CORE-NOISE RESEARCH

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Presented at the 2012 Technical Conference NASA Fundamental Aeronautics Program
Cleveland, Ohio, March 13-15, 2012

Summary

This presentation is a technical summary of and outlook for NASA-internal and NASA-sponsored external research on core noise funded by the Fundamental Aeronautics Program Subsonic Fixed Wing (SFW) Project. Sections of the presentation cover: the SFW system-level noise metrics for the 2015 (N+1), 2020 (N+2), and 2025 (N+3) timeframes; SFW strategic thrusts and technical challenges; SFW advanced subsystems that are broadly applicable to N+3 vehicle concepts, with an indication where further noise research is needed; the components of core noise (compressor, combustor and turbine noise) and a rationale for NASA's current emphasis on the combustor-noise component; the increase in the relative importance of core noise due to turbofan design trends; the need to understand and mitigate core-noise sources for high-efficiency small gas generators; and the current research activities in the core-noise area, with additional details given about forthcoming updates to NASA's Aircraft Noise Prediction Program (ANOPP) core-noise prediction capabilities, two NRA efforts (Honeywell International, Phoenix, AZ and University of Illinois at Urbana-Champaign, respectively) to improve the understanding of core-noise sources and noise propagation through the engine core, and an effort to develop oxide/oxide ceramic-matrix-composite (CMC) liners for broadband noise attenuation suitable for turbofan-core application. Core noise must be addressed to ensure that the N+3 noise goals are met. Focused, but long-term, core-noise research is carried out to enable the advanced high-efficiency small gas-generator subsystem, common to several N+3 conceptual designs, needed to meet NASA's technical challenges. Intermediate updates to prediction tools are implemented as the understanding of the source structure and engine-internal propagation effects is improved.

The NASA Fundamental Aeronautics Program has the principal objective of overcoming today's national challenges in air transportation. The SFW Quiet-Aircraft Subproject aims to develop concepts and technologies to reduce perceived community noise attributable to aircraft with minimal impact on weight and performance. This reduction of aircraft noise is critical to enabling the anticipated large increase in future air traffic.

Core-Noise Research

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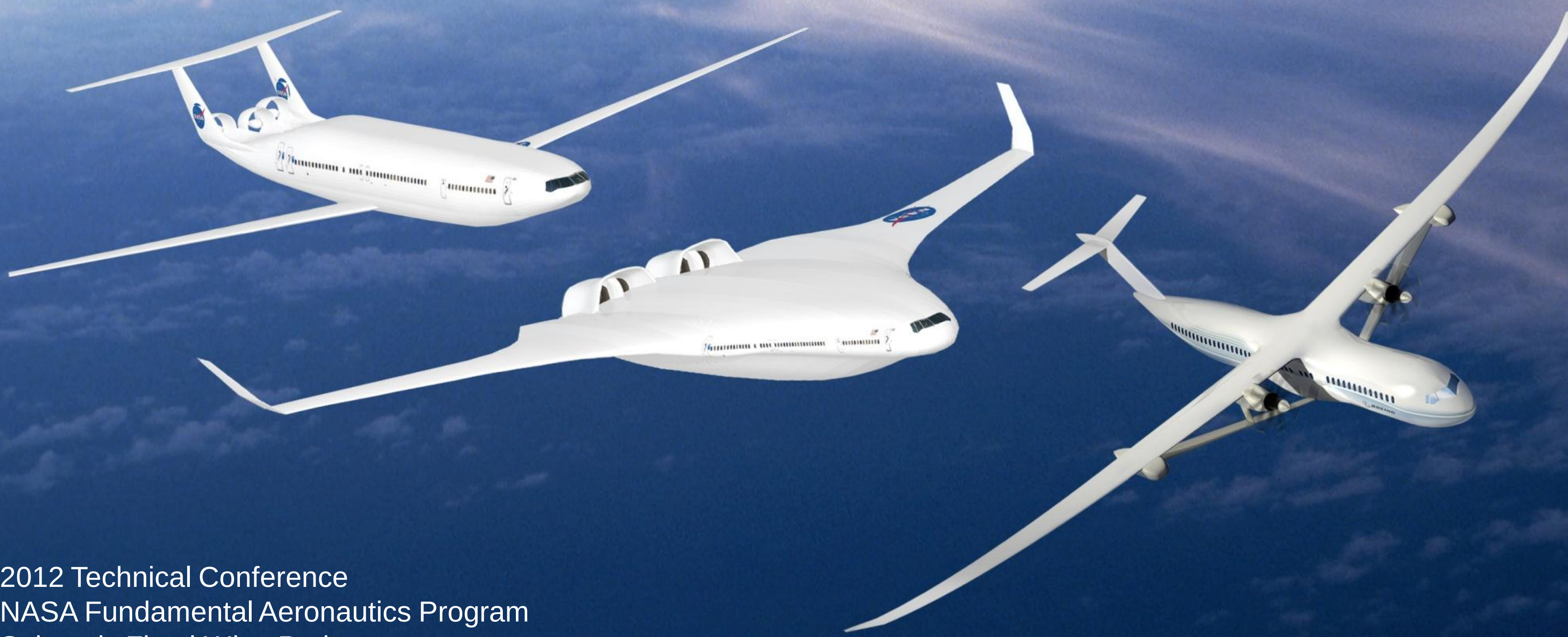


2012 Technical Conference
NASA Fundamental Aeronautics Program
Subsonic Fixed Wing Project
Cleveland, OH, March 13-15, 2012

NASA FAP SFW Quiet-Aircraft Core-Noise Research

…. outline

- Introduction
  - NASA subsonic transport system level metrics
  - NASA Subsonic Fixed Wing Project goals & challenges
  - increasing importance of core noise due to turbofan design trends
  - current noise-prediction tools based on 1970-80s technology

Why

- N+3 Core-Noise-Reduction Work
  - focus and technical content of program
  - in-house: examples of intermediate updates to prediction capability
  - NRA: 2 core-noise efforts (GRC monitored)
  - GRC/LaRC: high-temperature light-weight liners for broadband core-noise reduction

How

- Summary

Explore/develop tools, technologies, and concepts for improved energy efficiency and environmental compatibility for sustained growth of commercial aviation

NASA Subsonic Transport System Level Metrics

…. technology for dramatically improving noise, emissions, & performance

TECHNOLOGY BENEFITS*	TECHNOLOGY GENERATIONS (Technology Readiness Level = 4-6)		NASA SFW
	N+1 (2015) FAA CLEEN	N+2 (2020**) NASA ERA	N+3 (2025)
Noise (cum margin rel. to Stage 4)	-32 dB	-42 dB	-71 dB
LTO NOx Emissions (rel. to CAEP 6)	-60%	-75%	-80%
Cruise NOx Emissions (rel. to 2005 best in class)	-55%	-70%	-80%
Aircraft Fuel/Energy Consumption‡ (rel. to 2005 best in class)	-33%	-50%	-60%

* Projected benefits once technologies are matured and implemented by industry. Benefits vary by vehicle size and mission. N+1 and N+3 values are referenced to a 737-800 with CFM56-7B engines, N+2 values are referenced to a 777-200 with GE90 engines

** ERA's time-phased approach includes advancing "long-pole" technologies to TRL 6 by 2015

‡ CO_2 emission benefits dependent on life-cycle CO_{2e} per MJ for fuel and/or energy source used

Reduction of aircraft noise is critical due to anticipated large increase in air traffic

SFW Strategic Thrusts & Technical Challenges

.... energy and environment

Energy Efficiency Thrust *(with emphasis on N+3)*
Develop economically practical approaches to improve aircraft efficiency

Environmental Compatibility Thrust *(with emphasis on N+3)* ✓
Develop economically practical approaches to minimize environmental impact

Cross-Cutting Challenge *(pervasive across generations)*

Energy & Environment

TC1 - Reduce aircraft drag *with minimal impact on weight (aerodynamic efficiency)* — *Drag*

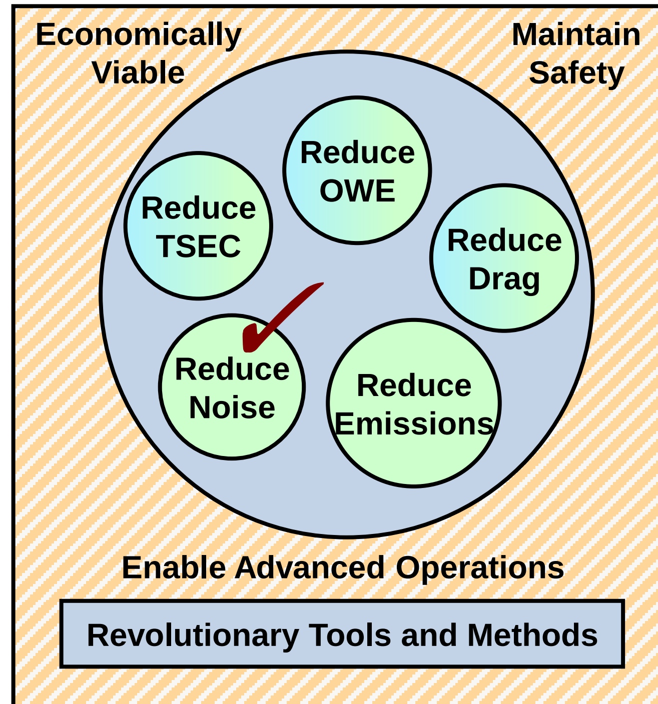
TC2 - Reduce aircraft operating empty weight *with minimal impact on drag (structural efficiency)* — *Weight*

TC3 - Reduce thrust-specific energy consumption *while minimizing cross-disciplinary impacts (propulsion efficiency)* — *TSEC*

TC4 - Reduce harmful emissions *attributable to aircraft energy consumption* — *Clean*

✓ ***TC5 - Reduce perceived community noise*** *attributable to aircraft with minimal impact on weight and performance* — *Noise*

TC6 - Revolutionary tools and methods *enabling practical design, analysis, optimization, & validation of technology solutions for vehicle system energy efficiency & environmental compatibility* — *Tools*

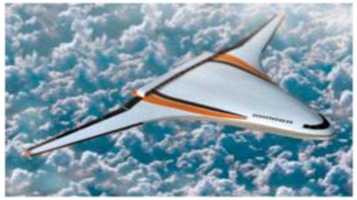


✓ *Quiet-Aircraft Subproject*

SFW N+3 Subsystem Concepts

.... broadly applicable to N+3 vehicle concepts

N+3 Vehicle Concepts



N+3 Subsystem Concepts

1. Tailored Fuselage
2. High AR Elastic Wing
3. Quiet, Simplified High-Lift — *Noise*
4. High Efficiency Small Gas Generator — *Noise* — *Core Noise*
5. Hybrid Electric Propulsion
6. Propulsion Airframe Integration — *Noise*

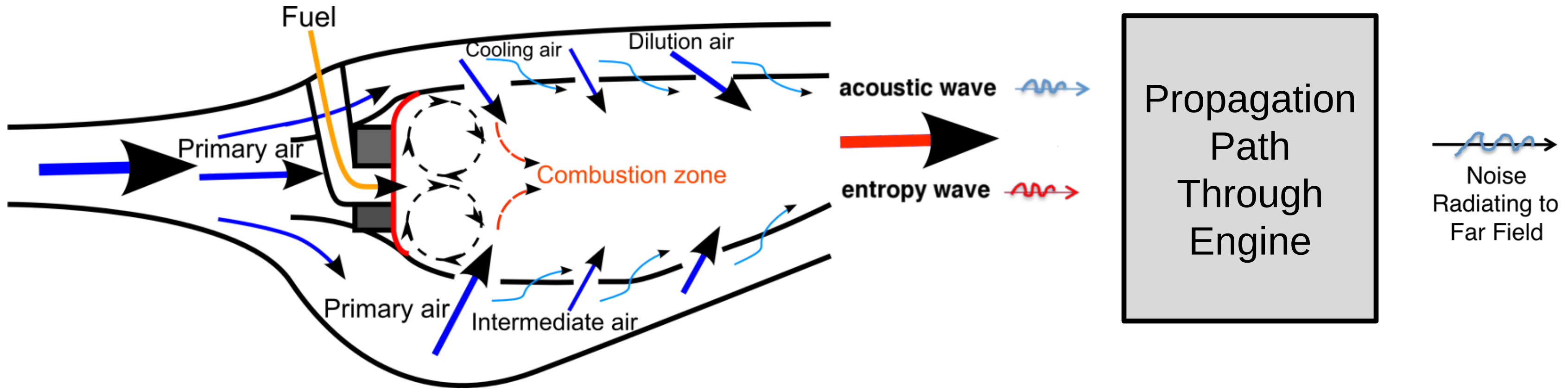
Near Term/Cross-cutting

7. Alternative Fuels
8. Tool Box (MDAO, Systems Modeling, Physics-Based) — *Tools*

Intermediate Impact

Core Noise
…. what are its components?

- Engine-Internal Propulsion Noise Other Than Fan and Jet
  - compressor noise – tonal in blade-passing frequency range (kHz)
  - combustor noise – low frequency (< 1 kHz) broadband
  - turbine noise – tonal in blade-passing frequency range (kHz)
- Combustor and Turbine Noise Most Important
- NASA SFW Emphasis on Combustor Noise
  - limited resources
  - judged to be most potential show stopper for noise reduction effort



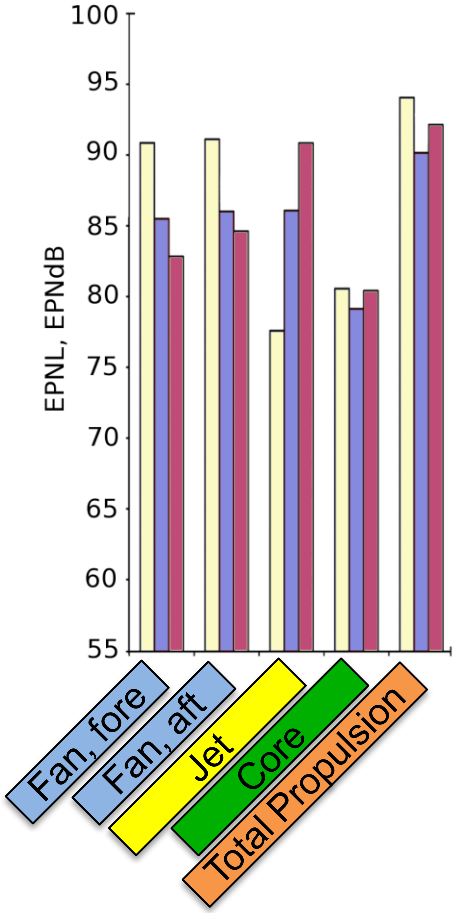
Must fully understand noise-source structure in combustor and the effects of propagation path through engine

Predicted N & N+1 Airplane Certification Levels

…. core noise becoming an important component of the total

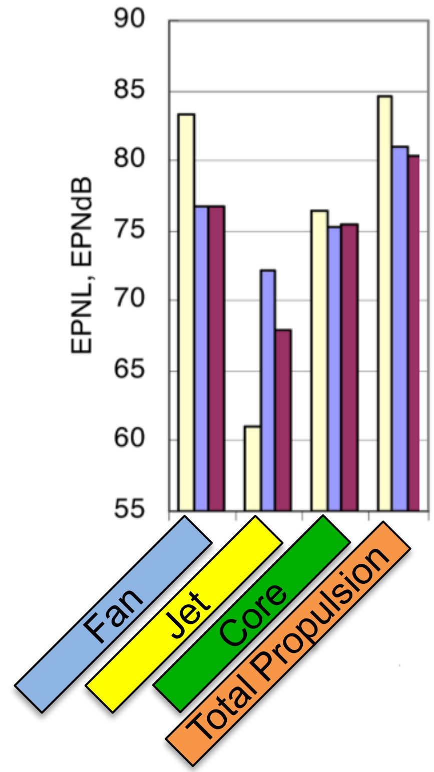
B737-800/CFM56-7B
Burley et al. NASA/TP-2011-215653

26,300 lbf
BPR = 5.1
FPR = 1.65
OPR = 32.8



Approach
Sideline
Flyover

Notional N+1 Aircraft
Berton et al. AIAA 2009-3144



23,000 lbf
BPR = 16
FPR = 1.3
OPR = 32

Relative importance of core noise is increased from N to N+1 generation

High-Efficiency Small Gas Generator

…. versatile core applicable to variety of propulsion systems/installations

Objective

Drag Weight TSEC Clean Noise

Explore and develop technologies to enable advanced, small, gas-turbine generators with high thermal efficiency

Approach/Challenges

Hot Section Materials

– *1500F HPC, 2700/3000F HPT blade/vane*

Tip/Endwall Aerodynamics

– *Minimizing losses due to short blades/vanes*

Fuel-Flexible Combustion

– *Fuel/Air Mixing/Stability Controls*

Decentralized Control

– *FADEC to networked to wireless*

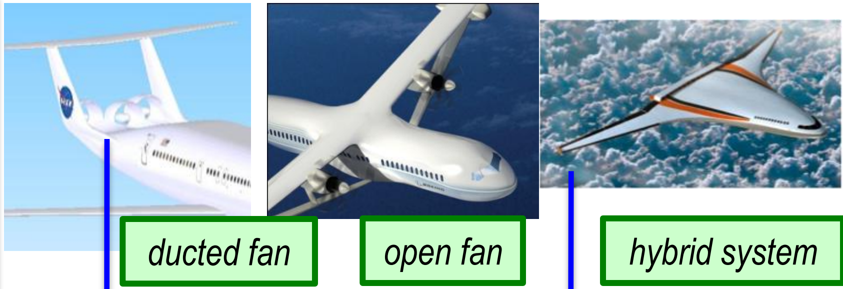
Core Noise

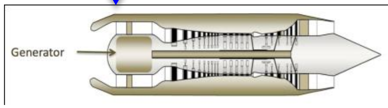
– *Understand and mitigate source noise (e.g., liners)*

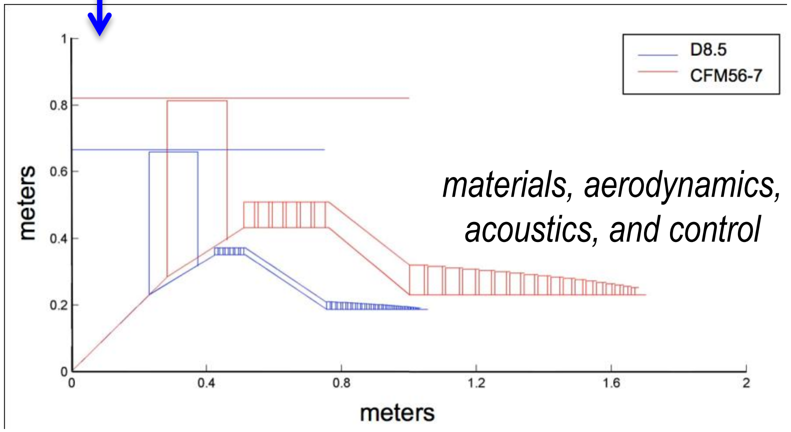
Benefit/Pay-off

– BPR 20+ *growth by minimizing core size*

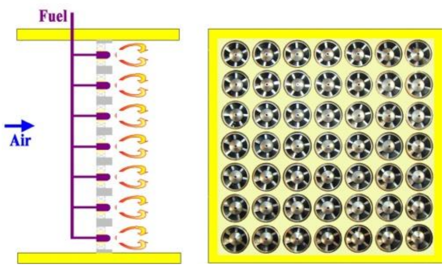
– *Low emission, fuel-flexible combustors with NOx reduction of 80% below CAEP6*







materials, aerodynamics, acoustics, and control



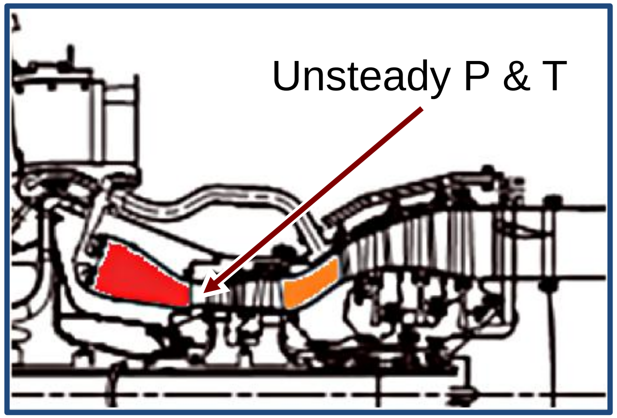
multi-point lean direct injection

High-Efficiency Small Gas Generator

… Quiet Aircraft Subproject focus and technical content

Noise | TC5

Focus: Improve understanding of the core noise generation process and implement noise-reduction technology to minimize the source and propagation



Technical Content:

Understanding Core-Noise Sources:

- **NRA**: "Acoustic Database for Core-Noise Sources," Honeywell Aerospace
  - full-scale turbofan engine (TECH977)
- **NRA**: "Measurement and Modeling of Entropic Noise Sources in a Single Stage Low-Pressure Turbine," University of Illinois Urbana-Champaign/University of Notre Dame
  - rig experiment and simulation
- **In-House:** Analysis of Existing Data
  - enhanced understanding and incremental improvement of tools
- **In-House:** Physics-Based Prediction Using URANS/LES (future activity)

Core-Noise Reduction:

- **In-House:** high-temp. low-weight CMC liners for broadband noise reduction

Focused N+3 work with intermediate impact as understanding is improved

Updated Turbine-Attenuation Factor

…. NASA/Honeywell EVNERT TECH977 engine-internal unsteady data

- EVNERT Program Full-Scale Turbofan Time-Series Data
  - true combustor-noise turbine-transfer function for TECH977 engine determined by using three engine-internal pressure sensors
  - updated turbine attenuation factor

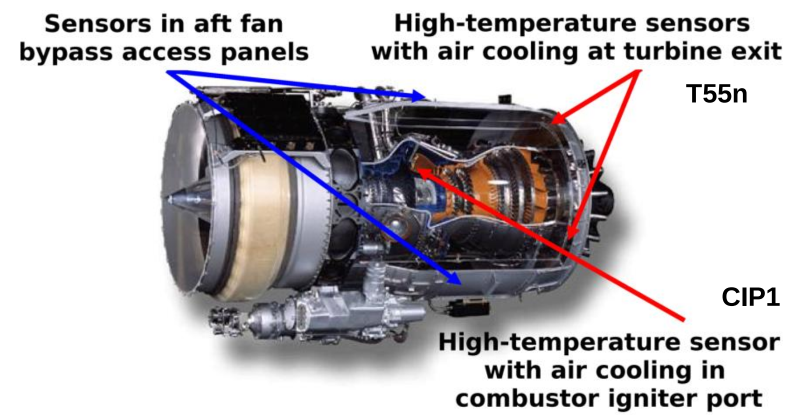
$$F_{TA} = \frac{0.8\zeta}{(1+\zeta)^2}$$

simplified Pratt & Whitney formula

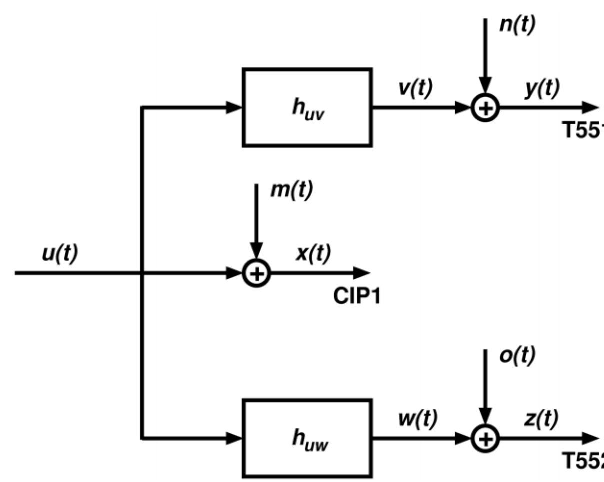
$$\zeta = \rho_{te} c_{te} / \rho_{ti} c_{ti}$$

impedance ratio across turbine

  - Hultgren AIAA 2011-2912
  - option in next release of ANOPP



Honeywell TECH977 Turbofan

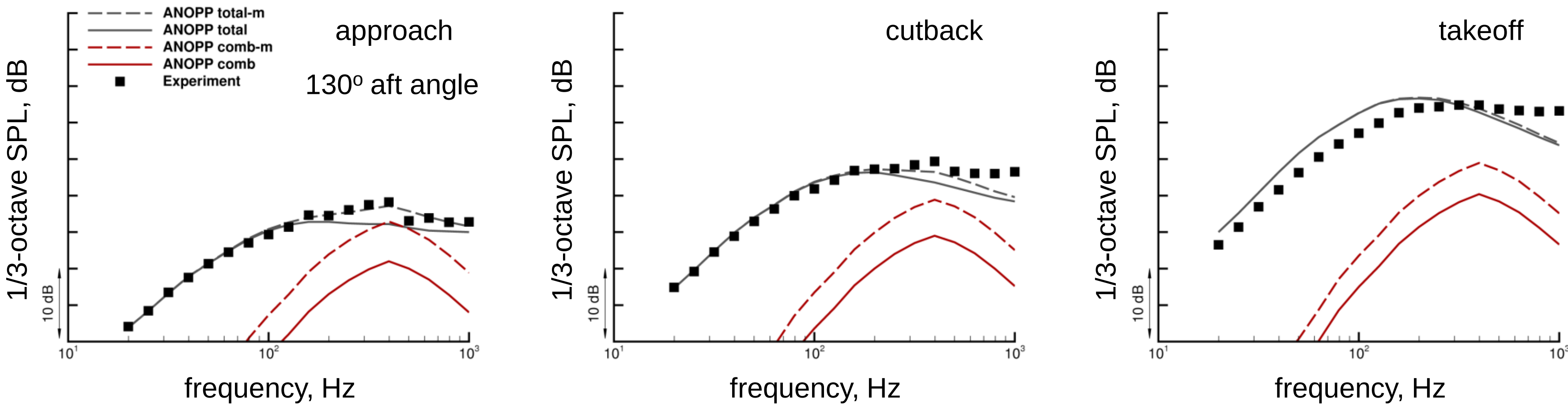


Source-Diagnostic Schematic

Source-separation techniques applied to real-engine data to aid modeling

Far-Field Comparison With ANOPP Predictions

…. total and combustor-component 1/3-octave SPL (EVNERT TECH977)



- AIAA 2011-2912 & AIAA 2009-3220
  - predictions post-corrected to use simplified P&W formula
  - modified predictions (dashed lines) are clear improvement
- New ANOPP/GECOR Module Attenuation-Formula Option

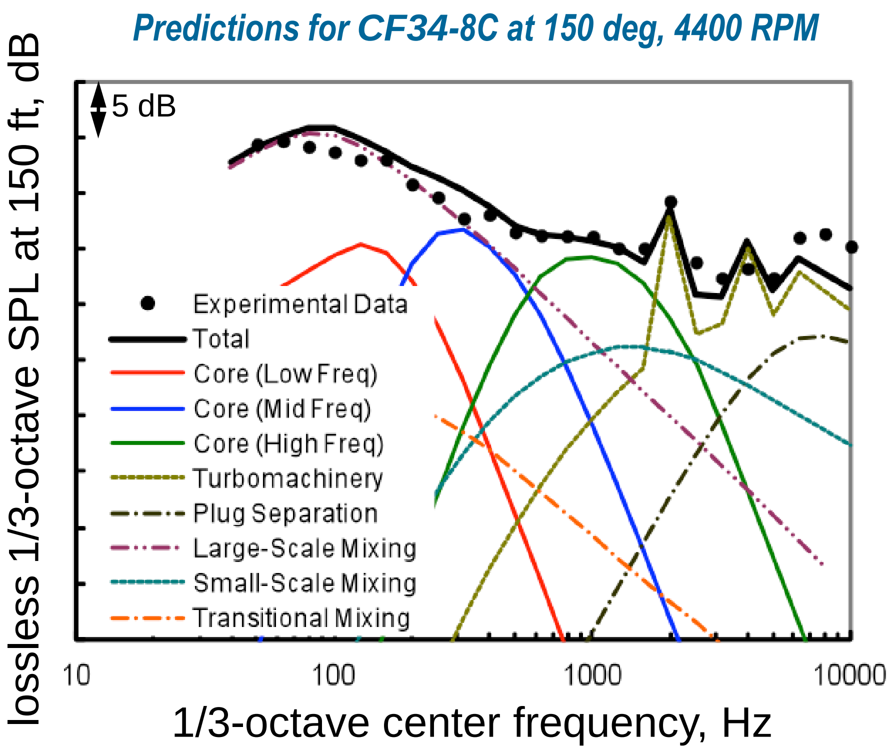
GE-option: $F_{TA} = \left(\dfrac{\Delta T_{des}}{T_\infty}\right)^{-4}$ PW-option: $F_{TA} = \dfrac{0.8\zeta}{(1+\zeta)^2}$

Substitution of simplified P&W formula improves ANOPP predictions

Stone et al. Empirical Combustor-Noise Model

…. empirical three-spectral-component model with roots in the QAT program

- NASA CR-2011-217026
  - model developed using CF6, CF34, CFM56 & GE90 static-engine data
  - multiple (3) spectral components assumed
  - frequency scaling based on combustor and core-nozzle dimensions
  - GRC/RTM MDAO branch



- GRC/RTA Acoustics branch preliminary assessment
  - potential improvement in prediction capability for GE (only) turbofans
- LaRC – future separate ANOPP module for combustor noise

Incremental improvements to ANOPP as understanding increases

NRA: Acoustic Database for Core-Noise Sources

…. Honeywell International, PI: Don Weir & Co-I: Bill Shuster

- 28-Month Effort (10/19/2011)

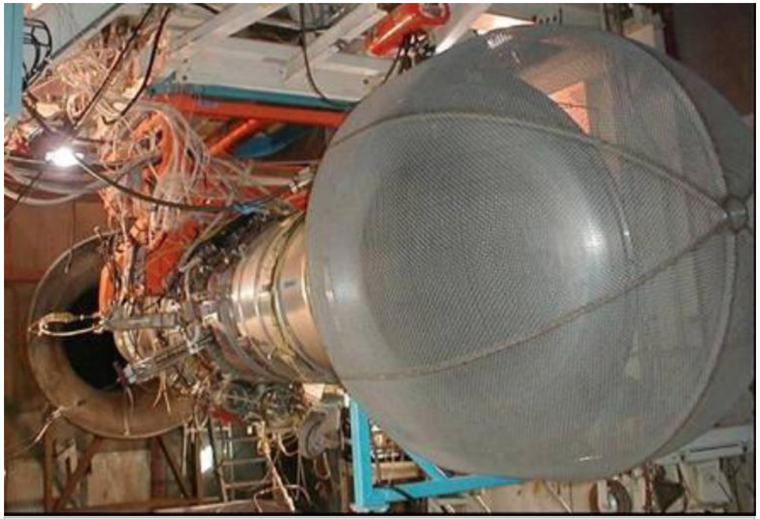
Key Research Points

Phase I

- significantly advance state-of-the-art for unsteady temperature measurements at real-engine conditions, high T & P
- unsteady temperature is very difficult to measure
  - sufficient frequency range

Phase II

- obtain unsteady temperature and pressure measurements in a TECH977 engine core
- hostile engine environment
- builds on EVNERT program



Honeywell TECH977 Turbofan in Test Cell

Impact

- better understanding of core-noise sources
- direct versus indirect noise
- intermediate updates to ANOPP core module
- theory and model validation

Understanding core-noise sources and propagation through engine core

TECH977 Instrumentation Layout

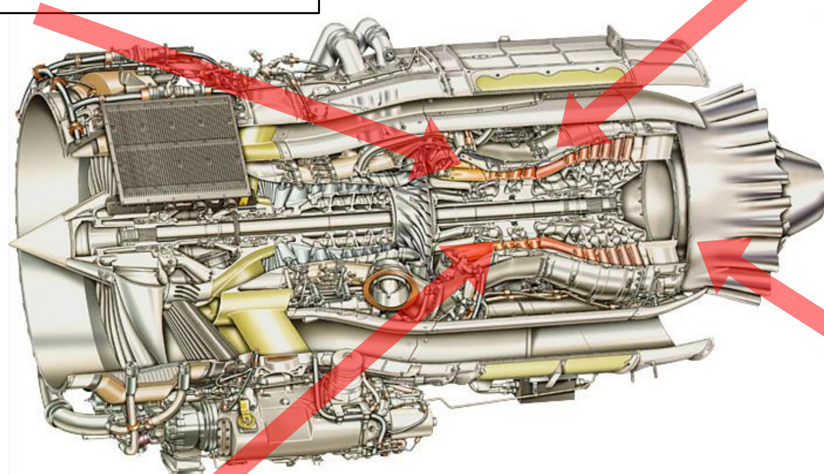
… combustor-noise instrumentation

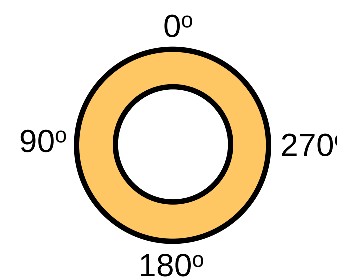
Honeywell

2 external microphones in test cell

LP Turbine Entrance @ 0° & 100°:
- 2 unsteady temp. axially spaced & offset by probe width
- 2 unsteady press. close to temp.

Portion of EVNERT circumferential array:
- 4 unsteady press. @ 0, 90, 180, 270°





Combustor cross section (looking aft)

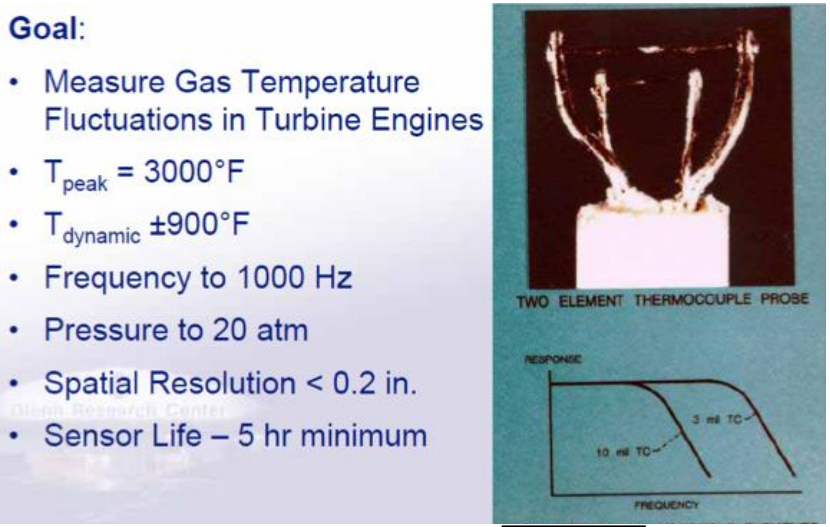
Combustor Exit @ 0° &100°:
- 2 unsteady temp. axially spaced & offset by probe width
- 2 unsteady press. close to temp.

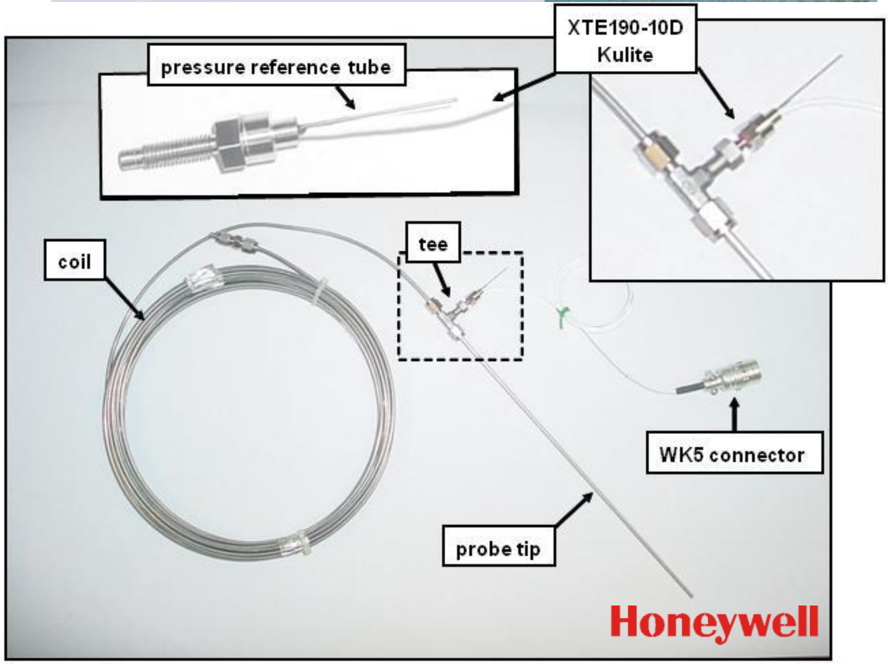
LP Turbine Exit @ 0° & 100°:
- 1 unsteady temp.
- 1 unsteady press.

Dynamic Gas Temperature and Pressure Sensors

… cooling and survivability are key issues

- NASA-Developed Dual-Wire Thermocouple Probe
  - each probe on traverse or in-out actuator for start-up survivability
  - each probe acquires 3 signals
    - AC from thin-wire thermocouple
    - AC from thick-wire thermocouple
    - DC from thick-wire thermocouple
  - frequency-compensation to obtain temperature time-series data
- Proven Semi-Infinite-Tube Unsteady Pressure Probe
  - N_2 purge flow
  - time-delay correction
- Risk Reduction: Burner Rig



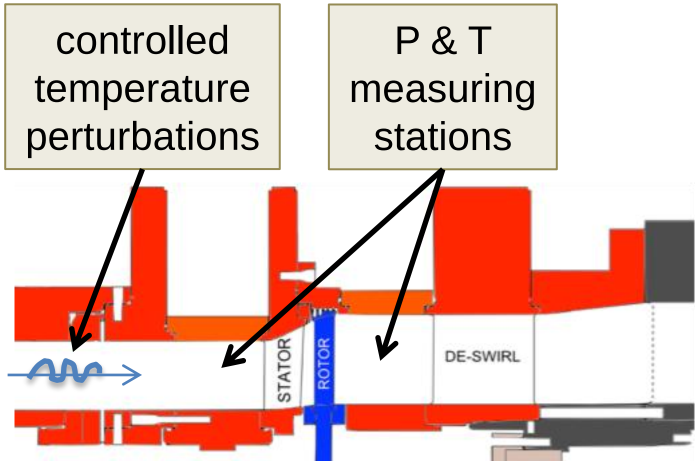


NRA: Measurement & Modelling of Entropic Noise Sources in a Single-Stage LPT – *PI: Daniel Bodony, UIUC & Co-I: Scott Morris, UND*

Three-Year Effort (6/15/2011)

Key Research Points

- turbine-rig test with controlled temperature perturbations
- steady and unsteady temperature and pressure through a realistic advanced-design turbine stage
- advancing testing state-of-art
- high-fidelity computations (LES) on the same geometry (synergy)



PR = 1.75 @ ADP

Impact

- experimental data will help identify direct versus indirect mechanisms
- comparison with computations will validate LES approach for core-noise analysis and design
- experimental and computational data will aid in development and validation of improved reduced-order models

Understanding core-noise sources – focused N+3 and intermediate impact

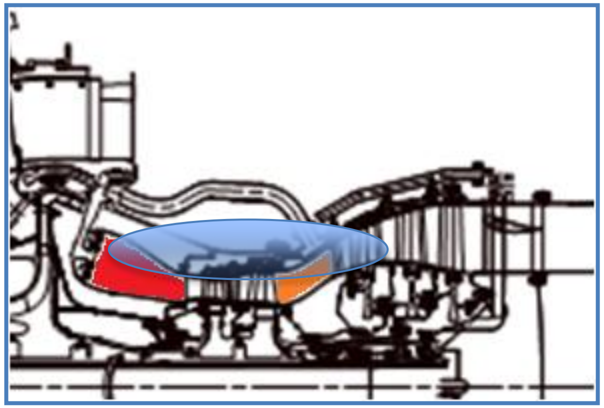
Ceramic-Matrix-Composite Liners for Core Noise

…. High-Efficiency Small Gas Generator N+3 Subsystem

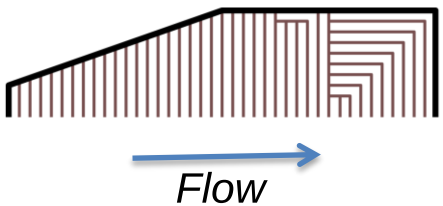
Noise | TC5

Ceramic-Matrix-Composite (CMC) Liners for Core:

- High-temperature light-weight liners for broadband attenuation



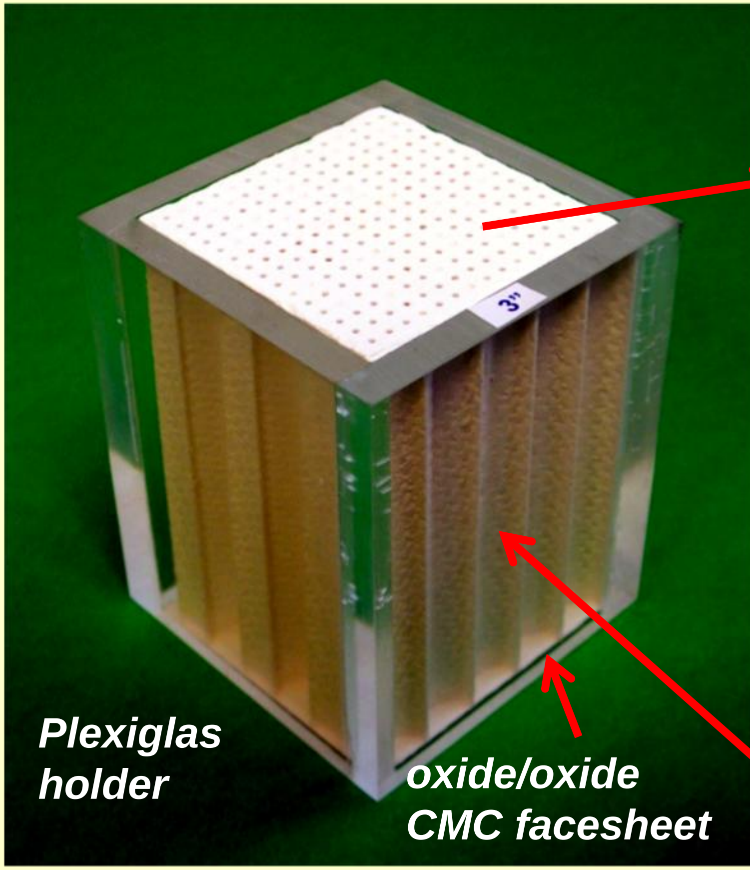
Notional cross section of variable-depth liner



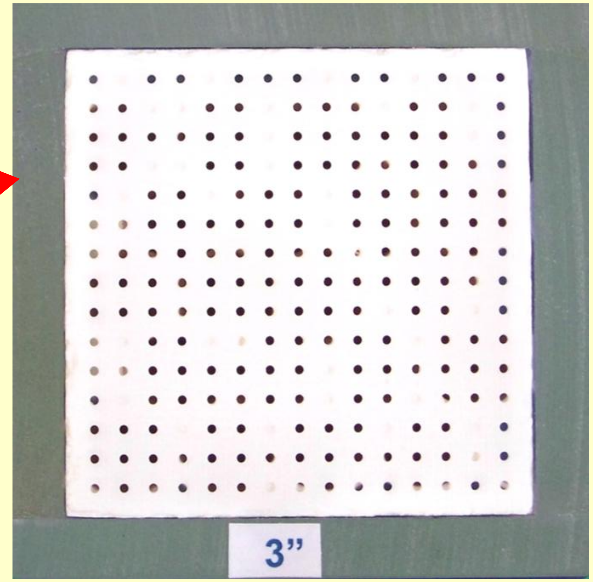
- NASA GRC and NASA LaRC are teaming to develop an acoustic liner containing channels of different lengths to provide broadband noise reduction over a typical range of 400 Hz to 3 kHz
- The channels (0.375” to 0.5” wide CMC honeycomb cells) will need to range in effective length from about 1.5” to 12”
- Fundamental research on effectiveness of core liners (TRL 2-3)
- TRL 4 demonstration

Acoustic Performance Characterization

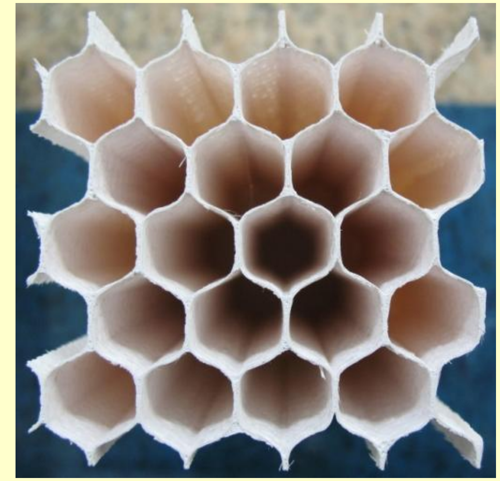
…. test article for the NASA LaRC Normal Incidence Tube (NIT)



3" depth NIT test article



2 x 2" perforated oxide/oxide CMC facesheet



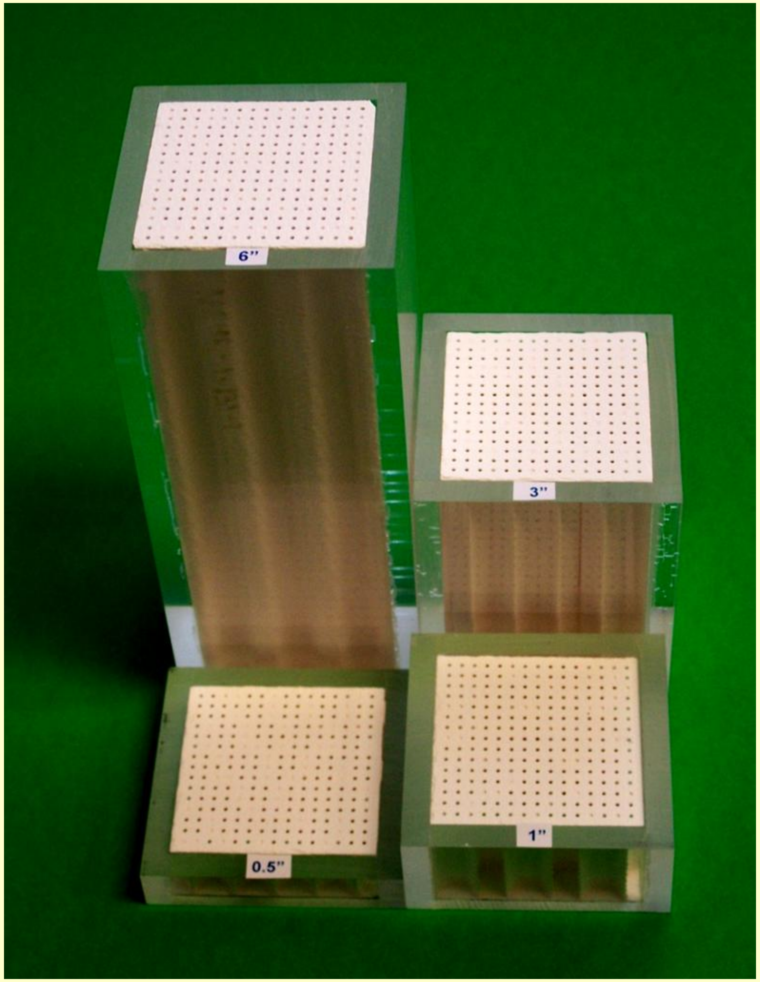
oxide/oxide CMC honeycomb core

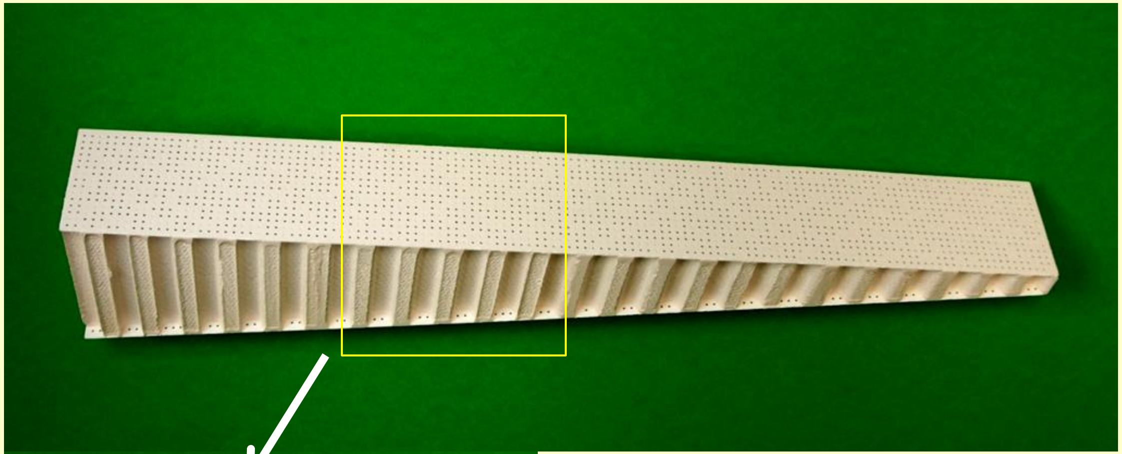
NASA Team:
Doug Kiser/GRC
Mike Jones/LaRC
J. E. Grady/GRC
L. S. Hultgren/GRC
C. J. Miller/GRC

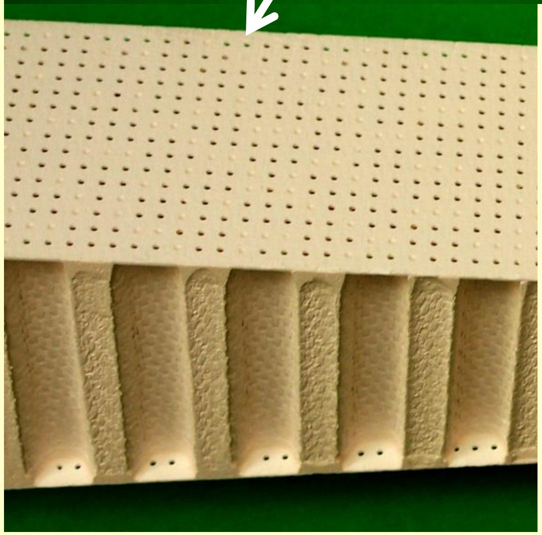
CMC: ceramic matrix composite
Fabricated by COI Ceramics, Inc. according to NASA specifications

Acoustic Performance Characterization

…. test articles for NASA LaRC liner facilities







Test article for Grazing Flow Impedance Tube (GFIT)

- *16" length*
- *0.5 to 3" depth*
- *both CMC facesheets are perforated – one will be covered when the other is subjected to grazing flow*

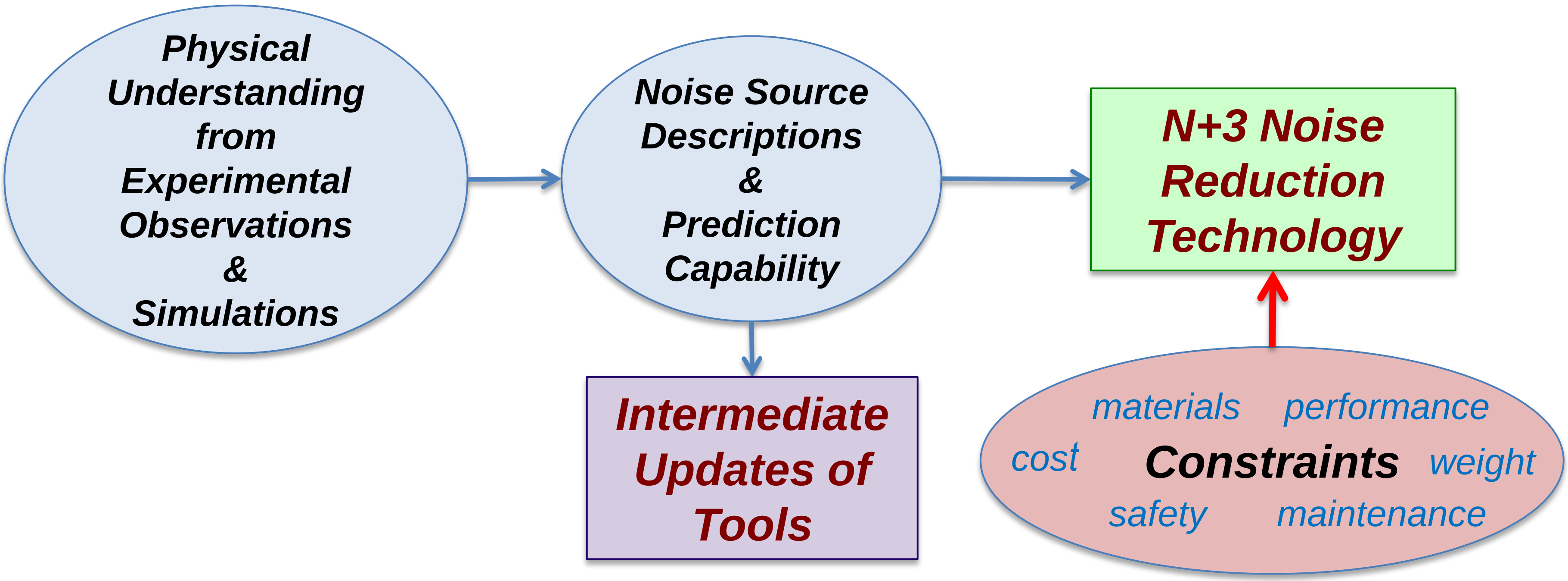
Test articles for Normal Incidence Tube (NIT) – 0.5, 1, 3, and 6" depth

CMC: ceramic matrix composite. Fabricated by COI Ceramics, Inc. to NASA specifications

Summary

…. core-noise research in support of N+3 goals

Noise | TC5



- Core Noise Must Be Addressed to Ensure N+3 Goals
- Focused Research Is Carried Out to Enable Advanced Subsystems That Meet NASA's N+3 Technical Challenges
- Noise-Prediction Tools Are Updated As Understanding Improves

TC5 – Reduce perceived community noise attributable to aircraft with minimal impact on weight and performance

NASA