DGEN Core Noise

Lennart S. Hultgren
NASA Glenn Research Center
Cleveland, OH 44135, USA

NASA GRC Team Members
Devin K. Boyle
Brenda S. Henderson

Acoustics Technical Working Group
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NASA Advanced Air Vehicles Program
Advanced Air Transport Technology Project

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INTRODUCTION / OUTLINE

Motivation

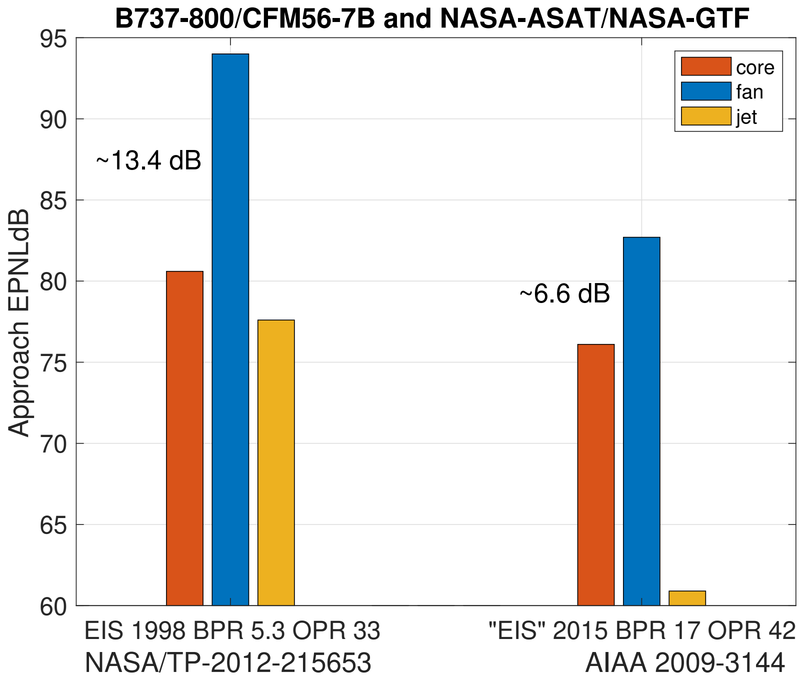
- Subsonic-Transport Airport-Community-Noise Reduction
- Propulsion-Noise Source Strengths Are Changing
- Impact of Design Trends on Combustor Noise

2019 DART Source-Diagnostic Test

- Continuation of 2017 DART Core/Combustor-Noise Test – AIAA 2018-3281
- Overall More Extensive Acoustic Instrumentation
  - 93 simultaneous high-data-rate channels
  - 24-microphone farfield (overhead), 61-microphone sideline, and 8-ITP core-nozzle-exit arrays
- GT2020-14194, NASA/TM-20205008042, …

PROPULSION-NOISE TRENDS ILLUSTRATION

Relative Strength of Propulsion-Noise Sources Are Changing



Illustrative Example

- Two NASA System Studies
  - Modern reference case: B737/CFM56-7B
  - Advanced NASA concept: ASAT/GTF
- BPR Increase Reduces Jet Noise
- Fan Is Dominant Noise Source:
  - Dominance halved between studies
  - Trends are likely to be continued
- Further Propulsion-Noise Reduction Is Essential Due to Traffic Increase
- Combustor a Future Limiting Issue

COMBUSTOR ACOUSTIC POWER SCALING

- ANOPP-GECOR Direct-Combustor-Noise Acoustic Power Π Scaling

$$\Pi \propto w_3 \times (\Delta T / T_3)^2 \times (OPR)^2 \times FTA$$

  - w_3 combustor mass flow rate; $\frac{\Delta T}{T_3}$ total temperature increase over inlet total temperature
  - OPR overall total pressure ratio: $\frac{P_3}{P_2} \approx \frac{P_3}{P_0}$; FTA turbine attenuation factor

- Idealized Assumption – Isentropic Compression

$$\Pi \propto w_{3x} \times (\Delta T)^2 \times (OPR)^\beta \times FTA\,, \quad w_{3x} = w_{3c}\,, \beta = 8/3.5$$

Corrected mass flowrate based on combustor inlet conditions

$$w_{3x} = w_3\,, \beta = 5/3.5$$

Corrected mass flowrate based on fan-face conditions

  - w_{3x} decreases and OPR increases for future compact high-OPR cores
  - ΔT depends on fuel heating value of combustion -> no change
  - FTA effects could be lessened due to reduced turbine solidity -> further increase

- Indirect Noise Could Also Become Important Due to Design Changes

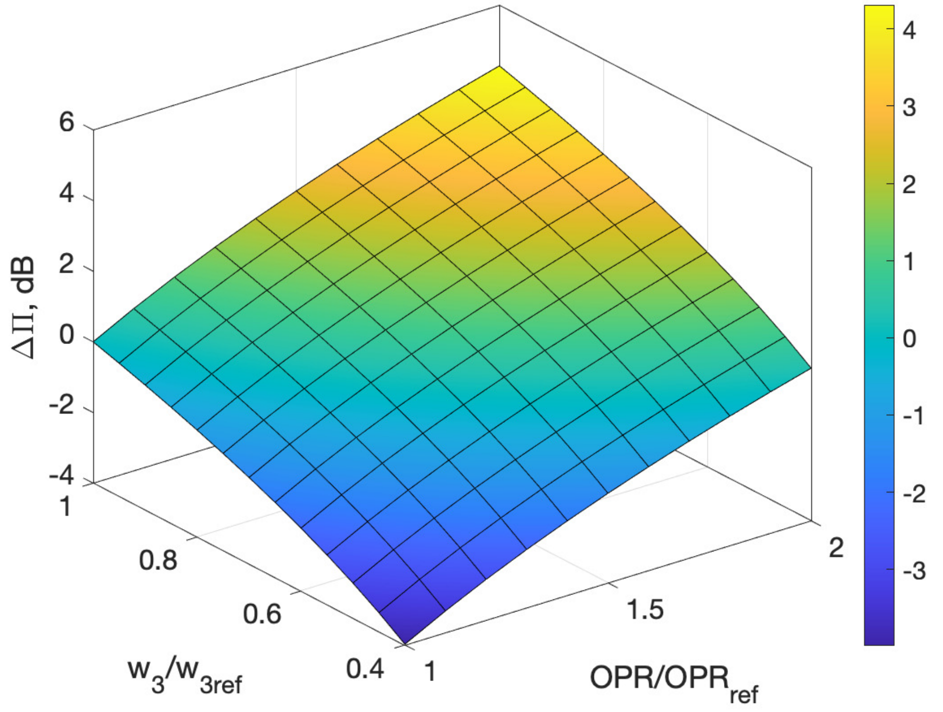
ACOUSTIC-POWER-SCALING INSIGHTS

Desired ~2035 EIS SAT Compact Core Characteristics (tentative)

- Double OPR & Reduce Core Corrected Mass Flowrate from ~ 6 to 2.5 lbm/s

Combustor-Noise Impact

- Increase, $\Delta\Pi$: +0.5 dB To +4.3 dB
- Essentially Unchanged At Best
- Not Good Enough If Further Noise Reduction Is Desired

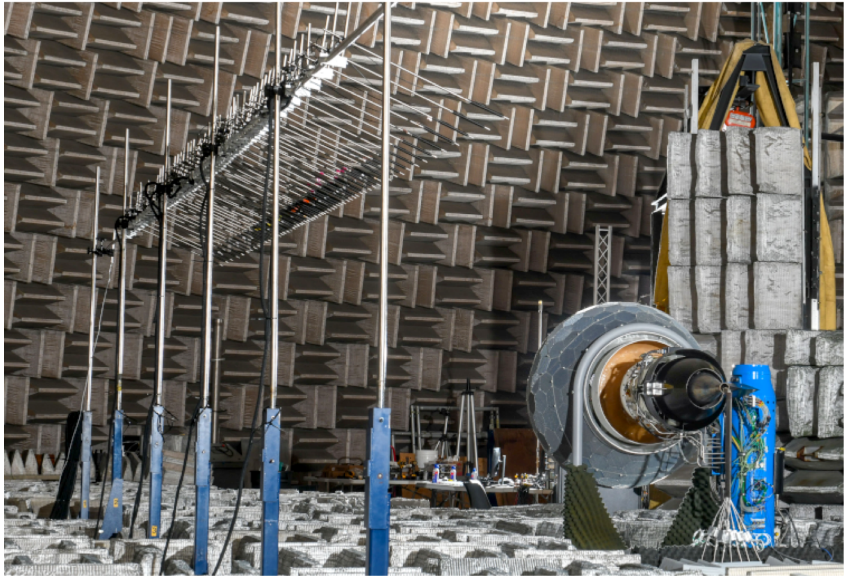


Other Uncertainties

- Turbine Attenuation Change
- Indirect-Noise Increase
- Thrust-Class Effects

2019 DART SOURCE-DIAGNOSTIC TEST

Combustor-Noise Source and Mitigation Research

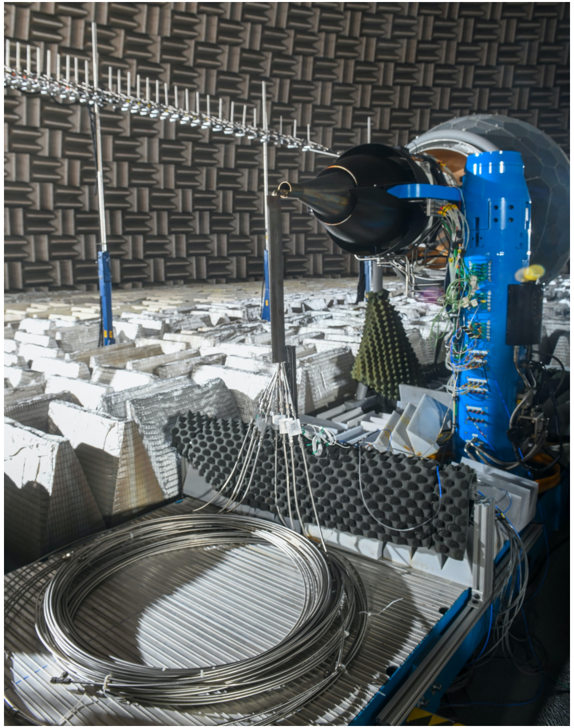


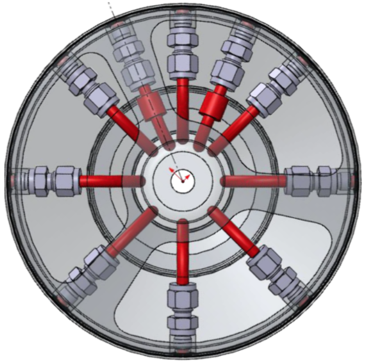
DART Testbed in AAPL (Anechoic) Facility

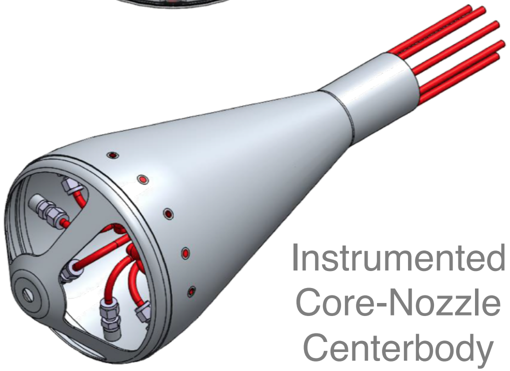
- NASA GRC DGEN Aeropropulsion Research Turbofan (DART) Testbed
  - DGEN 380 – 500-lbf-thrust-class GTF
  - BPR = 7.6 & fan-gear-ratio = 3.32
  - Small, but relevant aeroacoustics
- NASA GRC Aero-Acoustic Propulsion Laboratory (AAPL)
  - Anechoic dome – wedges on walls and floor
- Combustor-Source Characterization and Noise Propagation to Farfield
  - Farfield and sideline microphone arrays
  - Engine-internal sensors at core-nozzle exit

CORE-NOZZLE-EXIT 8-ITP ARRAY

8 Differential Kulite Sensors in Infinite-Tube-Probe Arrangement







Instrumented Core-Nozzle Centerbody

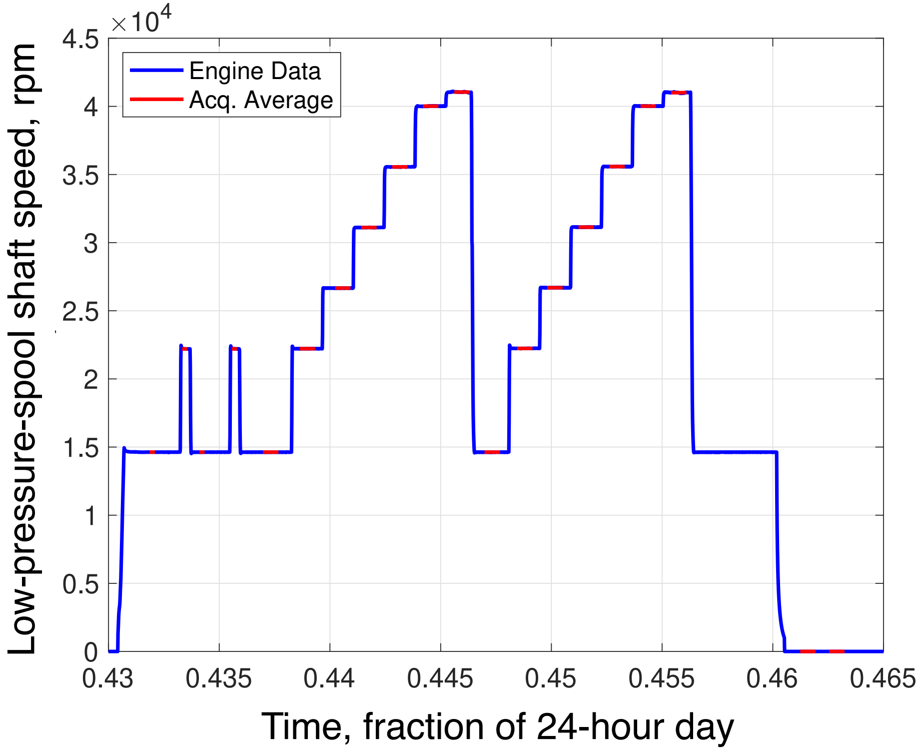
DATA ACQUISITION AND TEST POINTS

Data Acquisition

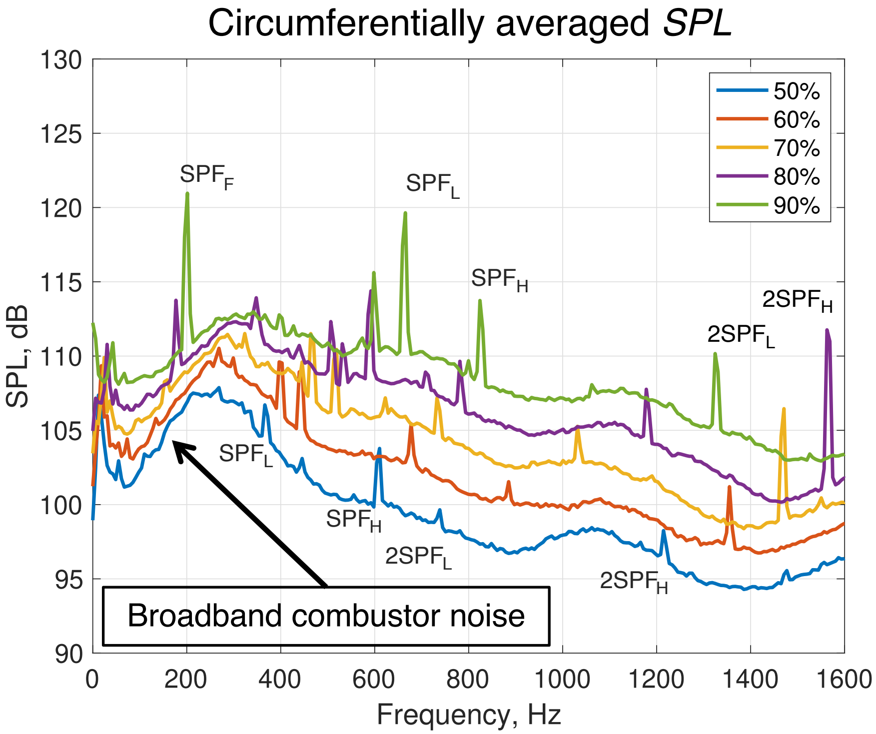
- 93 Channels Simultaneously
- 100 kHz Rate, 60 s Duration
- 24-bit ADC System
  - NI4499/8 – LabVIEW controlled
- Mean-Line & Ambient at 1 Hz
  - Engine data system

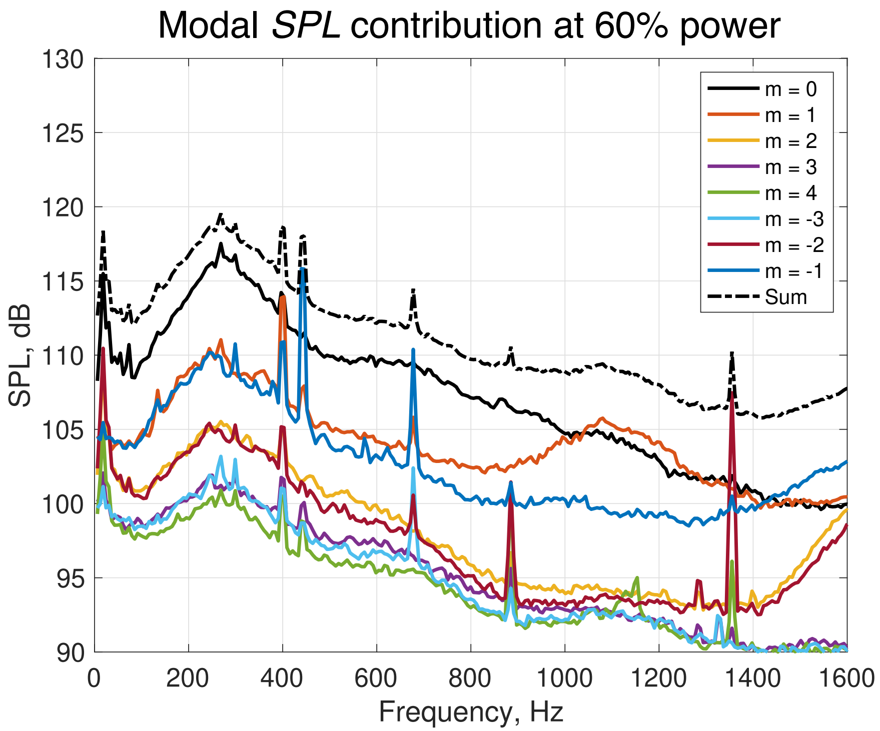
Test Points

- FADEC/ECU in Automatic Mode
- Data at Sequential Power Settings
  - Idle (33%), 50%, 60%, …, 90%, Max(T_{amb})
  - 120 s dwell time at each point
- Background Measurements



CORE-NOZZLE-EXIT ITP *SPL*

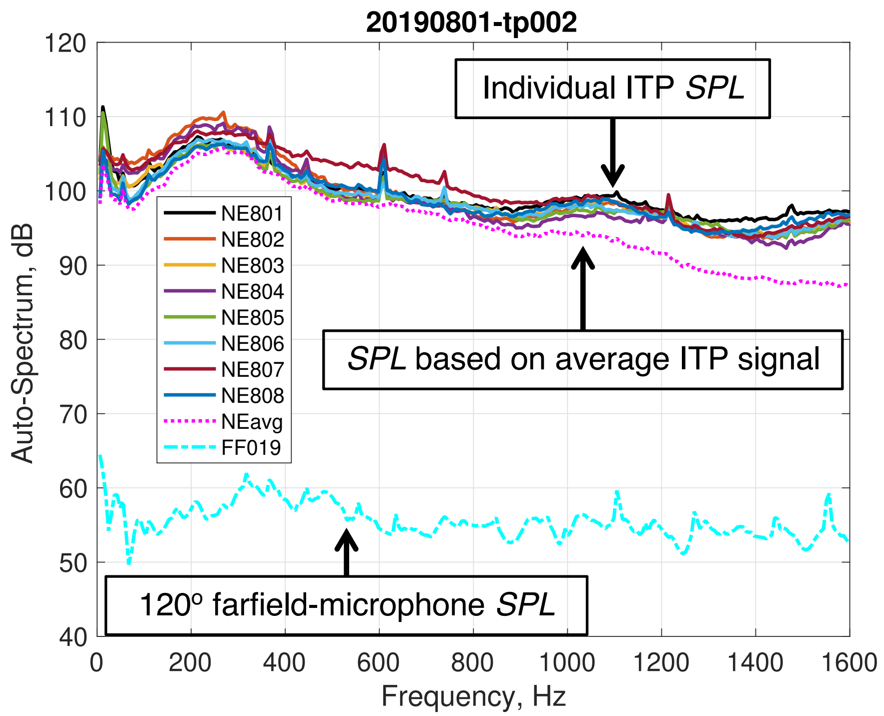




- Broadband and SPF Tones
- Plane Wave Dominates Below ~1 kHz

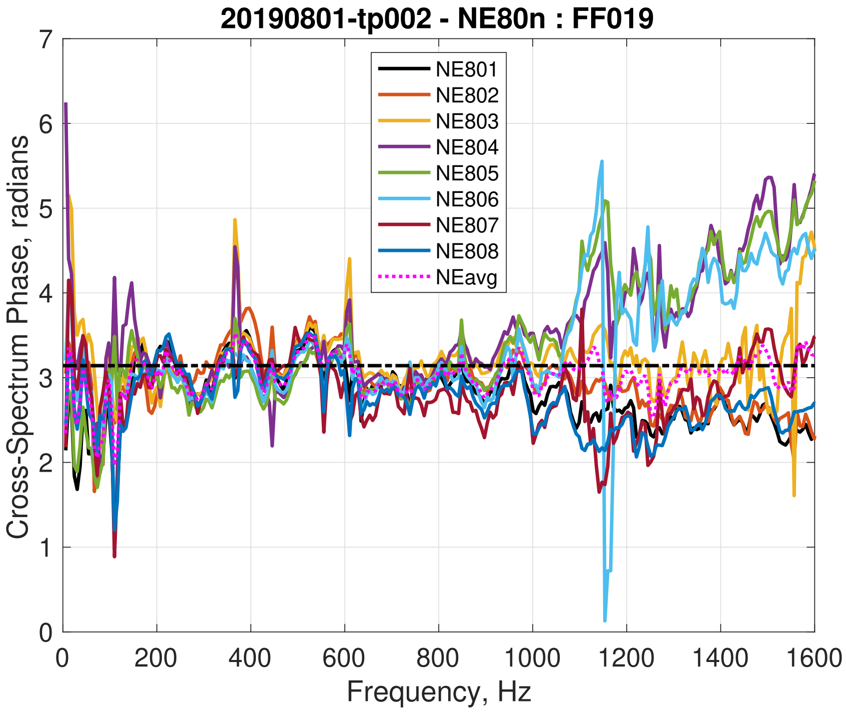
Boyle et al. GT2020-14194

ITP AND 120º FARFIELD *SPL* AT 50% POWER



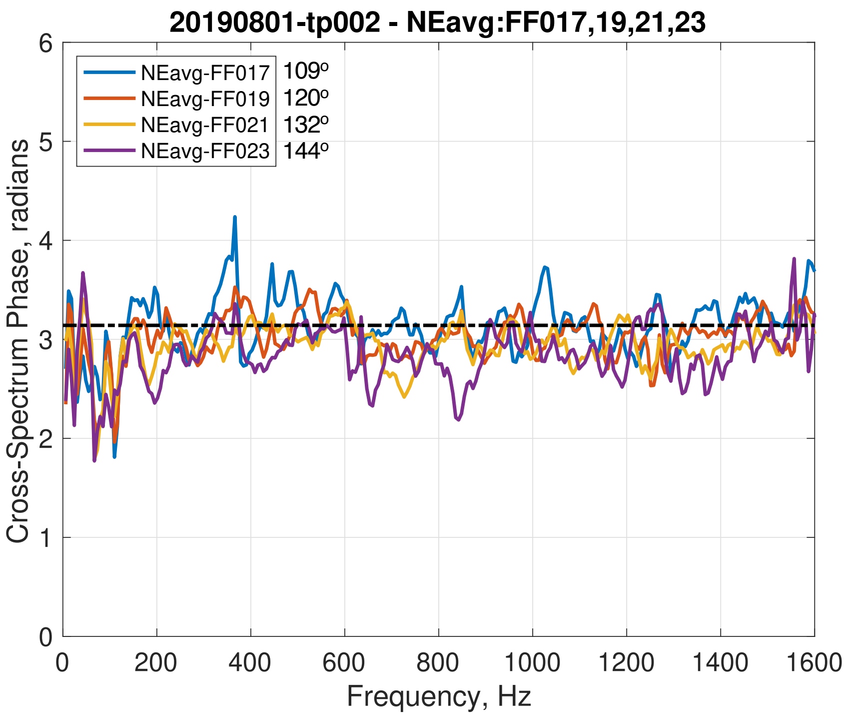
- 8 ITPs and 120º Farfield Microphone
- Solid Lines Denote Individual ITP *SPL*
- Dotted Cyan Line: Farfield Microphone
- Dotted Magenta Line: Average ITP Signal
- Average-ITP-Signal *SPL*:
  - Lower envelope up to about 600-800 Hz
  - Afterward, trends away downwards
  - Represents plane-wave component
- Plane Wave Dominates Below ~1 kHz
- First Azimuthal-Mode Cut-On ~800 Hz

ITP:FARFIELD-MIC CROSS-SPECTRUM PHASE



- 50% Power Setting
- 8 ITPs and 120° Farfield Microphone
- Solid Lines Denote Individual ITP Phase
- Dotted Magenta Line: Average ITP Signal
- Black Dot-Dash Line: Phase = π
- Time-of-Flight Adjustment: 29.98 ms
  - Based on microphone radial distance
  - ITP sense line adjustment: 3.54 ms
  - Additional adjustment: -0.20 ms
  - Curves qualitative horizontal before cut-on
  - Signals are adequately aligned
- First Azimutal-Mode Cut-On ~800 Hz

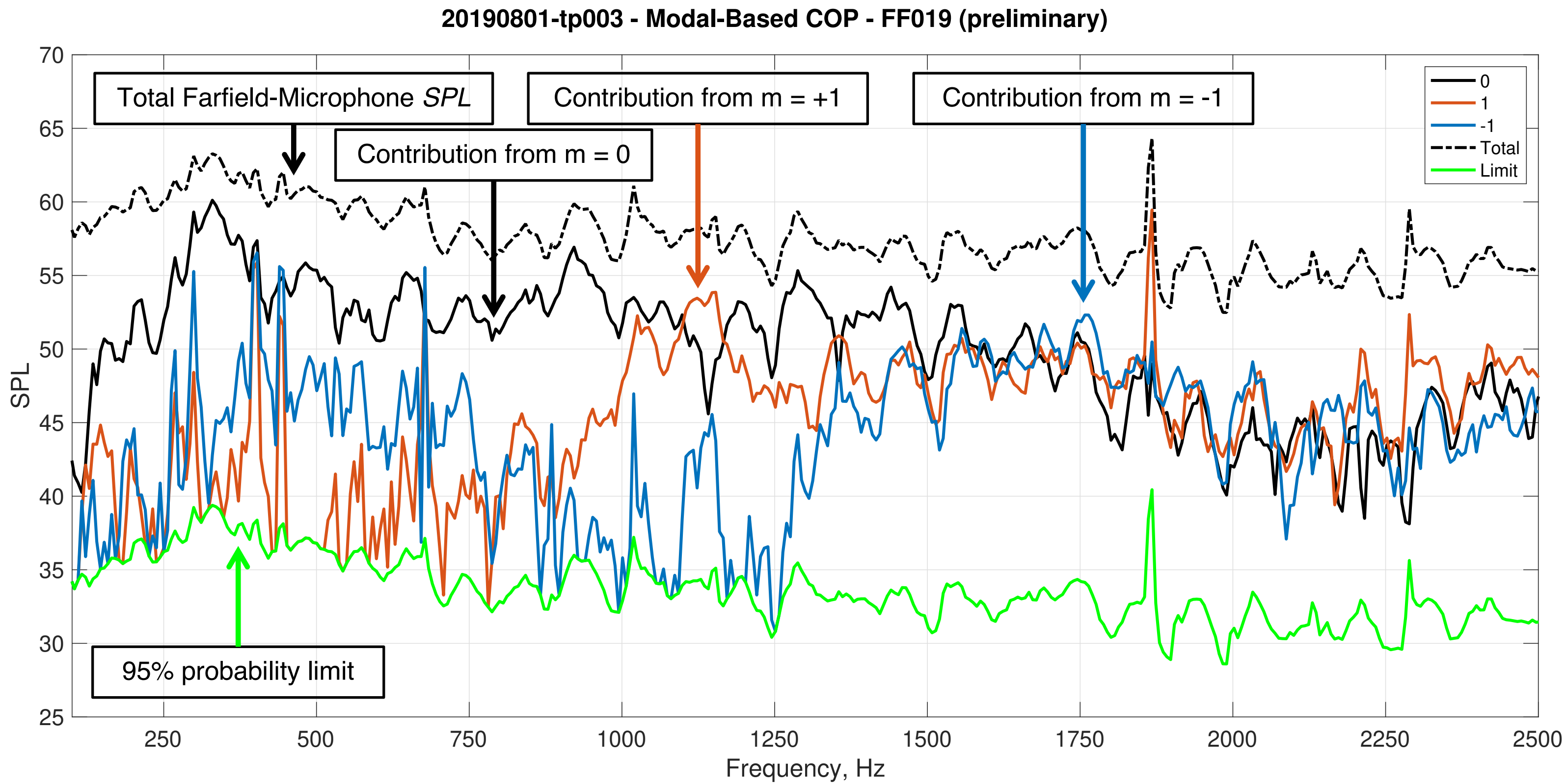
ITP:FARFIELD-MIC CROSS-SPECTRUM PHASE



- 50% Power Setting
- Average ITP signal and 4 Microphones
- Polar Angles: 109º, 120º, 132º and144º
- Solid Lines: Individual Microphone Phase
- Black Dot-Dash Line: Phase = π
- Time-of-Flight Adjustment Applied
  - Microphone radial distance & ITP sense line
  - Additional adjustment: -0.20 ms for all cases
- Alignment Procedure Works Well
  - For frequencies and polar angles of interest
- Average ITP Signal Equivalent to m = 0

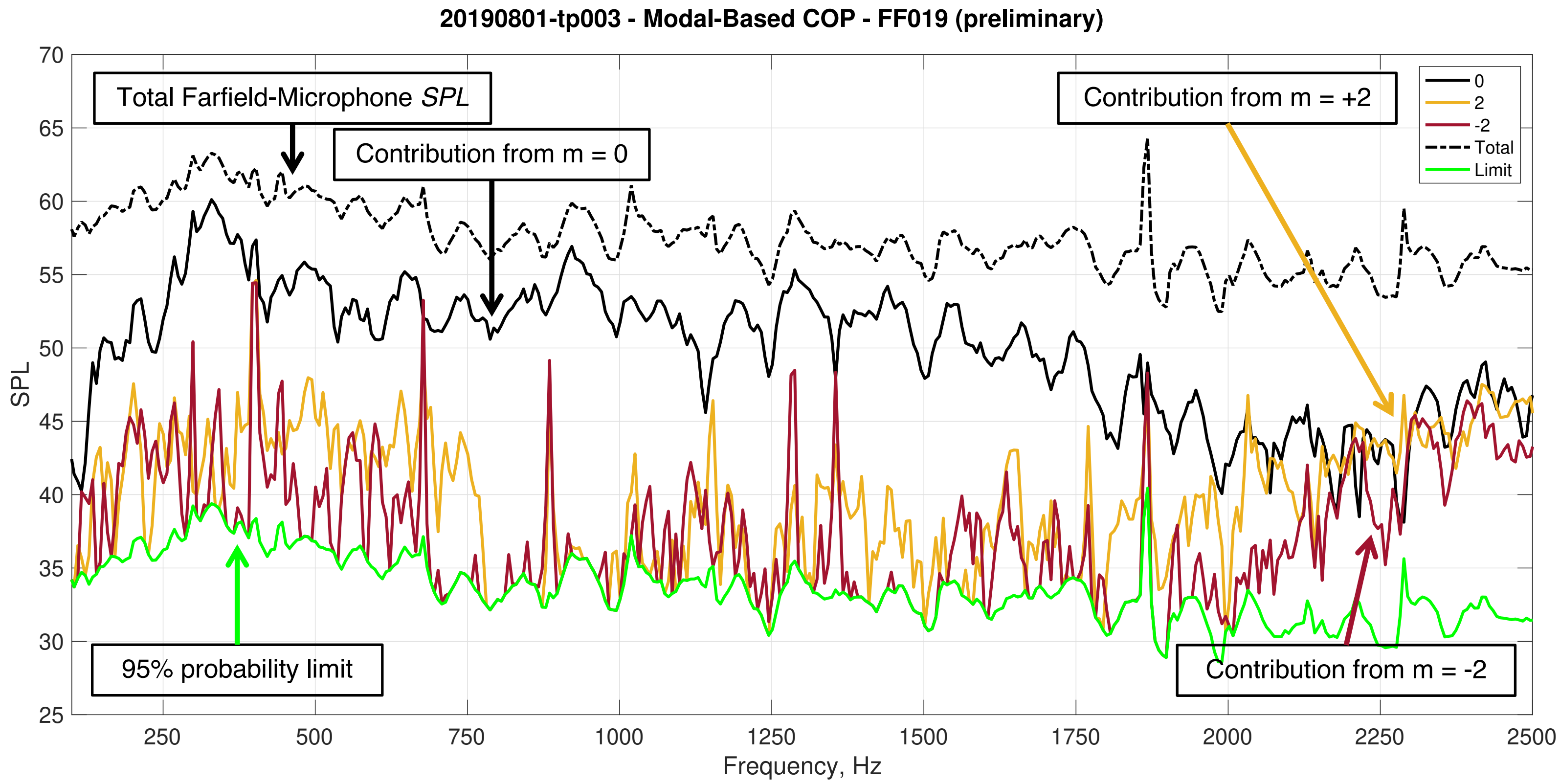
MODAL-BASED COP – 120º FARFIELD @ 60%

Only m = 0 and m = ±1 contributions are shown



MODAL-BASED COP – 120º FARFIELD @ 60%

Only m = 0 and m = ±2 contributions are shown

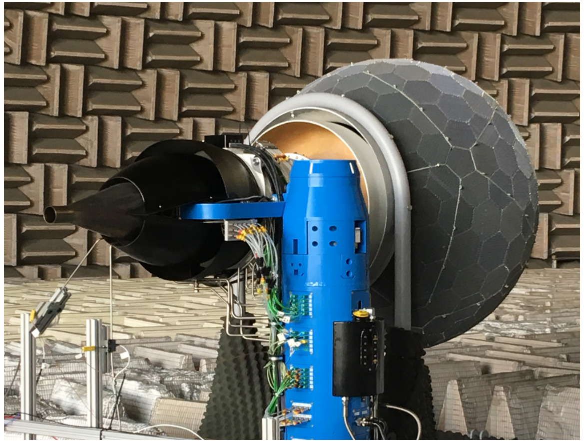


SUMMARY

- Compact-Core-Design Implication: At Best, Same Combustor-Noise Level

➡ Limited Room for Further Propulsion-Noise Reduction

- Need:
  - Continued examination of scaling laws for core/combustor acoustic power (active)
  - Concepts, design tools, and testing for compact, lightweight, high-temperature broadband acoustic treatment (on hold)
  - Evaluation/development of advanced source-separation methods under real-engine testing conditions (active)



DGEN Aeropropulsion Research Turbofan

- Modal-Based Source-Separation Techniques – In-House, 2019 DART-SDT Data
  - Based on ideas from Davis & Bennett (AIAA 2011-2830, AIAA J. Vol. 53 2015)
- Linear-Phased-Array Source-Separation Techniques
  - 2019 DART-SDT data shared with Brian J. Tester (Aero-Acoustics Research Consortium)

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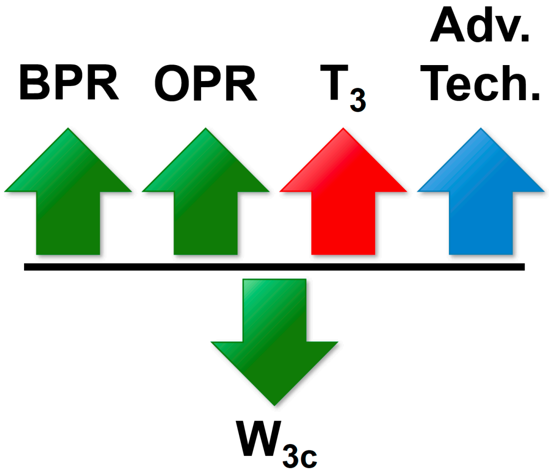
AIRPORT-COMMUNITY NOISE

Takeoff and Landing Noise: an Airport-Environmental Impact Issue

- Tremendous Progress Since 1960s
- Air Traffic Is Predicted to Increase
- Further Noise Reduction Is Essential
- Many Noise Sources
- Airframe and Propulsion Noise:
  - Slats, flaps, landing gear, wing and tail
  - Fan, core and jet
- Core Noise:
  - Compressor, combustor and turbine
  - Combustor noise likely a future issue

IMPACT OF DESIGN TRENDS ON CORE NOISE

Trends



- High BPR and OPR for Performance
  - Compact high-OPR core
- High OPR Implies High T_3 – Impacts Emissions
  - Lean-Lean, Fuel-Flexible Combustors
- Lean Combustion – Thermo-Acoustic Instability Risk
  - Advanced Technologies for Suppression
- Highly-Loaded, Low-Solidity Turbine Stages
- Low FPR and Advances in Fan-Noise Mitigation

Impact

- Reduction of Other Propulsion-Noise Sources
- Potential Increase in Combustor-Noise Source Strengths
- Less Combustor-Noise Attenuation by Turbine

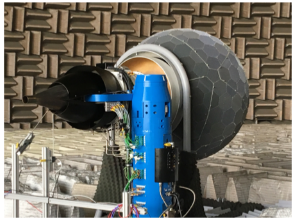
NASA CORE/COMBUSTOR-NOISE RESEARCH

Objective: Significantly Reduce Future Airport-Community Noise

- Align with NASA's Four Key Technologies – Small Core Gas Turbine (risk reduction)
- Improve Engineering Models for Prediction (1970s/1990s Models)
- Enable Mitigation Strategies at Early Design Stage

Approach: Core/Combustor-Noise Source and Mitigation Research

- Lightweight, High-Temperature Broadband Treatment (on hold), with LaRC
- Advanced Source-Separation Techniques to Extract Combustor Noise from Static-Engine Test Data (active)
- DGEN Aeropropulsion Research Turbofan (DART) Testbed (on hold)
- Continued Examination of Scaling Laws for Acoustic Power (active)



Core/Combustor Noise Must Be Addressed for Advanced-Concept Engines

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