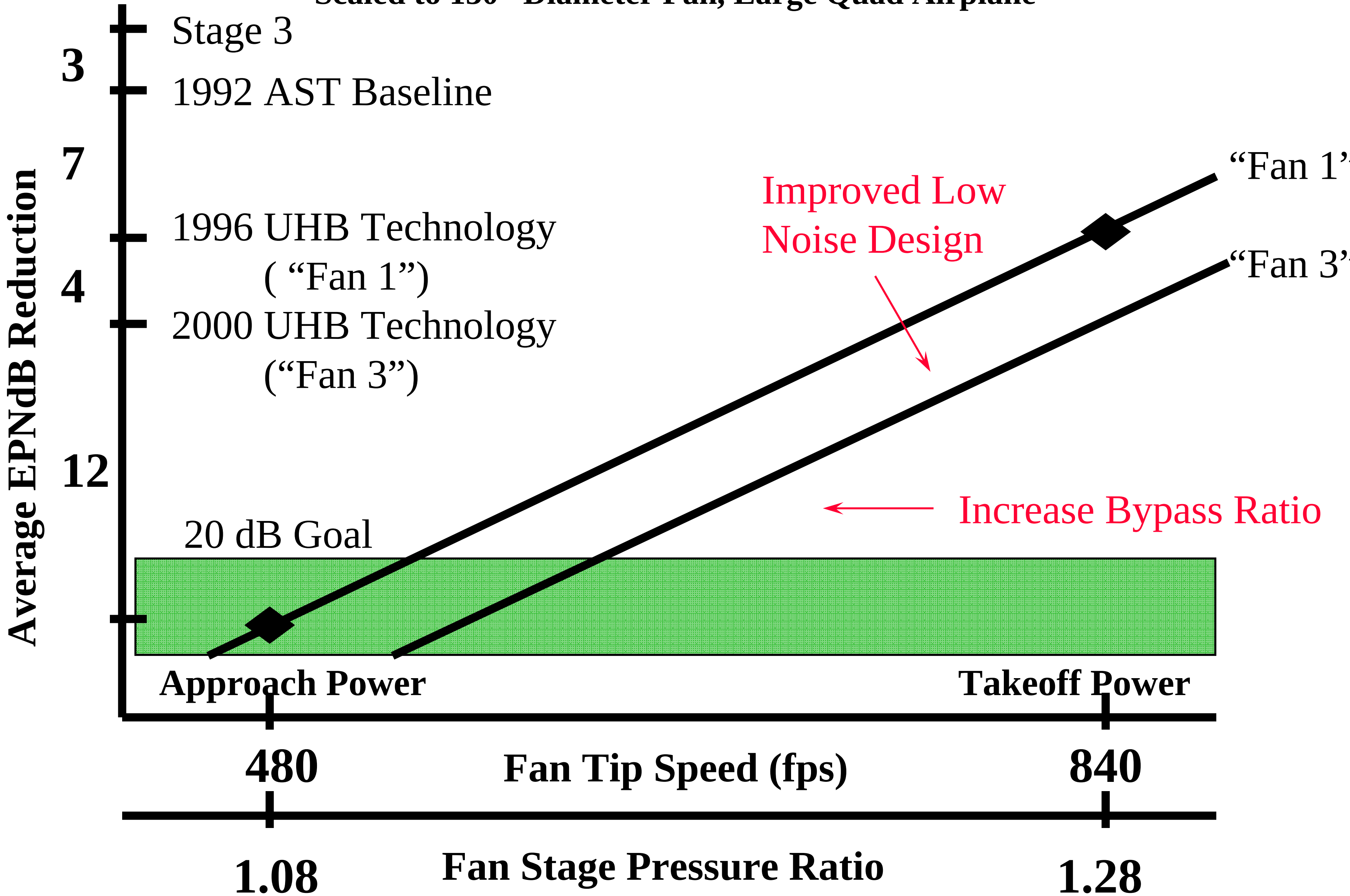


Engine Noise Reduction for a Large Quad Aircraft
Results From Pratt & Whitney Study
Sideline Power



Evolution of Ultra High Bypass Turbofan Noise Reduction

Based On NASA/P&W Advanced Ducted Propulsor Model Tests
Scaled to 130" Diameter Fan, Large Quad Airplane

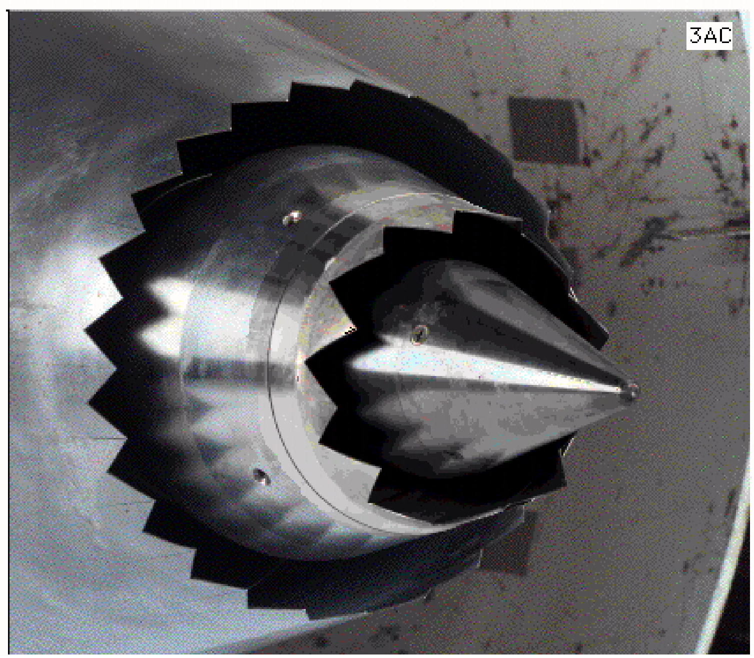


Jet Noise Reduction Research

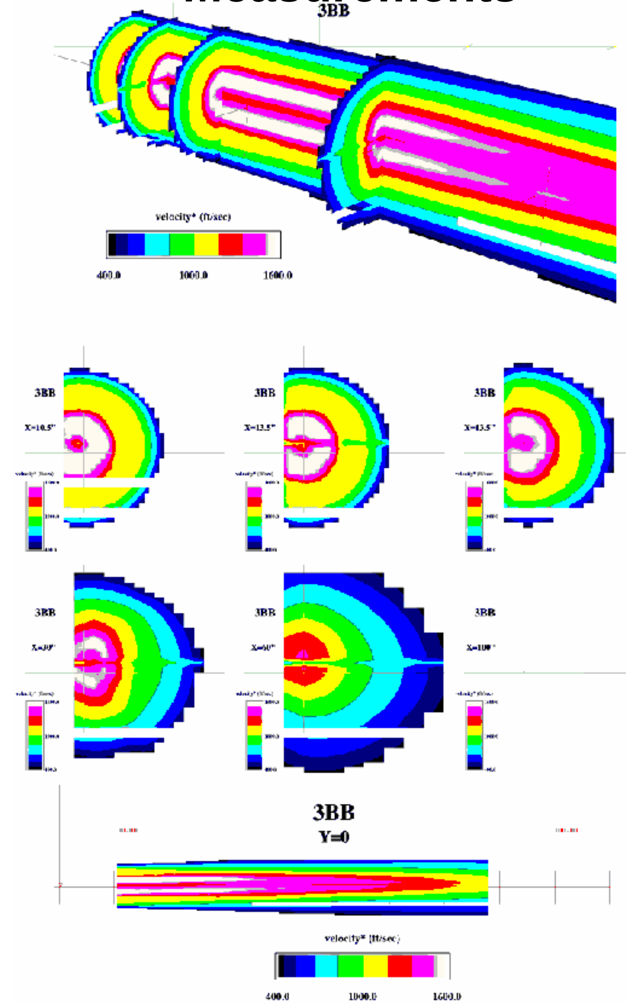
1997 NASA/GE/P&W Separate Flow Nozzle Test

Nozzles of the Future

Fan Chevrons with Core Alternating Chevrons



Flow Field Measurements



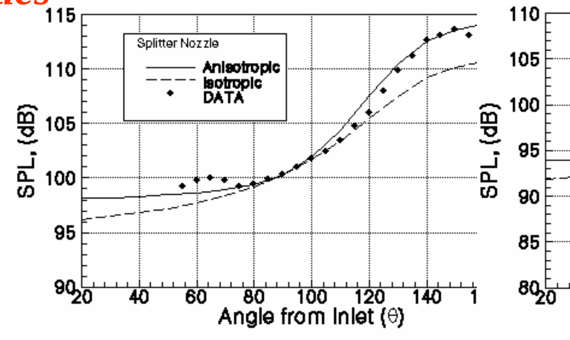
Jet Noise Prediction

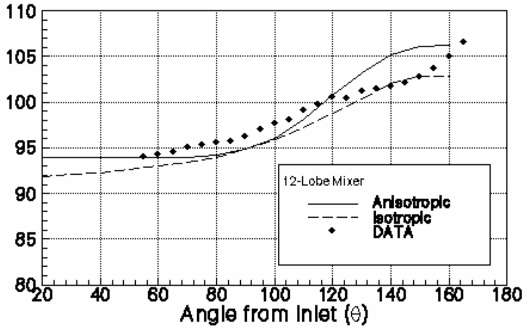
MODIFIED “MGB” CODE, now called “MGBK”

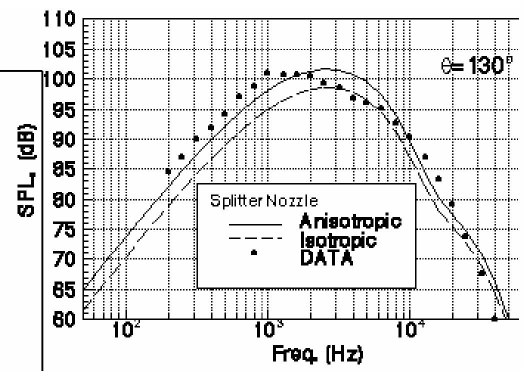
Combines CFD solutions with modeling of noise sources to predict far-field acoustics

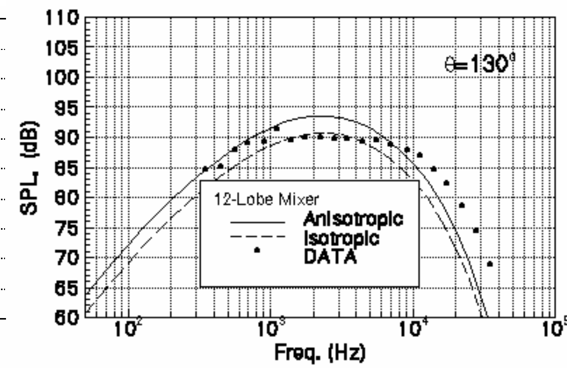
- **Small-scale turbulence noise**
- **External mixing noise only**
- **Accounts for both self and shear noise**
- **Non-isotropic turbulence**
- **Can be extended to a 3D geometry (assumes flow is locally axisymmetric)**

Splitter Nozzle | **12-Lobe Mixer**









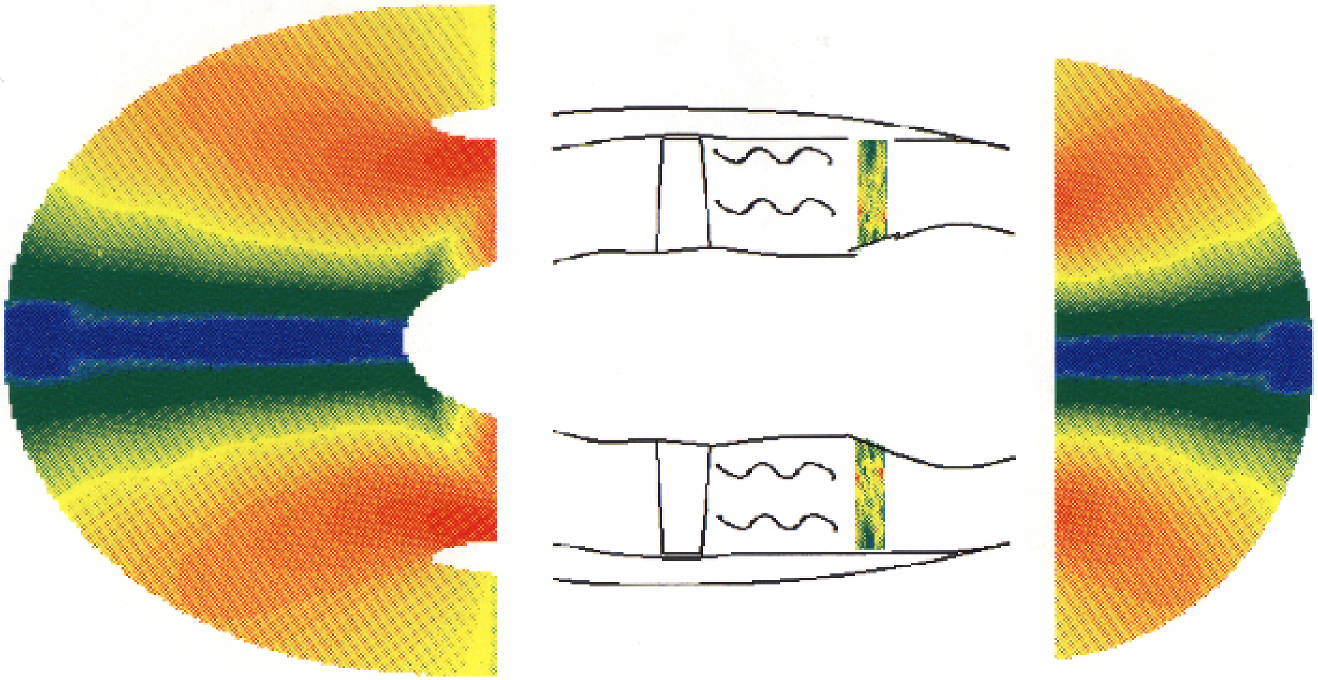
Isotropy: $L_2 / L_1 = 1, \quad \overline{u_2^2} / \overline{u_1^2} = 1$

Anisotropy: $L_2 / L_1 = 0.8, \quad \overline{u_2^2} / \overline{u_1^2} = 0.7$

First Integrated Fan Noise Source and Propagation Prediction Code (1994)

TFaNS: Theoretical Fan Noise Design/Prediction System

Joint Development By P&W/UTRC/NASA For Fully Coupled Interaction Tone Prediction

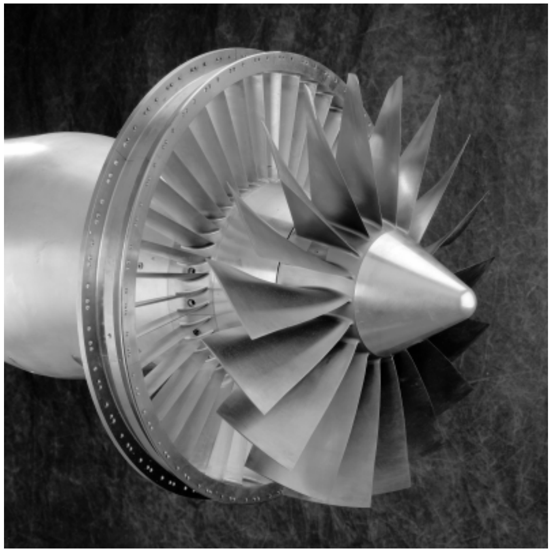


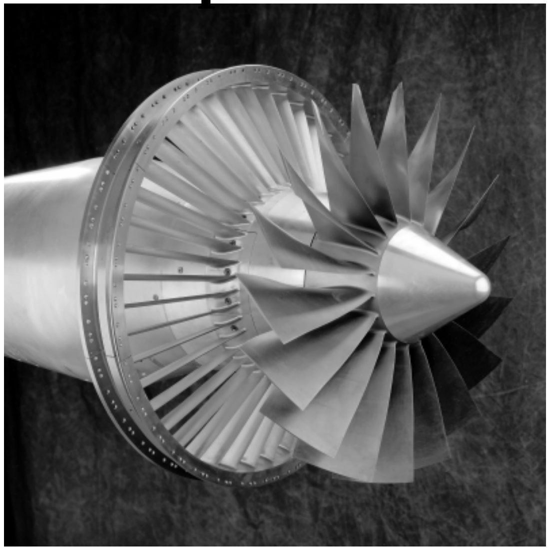
	RADIATION	**SOURCE**
1994	Eversman Inlet/Aft Code	Classical Flat Plate Theory
1996	Improved Eversman Code Caruthers Inlet/Aft Code	LINFLUX : 3D Linearized Euler Code
1998	Asymmetric Code	TURBO : 3D Navier–Stokes Code Linear/Non–Linear

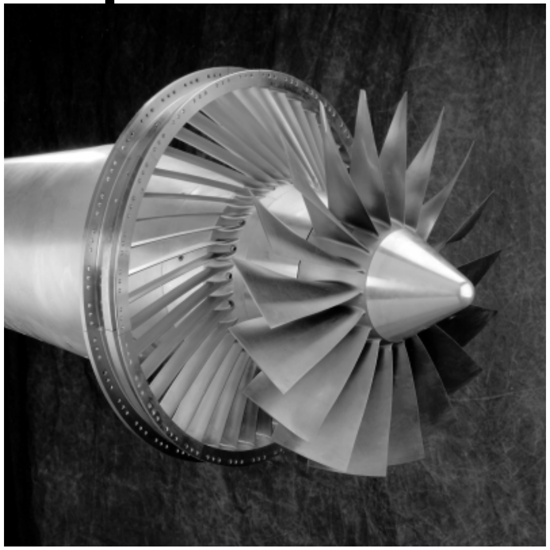
Fan Noise Reduction Research

1996 NASA/Allison Swept & Leaned Stator Test

Baseline | **Swept Stators** | **Swept/Leaned Stators**



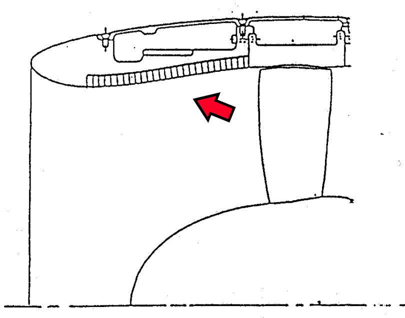




Fan Noise Reduction Research

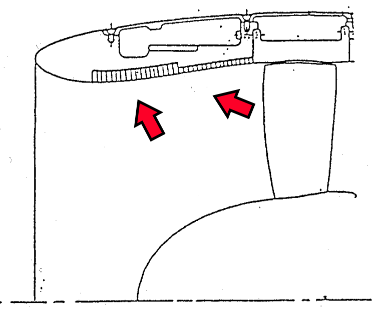
1996 NASA/Northrop Grumman Active Noise Control Fan Test

Uniform Passive



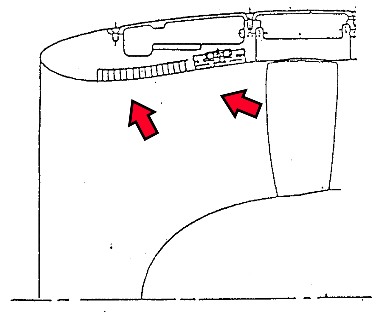
Near Grazing Incidence Fan Noise; Modest Overall Attenuation.

Two Segment Passive

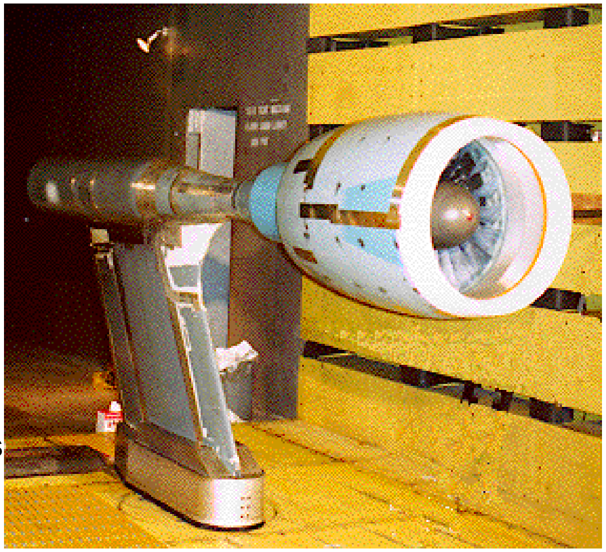


Initial Segment Scatters Modes into Higher Order Radial Modes.
Limited Bandwidth of Attenuation Since Liner is Efficient only near Design RPM.

Hybrid Active/Passive



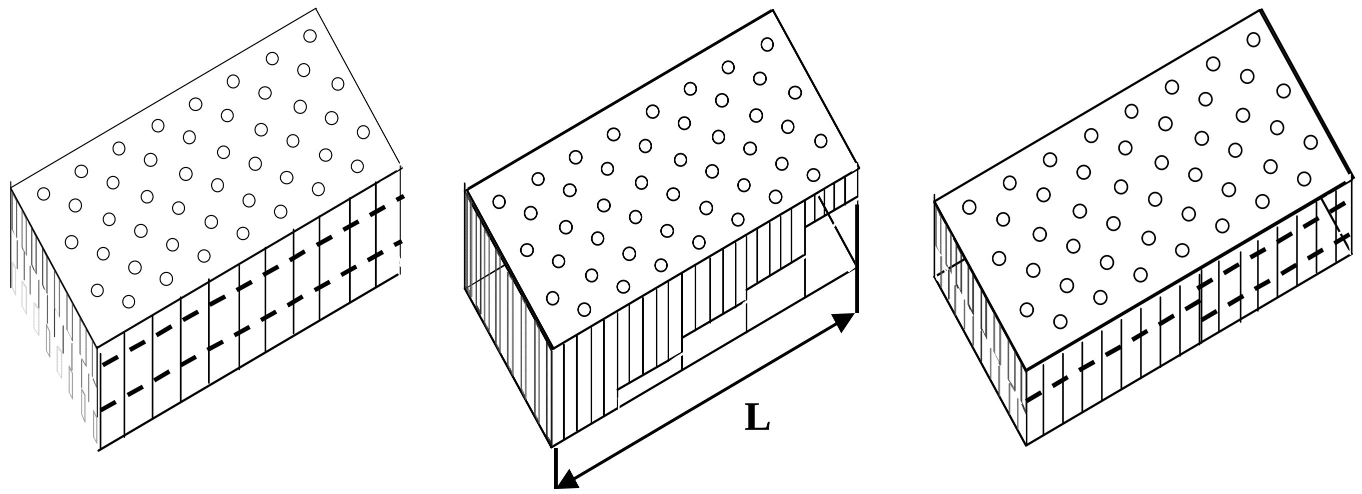
Initial Active Control Segment Compensates for Changing Parameters Resulting from Mode Mixture Variations with Fan Speed. High Bandwidth of Attenuation.



Northrop Grumman Hybrid Active/Passive Liner Installed in the NASA ADP Fan Rig at the NASA LeRC 9'x15' Wind Tunnel

- Superior Performance Relative to Conventional Uniform Passive Liners Over Extended Fan Speeds
- 3 to 10 dB Attenuation Increase Over Uniform Passive Liners for ADP Fan over the Speed Range of 5200 to 6000 RPM

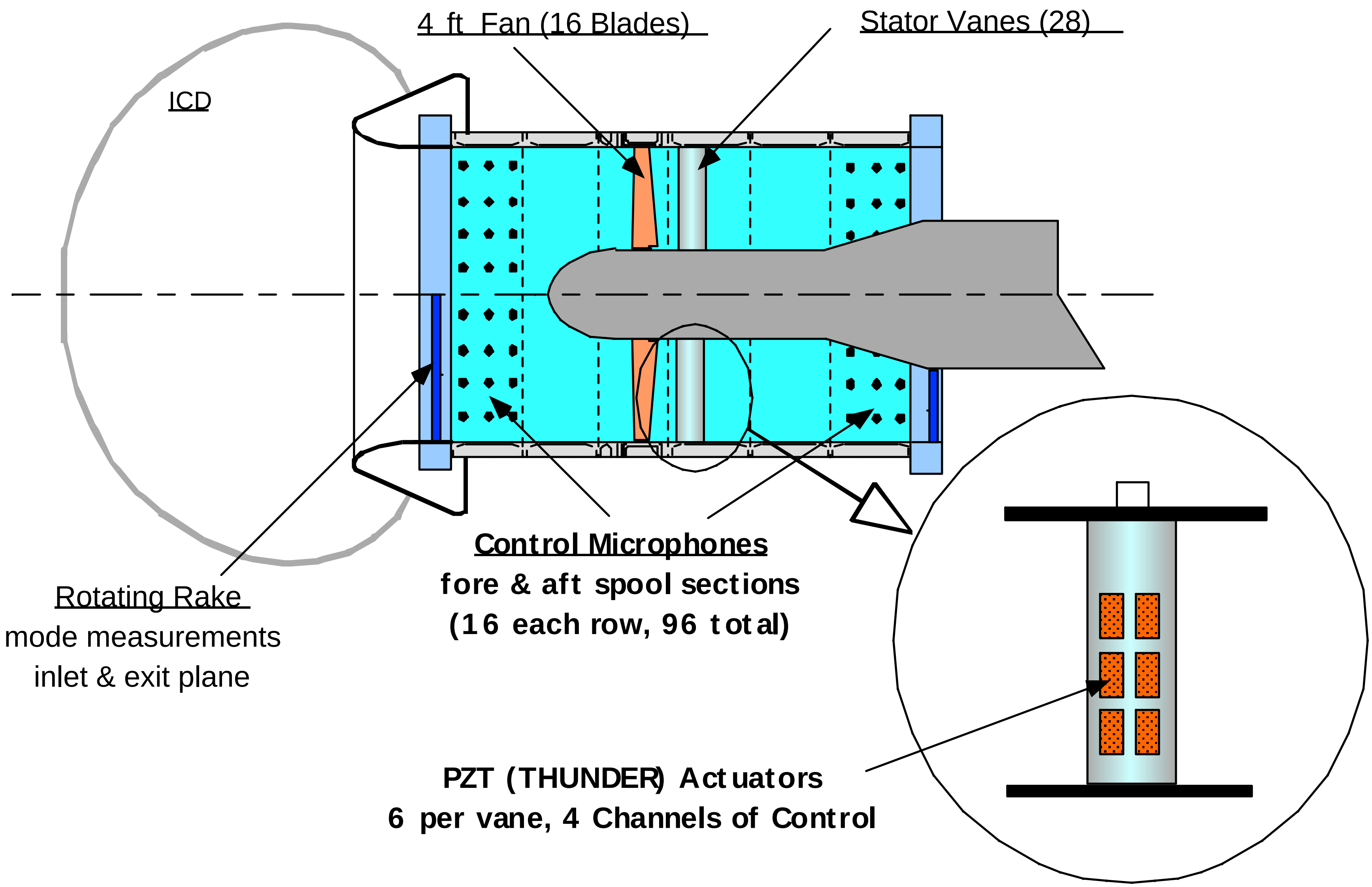
Best Performing Liner Configurations



Series elements (3 layers) | Parallel element (single layer) | Combined (series & parallel)

Fan Noise Reduction Research

1998 NASA/BBN Active Noise Control Fan Test

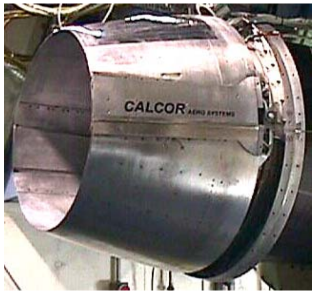


Honeywell TFE731-60 Engine Test

Chevron Nozzles

Rotating Microphone

TFE731-60 Engine with
Inflow Control Device (ICD)



Variable Area Nozzle

Scarfed Inlet