Core/Combustor-Noise Baseline Measurements for the DGEN Aeropropulsion Research Turbofan

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NASA Advanced Vehicles Program
Advanced Air Transport Technology Project
Aircraft Noise Reduction Subproject
Outline

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3. Test Scope
4. Repeatability and Comparison with Previous Results
5. Coherence Techniques and Results
6. Coherent Power and Coherence at Mid- & Far-field Locations
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Core/Combustor Noise – DART Facility

Core Noise Becoming More Important

- Turbofan design trends, engine-cycle changes, and noise-mitigation advances are expected to reduce other propulsion noise sources
- Emerging lean-combustor designs could increase combustor noise level; Also less transmission loss due to fewer wide-chord blades
- Airframe, combustor and fan noise (in no particular order) need reduction to meet future noise goals

Objectives for Initial 2017 Core Noise Testing

- Baseline core-noise acoustic measurements
- Comparison with 2014 DGEN test results
- (Ongoing) Development/Evaluation of measurement and noise-mitigation techniques
DART Core/Combustor-Noise Test Experimental Setup

- 7 farfield microphones at an average of 38 ft (∼ 51 core-nozzle diameters) with polar angle range: about 110° to 140°
- 1 midfield stand-mounted microphone (MF101)
  - 130° direction, engine-center height, 10 ft distance (∼ 13.5 core-nozzle diameters)
- 2 infinite-tube pressure sensors (ITPs) at core-nozzle exit
  - NE801 (6 o’clock) and NE802 (7 o’clock) azimuthal position
- Acoustic data acquired simultaneously
- Engine performance data recorded by DART engine-control system
Core Exit Measurement Locations

- Kulite XCS-190, 10 psi differential
- 50:1 ratio - tube length after:ahead of sensor
Engine RPM Profiles and Test Points

- **FADEC in automatic mode**
- **Holds RPM extremely steady**
- **Each run: idle to max power and back**
- **60 s per test point (120 s total dwell)**

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<th>Point #</th>
<th>Power, %</th>
<th>Point #</th>
<th>Power, %</th>
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- **3.32 fan gear ratio**
- **14 fan blades**
- **38 low-pressure turbine (LPT) rotor blades**
Background Noise/Measurement Repeatability, 33% $N_{1C}$

- Combustor broadband noise range $< 1$ kHz
- Excellent measurement repeatability
Comparing Core-Exit and Midfield SPL to 2014 Results

- Combustor broadband noise range $< 1$ kHz
- Comparable ITP levels for $f \leq 1$ kHz
- 2014 12.2 Hz SPL rescaled to 6.1 Hz binwidth
- 2014 MF results adjusted to 10 ft distance ($r^2$)
- MF broadband levels are in good agreement
**SPL Variation with Engine Power**

- 6 o’clock & 7 o’clock ITPs
- Midfield Microphone at 130°
- Farfield Microphone at 131°
- Fan BPF and harmonics
- Unclear reason for haystack around 2BPF<sub>F</sub>
- No clear evidence of ITP-tube vortex shedding
Coherence Techniques Used to Educe Core-Noise Components

• Direct measurement of core noise made more difficult due to presence of (often higher level) jet noise
  • Core noise is masked by jet noise during static tests at most power settings
  • Forward-flight effects reduce jet noise more than core noise in flight
• Coherence techniques allow identification of mid- and far-field core-noise components
• Two-signal source separation leads to eduction of core-noise constituents

\[ G_{vv} = \gamma_{xy}^2 G_{yy} \]

where:

- \( G_{vv} \) - Core-noise component
- \( \gamma_{xy}^2 \) - Magnitude-squared coherence
- \( G_{yy} \) - Total-noise signal
ITP Coherence Variation with Engine Power

- Coherence level below limit meaningless
- Shaft Passing Frequencies (SPF)
- Combustor broadband noise region identified
- Plane wave mode: $m = 0$
- Up to about 450 Hz at 60%
- Range increases with power
Mid/Farfield Coherent Power & Coherence at 60% $N_{1C}$

- 6 o'clock & 7 o'clock ITPs used as reference for 2-signal method
- Anything below statistical limit meaningless
- Combustor noise ($m = 0$) detected up to about 500 Hz using either reference ITP
- 2s-method with 7 o'clock ITP detects second broadband-noise range, possibly ($m = \pm 1$)
- 6 o’clock & 7 o’clock ITPs used as reference for 2-signal method
- Anything below statistical limit meaningless
- Combustor noise \((m = 0)\) detected up to about 500 Hz using either reference ITP
- 2s-method with 7 o’clock ITP detects second broadband-noise range, possibly \((m = \pm 1)\)
• 6 o’clock & 7 o’clock ITPs used as reference for 2-signal method
• Anything below statistical limit meaningless
• Combustor noise ($m = 0$) detected up to about 500 Hz using either reference ITP
• Weak evidence of second broadband-noise range, possibly ($m = \pm 1$)
Mid/Farfield Coherent Power & Coherence at 90% $N_{1C}$

- 6 o'clock & 7 o'clock ITPs used as reference for 2-signal method
- Anything below statistical limit meaningless
- Combustor noise ($m = 0$) detected up to about 500 Hz using either reference ITP
- Coherence too low to detect second broadband-noise range, ($m = \pm 1$)
## Duct Mode Cut-On/Off Frequencies at Core Exit

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- Estimates based on DGEN380 mean-line data from the 2014 test
- Radial \((n > 0)\) modes do not propagate until significantly higher frequencies due to thin duct
DART Core-Noise Research Road Map

Baseline Combustor Noise Measurements → Instrumentation Refinements → Core-Nozzle Circumferential Array Measurements

Design Tailpipe for Liner Testing → Hot-Liner Testing Circumferential and Axial Array

Summary

- Core/Combustor noise must be addressed to ensure that far-term concept aircraft meet anticipated noise limits
- DART/AAPL core-noise baseline test performed Aug 2017
- Initial data analysis and conclusions presented here
  - Acoustic data deemed to be of high quality, compares well with 2014 results and serves as a solid baseline for future work with DART
  - Combustor noise components of total noise signatures were educed using a two-signal source-separation method
  - Combustor coherent broadband noise was detected in expected frequency range
  - A second frequency range of coherent broadband noise was detected – likely first azimuthal mode of the combustor noise (preliminary-future testing will perform circumferential survey of pressure field at nozzle exit)

Special thanks to: Dr. Dan Sutliff and the Facilities Team for envisioning and realizing DART as well as AAPL staff for their expertise and dedication in preparing for and executing this test.
Questions?
## Backup (1): Shaft and Blade Passing Frequencies

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