Recent Progress in Aircraft Noise Research

ARMD Technical Seminar
October 16, 2007

Dr. Edmane Envia, NASA Glenn Research Center
Dr. Russell Thomas, NASA Langley Research Center
(on Behalf of NASA Acoustics Discipline Team)

An overview of the acoustics research at NASA under the Subsonic Fixed Wing project is given. The presentation describes the rationale behind the noise reduction goals of the project in the context of the next generation air transportation system, and the emphasis placed on achieving these goals through a combination of the in-house and collaborative efforts with industry, universities and other government agencies. The presentation also describes the in-house research plan which is focused on the development of advanced noise and flow diagnostic techniques, next generation noise prediction tools, and novel noise reduction techniques that are applicable across a wide range of aircraft.

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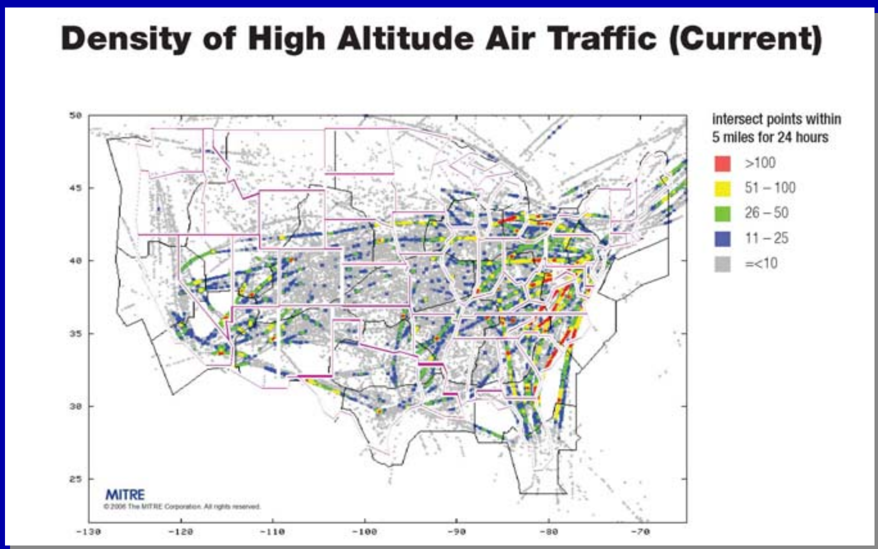
Presentation Outline

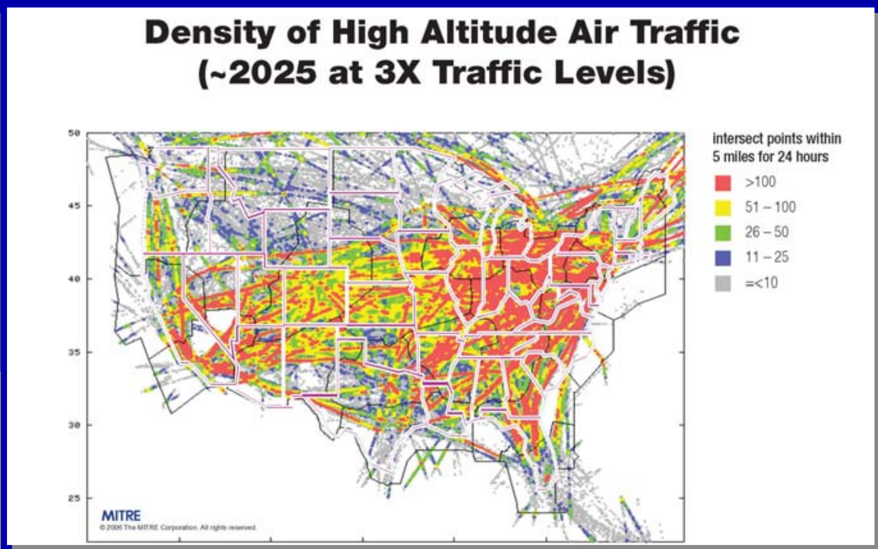
- Motivation
  - Background & Trends
  - Near- and-Long Term Technology Goals
- Strategy
  - Technology Paths
  - Partnerships and Collaborations
- Research Approach
  - Diagnostic Techniques
  - Prediction Methods
  - Noise Reduction Technology
- Summary

Motivation

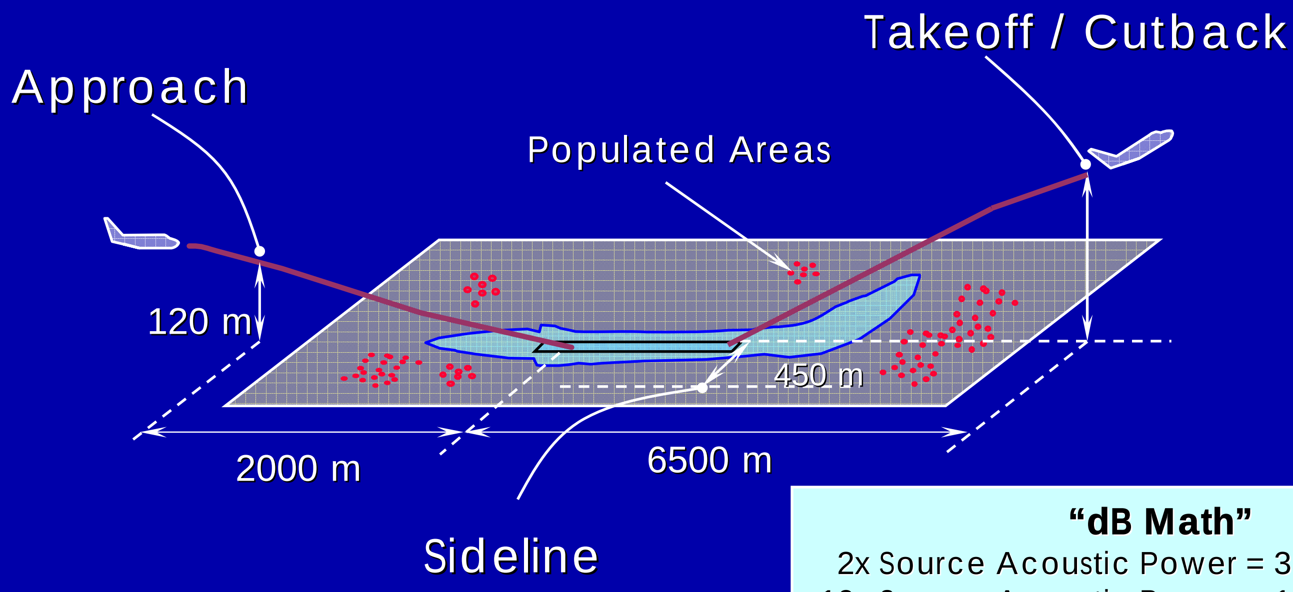
- The Joint Planning and Development Office (JPDO) is designing the Next Generation Air Transportation System (NextGen) with the potential for a 3x increase in air traffic capacity by 2025.

- Reducing aircraft noise is critical for enabling this anticipated growth. Recent JPDO studies indicate that, without a significant influx of new noise reduction technology into the fleet, the number of people exposed to objectionable noise levels (>65 DNL) will grow significantly.

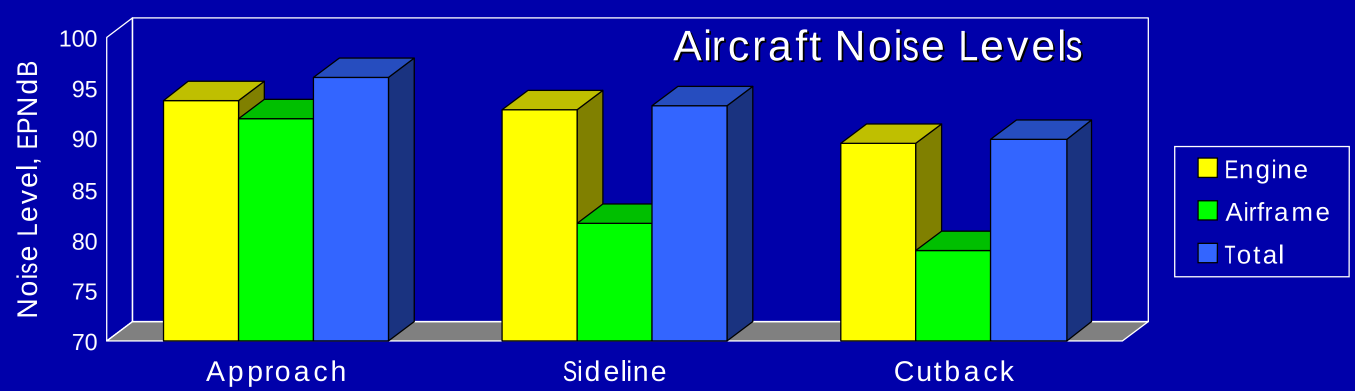




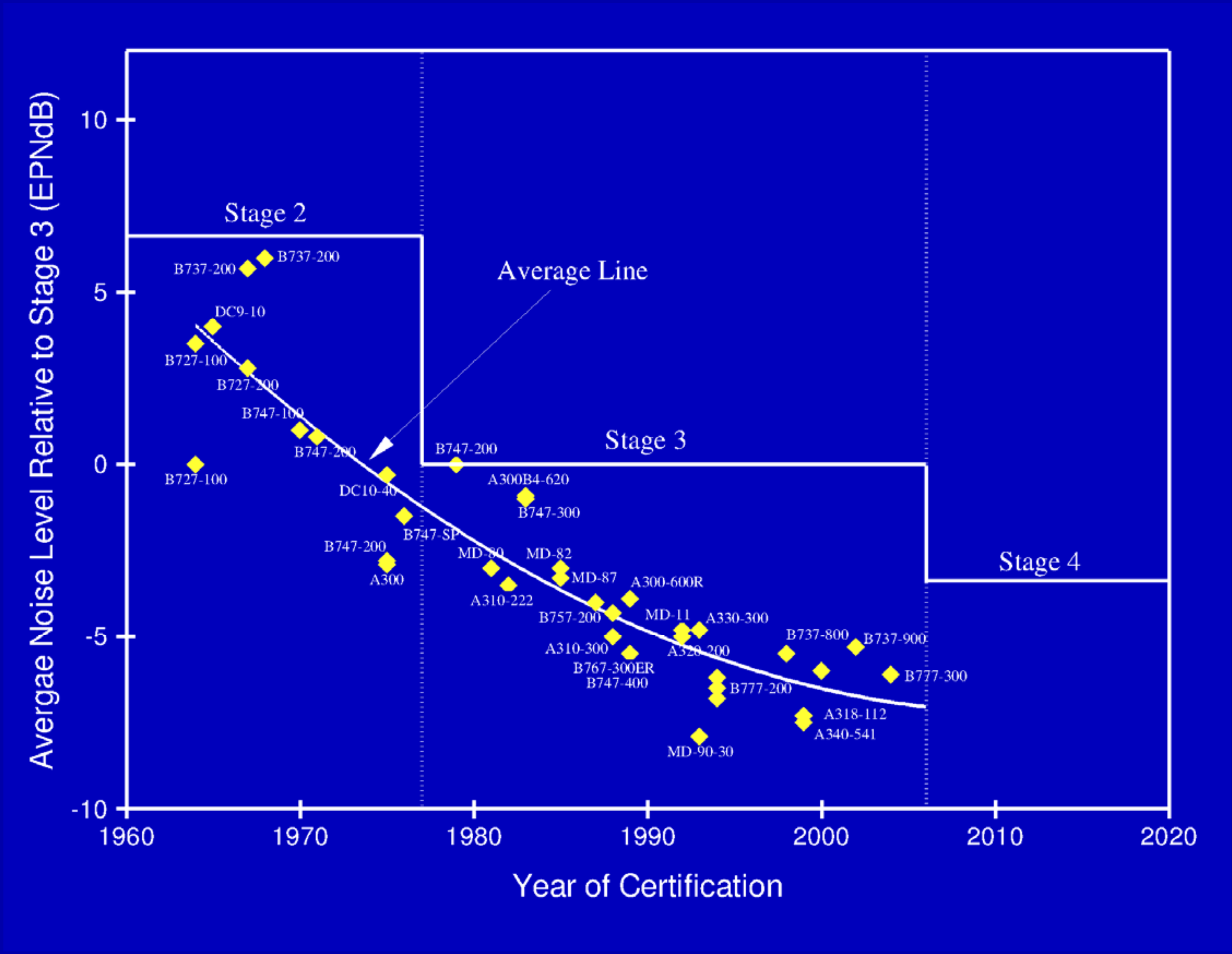
Aircraft Noise Metrics



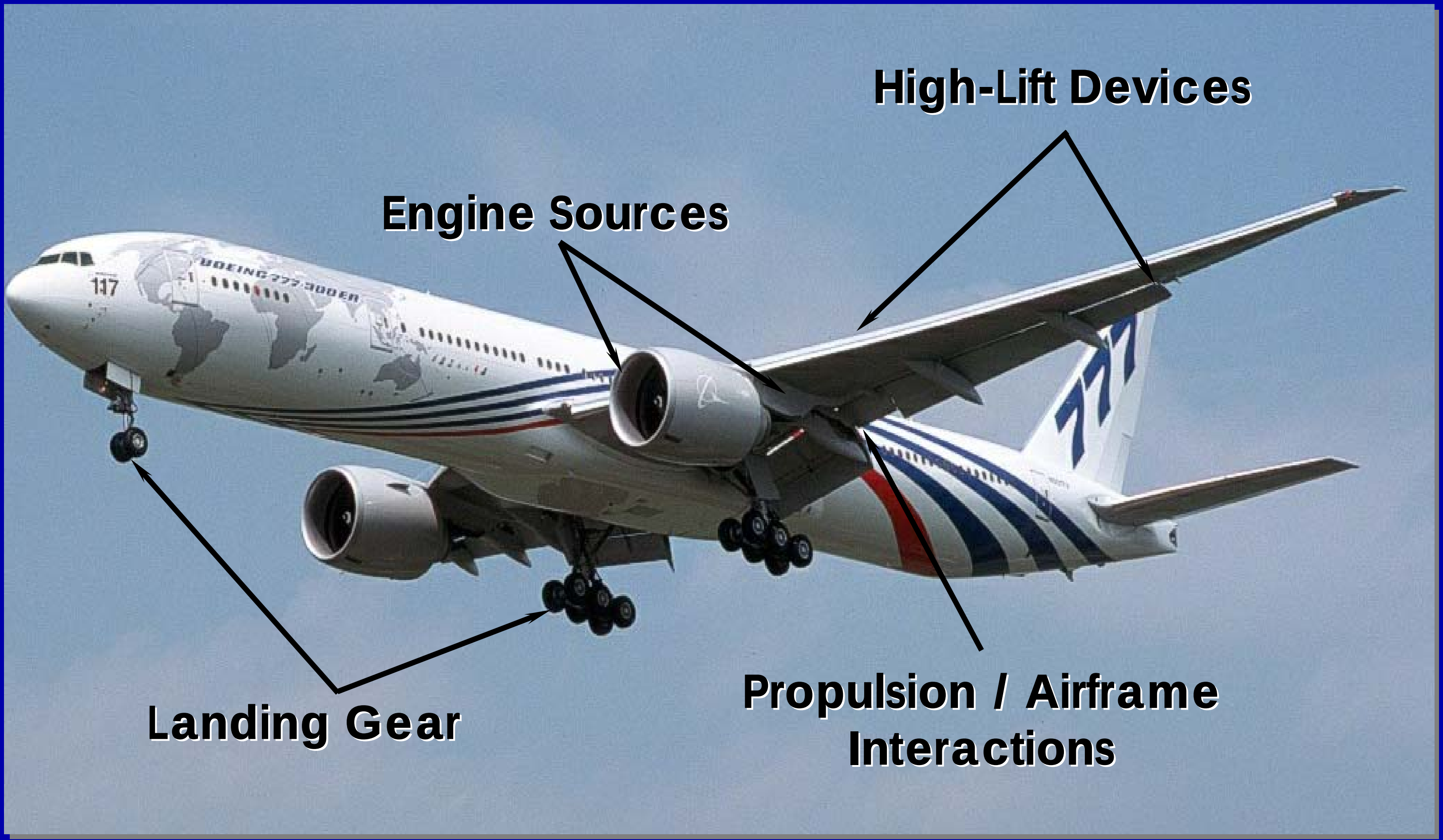
“dB Math”
2x Source Acoustic Power = 3 dB Increase
10x Source Acoustic Power = 10 dB Increase



Aircraft Noise Trend



The Challenge



Aircraft noise is a complex amalgam of sources, interactions, transmission, and propagation.

Subsonic Fixed Wing Project Goals

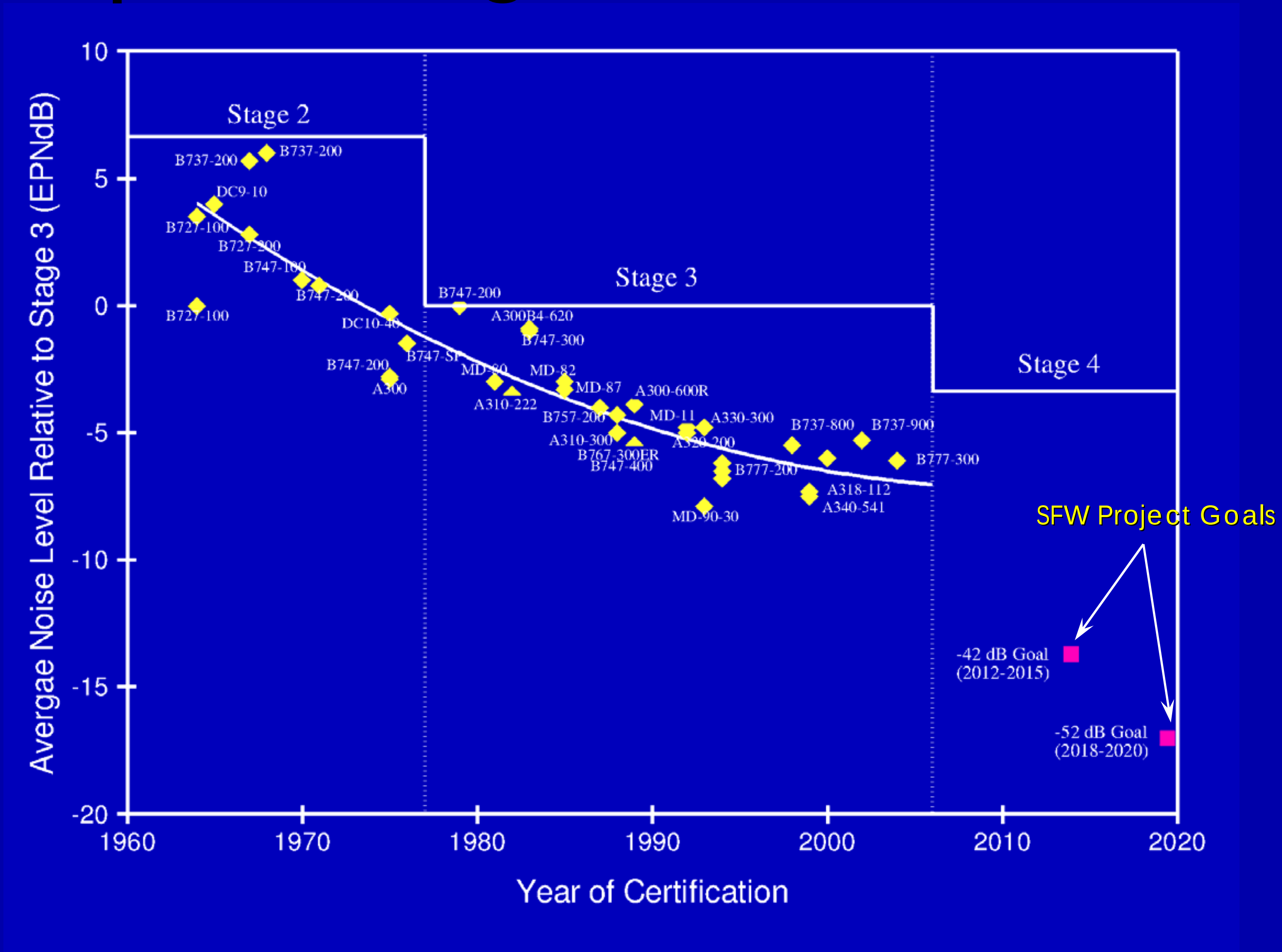
Corners of the Trade Space	*N+1* Generation Conventional Tube w/ Wing (2012-2015)	*N+2* Generation Unconventional Hybrid Wing Body (2018-2020)
Noise (cumulative below Stage 3)	**-42 dB**	**-52 dB**
Emissions (LTO NOx) (below CAEP/2)	**-70%**	**-80%**
Performance: Aircraft Fuel Burn (relative to 737/CFM56)	**-33%**	**-50%***
Performance: Field Length (relative to 737/CFM56)	**-33%**	**-50%**

N+1 Generation

N+2 Generation

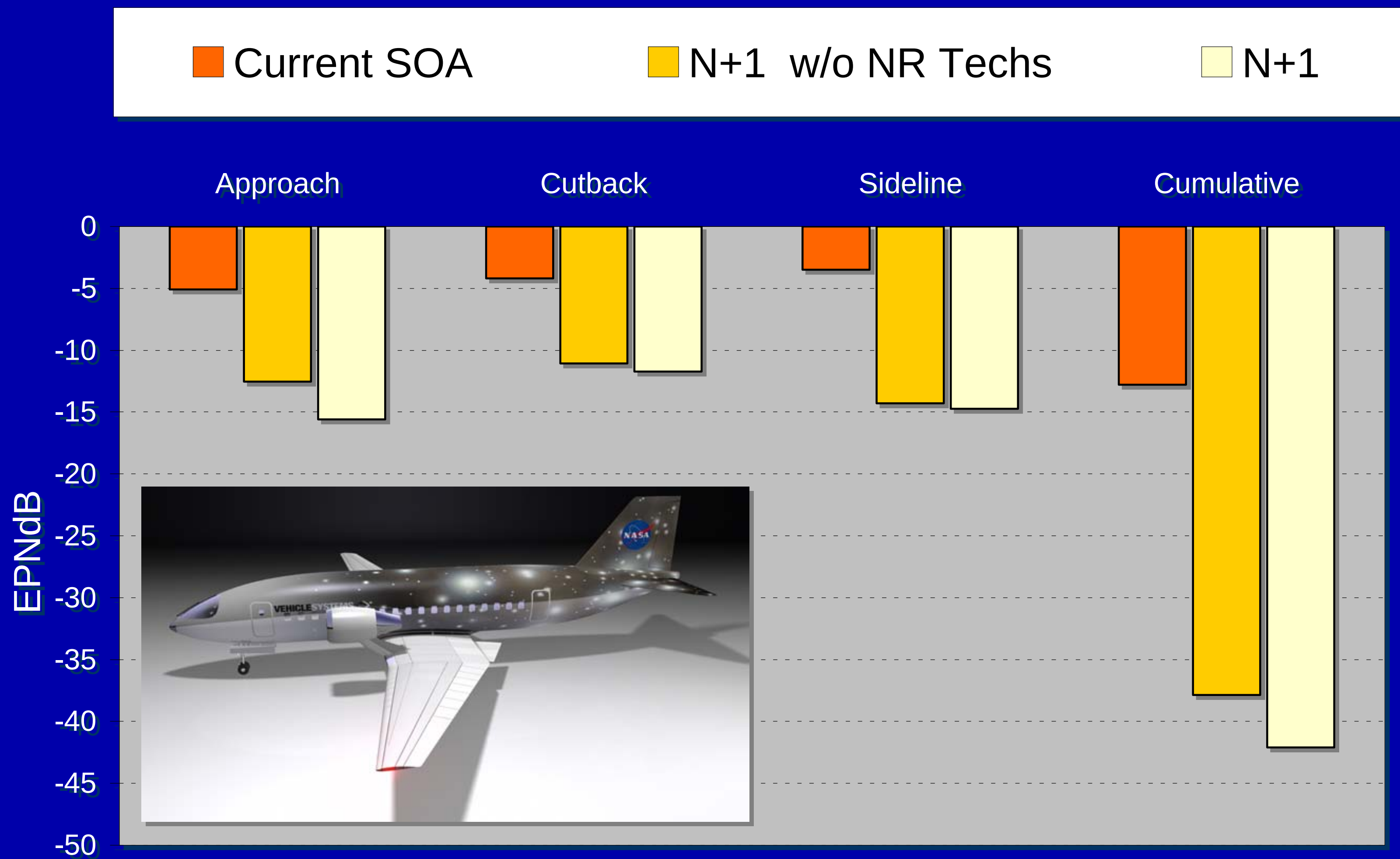
* Fuel burn for *N+2* being validated.

Step Change in Noise Trend



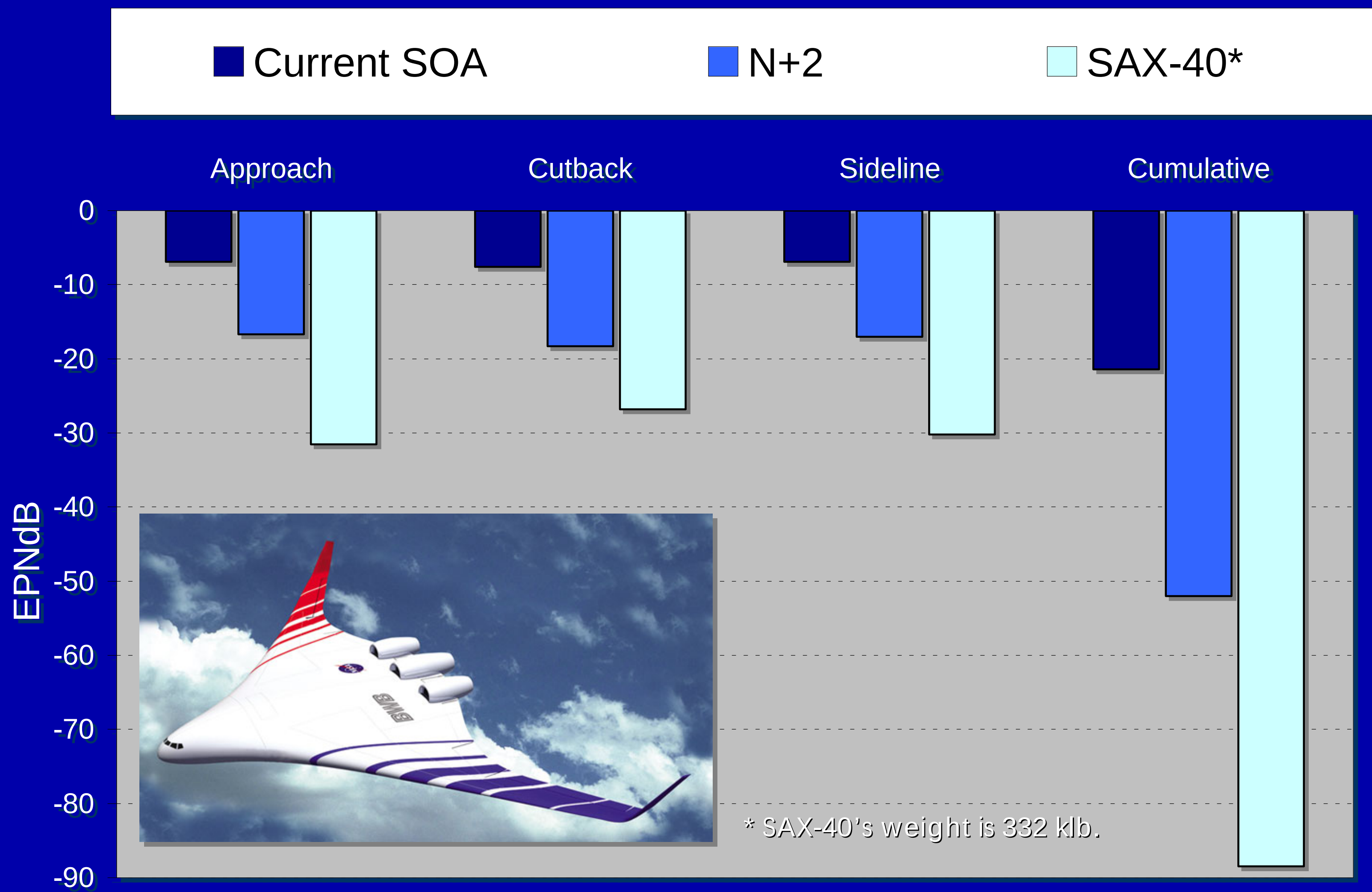
N+1 Aircraft Noise Margins

(All numbers relative to Stage 3 certification levels)

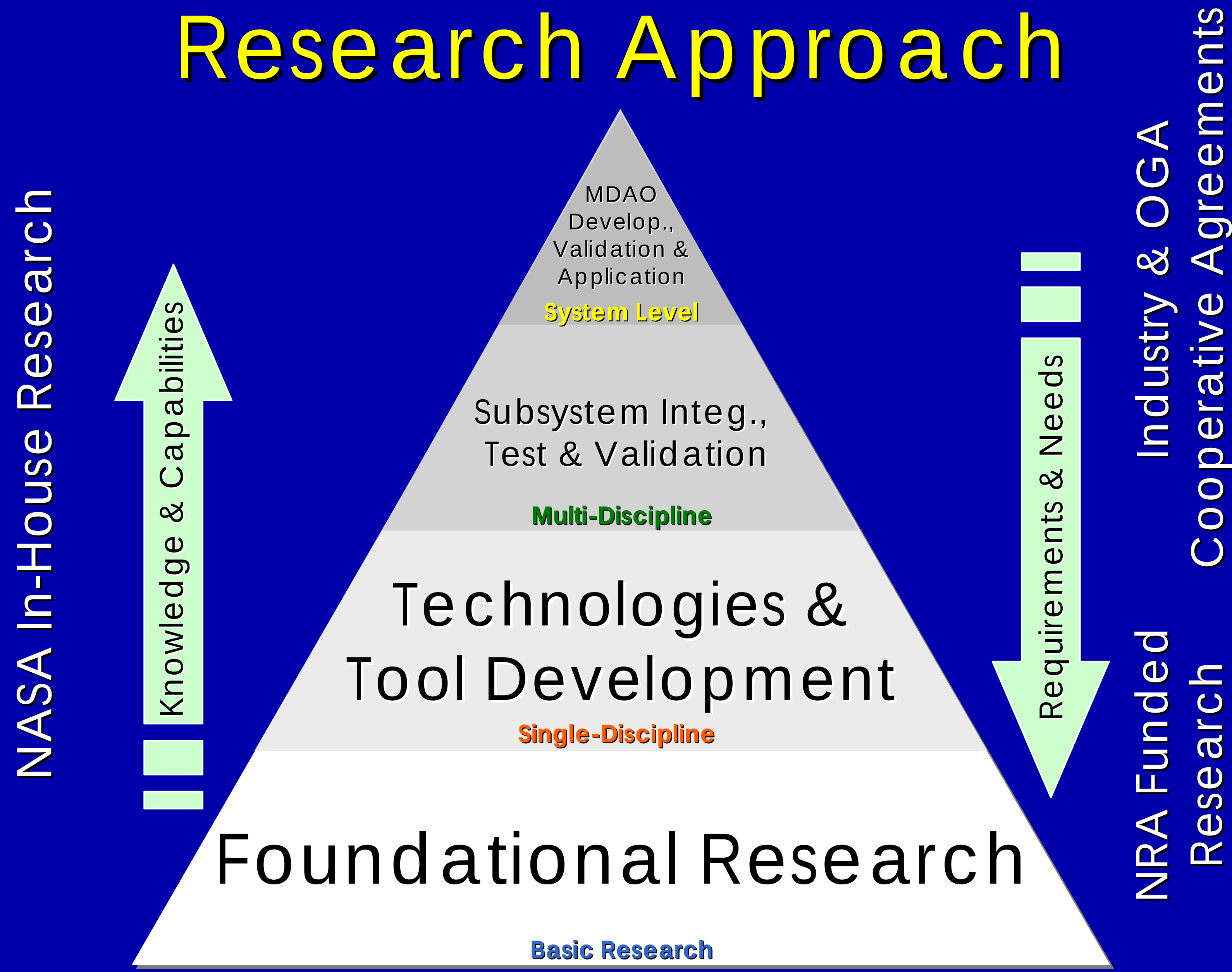


N+2 Aircraft Noise Margins

(All numbers relative to Stage 3 certification levels)



Research Approach



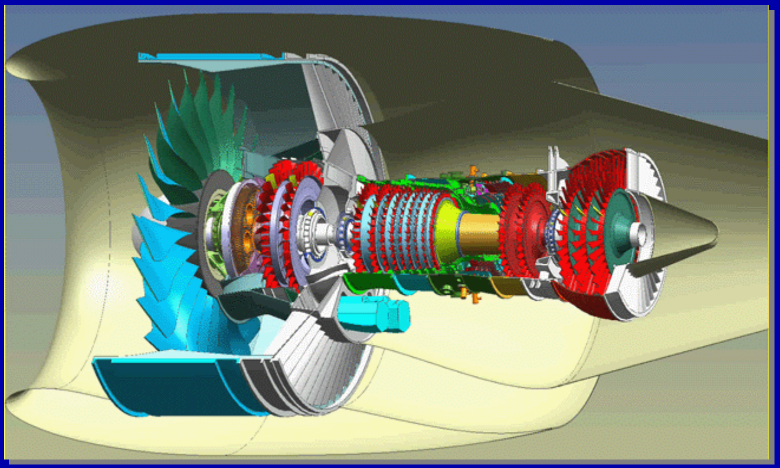
N+1 Technology Path

Airframe Noise Reduction Technologies:

- Slat Cove Filler & Continuous Mold Line (CML)
  (for high-lift systems noise reduction)
- Toboggan Fairing
  (for landing gear noise reduction)

Engine Noise Reduction Technologies:

- Ultra High Bypass (UHB) Cycle
  (e.g., geared turbofan)
- Soft Vane Stator
- Over-The-Rotor Treatment
  (all for fan noise reduction)



Pratt & Whitney Partnership

- 9’x15’ Acoustic Wind Tunnel Fan Noise Reduction Validation Test:

- UHB Cycle Noise Benefits (*Test Completed in November ‘06 - Cycle Benefits Validated*)
- Over-The-Rotor & Soft Vane Fan NR Tech. Validation *Test (Scheduled or September ‘08*)

- 11’ Transonic Wind Tunnel Test:

- Potential Aerodynamic Integration Study (*Scheduled for April ‘08*)

- Geared Turbofan (GTF) Static Engine Test

- Potential for Sub-Scale/Full-Scale Fan Noise Data Comparison (*Scheduled for Nov. ‘07*)

P&W GTF Model Scale Fan
in 9’x15’ WT

Fan Noise Reduction Technology
Testbed in 9’x15’ WT

Gulfstream Partnership

FY07 Flight Test at

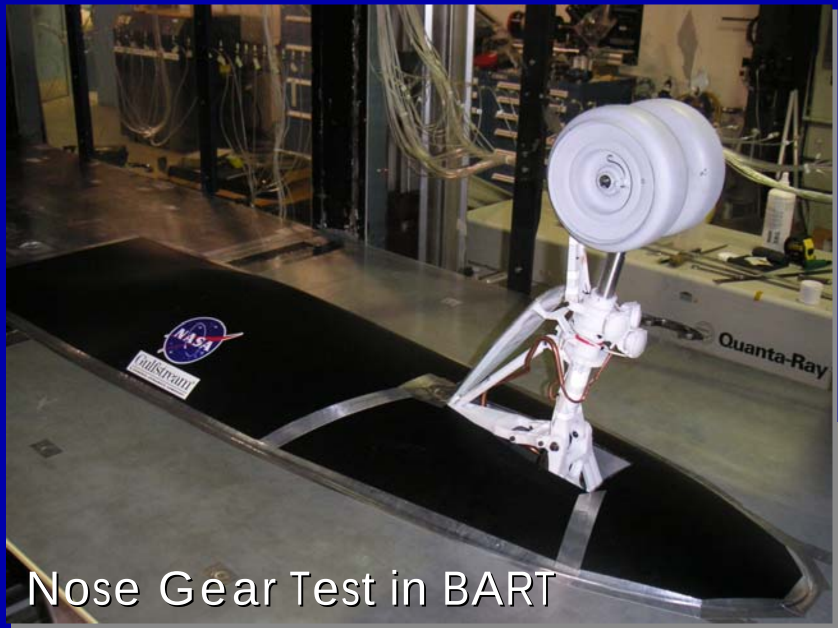
Wallops Island Flight Facility

• Airframe Noise Source Investigation and Mitigation Study:

- Landing Gear Noise
- Flap Side Edge Noise

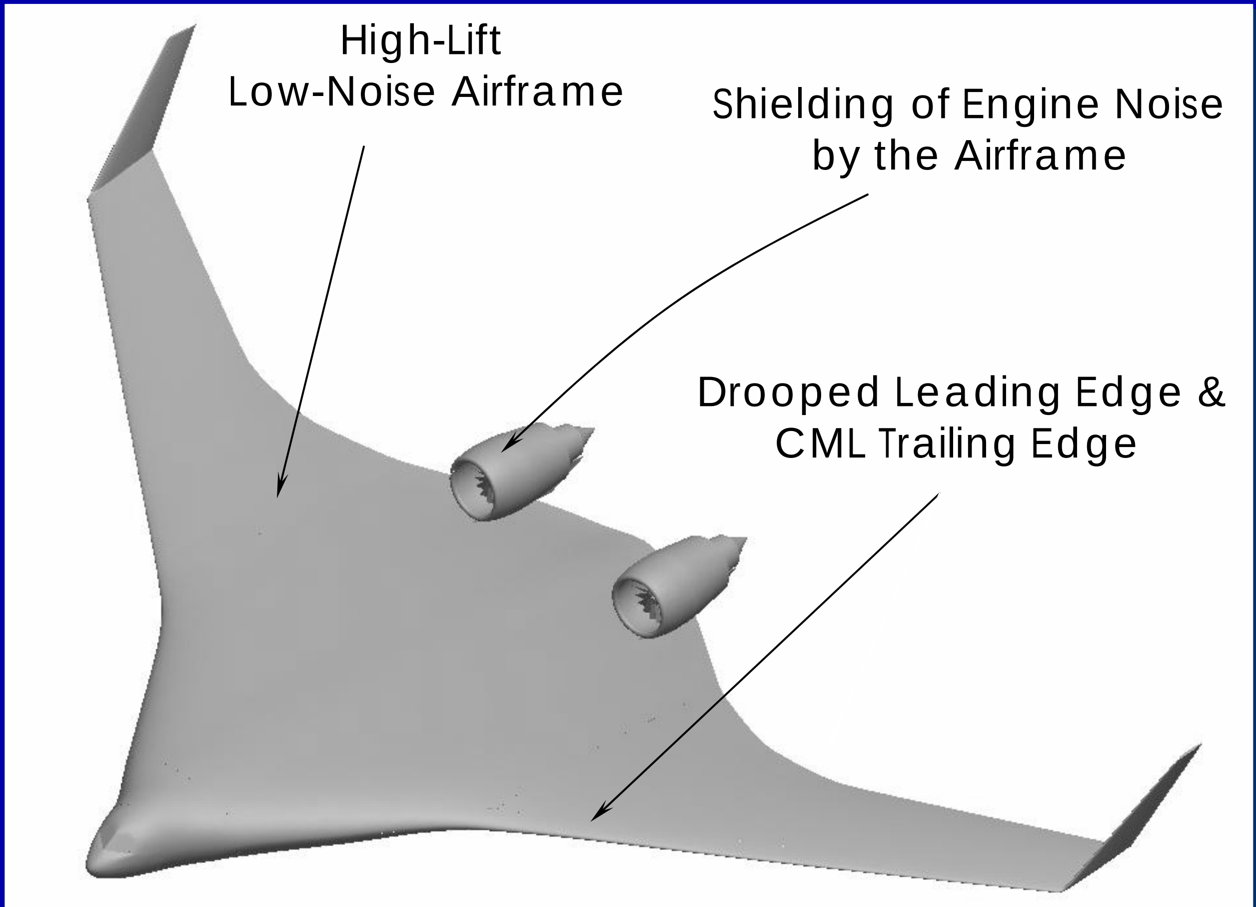
• Multi-Year, Comprehensive Project:

- Component Flow & Noise Testing
- Noise Prediction
- Flight Testing



Nose Gear Test in BART

N+2 Technology Path
Hybrid Wing Body (HWB)



Notional *N*+2 Generation Aircraft: Hybrid Wing Body

Boeing/MIT/UCI Round 2 NRA (1/2)

(Acoustics, Aerodynamics, and SADO Disciplines)

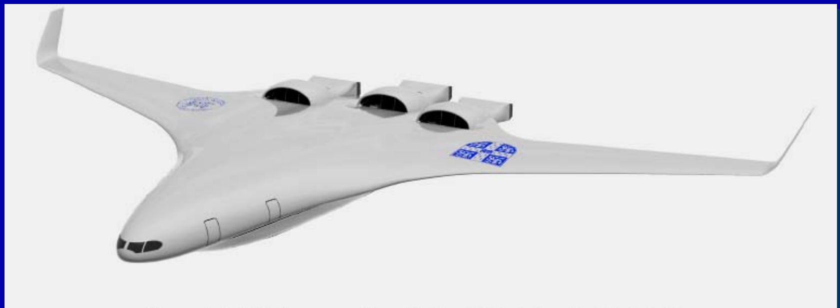


Figure 6-1: SAI Concept Aircraft #1 – high risk embedded design

Figure 6-2: SAI Concept Aircraft #2 – reduced risk podded design

Cambridge-MIT SAX-40 Conceptual Designs for 2025

- Boeing Phantom Works NRA:

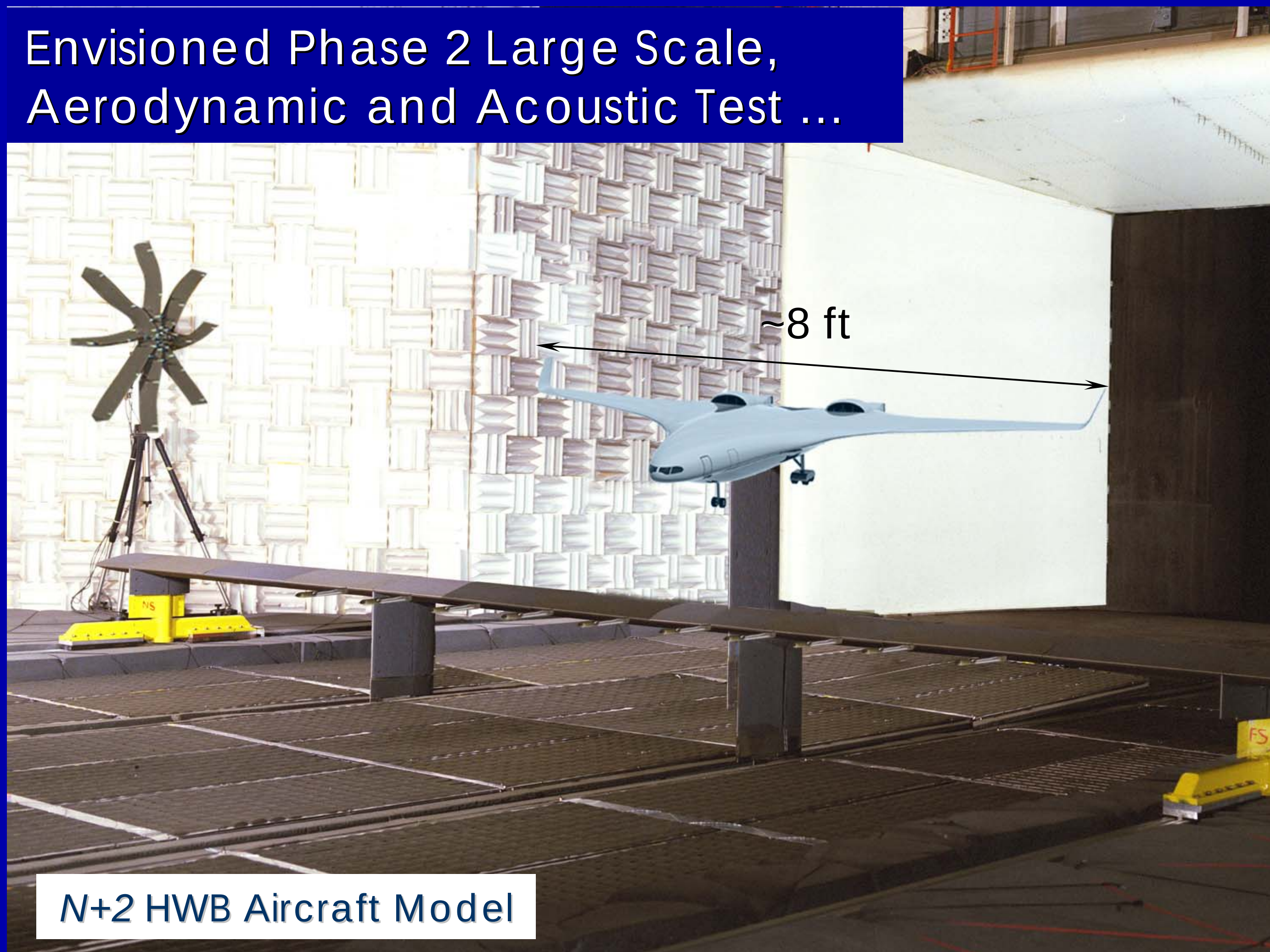
- Start with both SAX-40 Concepts (Embedded and Podded Engines)

- Mature Design for both Concepts; NASA/MIT/UCI Team to Carry Out Noise Assessment

- Technology and Validation Wind Tunnel Selection for Phase 2

Boeing/MIT/UCI Round 2 NRA (2/2)

(Acoustics, Aerodynamics, and SADO Disciplines)



Cal-Poly/Georgia Tech Round 2 NRA
(Aerodynamics and Acoustics Disciplines)

- Objective:

- Develop & Validate Predictive Capabilities for Cruise Efficient, Short Take-Off and Landing (CESTOL) Subsonic Aircraft

- Technology Portfolio:

- Upper Wing Surface Blowing
- Externally Blown Flaps
- Circulation Control Wings

- Approach in Year 1:

- Determine Low-Speed Aerodynamics
- Determine Acoustic Characteristics
- Select and Refine CESTOL Concept

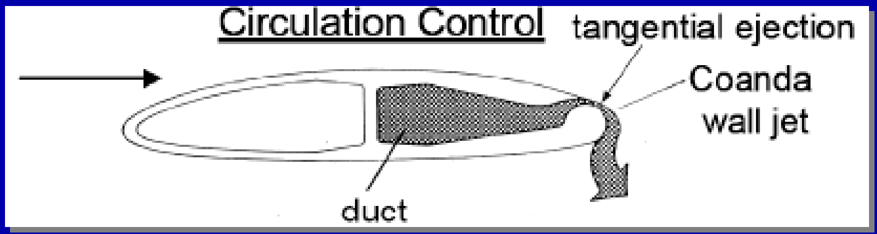
- Approach in Years 2 & 3:

- Large Scale, High-Fidelity Wind Tunnel Validation Experiments

Additional HWB Technology Portfolio

- University of Florida NRA 2

- Pulsed Circulation Control to Increase Lift at Reduced Mass Flow Rates



- University of Notre Dame NRA 2

- Plasma Actuators to Provide Virtual Fairing for Landing Gear and High Lift Side Edges

NASA In-House Research

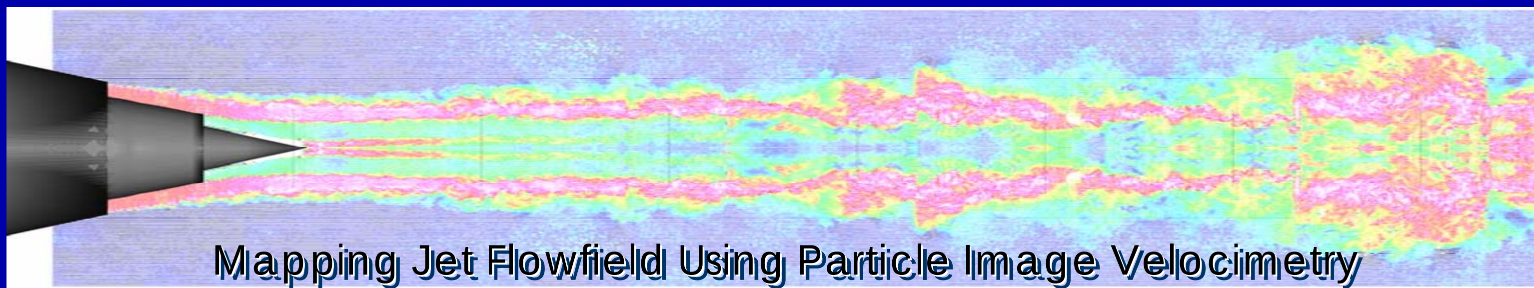
- Noise Diagnostics
  - Understand Underlying Noise Generation Mechanisms
- Noise Prediction
  - Improve Existing Capabilities
  - Develop New Capabilities
  - MDAO Challenge: Developing a Multi-Fidelity MDAO Capability for both Detailed Component Analysis and Efficient System Level Assessment
- Noise Reduction
  - Develop Concepts and Technologies with Minimum Impact on Other Performance Aspects of Aircraft

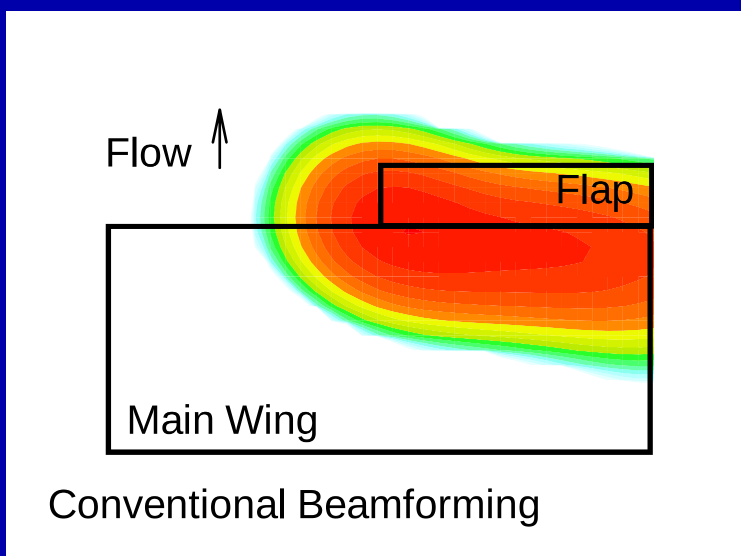
MDAO: Multi-Disciplinary Analysis and Optimization

Noise & Flow Diagnostics

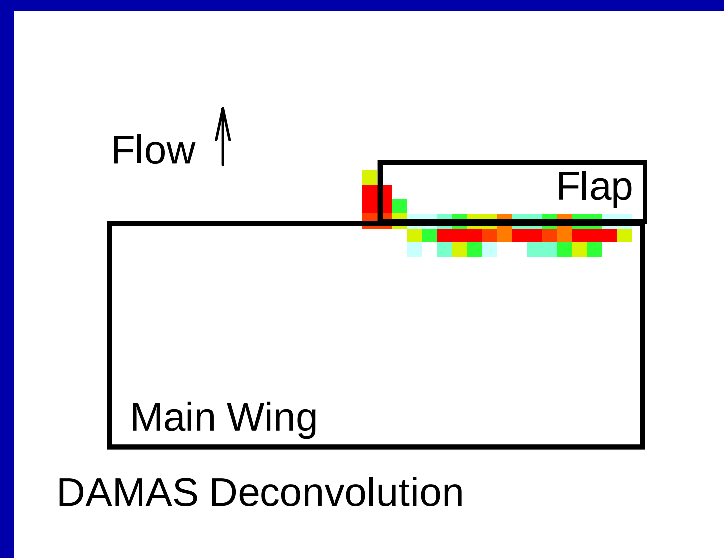
- Particle Image Velocimetry
- Acoustic Phased Arrays
- Curved Duct Test Rig

PIV & Phased Arrays


Mapping Jet Flowfield Using Particle Image Velocimetry



Conventional Beamforming

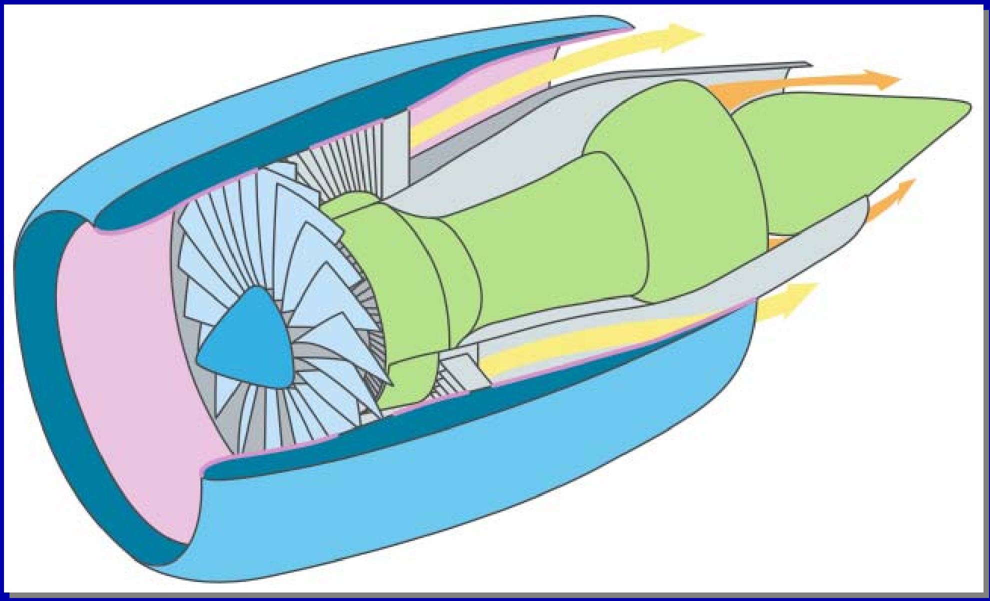


DAMAS Deconvolution

Mapping Noise Sources with Conventional and DAMAS Array Processing Techniques

Liner Diagnostic Techniques

Nacelle Length ↓ ⟶ Liner Attenuation ↓



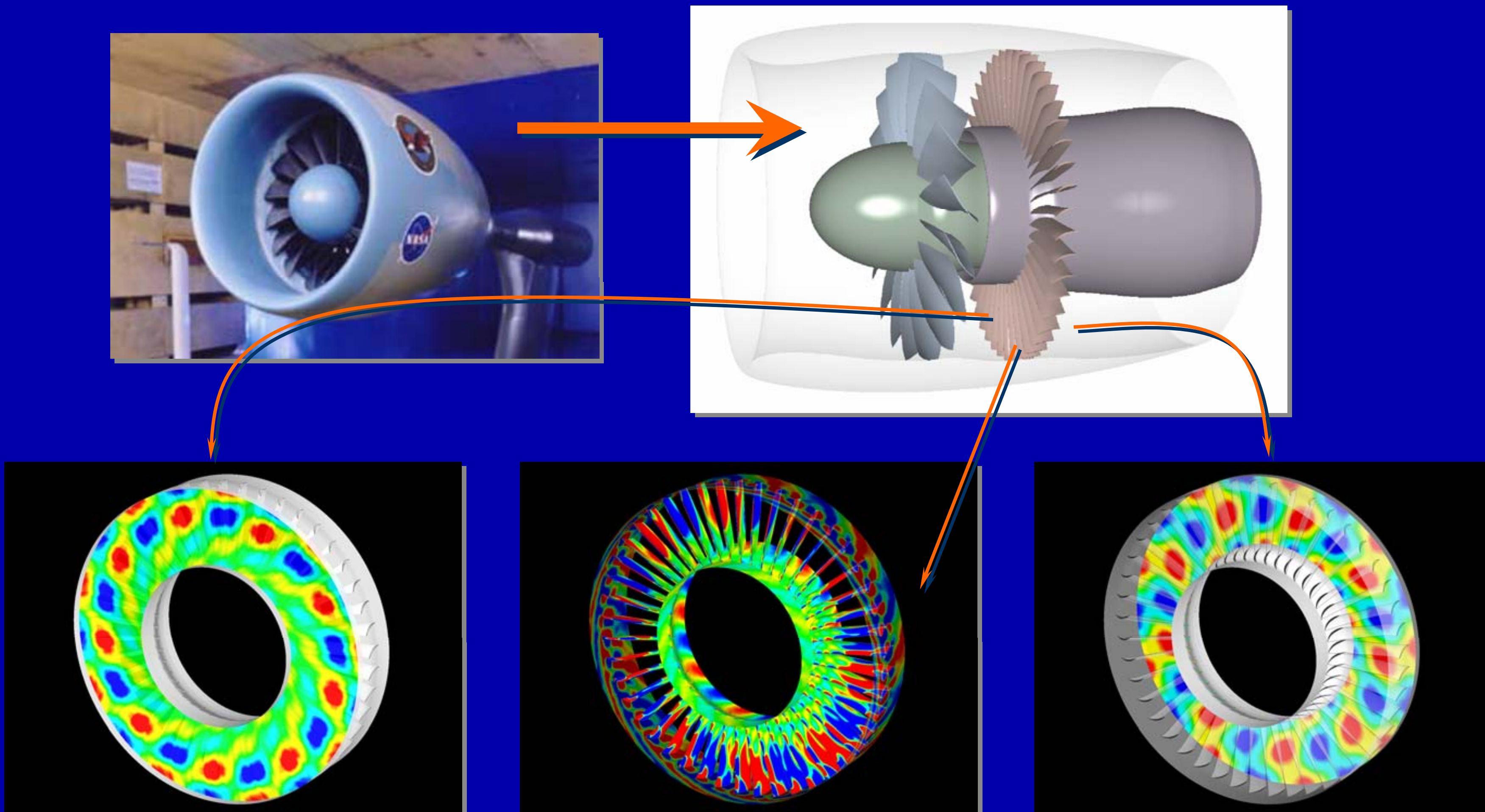
LinerPhysicsTech.mov

Must Improve Understanding of Effects of Grazing Flow Over Liners and Propagation Through Curved Ducts

Noise Modeling & Prediction

- Fan and Jet
  - Rotor-Stator Interaction (R/S) Tone Noise
  - Jet Noise
- Airframe
  - Slat Noise
  - Landing Gear Noise
- Propulsion Airframe Aeroacoustics
  - Flow Interactions
  - Acoustic Scattering
- Aircraft System Noise
  - Aircraft NOise Prediction Program (ANOPP)
  - ANOPP II

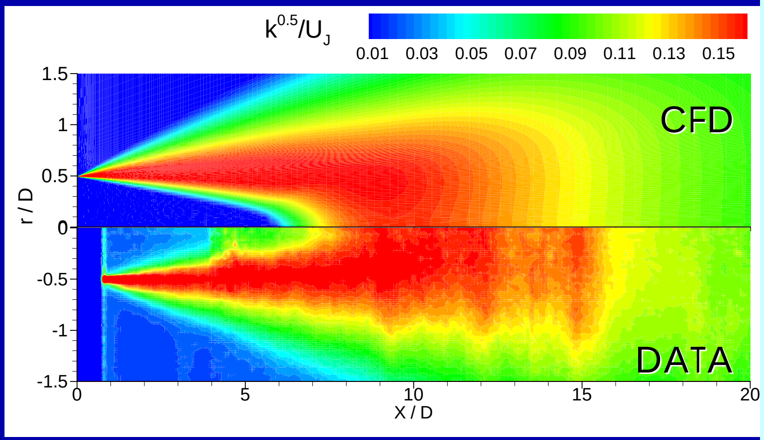
R/S Tone Noise Prediction



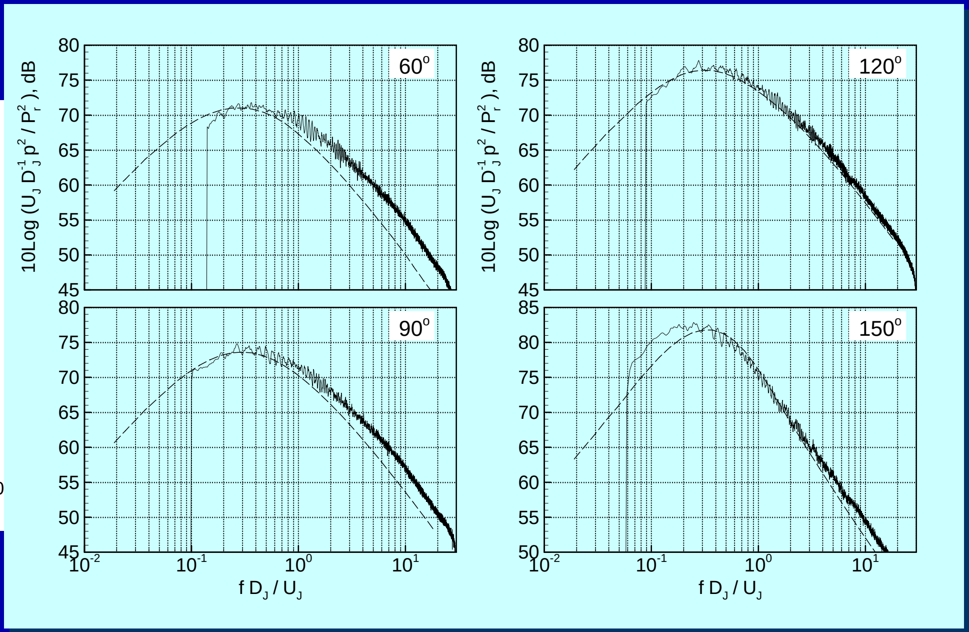
Numerical Computation of Blade Passing Frequency Tones

Jet Noise Prediction

Physics-Based (Statistical) Jet Noise Prediction

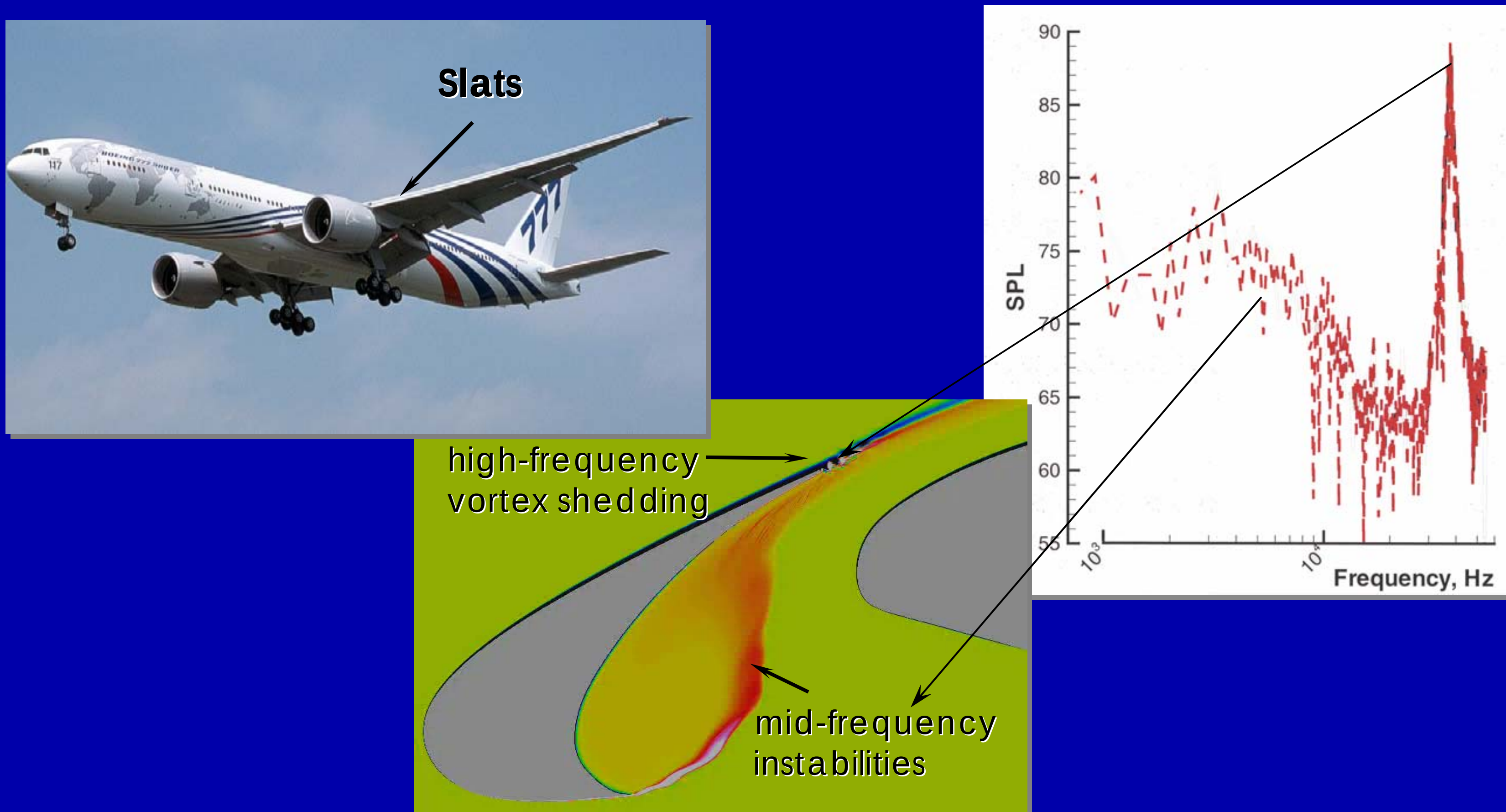


Turbulence: Predicted vs. Measured



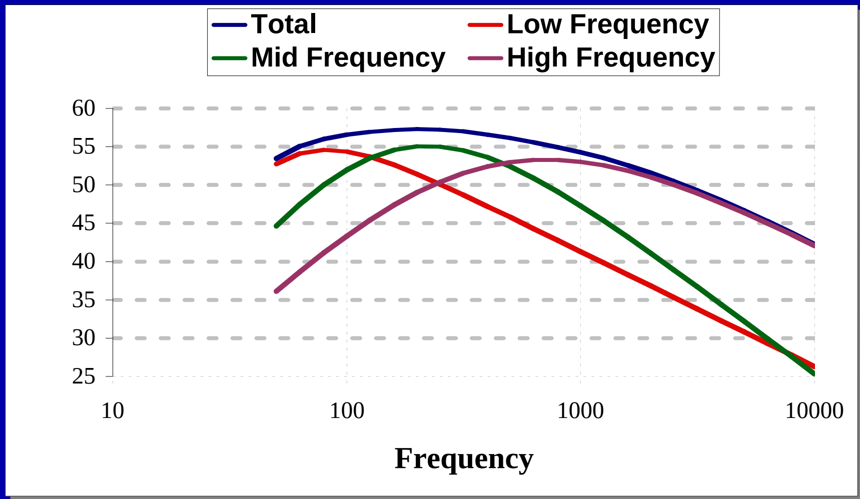
Jet Noise Spectra: Predicted vs. Measured

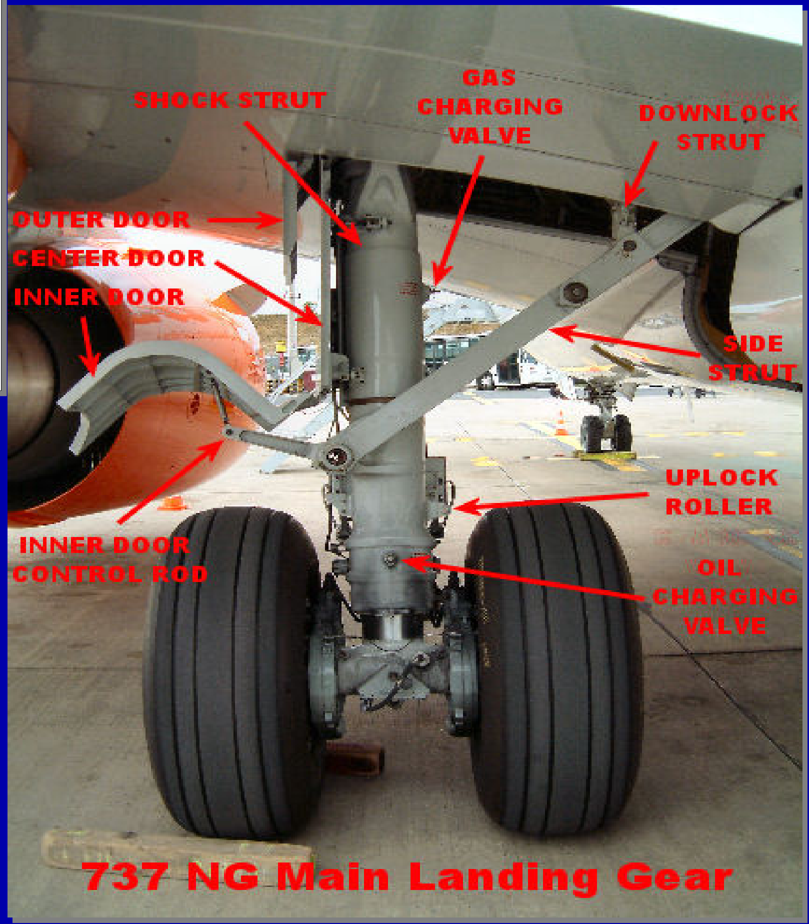
Slat Noise Prediction



- Two Dominant Noise Generation Mechanisms Identified via Computation
- Noise Reduction Concepts (e.g., Slat-Cove Filler) Under Development Have Shown Great Promise to Control These Noise Sources

Landing Gear Noise Prediction





- Low-Frequency Noise

- Generated by the Wheels

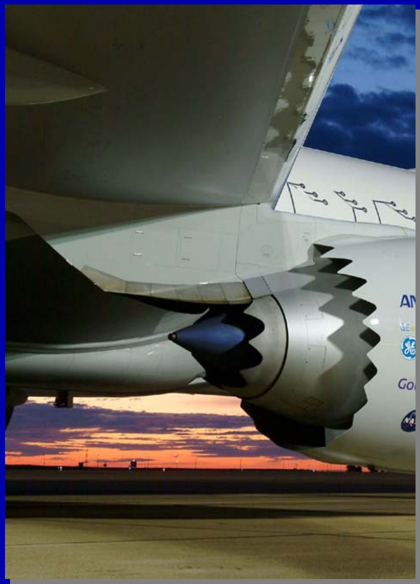
- Mid-Frequency Noise

- Generated by the Main Strut

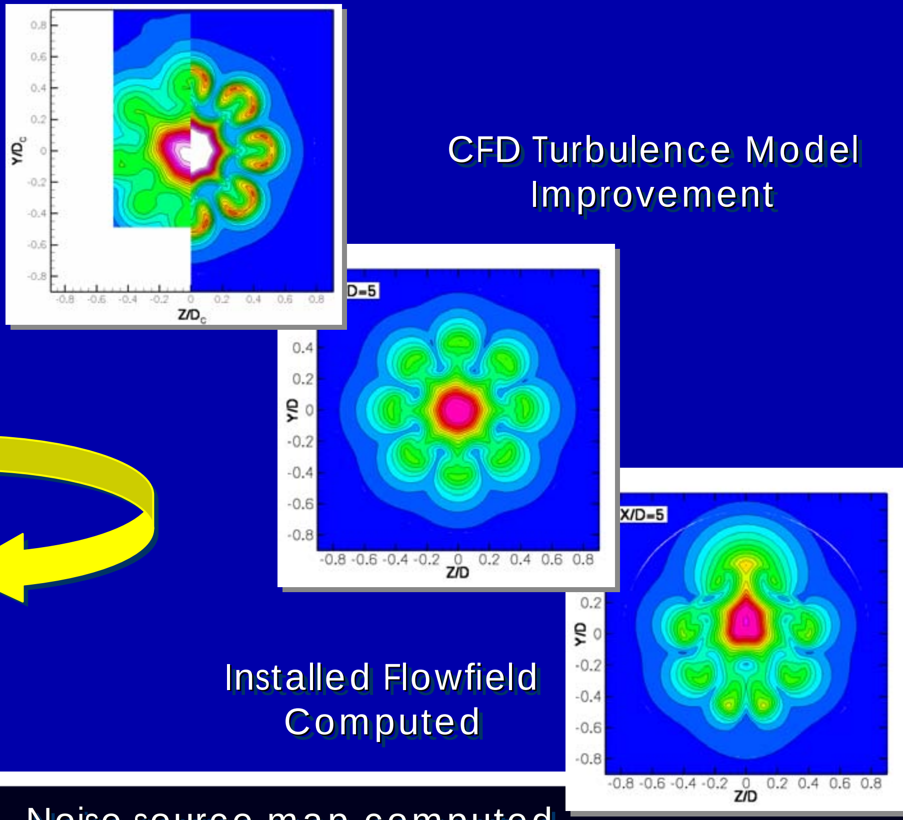
- High-Frequency Noise

- Generated by the Small LG Parts

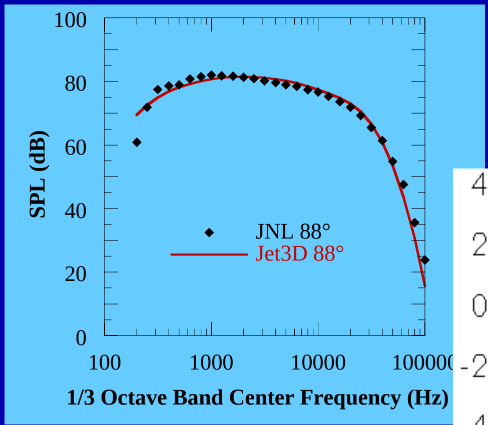
Jet-Pylon Interaction Noise Prediction



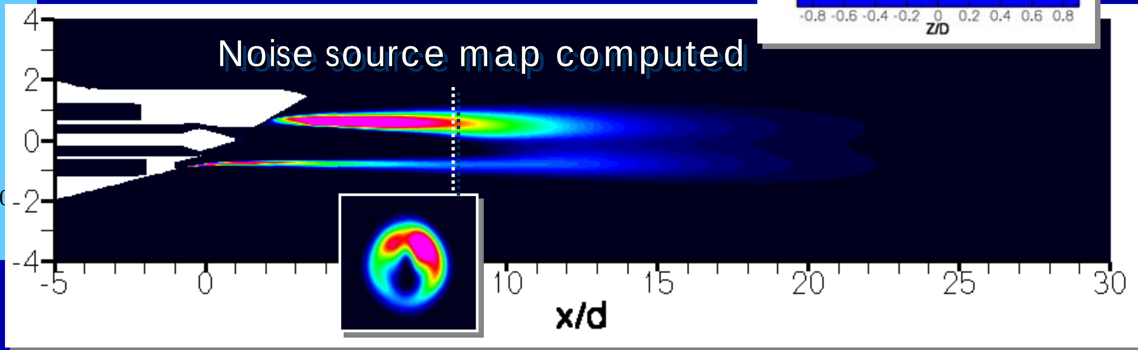
Initial CFD Comparisons



CFD Turbulence Model Improvement

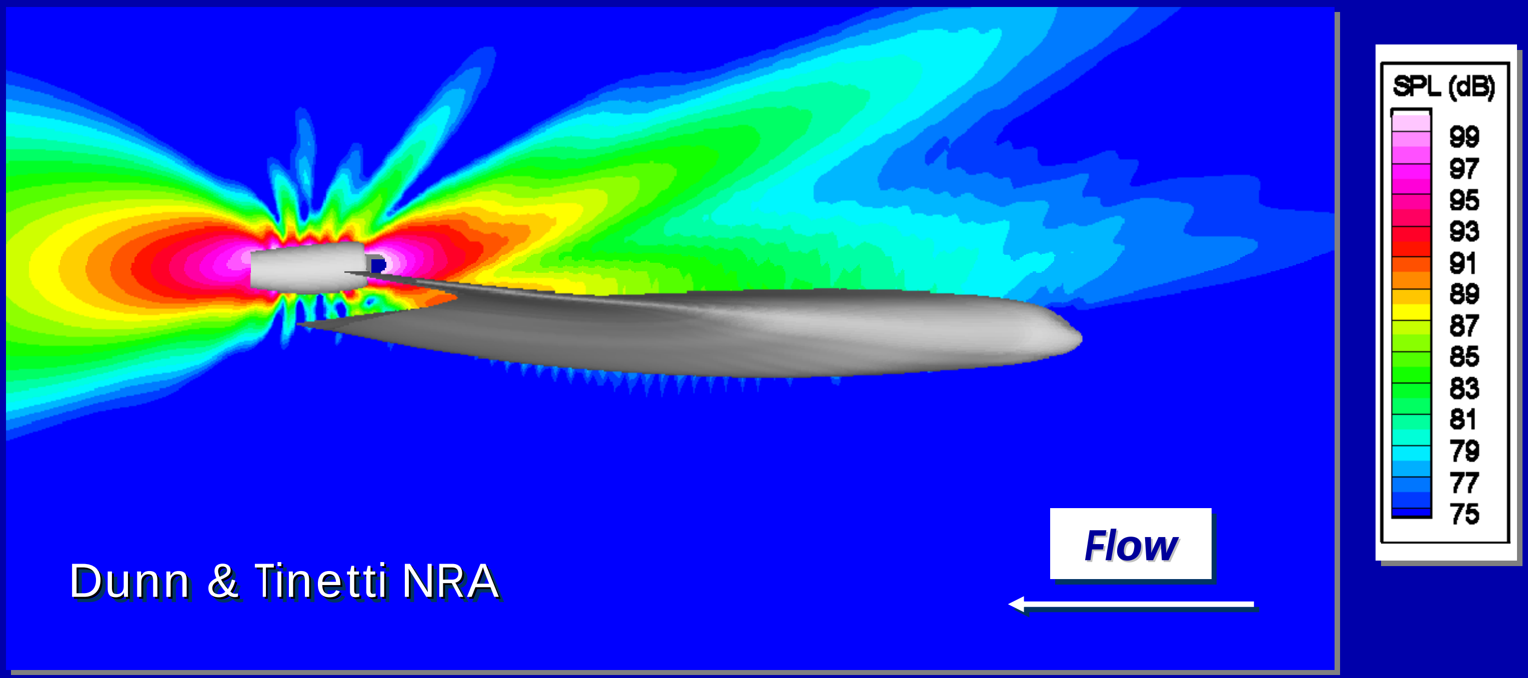


Installed Flowfield Computed



Acoustic Scattering Prediction

- Fast Scattering Code is Used to Compute the Scattering of Engine Noise Sources by the Airframe.



Aircraft System Noise

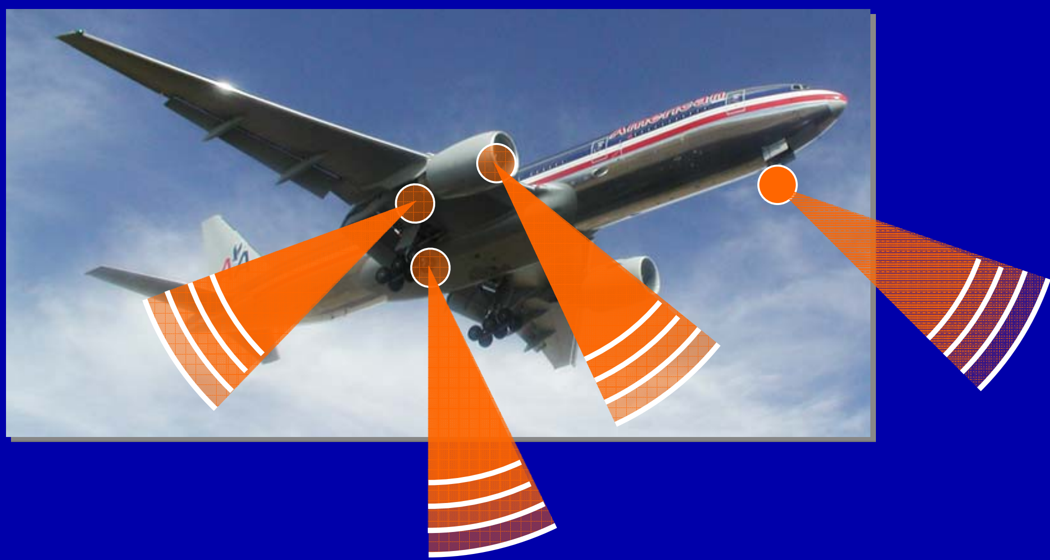
ANOPP & ANOPP II

(Link to MDAO)

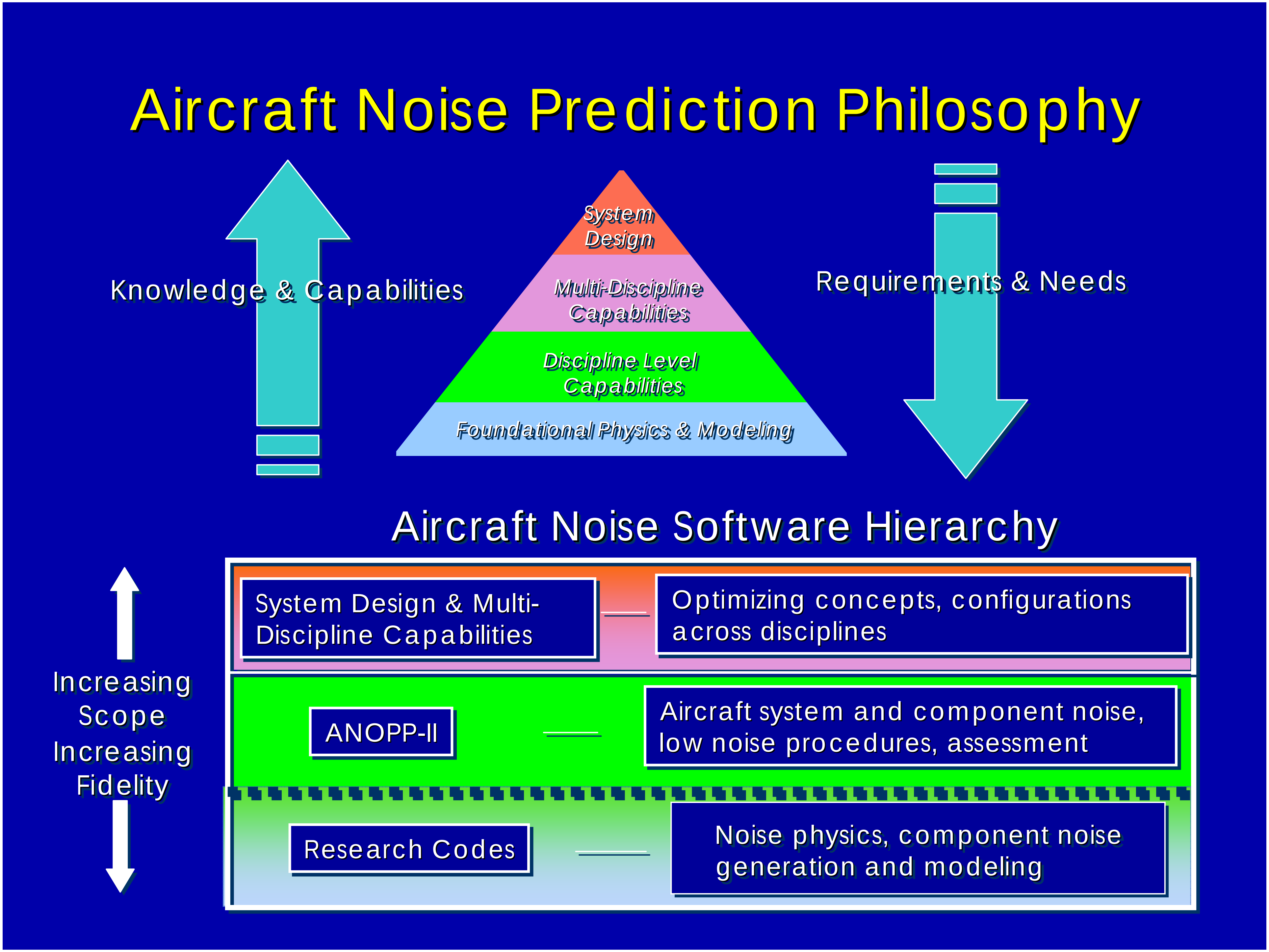
Aircraft Noise Prediction ANOPP (Current)

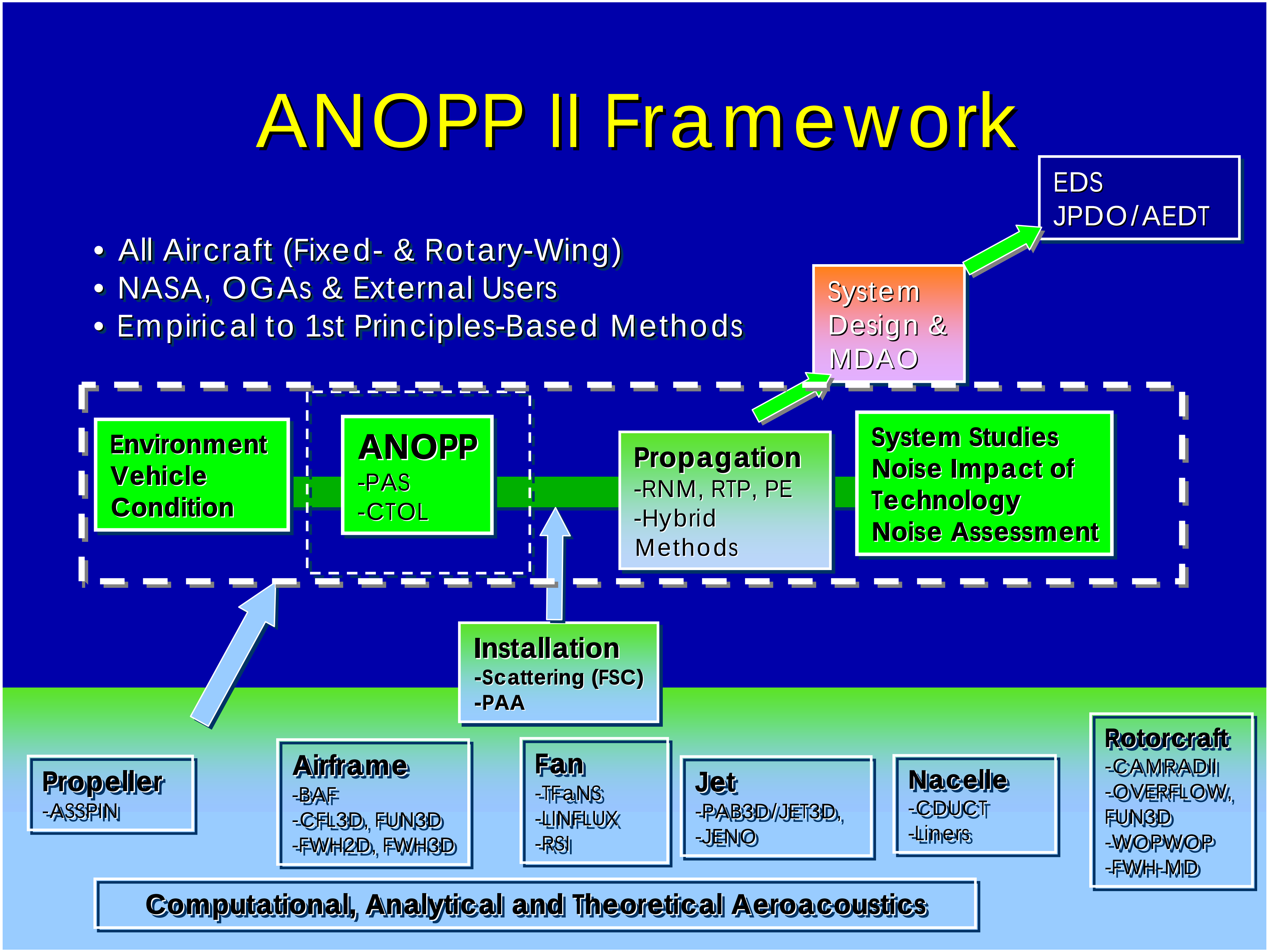
- Aircraft Noise Sources Are Placed at a Single Point
- Effects of Engine Installation Are Added Based on Experience
- Effects of Atmosphere Are Primitive
- Cannot Venture Too Far Outside Experience Base

Aircraft Noise Prediction
ANOPP II (Future)



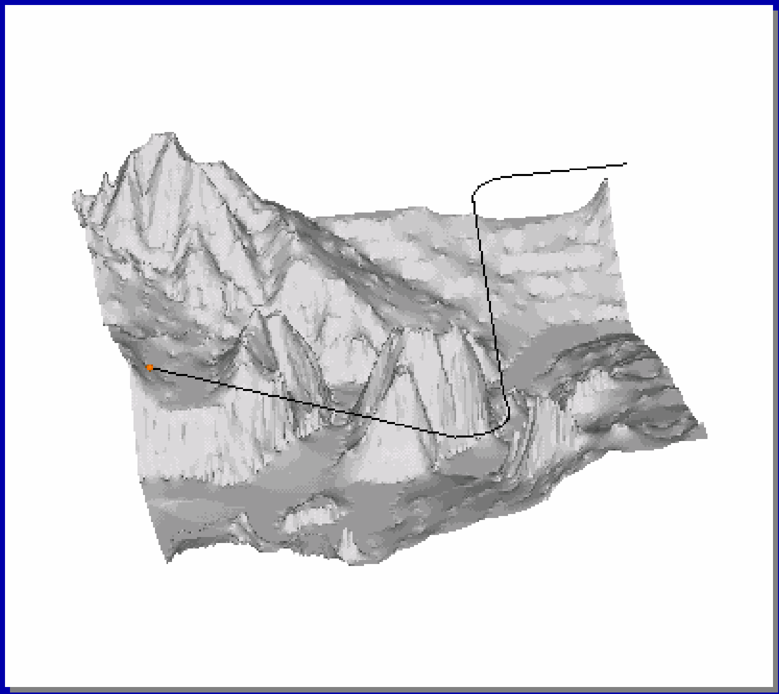
- Aircraft Noise Sources Are at Their True Locations
- Effects of Engine Installation and Interactions Are Modeled
- Effects of Atmospheric Gradients and Winds Are Included
- Can (and Must) Venture Outside of Experience Base


Aircraft Noise Prediction Philosophy
Knowledge & Capabilities
System Design
Multi-Discipline Capabilities
Discipline Level Capabilities
Foundational Physics & Modeling
Requirements & Needs
Aircraft Noise Software Hierarchy
Increasing Scope
Increasing Fidelity
System Design & Multi-Discipline Capabilities
Optimizing concepts, configurations across disciplines
ANOPP-II
Aircraft system and component noise, low noise procedures, assessment
Research Codes
Noise physics, component noise generation and modeling


ANOPP II Framework
EDS
JPDO/AEDT
• All Aircraft (Fixed- & Rotary-Wing)
• NASA, OGAs & External Users
• Empirical to 1st Principles-Based Methods
System Design & MDAO
Environment Vehicle Condition
ANOPP
-PAS
-CTOL
Propagation
-RNM, RTP, PE
-Hybrid Methods
System Studies
Noise Impact of Technology
Noise Assessment
Installation
-Scattering (FSC)
-PAA
Propeller
-ASSPIN
Airframe
-BAF
-CFL3D, FUN3D
-FWH2D, FWH3D
Fan
-TFaNS
-LINFLUX
-RSI
Jet
-PAB3D/JET3D,
-JENO
Nacelle
-CDUCT
-Liners
Rotorcraft
-CAMRADII
-OVERFLOW,
FUN3D
-WOPWOP
-FWH-MD
Computational, Analytical and Theoretical Aeroacoustics

Aircraft Noise Prediction Demo

- Demonstration: ANOPP-RNM Aircraft Noise Footprint Prediction
- ANOPP Deck for 777 and GE90-85B (Using NPSS Engine Simulation)
- ANOPP Creates Noise Hemispheres for Full Power Condition
- RNM Propagates Aircraft Noise to Ground; Propagation Includes Atmospheric Absorption, Spherical Spreading, Terrain, but No Wind



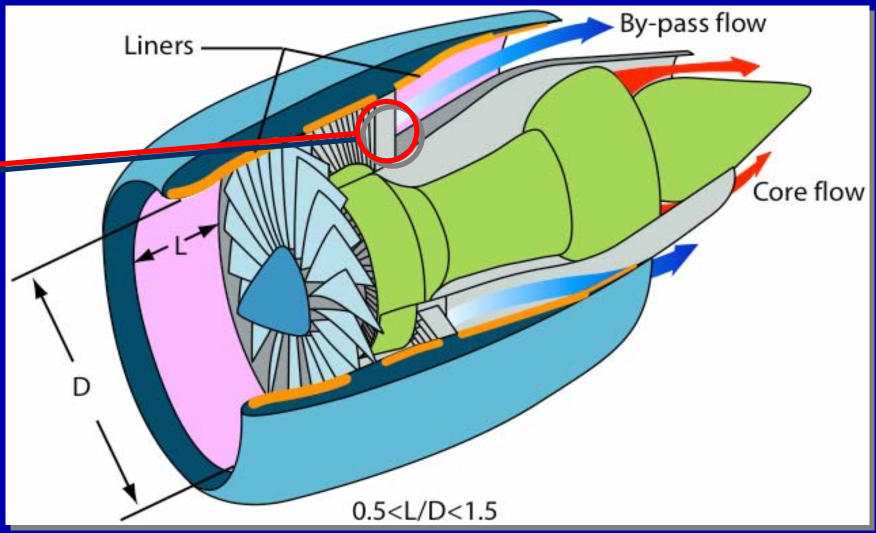
777_GE90-85B.avi

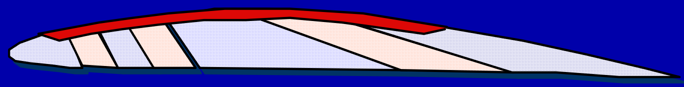
Noise Reduction Technologies

- Engine
  - Soft Vane Stator
- Propulsion Airframe Aeroacoustic
  - Airframe Integrated PAA Chevrons
- Airframe
  - Continuous Mold Line Flaps
  - Landing Gear Fairings

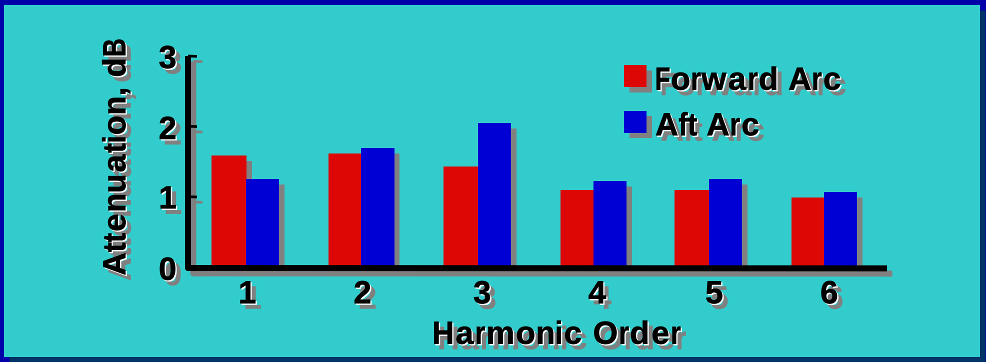
Soft Vane

Prototype Soft Vane





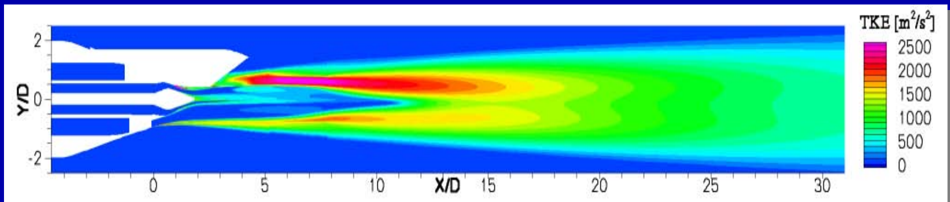
Vane Cross-Section View

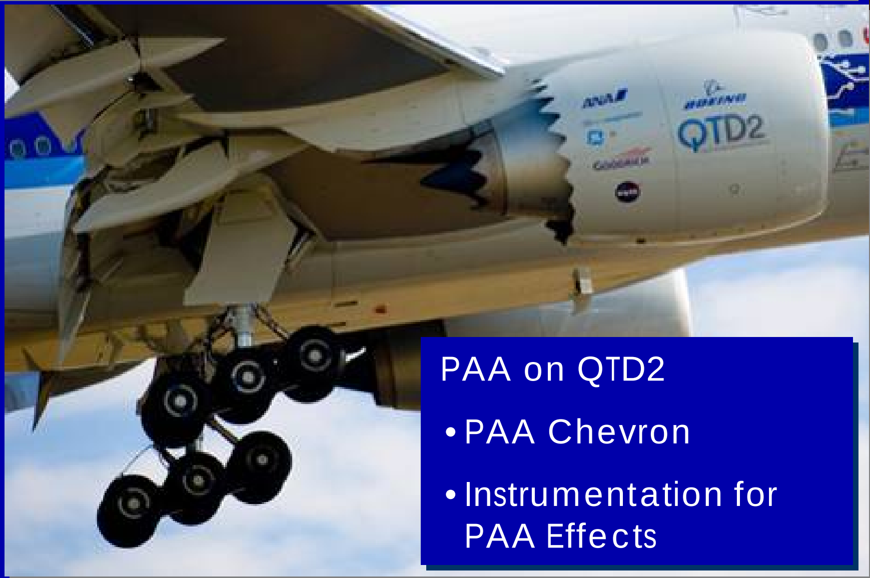


PAA Integrated Chevrons

NASA/Boeing/GE/Goodrich/FAA Extensive Exploration of Several PAA Concepts

Extensive CFD/Prediction Work within PAA and Liner Technology





PAA on QTD2

- PAA Chevron
- Instrumentation for PAA Effects

LSAF Instrumentation

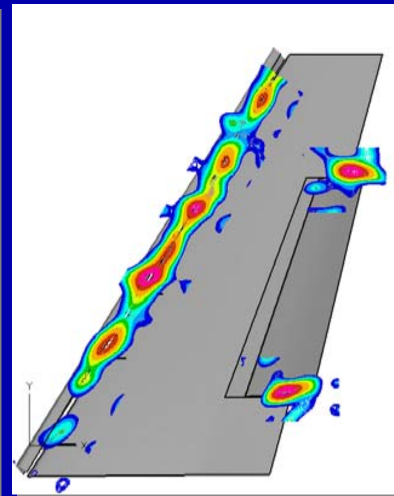
- Farfield Acoustics
- Surface Kulites
- Infrared
- Phased Array

PAA in Boeing LSAF

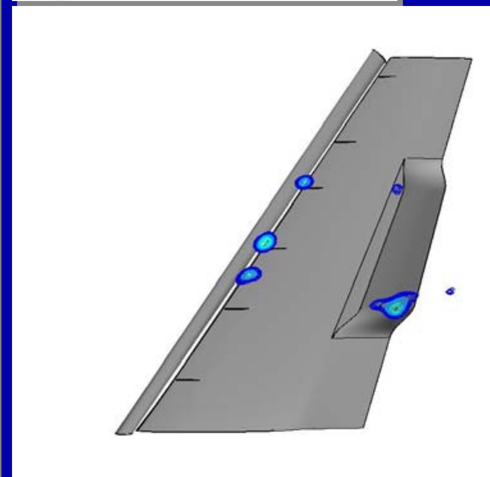
PAA Installation Effects and Noise Reduction Technologies Studied

- PAA Asymmetric Chevrons
- Flapperon Treatment
- Passive Porosity Cowl

Continuous Mold Line Link



Original Wing
(Noise Source Strength
Shown by Contours)



Modified Wing
(Noise Sources
Reduced to
Background Level)

Landing Gear Noise Reduction

Summary

- Aircraft noise is critical to the future growth of the air transportation system.
- NASA is working closely with the JPDO and FAA to enable future growth of the air transportation system.
- Three pronged in-house research approach involving diagnostics, prediction and noise reduction.
- Excellent industry partnerships already in place and many universities engaged through the NRA process.
- Subsonic Fixed Wing project has aggressive noise level targets for *N+1* and *N+2* generation aircraft.