



# ***A 20 Year Retrospective of the Advanced Noise Control Fan – Contributions to Turbofan Noise Research***

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**NOTE:** Paper/presentation is a pictorial excerpt from:

**“The Advanced Noise Control Fan:**

**A 20 Year Retrospective of Contributions to Aeroacoustics Research”**

SP-2019-643

**19 August 2019**

[www.nasa.gov](http://www.nasa.gov)





# Outline



**Why was the ANCF BUILT?**

**(to SOLVE AEROACOUSTIC PROBLEMS)**

**What are the  
BASIC FEATURES of the ANCF?**

**How did the ANCF  
CONTRIBUTE to SOLVING  
AEROACOUSTIC PROBLEMS?**

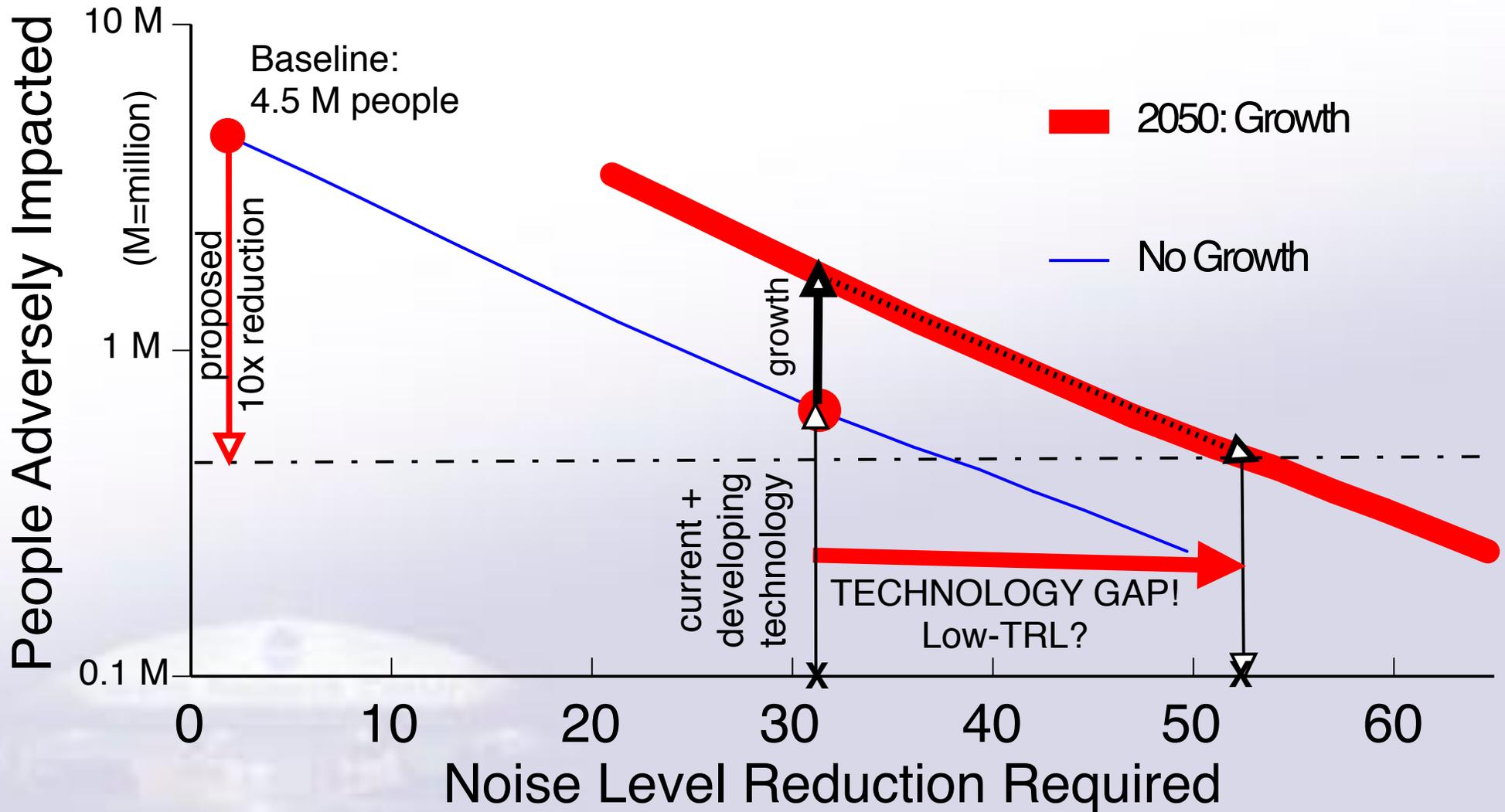


# ***Why was the ANCF Built?***

***(to SOLVE AEROACOUSTIC PROBLEMS)***



# Community Noise Issue



ARMD Strategic Thrust 3: Ultra-Efficient Commercial Vehicles Subsonic Transport  
Fay Collier, Rich Wahls, and the Roadmap Team 3A  
Aeronautics R&T Roundtable, Washington DC May 24, 2016

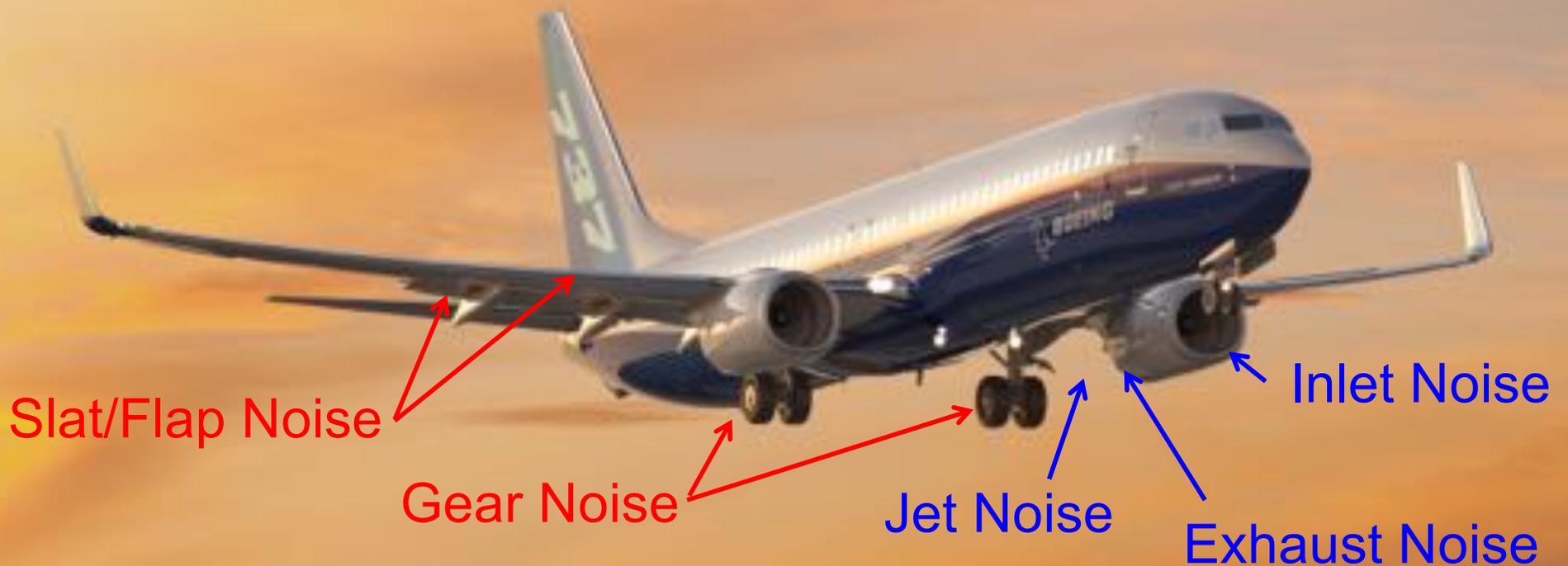


# Sources of Aircraft Noise



## Airframe Noise

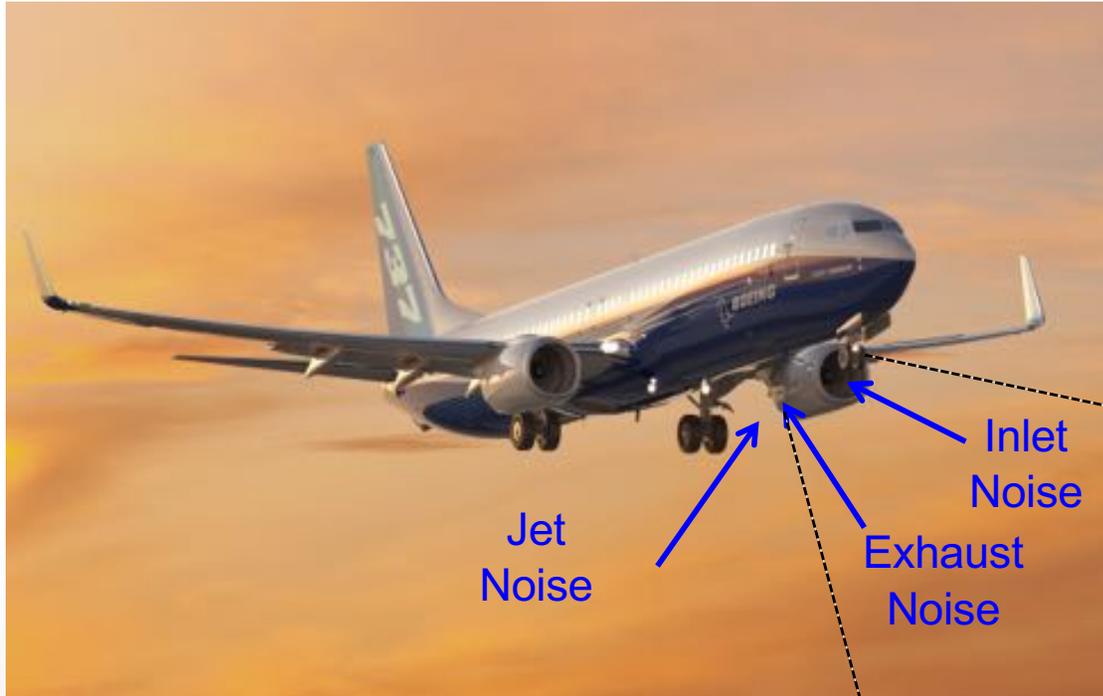
## Propulsion Noise



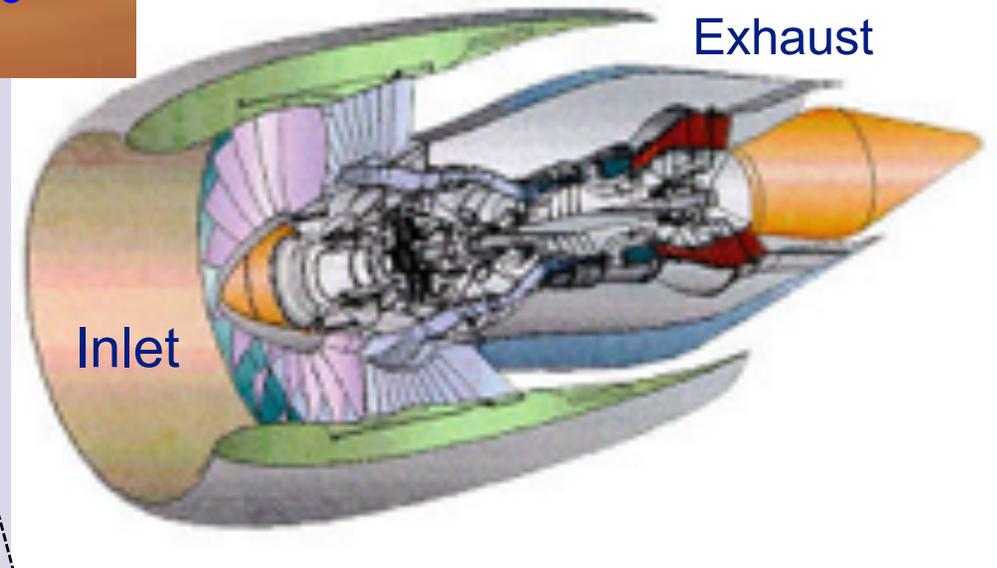
BoeingImages.com BI4ORD4836 authorized for download by NASA Glenn Research Center



# 'Important' Sources of Aircraft Noise



## Turbofan Noise





# Sources of Turbofan Noise



## Rotor:

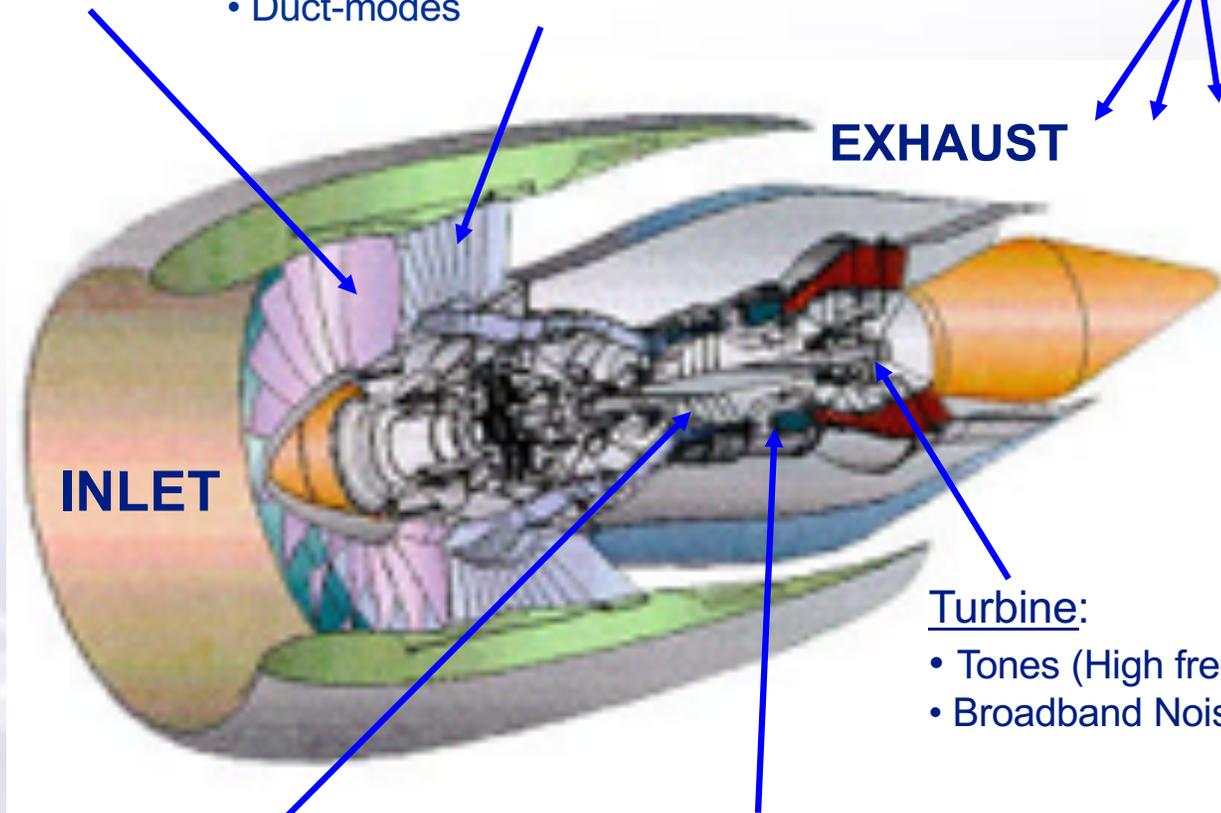
- Tones (harmonics)
- Broadband Noise
- “Buzz-Saw” Noise

## Stator:

- Tones (harmonics)
- Broadband Noise
- Duct-modes

## Jet:

- Broadband Noise (Low frequency)
- Distributed



## Compressor:

- Tones (High frequency)
- Broadband Noise

## Combustor:

- Broadband Noise (Low frequency)

## Turbine:

- Tones (High frequency)
- Broadband Noise (High frequency)



# Turbofan Noise → ANCF

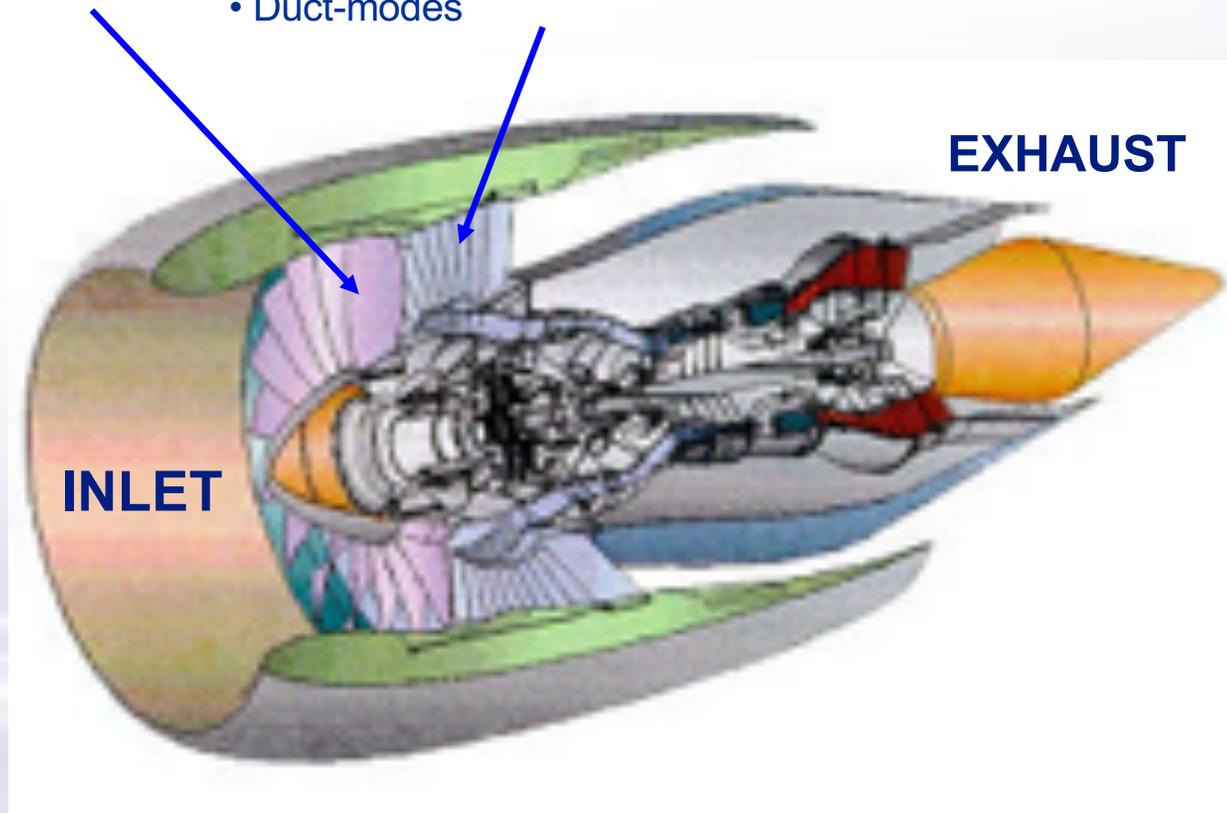


## Rotor:

- Tones (harmonics)
- Broadband Noise

## Stator:

- Tones (harmonics)
- Broadband Noise
- Duct-modes



Rotor/Stator; Fan/Duct aero-acoustics  
**Duct-mode generation & propagation**



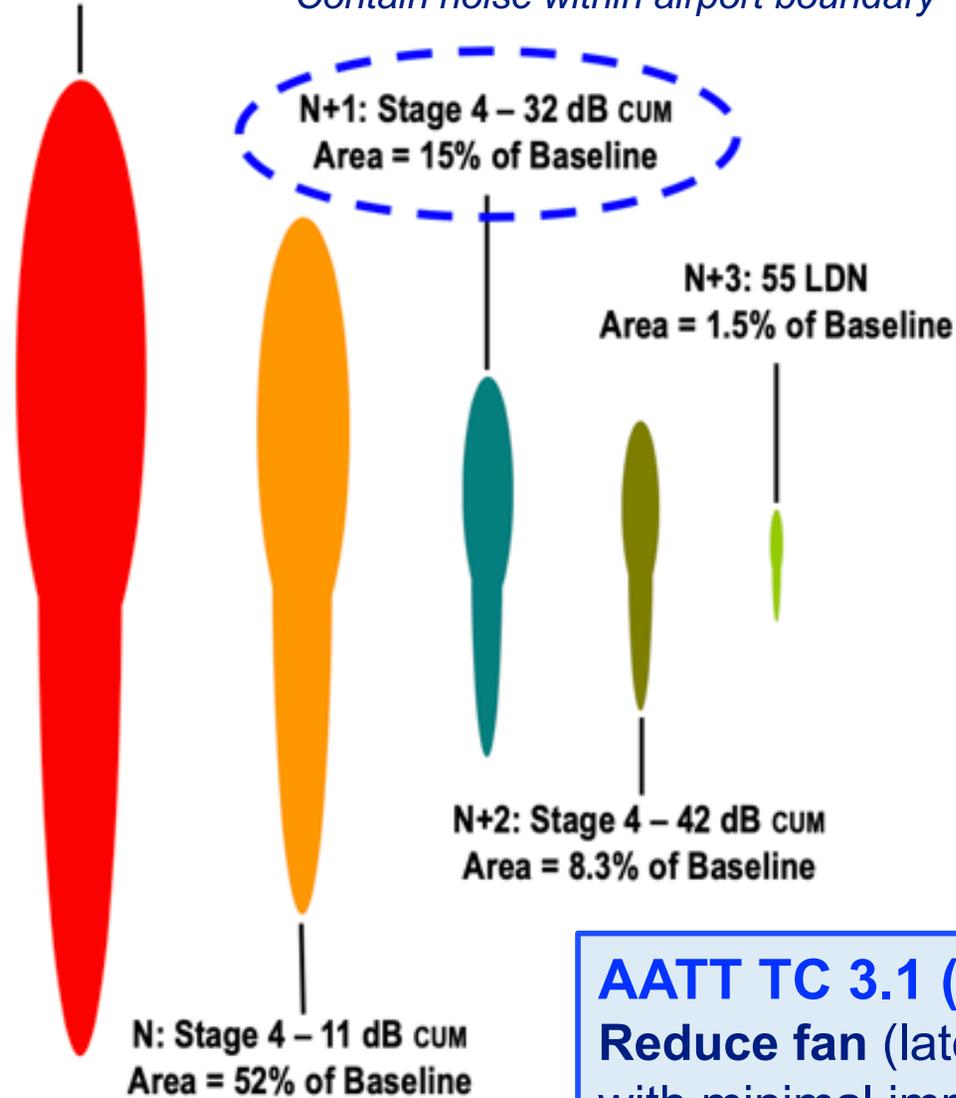
# NASA Noise Reduction Goals



Current Rule: Stage 4  
Baseline Area

## SFW Noise Reduction Goals

*Contain noise within airport boundary*



ARMD Strategic Thrust 3:

Ultra-Efficient Commercial Vehicles Subsonic Transport

Fay Collier, Rich Wahls, and the Roadmap Team 3A  
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2015 NASA Technology Roadmap – TA15:  
Aeronautics

NASA Fundamental Aeronautics Program Overview  
Research Activities on Noise Impacts  
Annual Meeting April 19-20, 2011

### **AATT TC 3.1 (FY19) Fan & High-Lift Noise**

**Reduce fan (lateral and flyover) ... noise ... by 4 dB  
with minimal impact on weight and performance (TRL5)**



***What are the  
BASIC FEATURES  
of the ANCF?***



# Advanced Noise Control Fan (née: Active)



**Was** located in Aero-Acoustic Propulsion Laboratory at NASA Glenn Research Center [65' radius anechoic dome for acoustic and other measurements (anechoic to 125 Hz)]

## Conceived of by Larry Heidelberg

Originally built as part of the AST/QAT engine noise reduction program in ~ 1992 to evaluate *active* noise control technologies and develop a duct mode database.

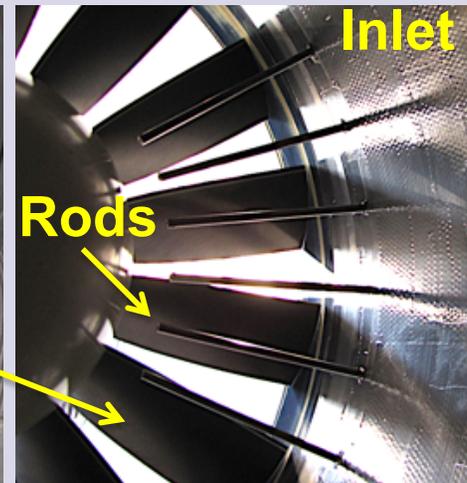
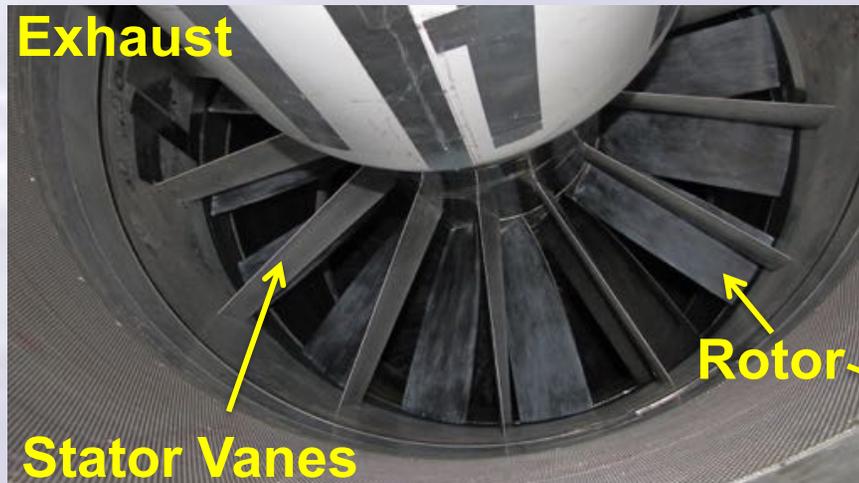
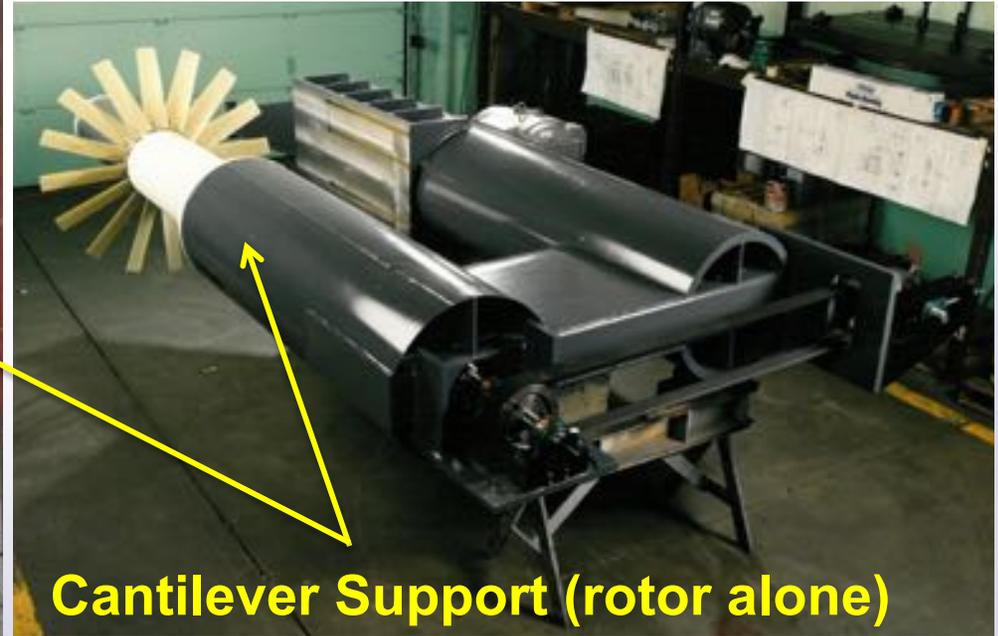
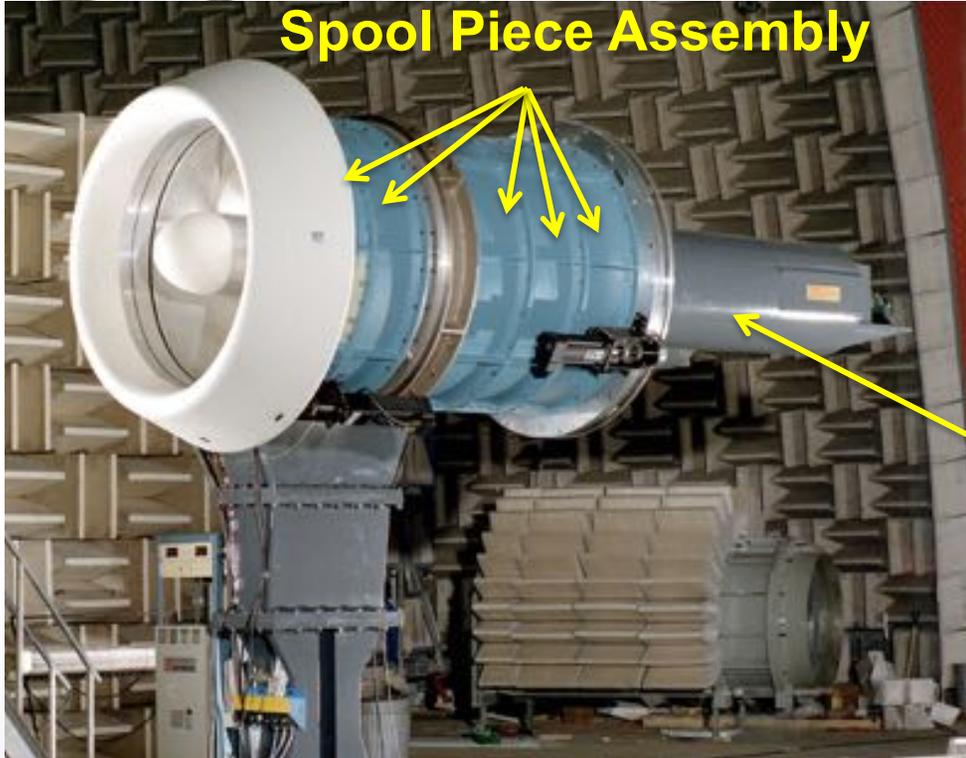
- Initial Operation in 1994/**1995**
- Highly flexible, fundamental test bed capable of multiple configurations, including rotor alone.
- 4-foot diameter ducted fan
- Low speed: variable – 75 HP electric motor  
 $\Omega=1886$  rpm,  $V_{tip} \sim 400$  ft/sec,  $M_{duct} \sim 0.14$
- In early 2000's upgraded to 200 HP motor:  
 $\Omega=2500$  rpm,  $V_{tip} \sim 525$  ft/sec,  $M_{duct} \sim 0.2$



Renamed to Advanced Noise Control Fan when research emphasis changed.



# ANCF Test Bed





# ANCF Test Bed



## 16 Rotor blades mounted on hub

- 5.25" chord, ~ 15" span
- variable pitch (18, 28, 38)

## 26/28/30 count stator vane hubs

- 4.5" chord, ~ 15" span
- variable spacing (typically 0.5, 1.0, 2.0 C)

ICD for flow conditioning.

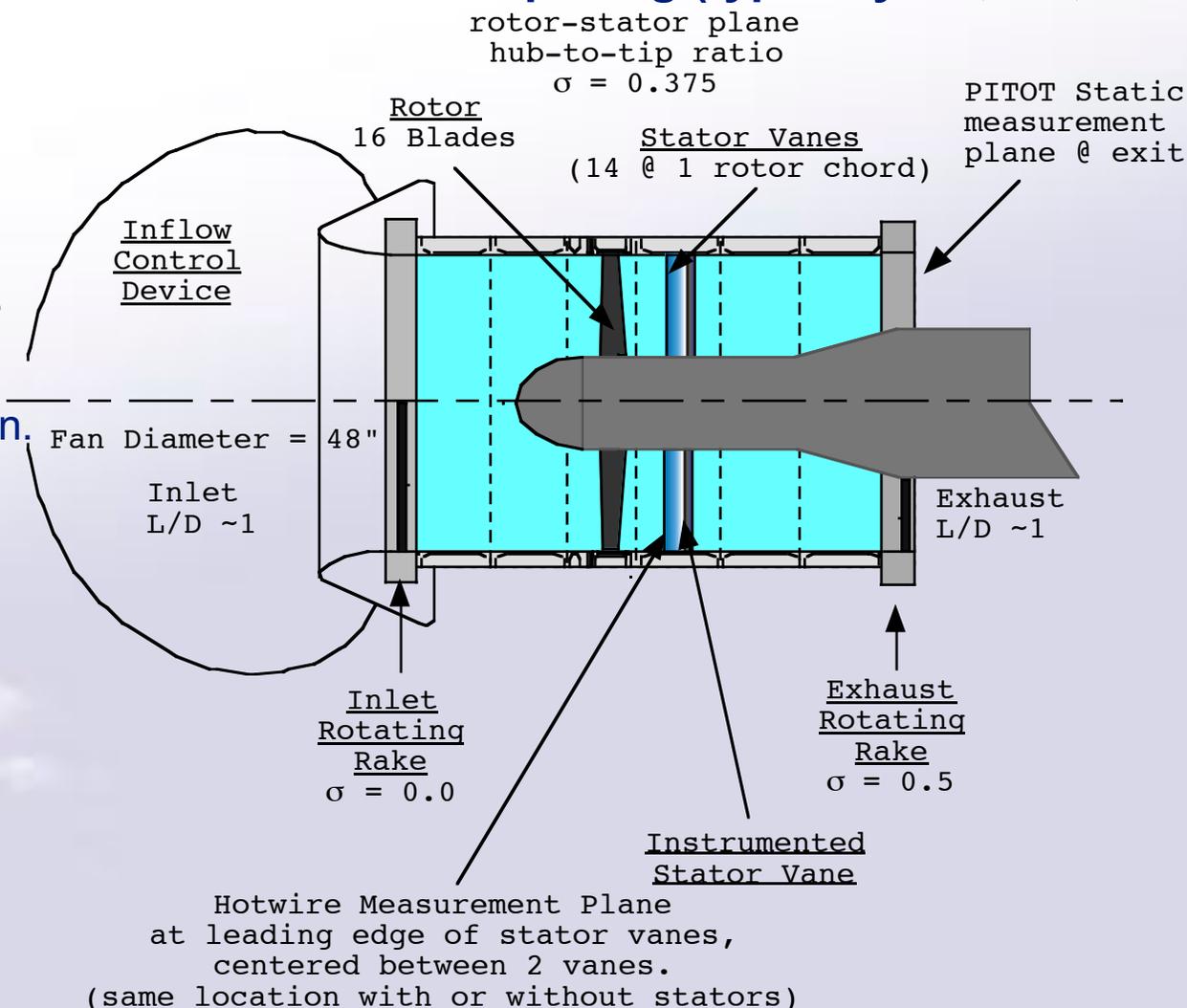
Spool pieces can be configured and rearranged (e.g. install microphones, pressure taps) or replaced with specialized spool.

Center-body is also configurable and available for instrumentation.

Location of traverse mechanism can be varied: (hotwire, Kiel or Static pressure probes)

### Measurement Capabilities

- In-Duct Mode Levels (RR)
- Rotor Wakes (HW)
- Stator Vane Pressures
- Duct Wall Pressures
- Farfield Directivity





# Internal Acoustic Measurement



## Duct modes measured by Rotating Rake\*

Continuously rotating, radially distributed from tip to hub array of pressure transducers installed at inlet/exhaust duct acoustic release point.

A complete circumferential and radial modal magnitude & phase map is obtained for the 1<sup>st</sup> three harmonics.

Carbon fiber vane with embedded/flush mounted microphones for measuring vane surface dynamic pressures.

- 30 per side
- 20% leading edge line
- 3 chord lines

Used to determine response of stator vane to rotor viscous wake.

\*Sutliff, D.L. "Rotating Rake Turbofan Duct Mode Measurement System" NASA TM-2005-213828, November 2005.



# Compact Farfield Arena



Enclosed compact farfield arena for continuous usage & 'final' answer.

30 Farfield microphones

- Piezotronics 130E20 'array' microphones
- 10 KHz best range
- 6 stands of 5 mics
- 15 fwd/15 aft arcs @ 12' radius/10' height





# CFANS

## (Configurable Fan Artificial Noise Source)

Initially 32 channels (upgrade to 64).

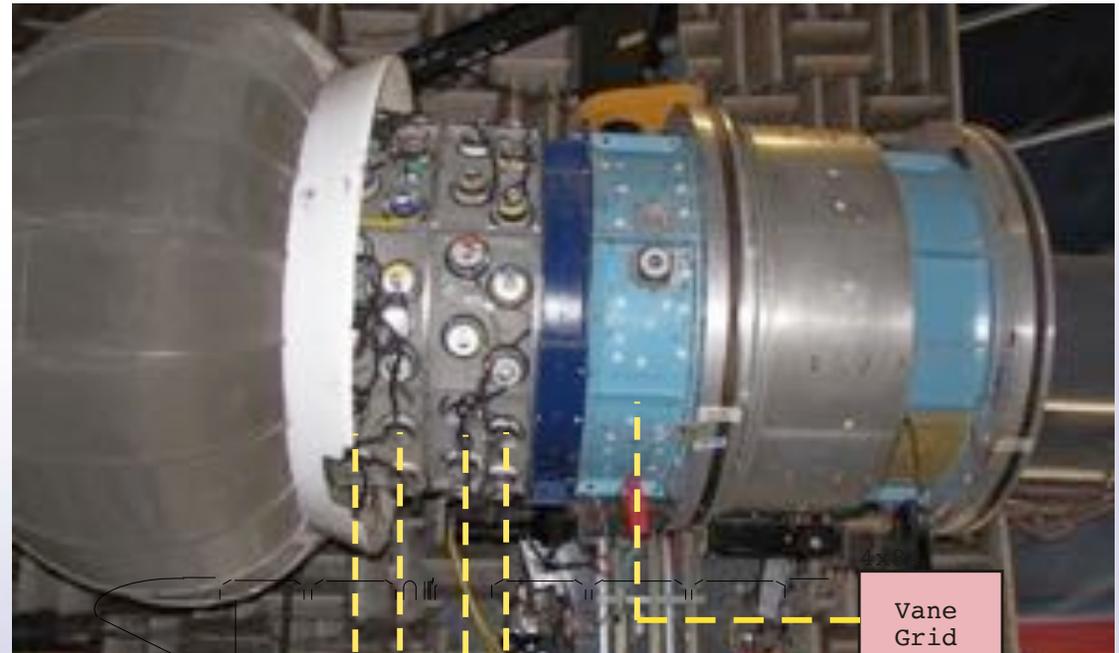
4 rows of 16 drivers each

Generate noise source in S/W.  
Each channel independent.

Labview VI's or 2x32 channels of  
FIR filters to 'shape' output.

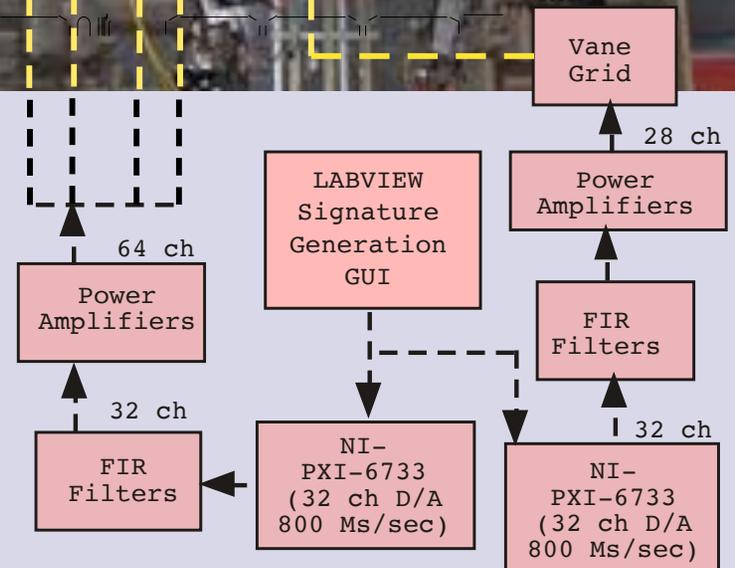
Use of phase delays to simulate  
modal vs random sources.

Use of time delays to simulate  
rotating vs stationary sources.



General Range:  
 $250 \text{ Hz} < \text{freq} < 1500 \text{ Hz}$   
 $|m| < 6; n < 4$

Led to (U)ltrasonic-CFANS & (B)road(B)and-CFANS



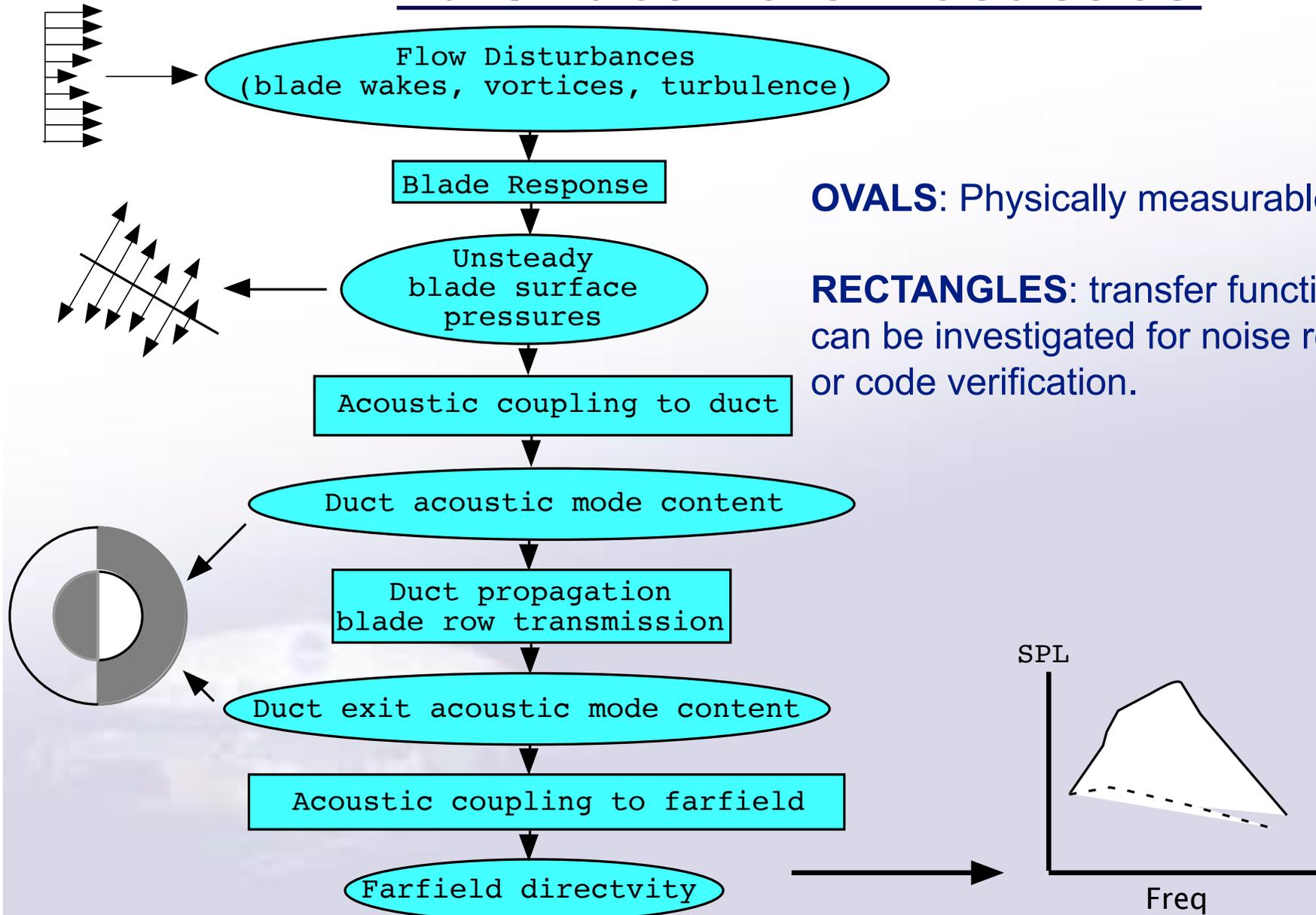


# *How did the ANCF CONTRIBUTE to SOLVING AEROACOUSTIC PROBLEMS?*





# Physics/M Measurement of Fan/Duct Aero-Acoustics



**OVALS:** Physically measurable quantity.

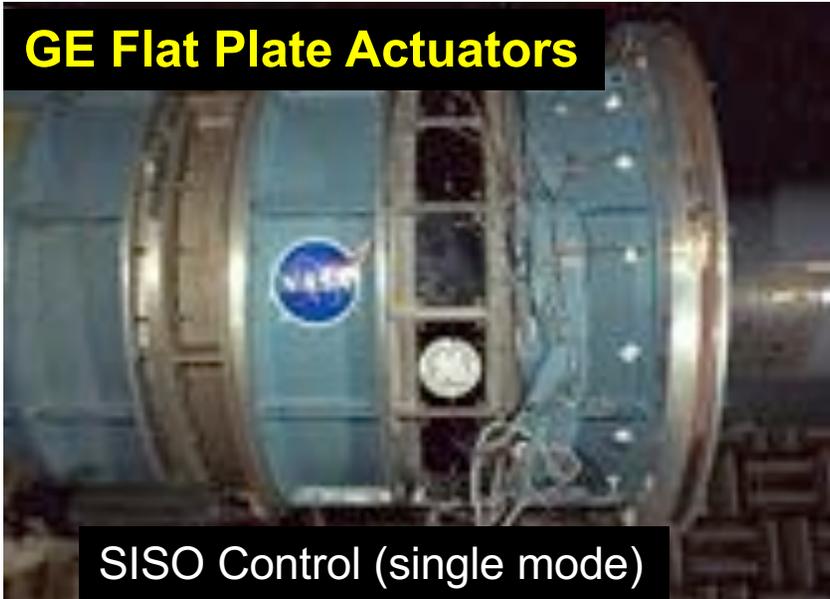
**RECTANGLES:** transfer function that can be investigated for noise reduction or code verification.



# Active Noise Control



**GE Flat Plate Actuators**



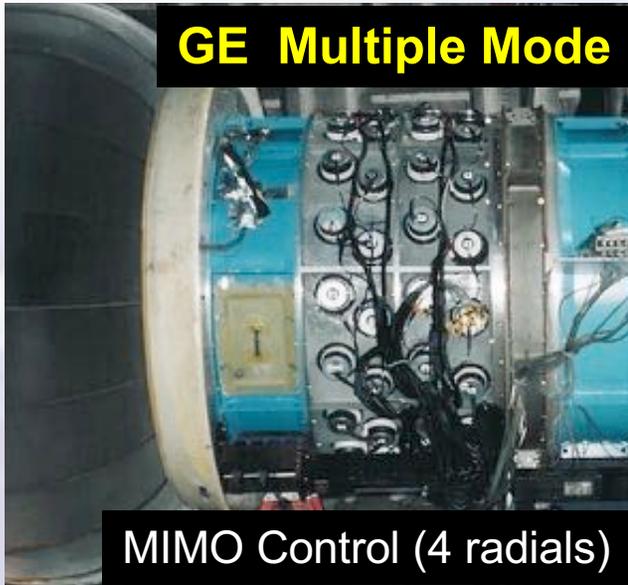
SISO Control (single mode)

**HWAE Control near Source**



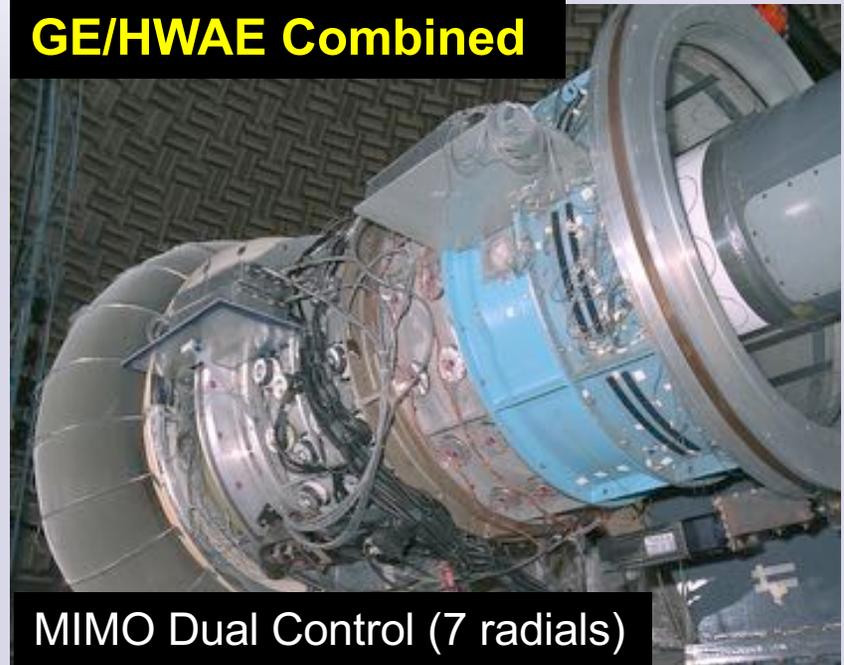
Multi-directional Control (2x2 radials)

**GE Multiple Mode**



MIMO Control (4 radials)

**GE/HWAE Combined**



MIMO Dual Control (7 radials)

1995

2000

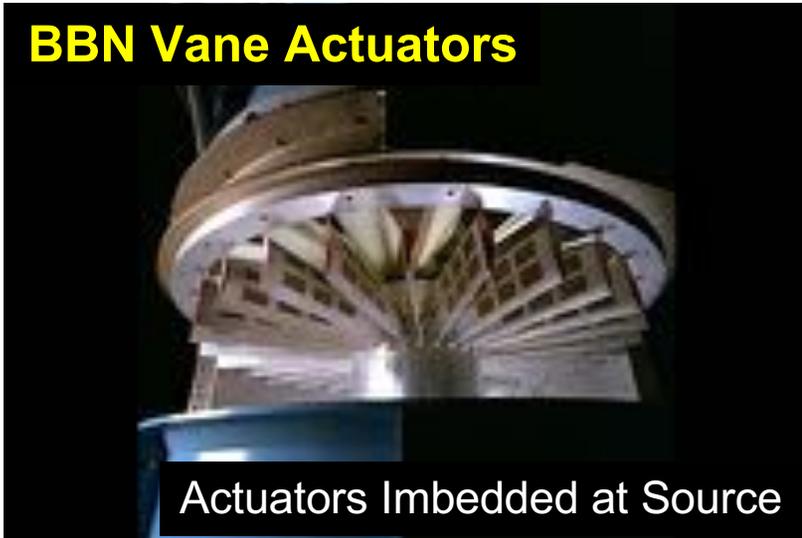
Active Noise Control



# Active Noise Control

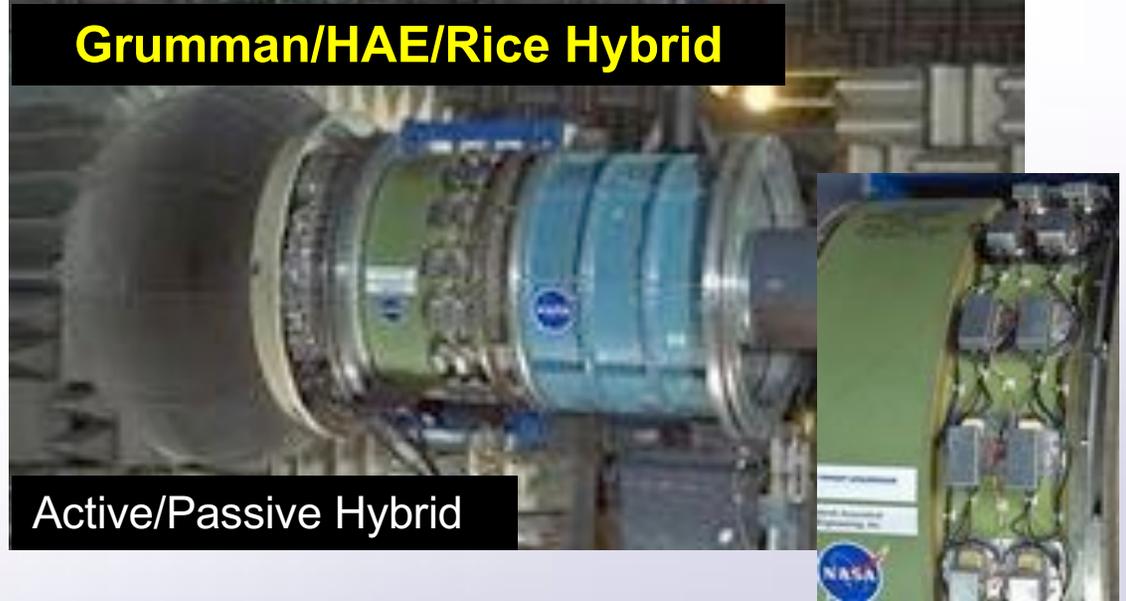


## BBN Vane Actuators



Actuators Imbedded at Source

## Grumman/HAE/Rice Hybrid



Active/Passive Hybrid

## HWAE Active Resonators

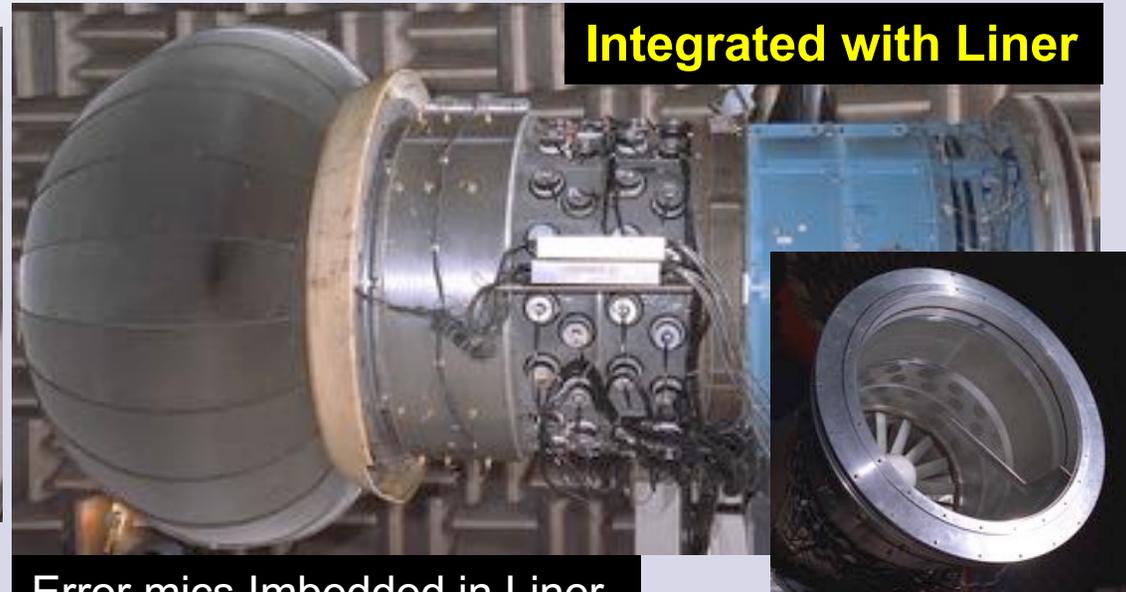


Active Resonators (2 Harmonics)

1995

2000

## Integrated with Liner

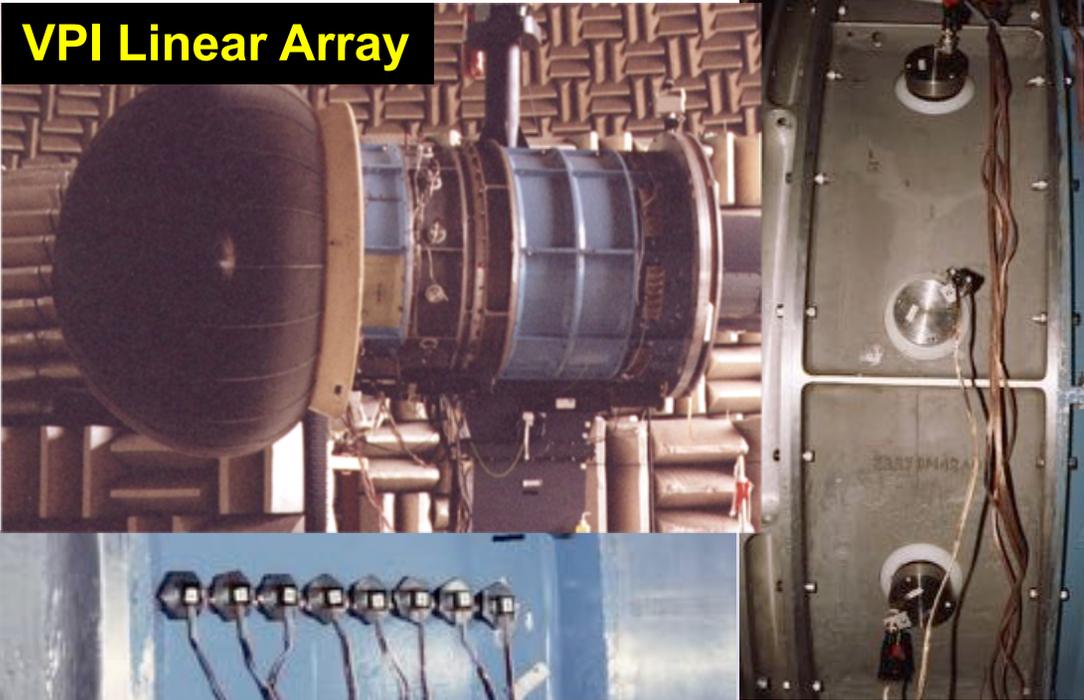


Error mics Imbedded in Liner

Active Noise Control



# Active Noise Control



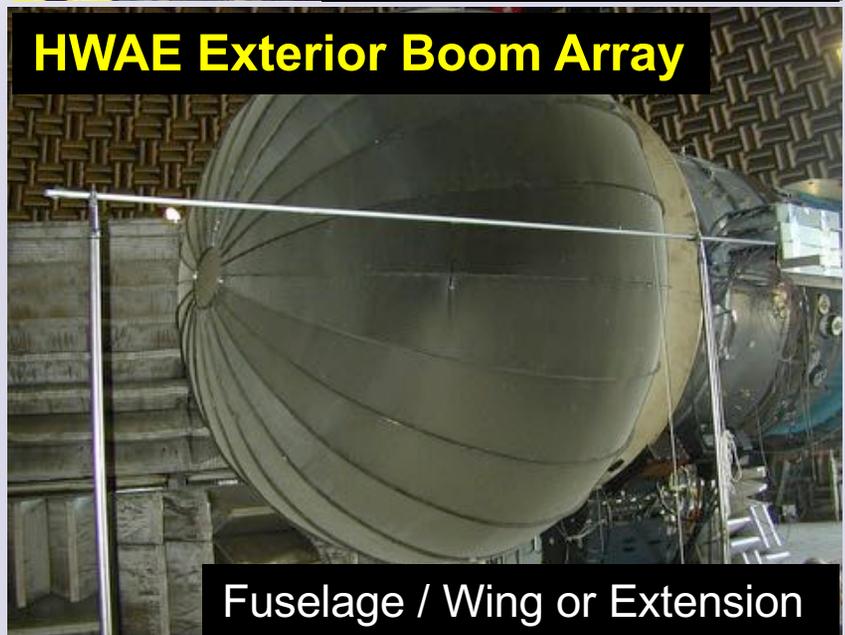
**VPI Linear Array**

**Directed Reduction in Farfield**



**HWAE Pylon Arrays**

**Existing Radial Surface**



**HWAE Exterior Boom Array**

**Fuselage / Wing or Extension**

1995

2000

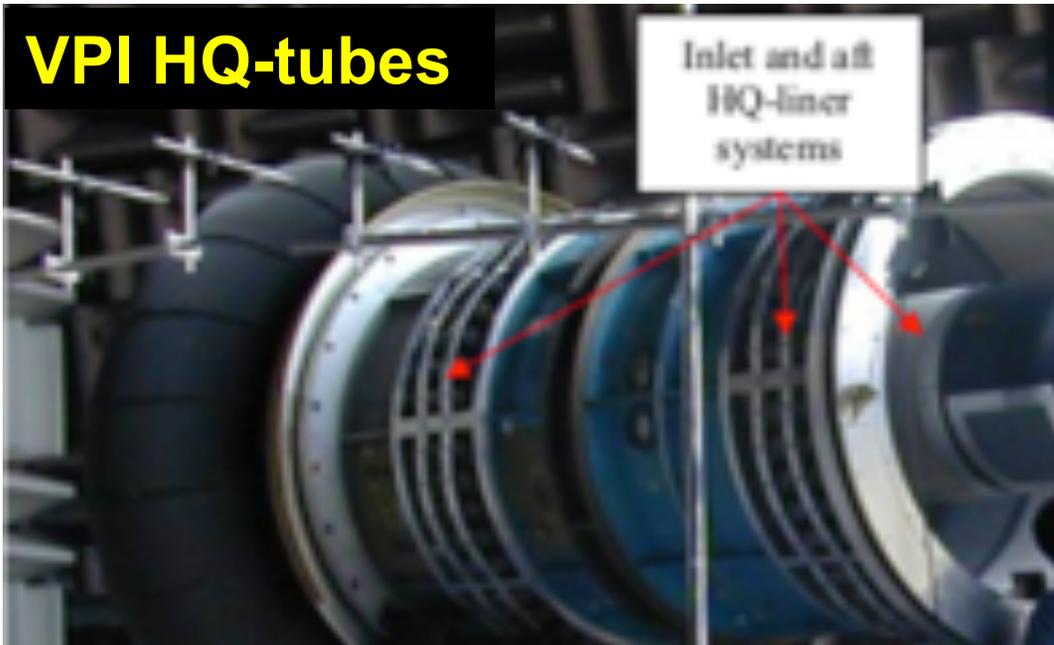
Active Noise Control



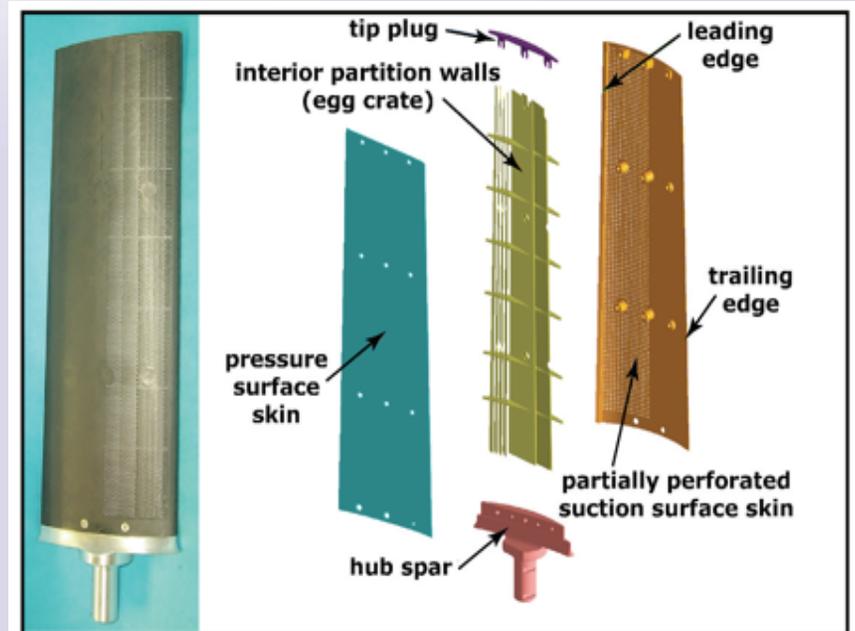
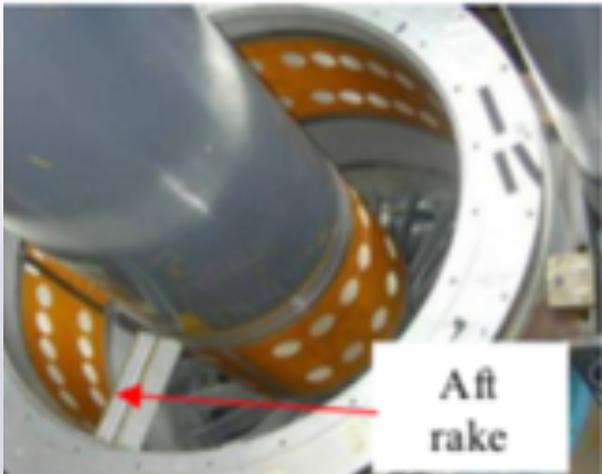
# Unique Noise Reduction



## VPI HQ-tubes



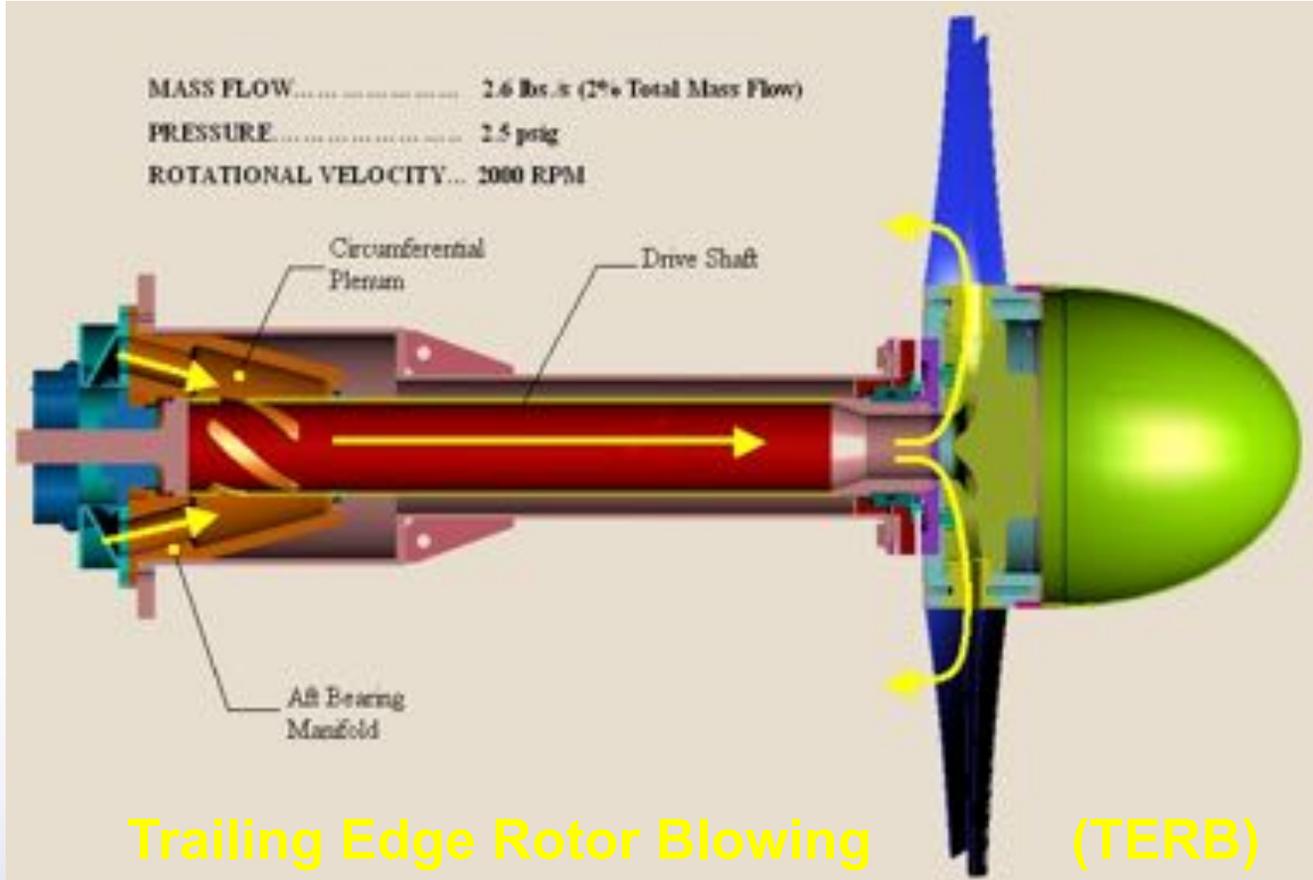
## “Soft”-Vanes



2005



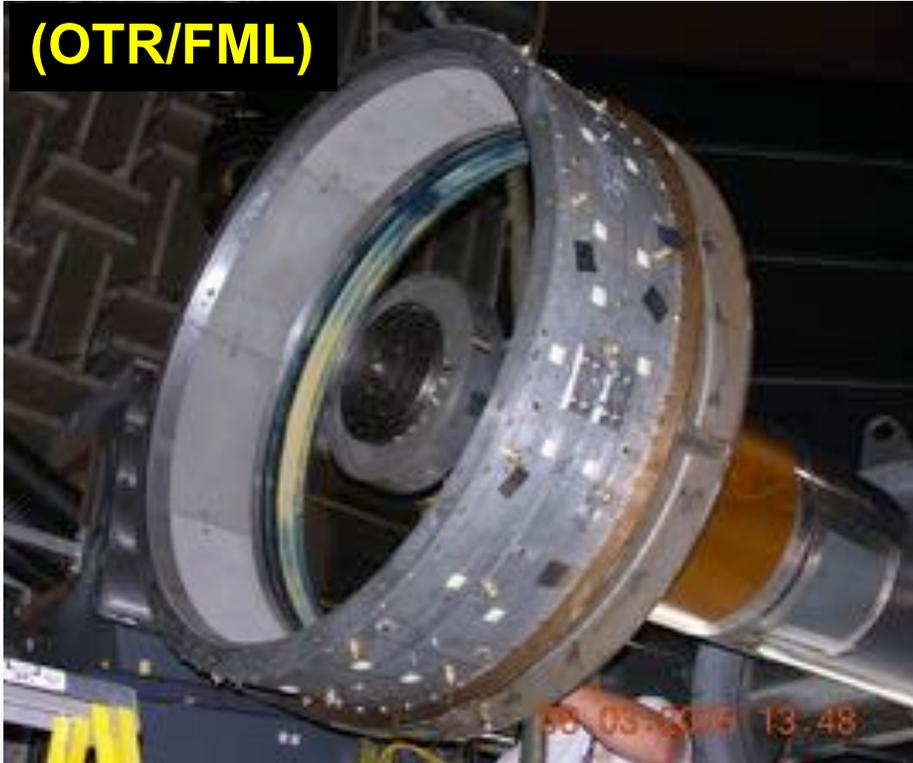
# Unique Noise Reduction



2005



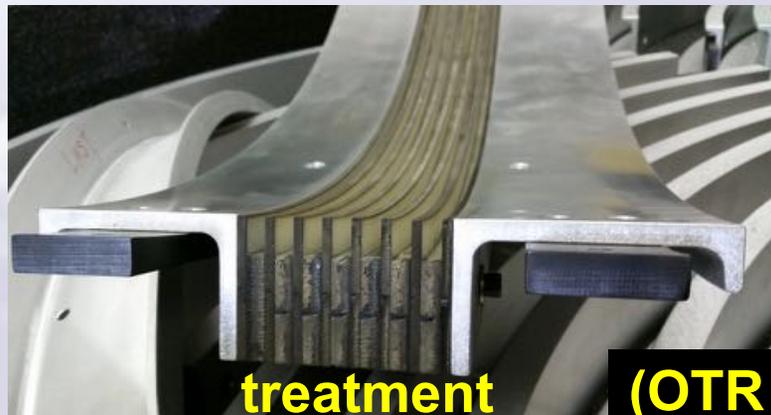
# Unique Noise Reduction



**(OTR/FML)**



**Over-the-Rotor Foam Metal Liner**



**treatment**



**grooves**

**(OTR Advanced)**

2005



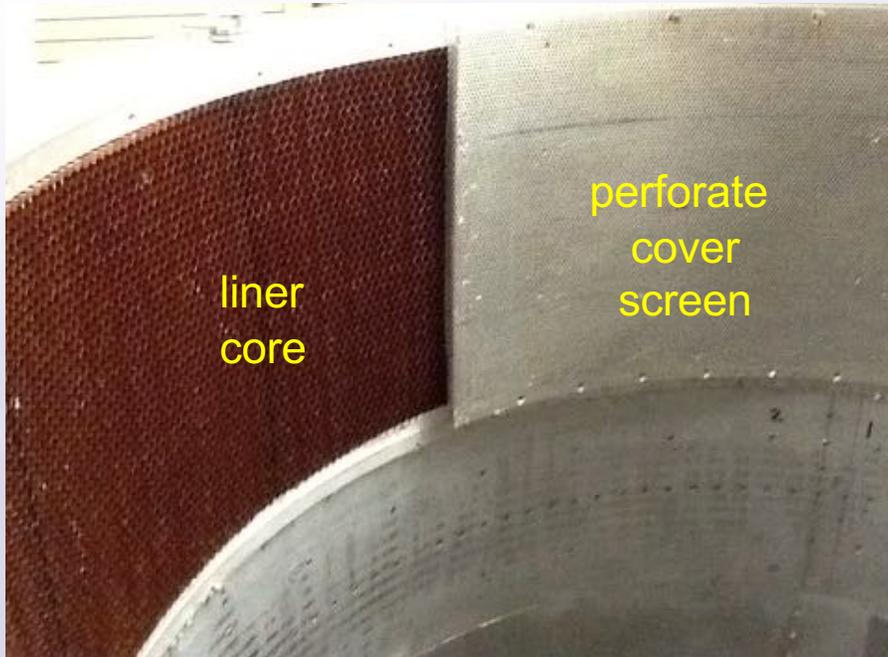
# Novel Liner Development



**Splice/  
No-Splice  
Liner**

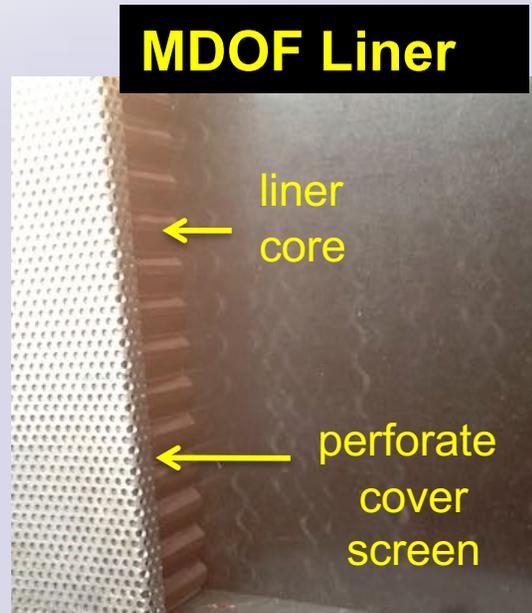


**'Checkerboard' Liner**



liner  
core

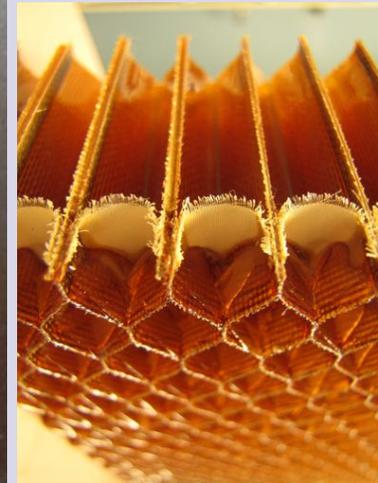
perforate  
cover  
screen



**MDOF Liner**

← liner  
core

← perforate  
cover  
screen



2015



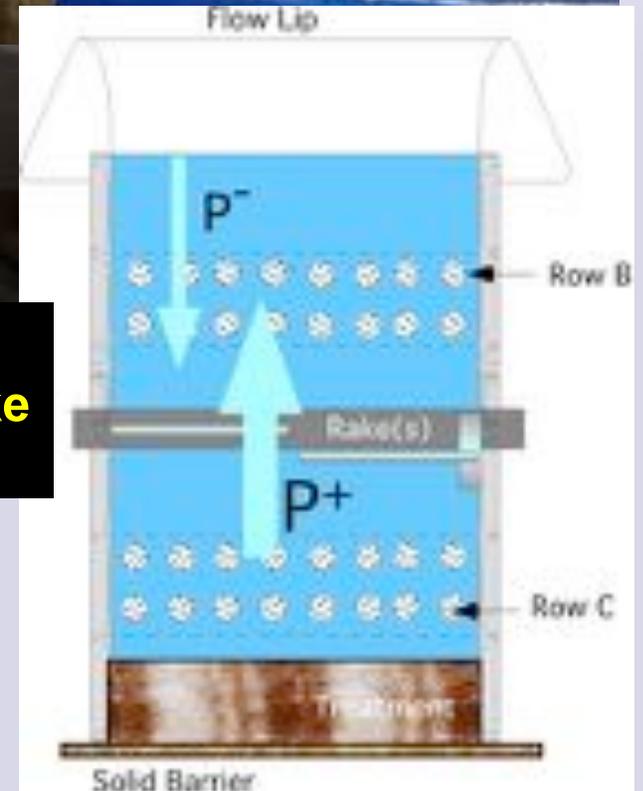
# Measurement Technologies



**Mode Measurement  
over Treatment  
(in-situ impedance)**



**Dual-  
Rotating Rake  
(reflections)**



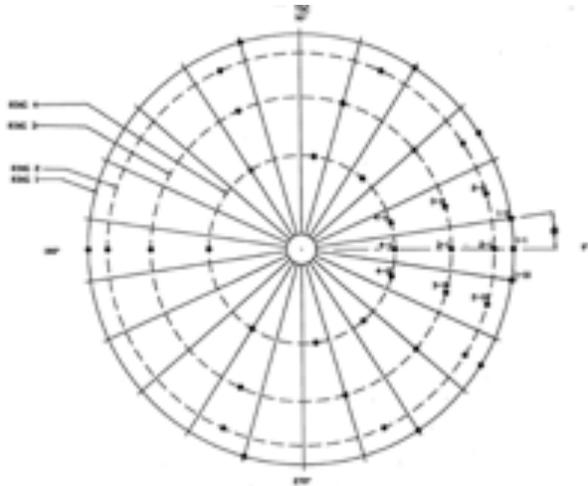
2005

2010

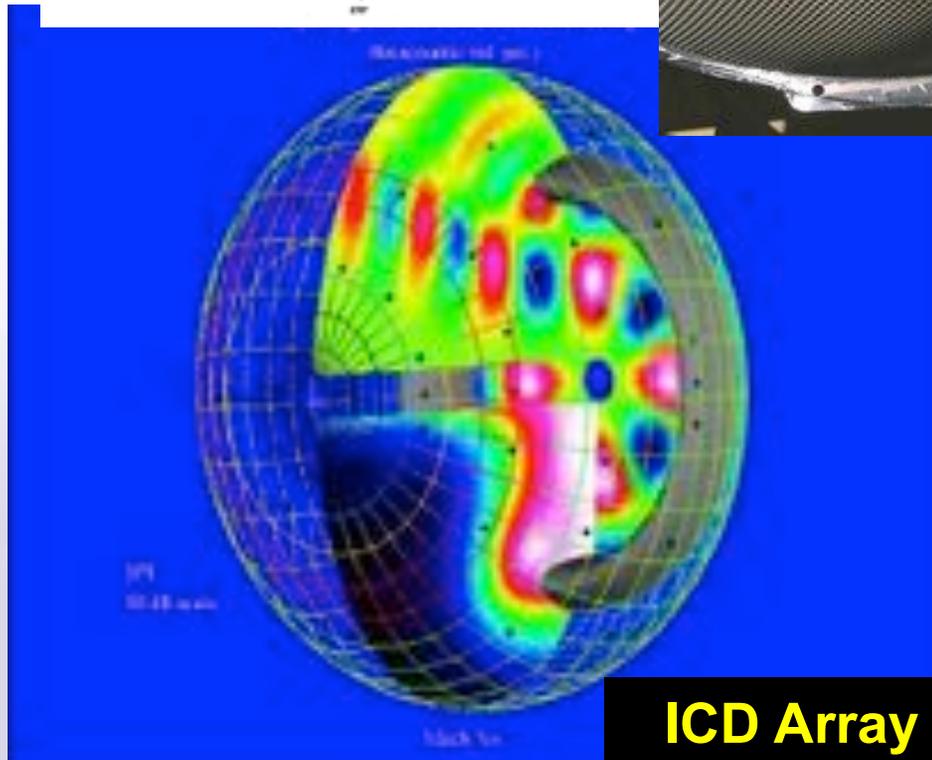
2015



# Measurement Technologies

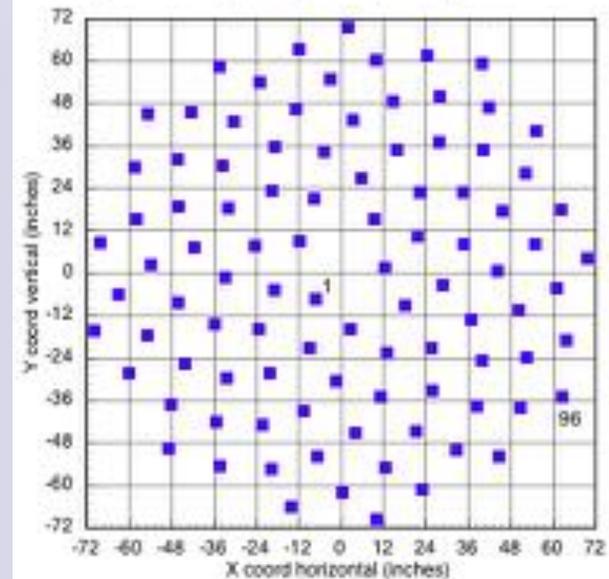


**External Planar Array**



**ICD Array**

Standing behind the array (facing the array and, beyond it, the ICD and the ANCF)



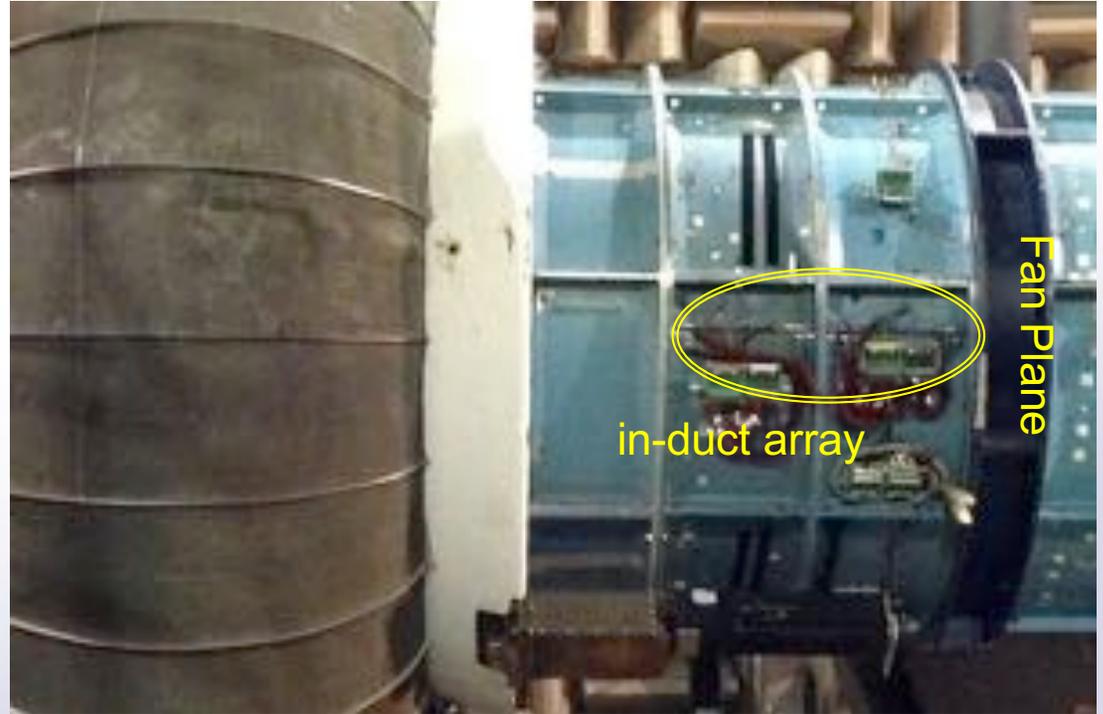
2005

2010

2015



# Measurement Technologies

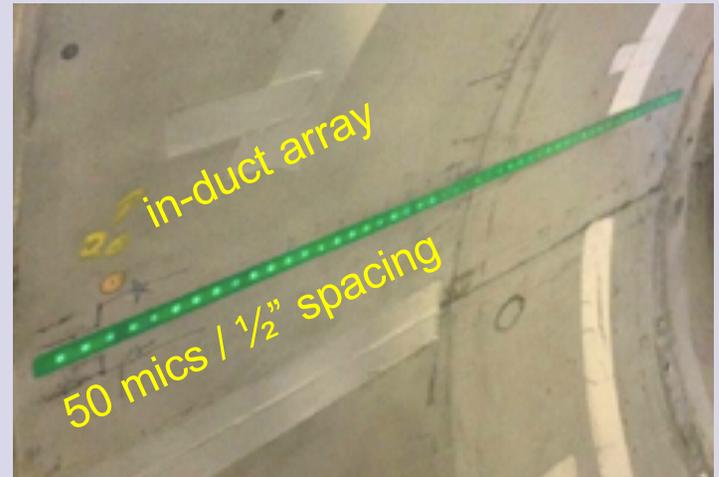


Fan Plane

in-duct array

Institute of Sound and Vibration Research

UNIVERSITY OF Southampton



in-duct array  
50 mics / 1/2" spacing

**In-Duct Arrays**



Channel Islands Acoustics

2005

2010

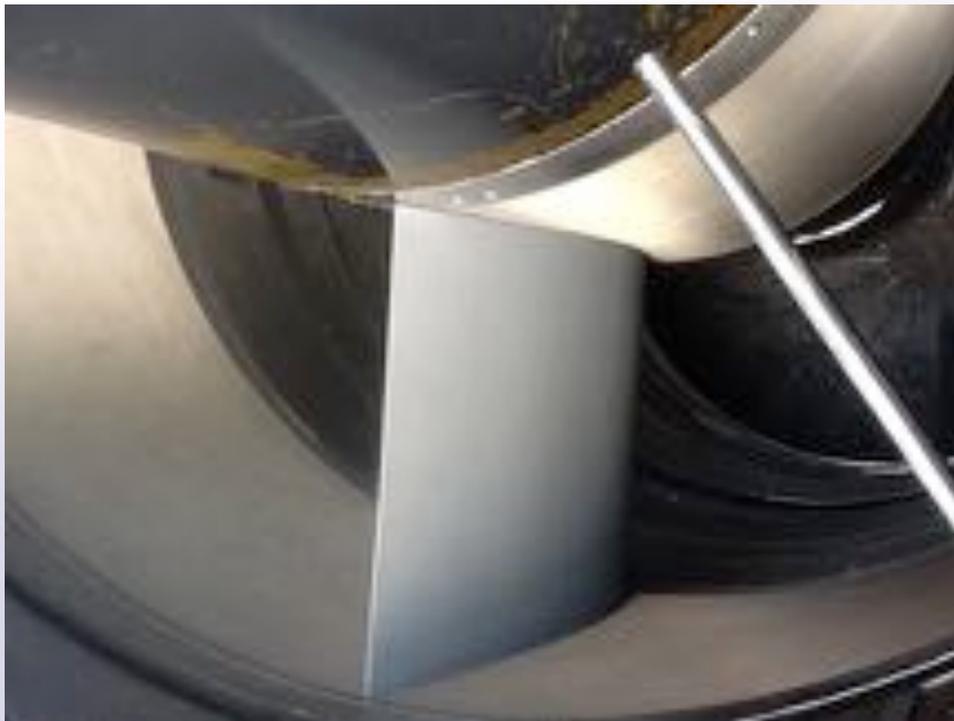
2015



# Code/Database Development



## Pylon/Liner Interactions



1995

2000

## Inlet Distortion

Four rod configurations tested in 2007

6 rods



6 rods



15 rods



8 rods



2005

2010

2015



# ANCF - Summary



Design, test, and evaluation for technical risk-mitigation of most of the innovative fan noise reduction technologies developed by NASA over the past 20 years.

**1995 – 2015: Low-TRL research performed on ANCF enabled the advancement of multiple noise reduction and measurement technologies.**

The ANCF has been used in over 6 internal, 8 external programs (2 reimbursable), 2 NRAs, 3 SBIRs, and 2 Aero Acoustic Research Consortium projects. These were integrated in GRC's noise reduction program milestones. It is the only complete aero-acoustic data/geometry set publically available.

100+ papers written based on ANCF data. (~4-6 per AIAA Aero-Acoustics Conference)



**ANCF projects that led to Static Engine/Flight tests:**  
**ANC; HQ Tubes; FML/OTR; Checkered/Spliced, MDOF Liners**

**Databases requested & utilized for IR&D by:**

GEAC/GEGR  
Honeywell  
Goodrich  
Pratt & Whitney

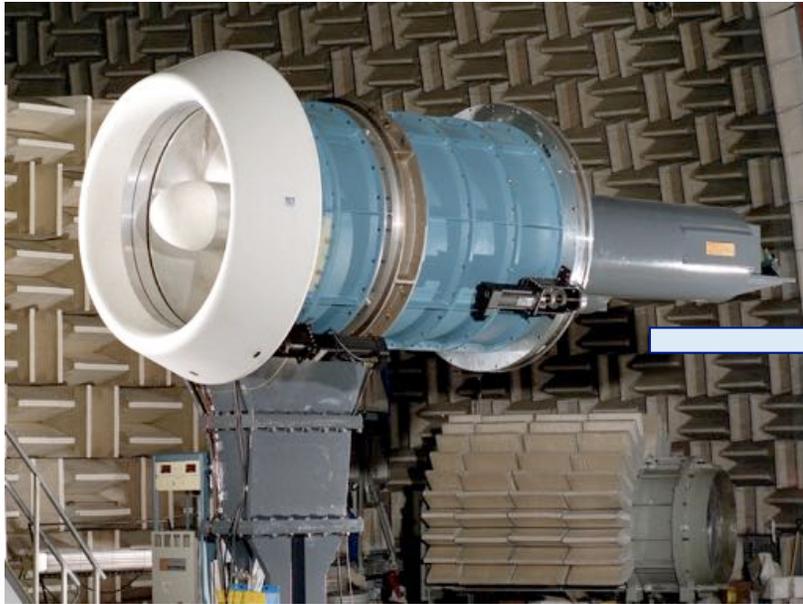
VPI/Techsburg  
Illinois State University  
U of Cincinnati  
The OSU

EXA, Inc  
Embraer, Inc  
NUMECA  
ONERA

University of Sherbrooke  
Federal University of Brazil  
University of Sao Paulo  
ISVR/U of Southampton

**2016+: Transferred the ANCF to University of Notre Dame to jointly operate and maintain research capability, & to provide STEM opportunities, in the area of fan/duct acoustics.**

# Questions?



Now this is not the end.  
It is not even the beginning of the end.  
But it is, perhaps, the end of the beginning.  
– Winston Churchill