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

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Advanced Air Transport Technology Project
Aircraft Noise Reduction Subproject

Outline

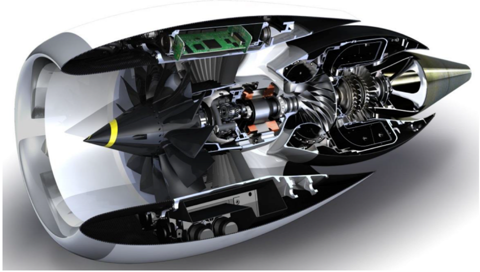
Core/Combustor Noise – DART Facility

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



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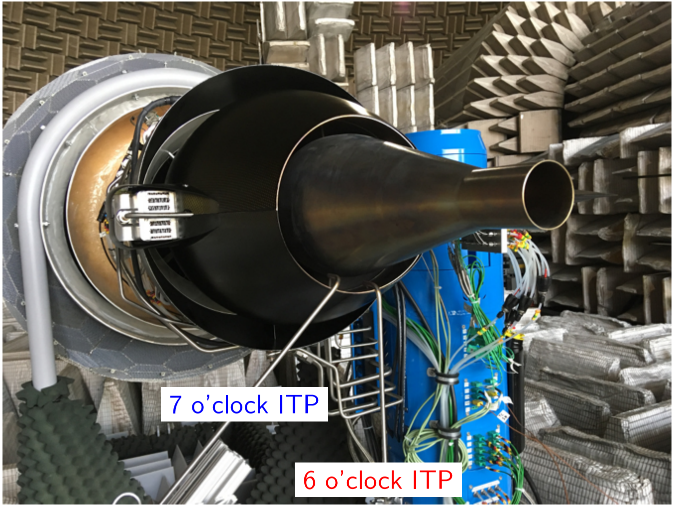
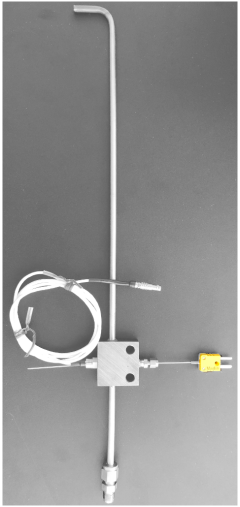
DART Core/Combustor-Noise Test Experimental Setup

- 7 farfield microphones at an average of 38 ft ($\sim$ 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 ($\sim$ 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

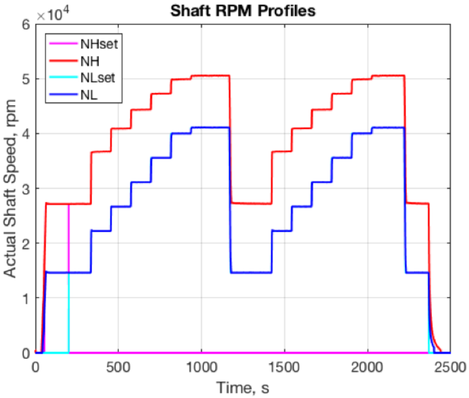
Core Exit Measurement Locations





- Kulite XCS-190, 10 psi differential
- 50:1 ratio - tube length after:ahead of sensor

Engine RPM Profiles and Test Points

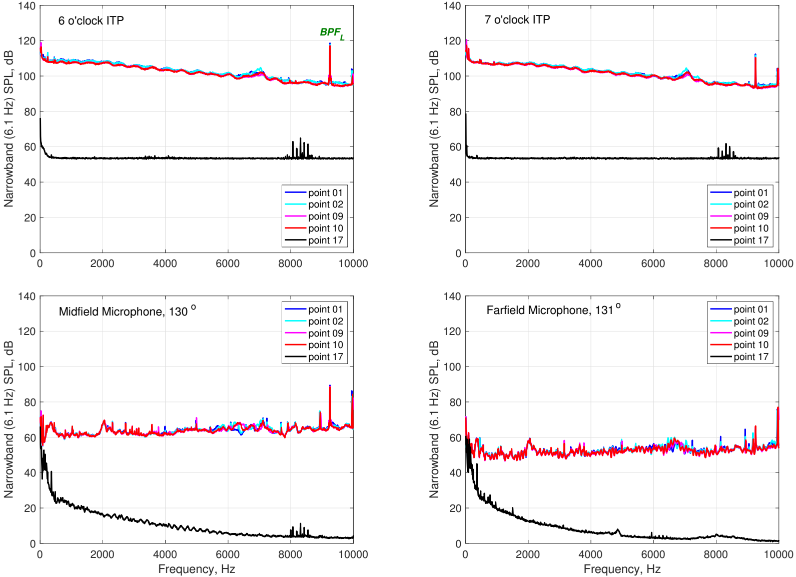


Point #	Power, %	Point #	Power, %
1	33	9	33
2	33	10	33
3	50	11	50
4	60	12	60
5	70	13	70
6	80	14	80
7	90	15	90
8	92.5	16	92.3
		17	0

- 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)

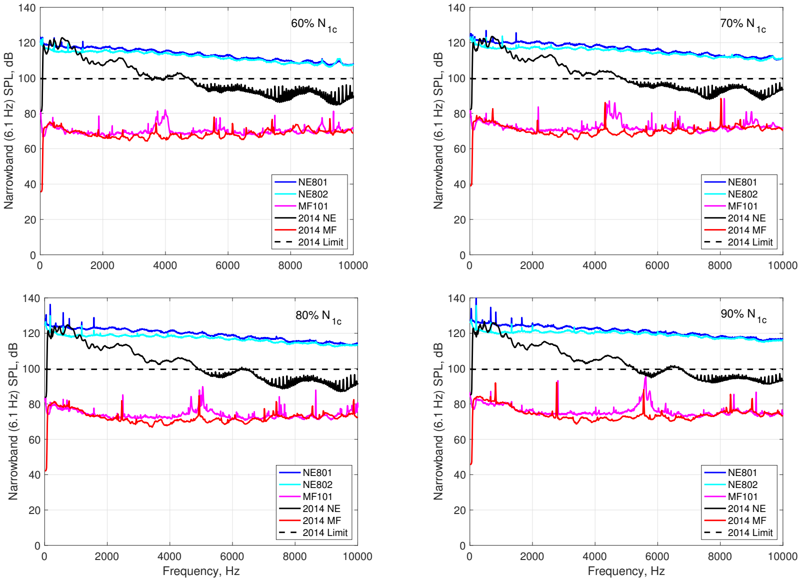
- 3.32 fan gear ratio
- 14 fan blades
- 38 low-pressure turbine (LPT) rotor blades

Background Noise/Measurement Repeatability, 33% N_{1C}



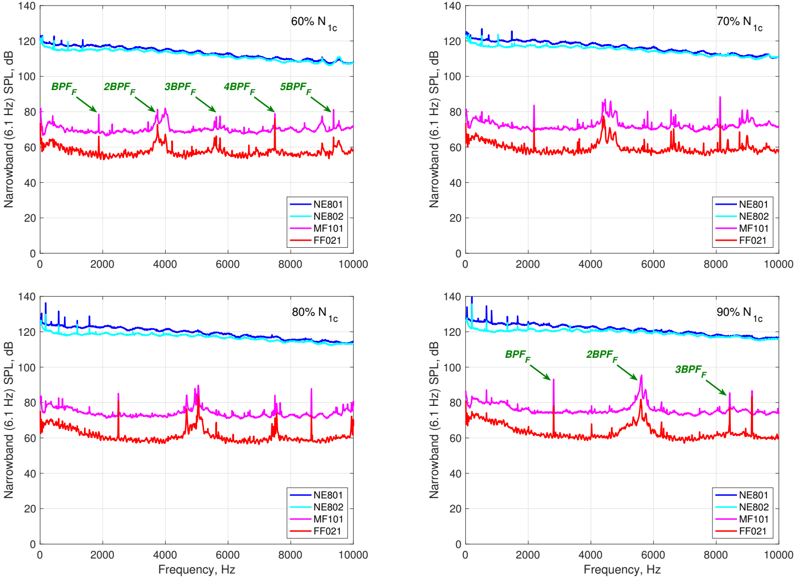
- Combustor broadband noise range < 1 kHz
- Excellent measurement repeatability

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

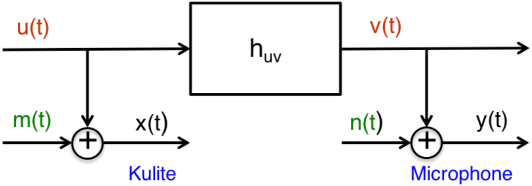


- 6 o'clock & 7 o'clock ITPs
- Midfield Microphone at 130°
- Farfield Microphone at 131°
- Fan BPF and harmonics
- Unclear reason for haystack around $2BPF_F$
- No clear evidence of ITP-tube vortex shedding

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

u(t) & v(t): coherent signals
m(t) & n(t): uncorrelated signals
x(t) & y(t): measurable signals



$$G_{vv} = \gamma_{xy}^2 G_{yy}$$

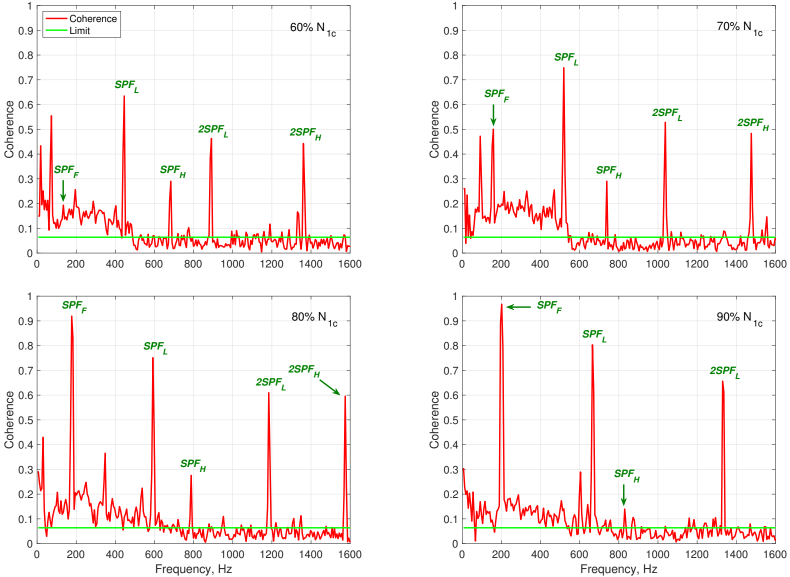
where:

G_{vv} - Core-noise component

γ_{xy}^2 - Magnitude-squared coherence

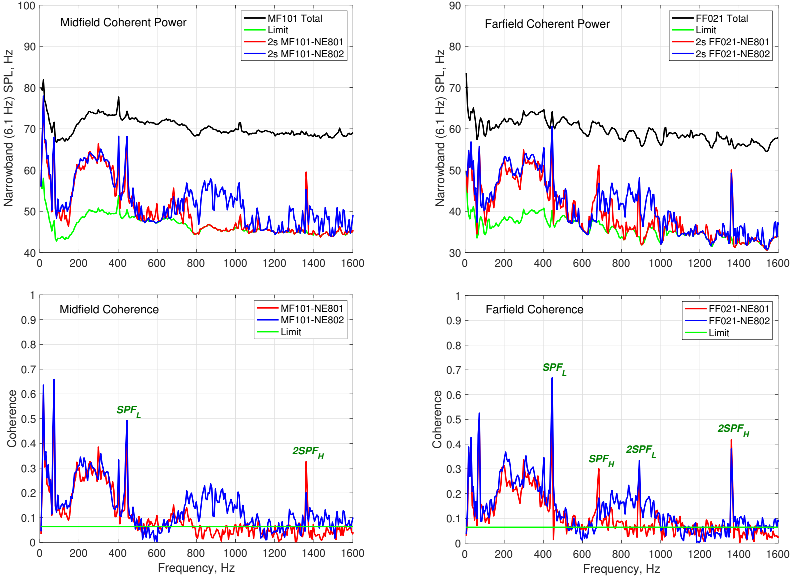
G_{yy} - Total-noise signal

ITP Coherence Variation with Engine Power



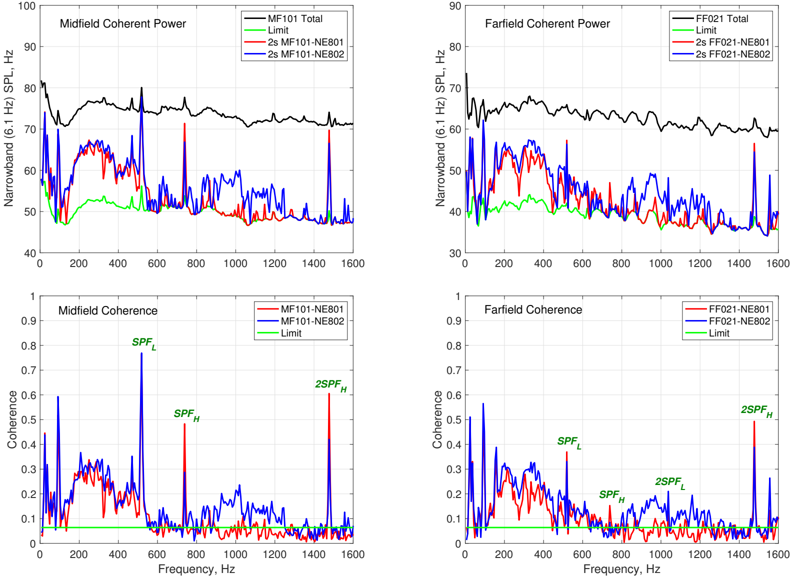
- Coherence level below limit meaningless
- Shaft Passing Frequencies (SPF)
- Combustor broadband noise region identified
- Plane wave mode: $m = 0$
- Up to about 450 Hz at 60%
- Range increases with power

Mid/Farfield Coherent Power & Coherence at 60% N_{1C}



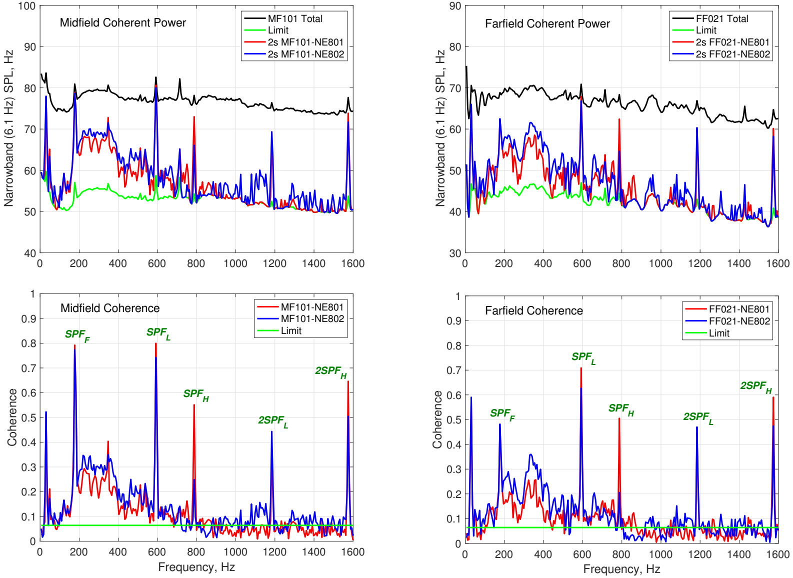
- 6 o'clock & 7 o'clock ITPs used as reference for 2-signal method
- Anything below statistical limit meaningless
- Combustor noise $(m = 0)$ detected up to about 500 Hz using either reference ITP
- 2s-method with 7 o'clock ITP detects second broadband-noise range, possibly $(m = \pm 1)$

Mid/Farfield Coherent Power & Coherence at 70% N_{1C}



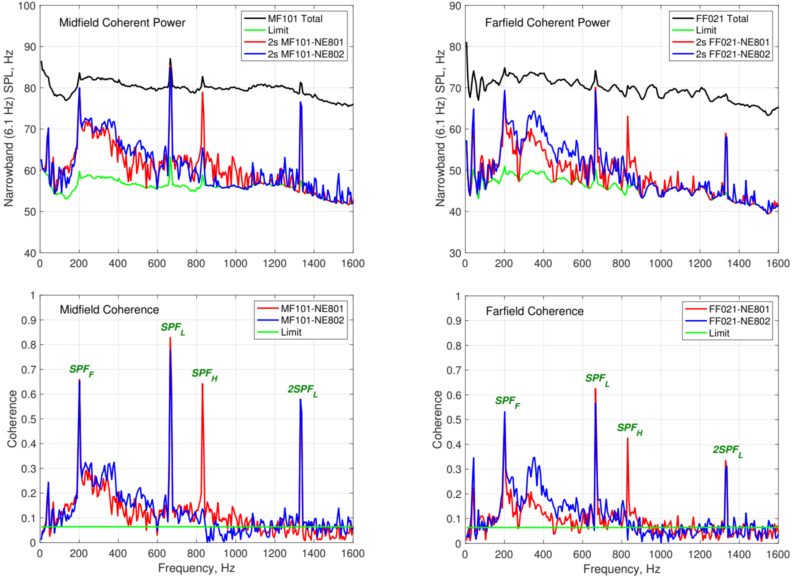
- 6 o'clock & 7 o'clock ITPs used as reference for 2-signal method
- Anything below statistical limit meaningless
- Combustor noise $(m = 0)$ detected up to about 500 Hz using either reference ITP
- 2s-method with 7 o'clock ITP detects second broadband-noise range, possibly $(m = \pm 1)$

Mid/Farfield Coherent Power & Coherence at 80% 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
- 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, $(m = \pm 1)$

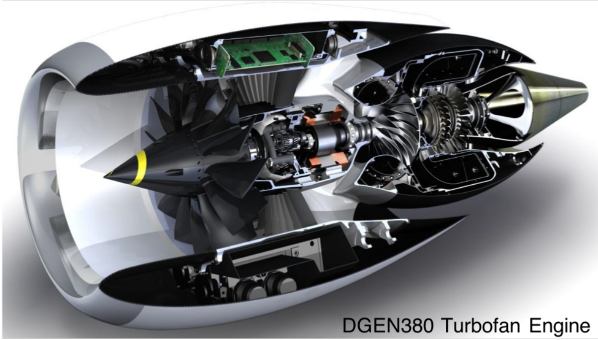
Duct Mode Cut-On/Off Frequencies at Core Exit

Power		n = 0	n = 1	n = 2	n = 3
60 %	m = 0	0	11,532	23,033	34,541
	m = 1	793	11,559	23,047	34,550
	m = 2	1,586	11,642	23,088	34,577
	m = 3	2,378	11,779	23,157	34,623
70 %	m = 0	0	11,491	22,951	34,417
	m = 1	790	11,518	22,964	34,426
	m = 2	1,580	11,601	23,005	34,454
	m = 3	2,370	11,738	23,074	34,500
80 %	m = 0	0	11,465	22,900	34,341
	m = 1	789	11,493	22,913	34,350
	m = 2	1,577	11,575	22,954	34,377
	m = 3	2,365	11,711	23,023	34,423
90 %	m = 0	0	11,414	22,797	34,187
	m = 1	785	11,441	22,810	34,196
	m = 2	1,570	11,523	22,851	34,223
	m = 3	2,355	11,659	22,919	34,268

- 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**



DGEN380 Turbofan Engine

- Source Separation Techniques
- Determine Noise-Source Structure
- Update Core-Noise Prediction Tools
- Validate Liner-Design Tools for Hot Conditions

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

Point #	Power, %	SPF_H, Hz	SPF_L, Hz	SPF_F, Hz	BPF_L, Hz	BPF_F, Hz
1	33	452	244	73	9253	1027
2	33	453	244	73	9256	1027
3	50	611	370	112	14069	1561
4	60	681	444	134	16884	1874
5	70	739	518	156	19701	2186
6	80	787	593	179	22518	2499
7	90	831	667	201	25332	2811
8	92.5	842	685	206	26022	2888
9	33	454	244	73	9255	1027
10	33	453	244	73	9256	1027
11	50	612	370	112	14074	1562
12	60	682	445	134	16890	1874
13	70	739	519	156	19707	2187
14	80	787	593	179	22521	2499
15	90	831	667	201	25337	2812
16	92.3	842	684	206	26002	2885