Development of a Large-Scale Microphone Array for Aircraft Jet Plume Noise Source Characterization

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Near Field Sound Measurement of F-22

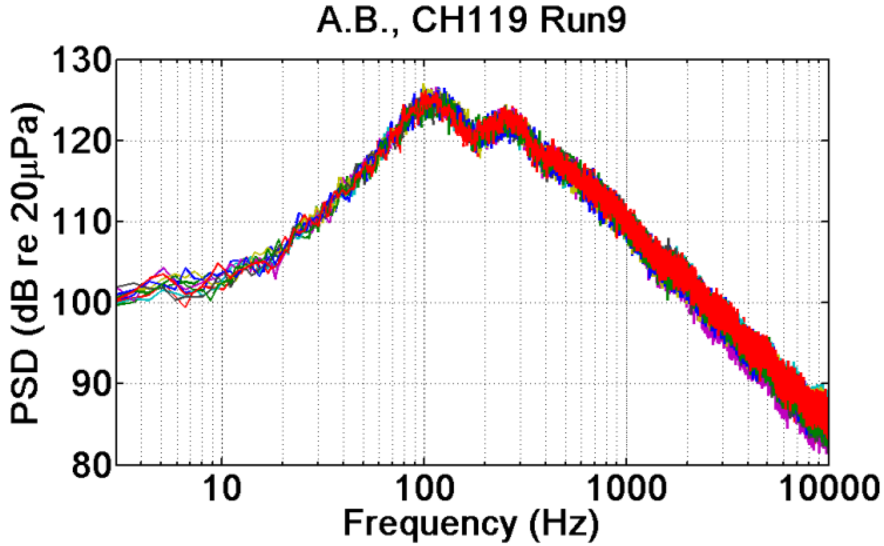
- Introduction
- Near-Field Acoustic Holography Approach
- System Design
- Measurement Layout
- Measurement Results
- Summary

Objective

- Problem:
  - Military jet aircraft generate high levels of noise
  - Innovative measurement and analysis methods are required for jet noise characterization
- Objective: Develop measurement system to characterize jet noise
  - Predict ground maintenance personnel noise exposure
  - Model refinement and benchmarking
  - Evaluate performance of noise control devices
- Proposed: Near Field Acoustic Holography (NAH) system

Jet Noise Radiation Characteristics

- Broadband
- Non-compact
- Partially-spatially correlated



- Described as a sum of wave functions
  - Some wave numbers radiate to the far field
  - While others decay away exponentially (evanescent waves).

Acoustical Inverse Methods

- Beamforming
- The acoustic telescope
- The acoustic mirror
- The polar correlation technique

- These methods typically assume a source distribution of uncorrelated monopoles, and are performed in the far field. This can lead to significant errors.

Near-Field Acoustical Holography (NAH)

- Why NAH?
  - No assumptions about source correlation
    - More accurate at low frequencies
  - Near-field measurement
    - More evanescent waves are captured
    - Higher resolution
    - Provides more information about the noise source characteristics
- NAH Theory
  - A two-dimensional “hologram" measurement may be used to reconstruct the sound field in a three-dimensional volume
    - Spatial distribution of the jet noise sources
    - Magnitude, directivity, and spectral content, velocity

Jet Noise Characterization Process via NAH

Near-field measurements:

1. Patch-and-scan hologram
2. Reference microphones

→

Partial field decomposition:

Virtual coherence

↓

Select number of partial fields to keep.

←

Partial field sound source reconstruction:

NAH

Approach: Patch and Scan

- Methodology
  - Array extends over a ‘patch’ of the source field
  - Array is moved parallel to the plume’s shear layer
  - Capturing the entire hologram surface in a number of scans
  - Stationary reference microphones are required
- Pro: Decreases the number of microphones
- Con: Increases engine run-times


Patch and Scan Movie

Test Script

Idle – 30 sec

Intermediate – 30 sec

Military – 30 sec

Afterburner – 30 sec

Idle – 210 sec

(cool down period, reposition NAH array and repeat script)

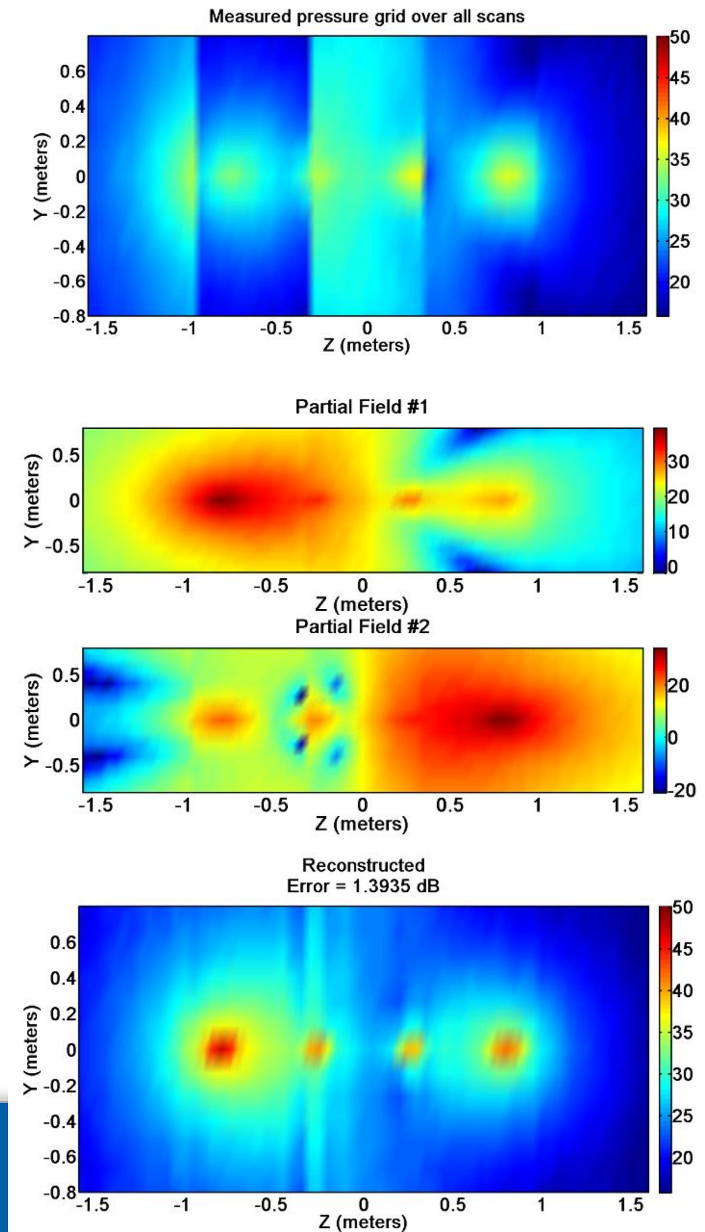
~ 1 hr Per Full Run

Approach: Reference Microphones

- Coherent Source
  - Only one reference microphone is required
- Jet Source
  - Multiple uncorrelated sub-sources
  - Finite correlation lengths exist because of turbulence
  - Multiple reference microphones are required to
    - Normalize multiple scans of non-stationary source
    - Decompose the pressure field into mutually incoherent partial fields
- Number of Reference Microphones
  - One reference microphone for each uncorrelated sub-source
  - Challenge is determining the number and location of the reference microphones before the test
  - Post measurement
    - Relative magnitude of the singular values
    - Virtual coherence function approaches 1 for all the measurement points

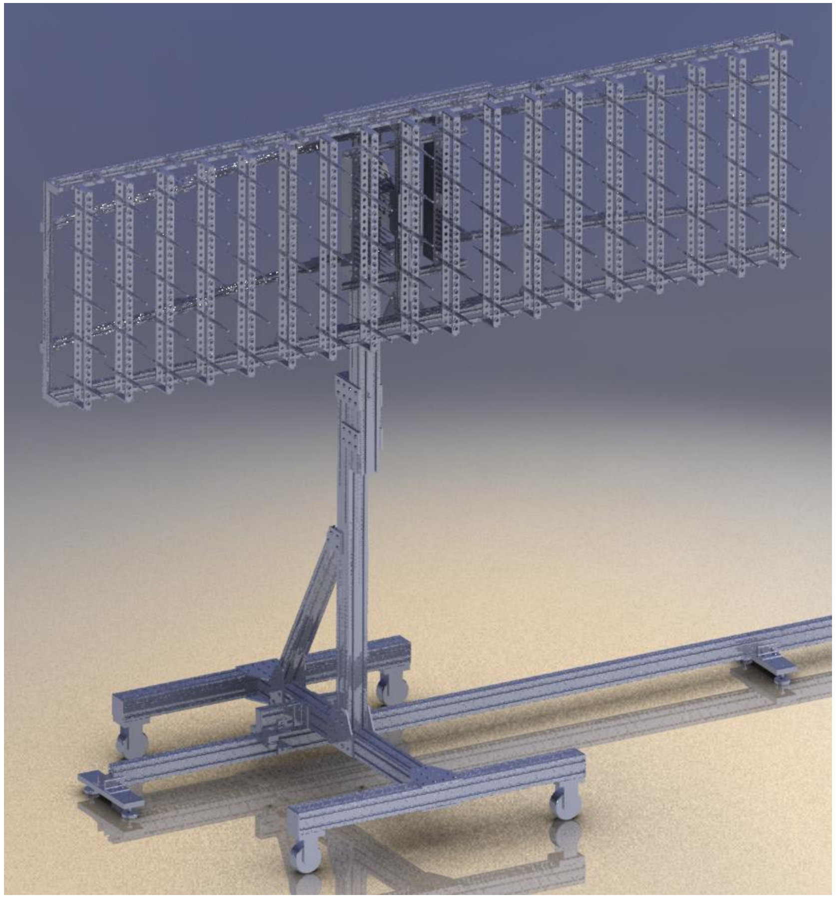
Approach: Virtual Coherence

- Measurements are made using a patch and scan methodology
  - Source level variation between scans
- Holographic projection of the sound is performed using the Helmholtz equation
  - Required sound field to be fully coherent
- A single value decomposition is used to decompose the sound field into coherent partial fields that are mutually incoherent (orthogonal)
- NAH projects the partial fields onto desired surface
- Individual projected fields are added together on an intensity basis since they are mutually uncorrelated
  - Entire field reconstructed



Design: NAH Jet Noise Array Overview

- Design Requirements
  - Characterize entire jet noise source
  - Use less than 150 microphones
  - Minimize setup time - simplicity in design
  - High channel count system that can measure
    - Levels up to 170 dB, 5 Hz to 30 kHz
- 2D Microphone Array
  - Three separate panels
    - Smaller package
    - 32-channel breakout box per panel
    - 30 microphone / 2 other sensors per panel
  - Individual array modules can be shipped assembled to minimize setup time



Conceptual Image of the NAH Test Rig

Design: NAH Array Configurations

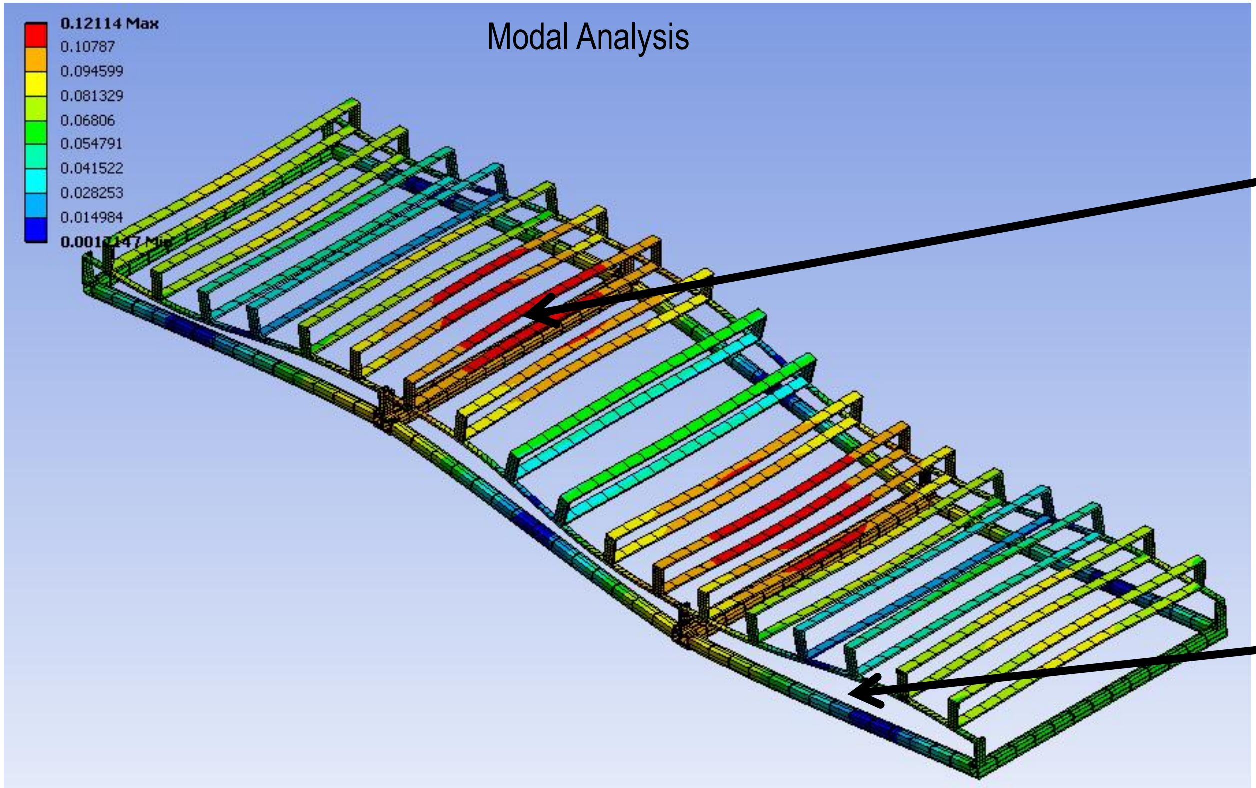
- NAH Measurement System
  - 2-dimensional microphone array
    - 90 microphones, 6 in. spacing
    - Center height of array adjustable between 2 ft to 6 ft
  - Reference Microphones
    - 50 microphones
- Horizontal and Vertical Configuration
  - Horizontal - minimize time to measure the length of the plume
  - Vertical - detailed simultaneous collected vertical profiles, effects of the ground plane


Horizontal Configuration


Vertical Configuration

Design: Structural Response

- Test Rig Design
  - Ensure rig is not acoustically receptive
  - Structural resonances are not excited by the sound field



Placement of the 90 microphones stiffened structure significantly

Addition supports were added later to minimize potential of flexing

Design: Instrumentation

- Microphones / Preamplifier
  - ¼ inch G.R.A.S. 40BE free-field microphone
  - G.R.A.S 26CB preamplifier
  - Frequency response of 4 Hz – 100 kHz ± 3 dB
  - Nominal sensitivity of 1 mV/Pa – 173 dB
  - Preamp housing necks from ¼ in. to ½ in. female BNC
    - Minimize cable connections
    - Extend microphone away from measurement array
- Data Acquisition
  - National Instruments PXI platform
  - Sixteen 24-bit analog inputs per module
  - Simultaneous sampling rate of up to 204.8 kS/s
  - 4 mA ICP power supply
  - Four 250 GB hard drives
    - 150+ channels at 96 kHz for 30 sec > 1.7 GB
    - Non-proprietary binary format

G.R.A.S. 40BE/G.R.A.S. 26CB

NI PXI-4496

NI PXI Chassis
Mil Spec Shipping Case

Design: Data Acquisition and Post Processing Software

- Real-Time Monitoring via NI Labview
  - Custom control panel
  - System checks: overload detection, saturating, ranges
  - Data signals: Bar graphs, time history viewer, 3rd octave spectra
  - Data quality checks reduce the expense of military aircraft testing
- Data Visualization and Post Processing
  - Provides comprehensive view of results
  - Post processing is performed in MATLAB

LabView Front Panel: Configuration

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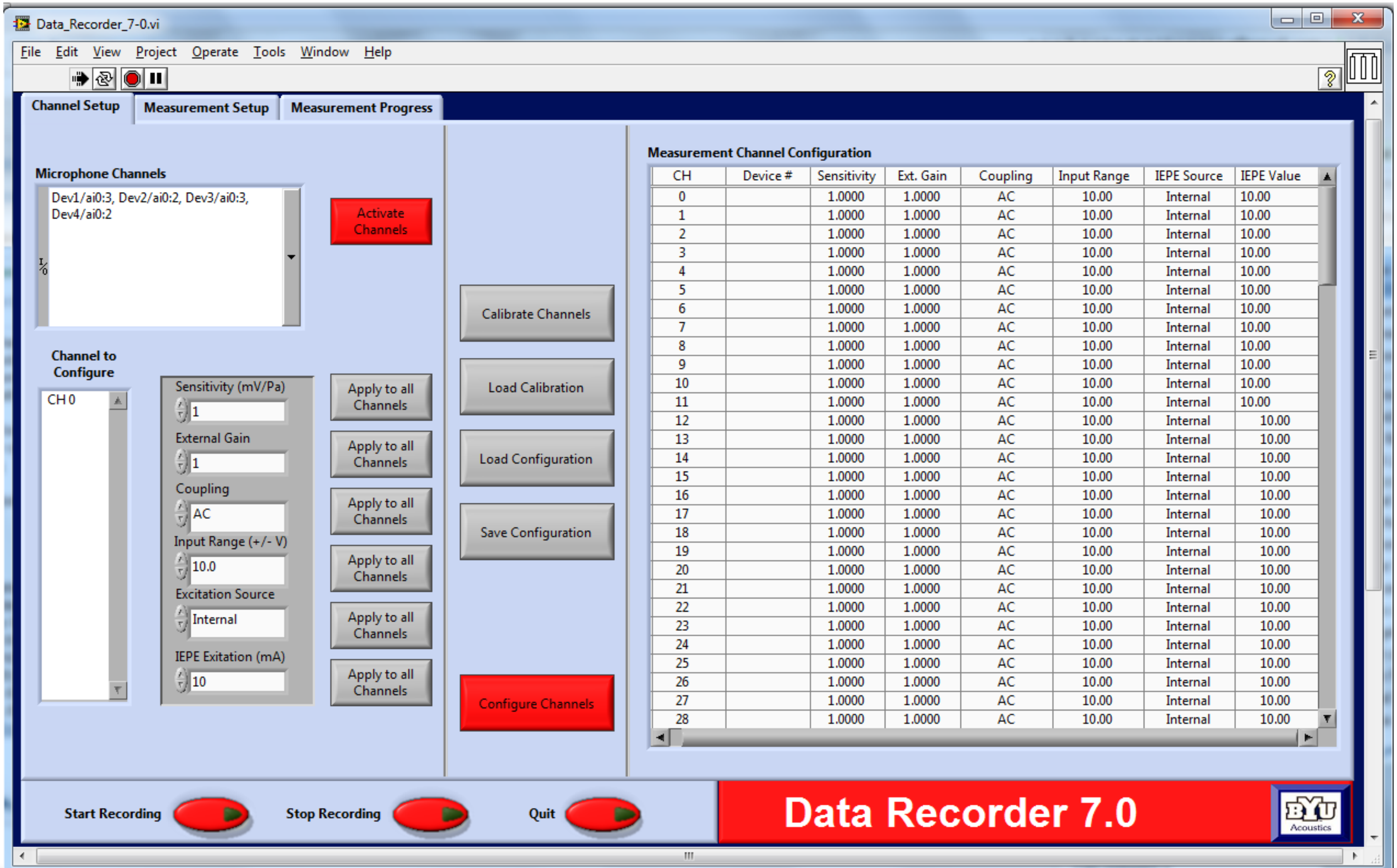
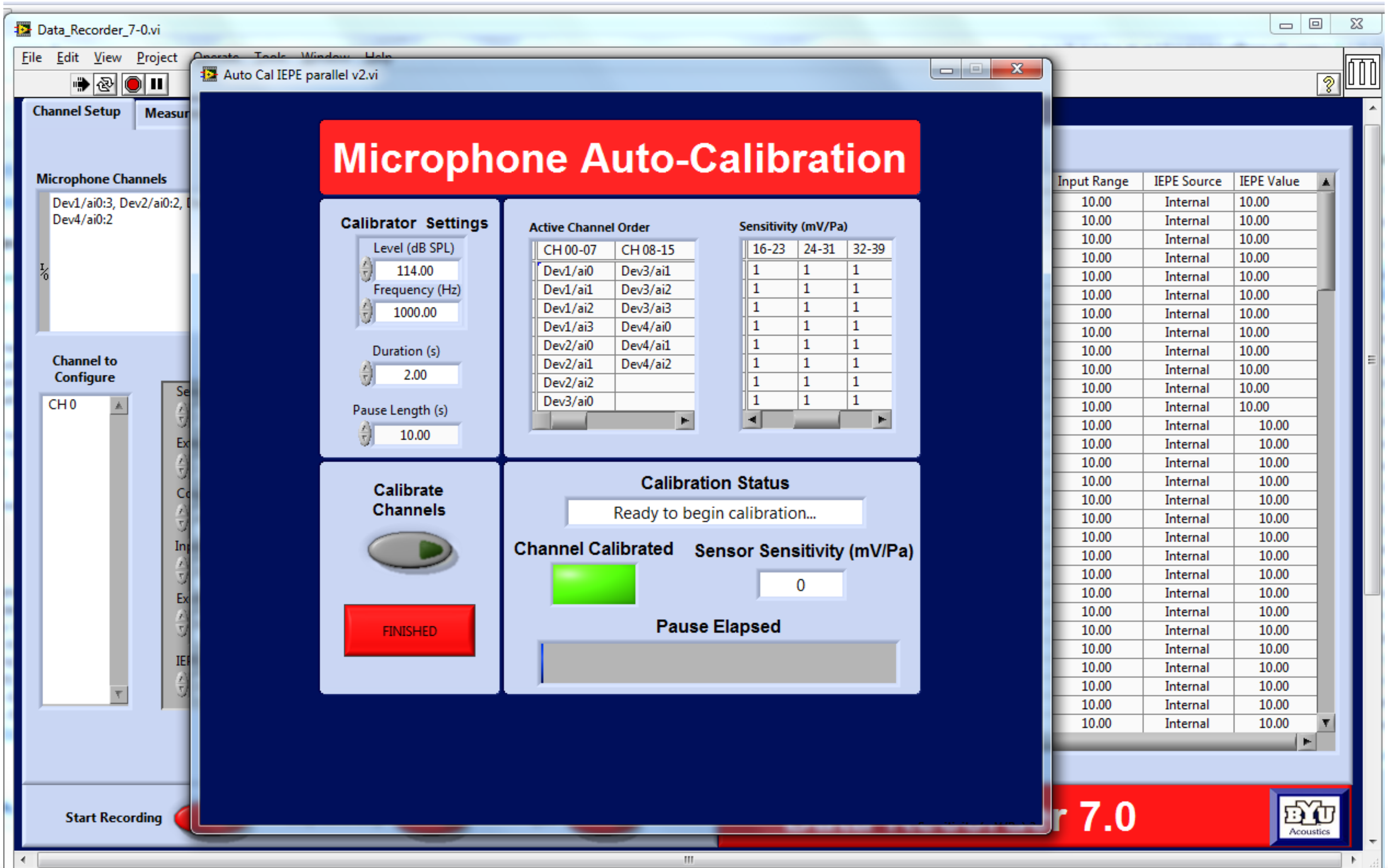
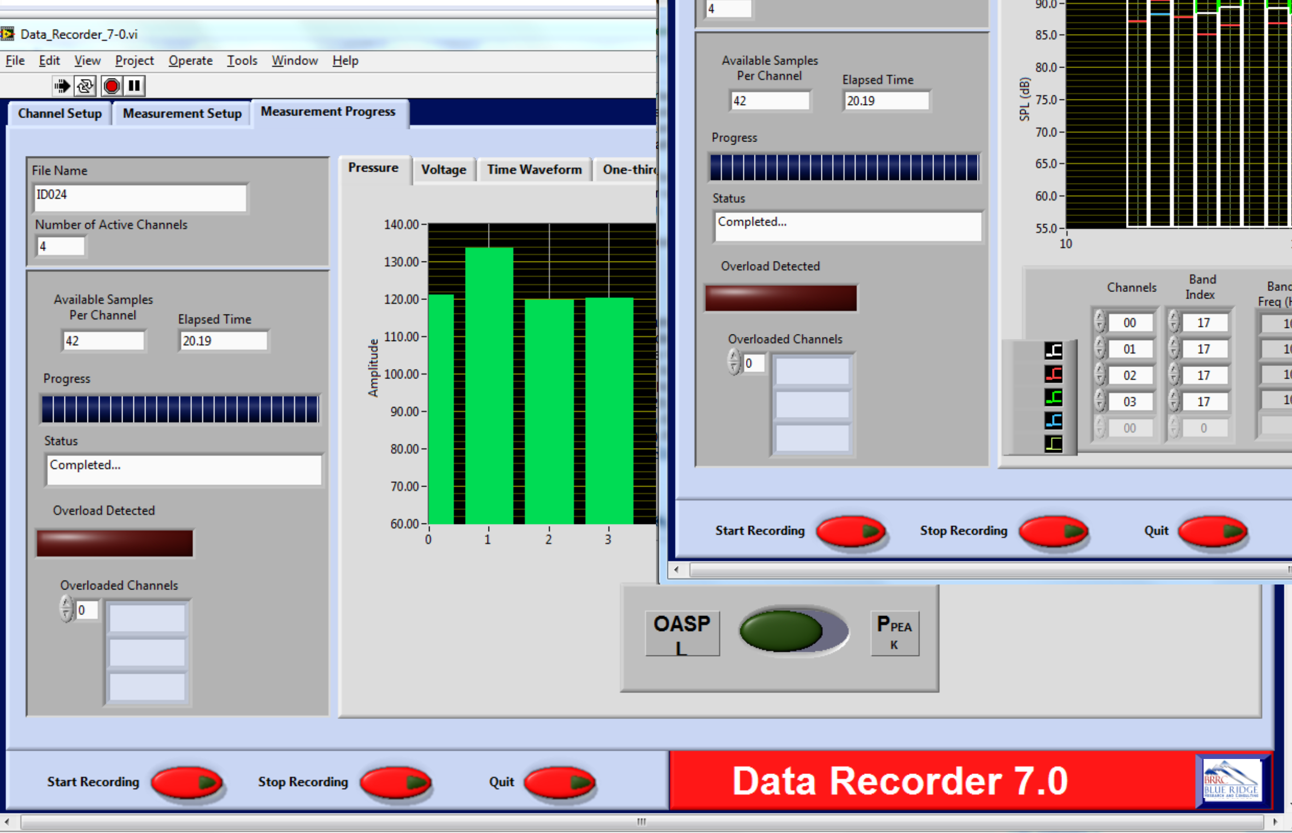


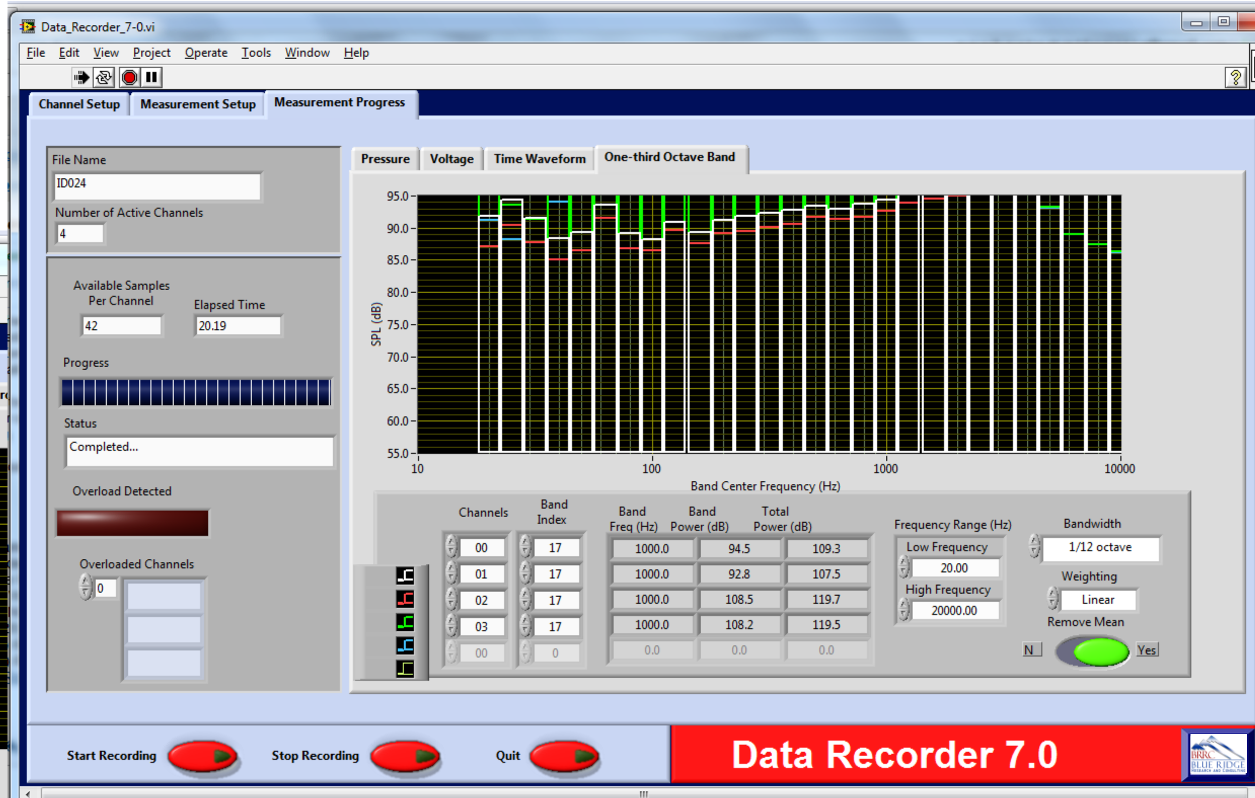
LabView Front Panel: Calibration



LabView Front Panel: Pressure Levels

Overall Levels



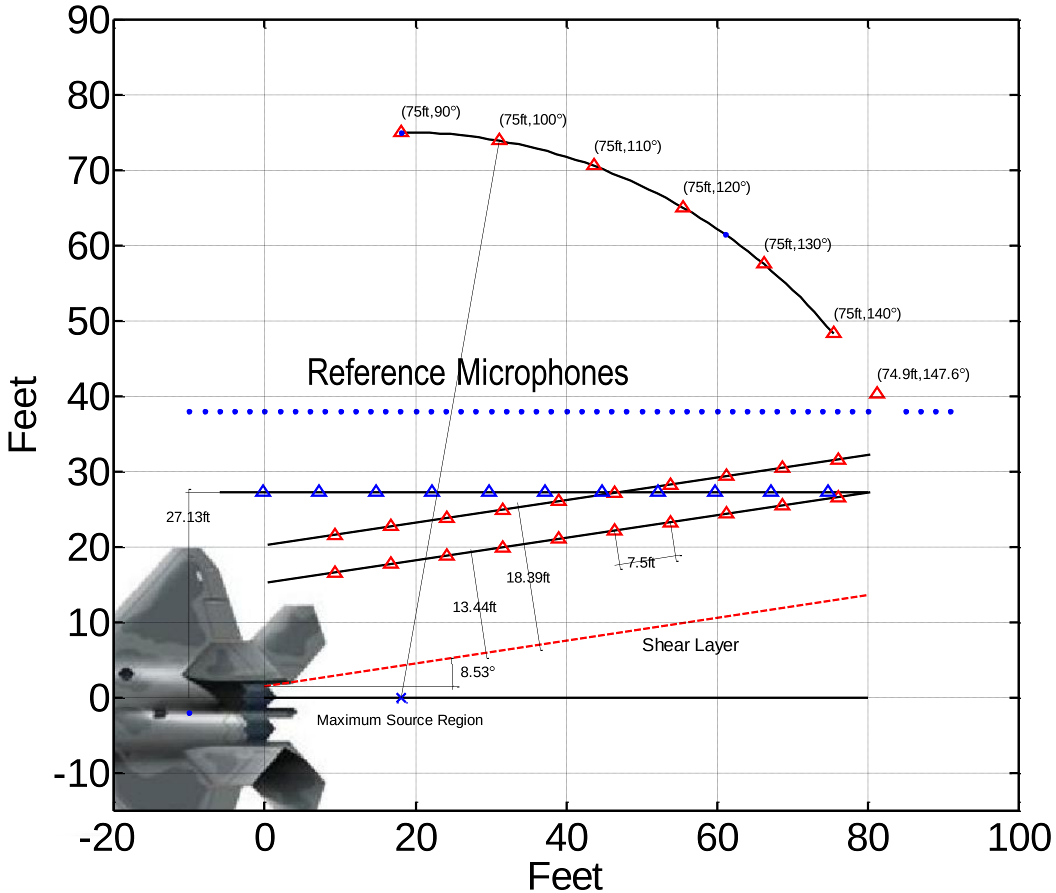


Octave Band Analysis

Measurement Layout & Test Matrix

- Holloman AFB Ground Run-Up Paid, July 27th - July 30th 2009

Measurement Layout



Test Matrix

Run	Guide Rail Offset (ft.)	NAH Array Orientation	NAH Array Height (in.)
1	13.44	Horizontal	75
2	13.44	Horizontal	51
3	18.39	Horizontal	51
4	18.39	Horizontal	75
5	18.39	Horizontal	27
6	13.44	Horizontal	27
7	27.13	Horizontal	51
8	27.13	Horizontal	75
9	18.39	Horizontal	75
10	18.39	Horizontal	51
11	75 (arc)	Horizontal Beamforming	75
12	18.39	Vertical	76.5

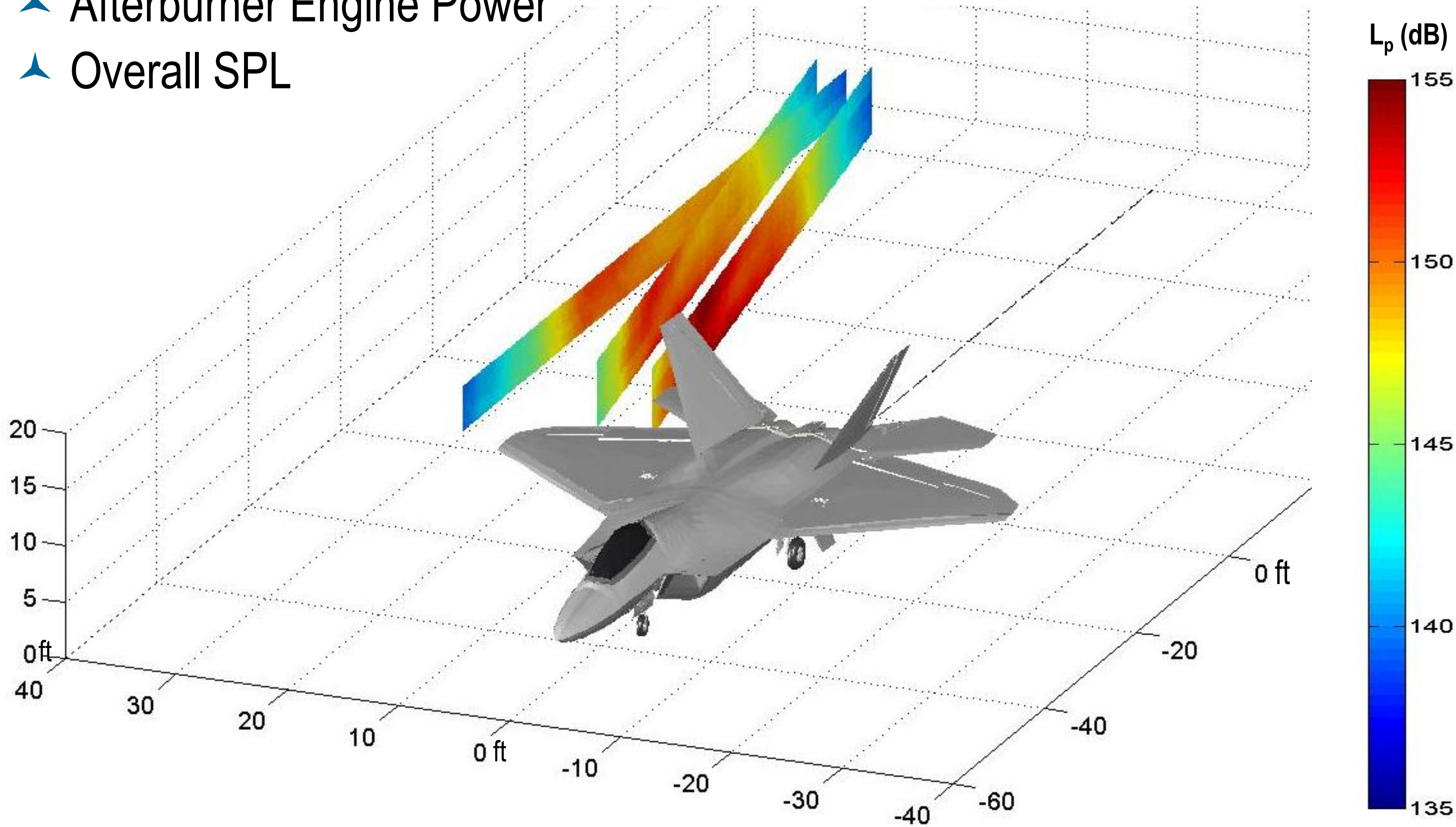
Pressure Measurements

650 GB of binary data

83,425 - 25 sec recordings

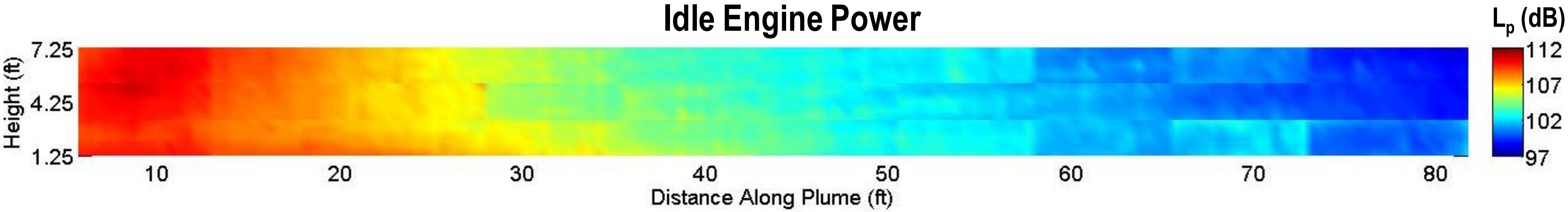
Measurements Planes

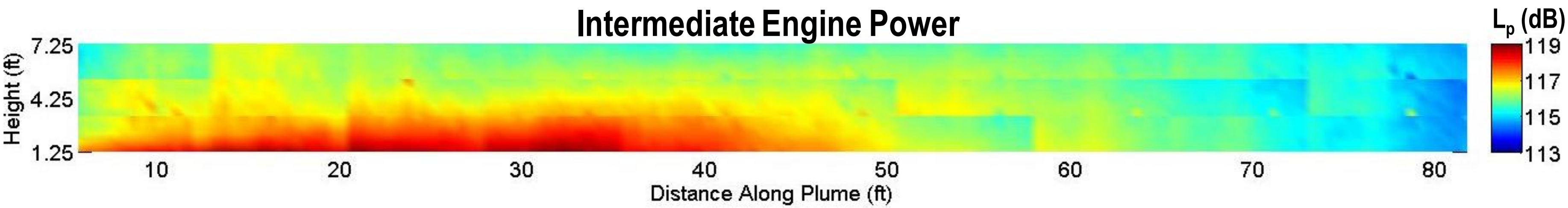
- Afterburner Engine Power
- Overall SPL

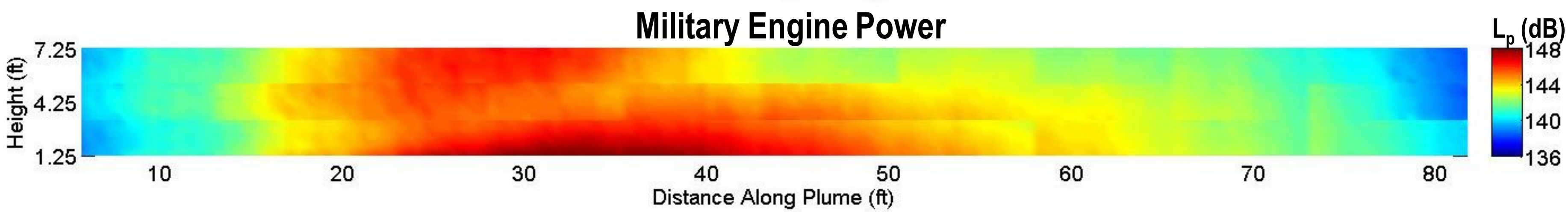


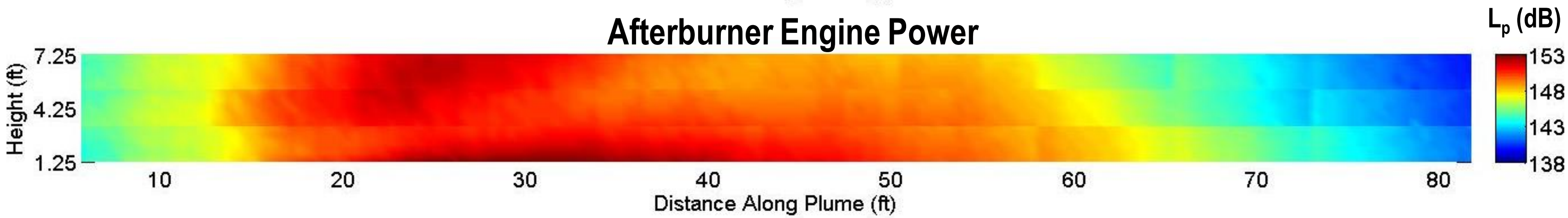
Overall SPL

- 18 ft Offset, 1,800 Measurements Per Plane





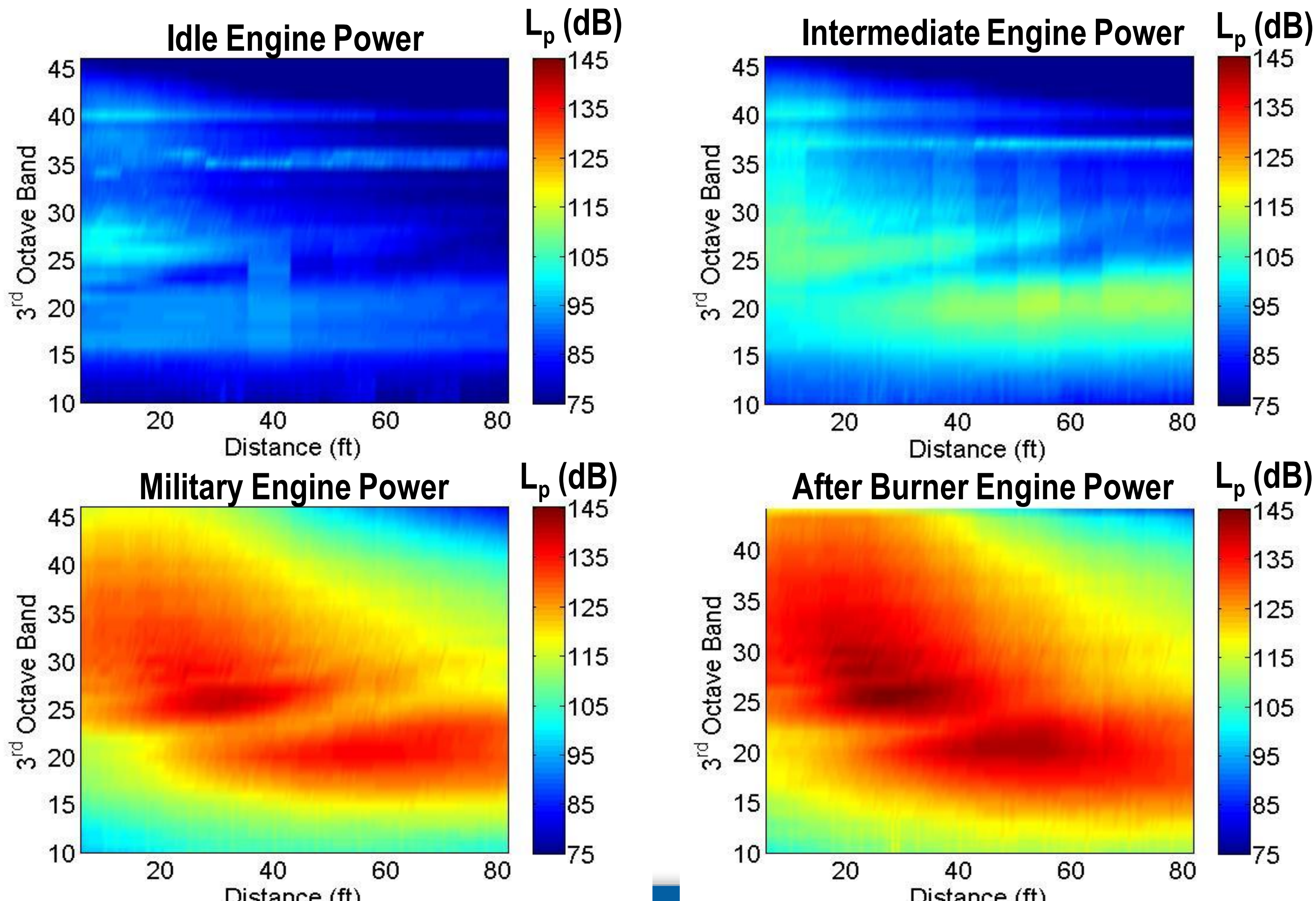




Note: Different color scales are used to show pressure map features

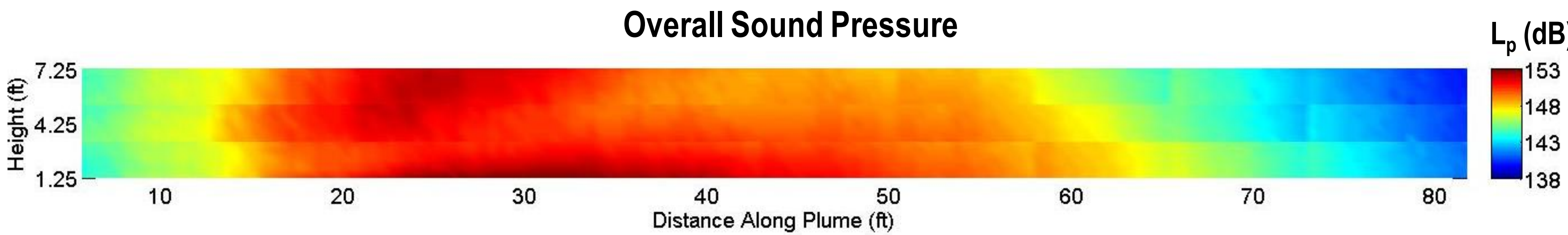
Distance Along Plume vs. 3rd Octave Band

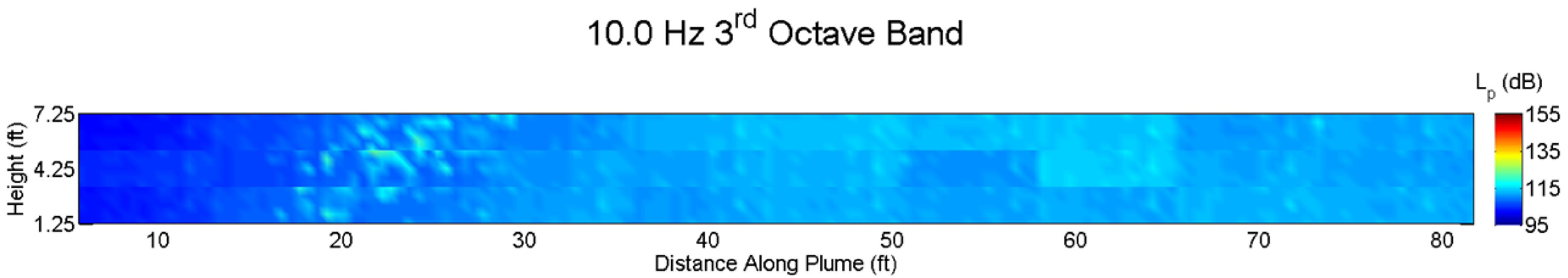
- 18 ft Offset, 7.25 ft Height



3rd Octave Band

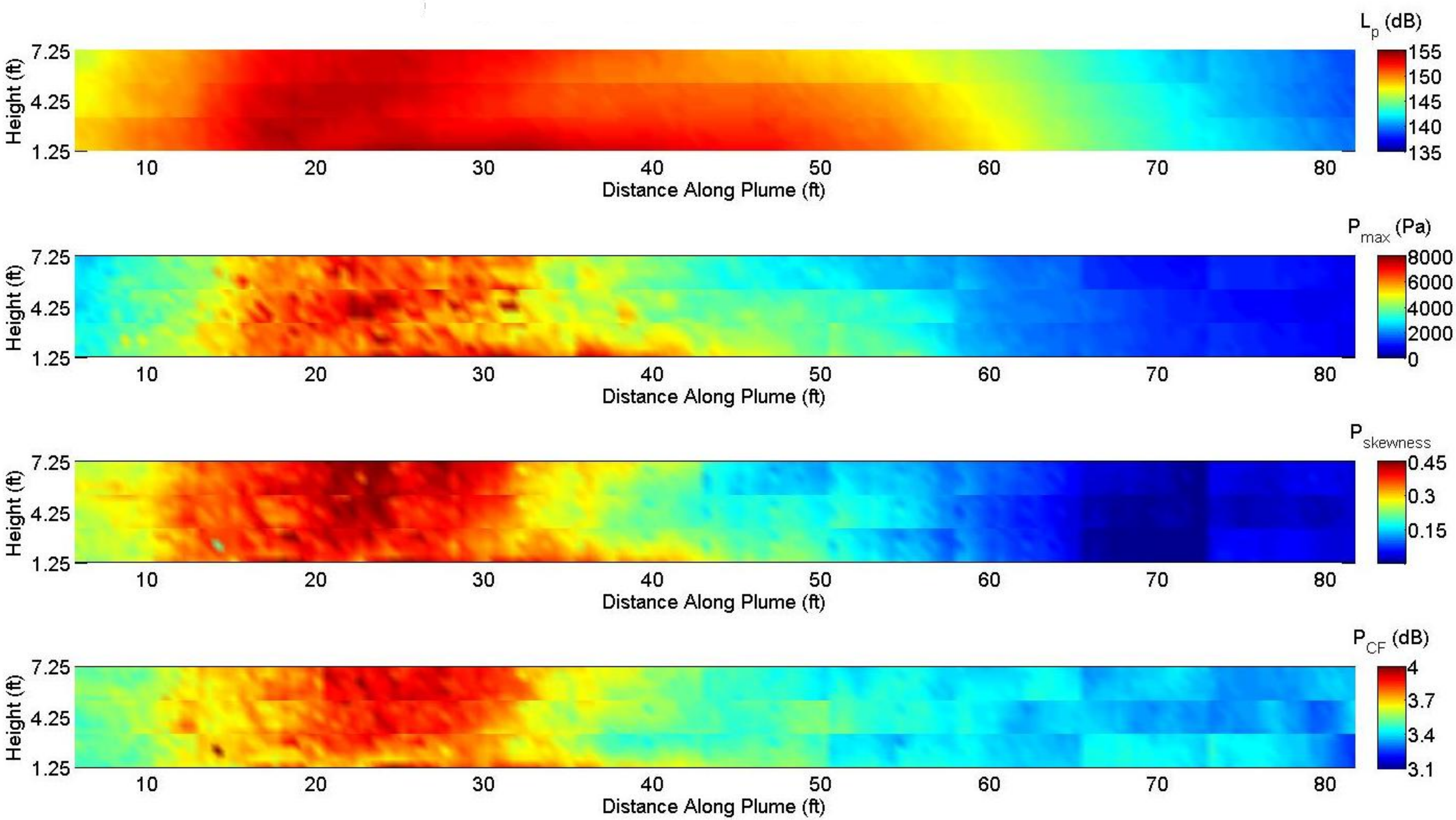
- 18 ft Offset Parallel from Estimated Shear Layer
- Afterburner Power





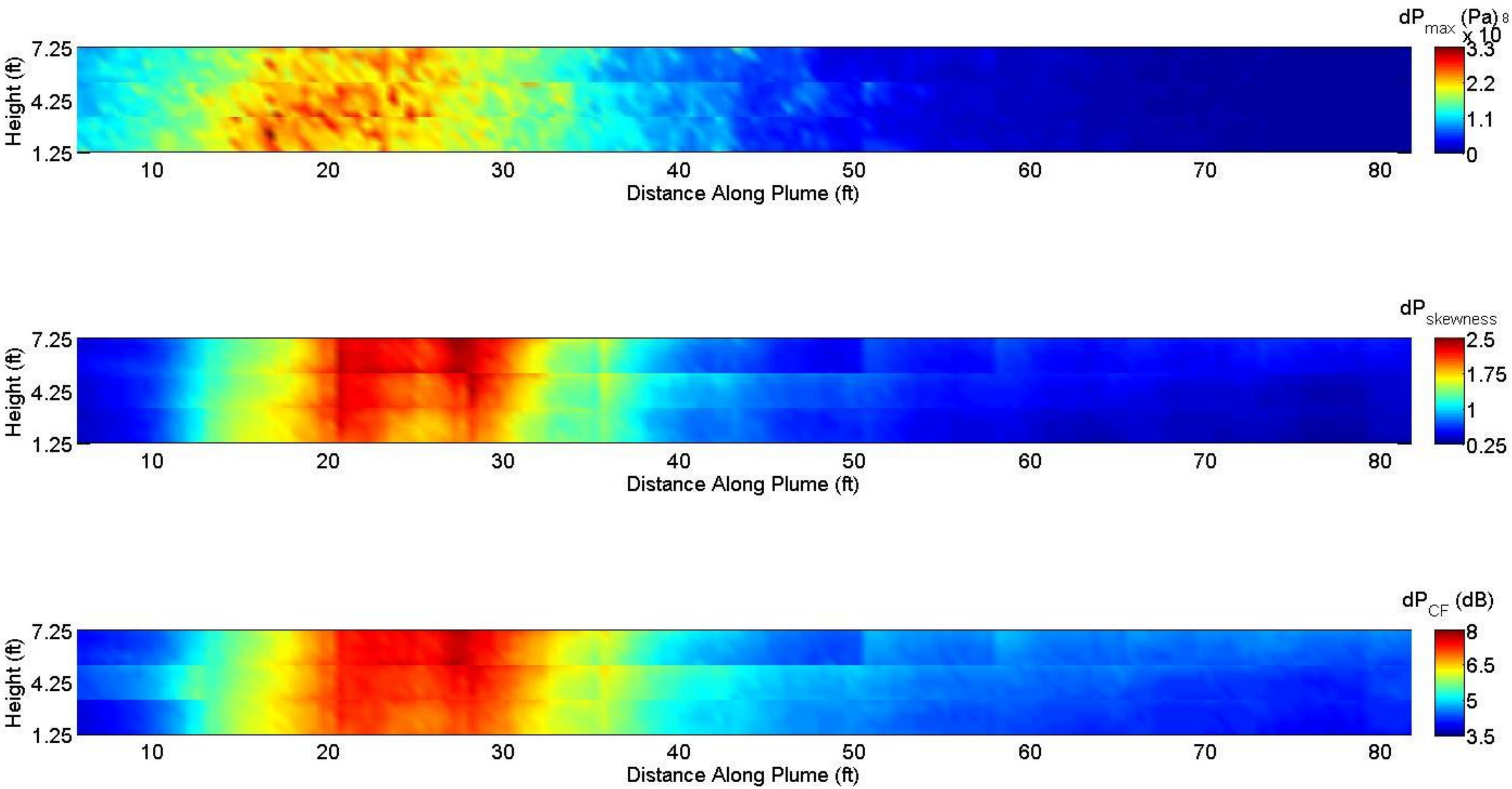
Pressure Metrics

- Afterburner Power, 13 ft Offset Parallel from Estimated Shear Layer



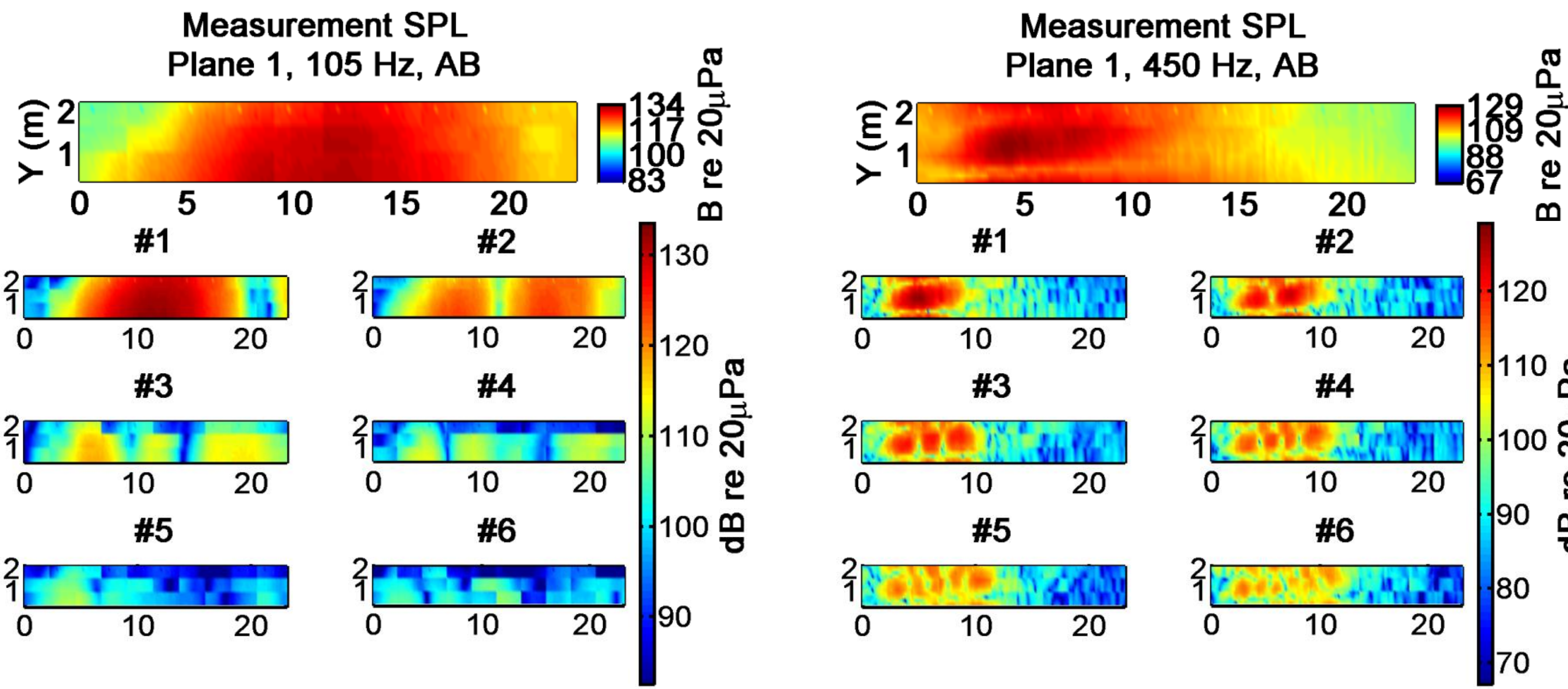
Pressure Gradient Metrics

- Afterburner Power, 13 ft Offset Parallel from Estimated Shear Layer



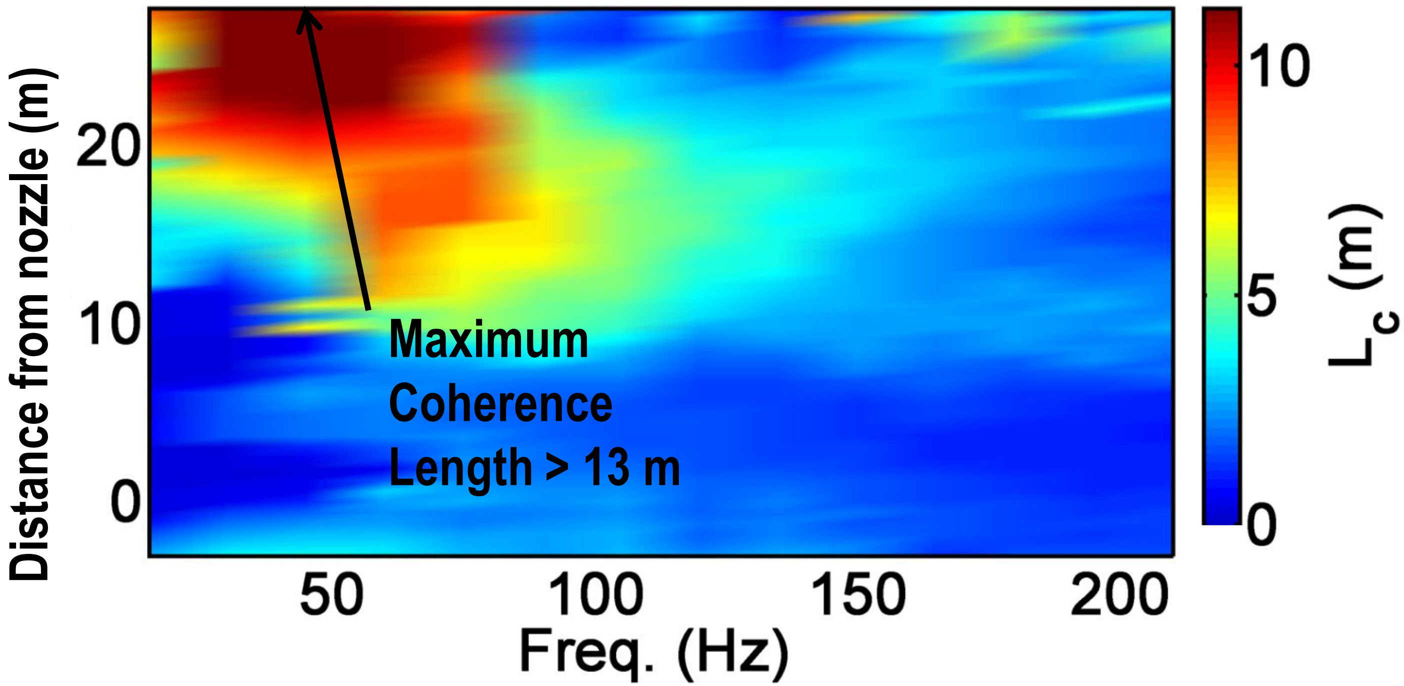
Partial Field Decomposition (PFD)

- Measured sound pressure levels for two frequencies.
- The first six partial fields of 50 total



Near-Field Jet Coherence Lengths

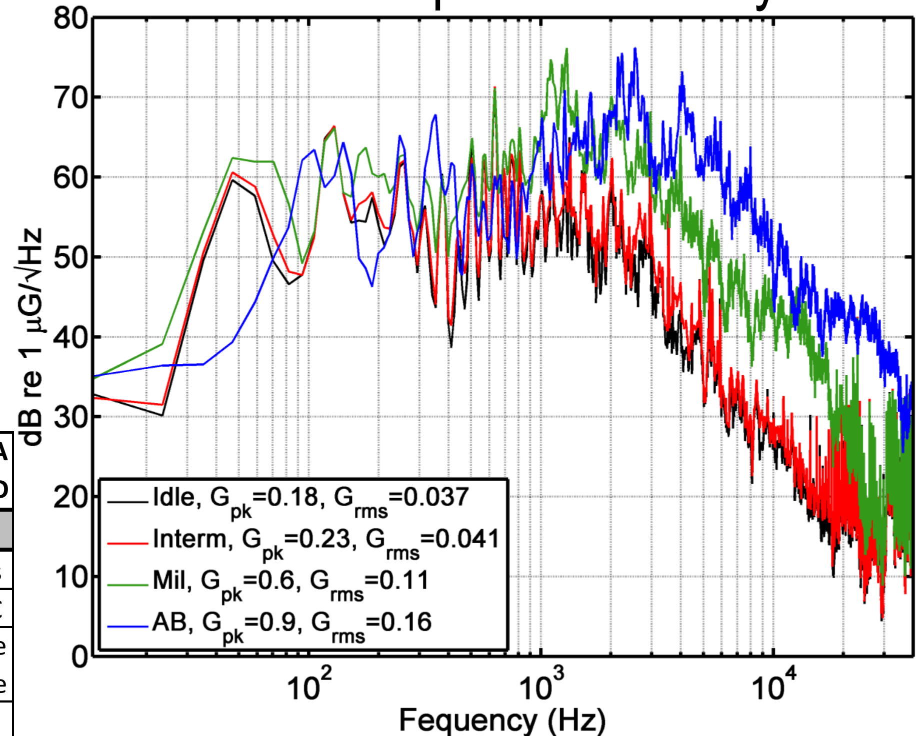
- Coherence length increases as frequency decreases
- Low frequencies are generated by large-scale turbulence.
- Sound field may be decomposed with a reasonable number of reference microphones.



Hard Drive Vibration

- Excess vibration of traditional hard drive on after burner required sampling rate reduction from 96 kHz to 48 kHz for 155 data channels
- Move to solid state drives and fiber optic MXI connection to minimize impact of vibraction

Acceleration Power Spectral Density



Example OEM Specifications

Description	Samsung 2.5in SATA SLC SSD	Fujitsu 2.5in SATA Standard HDD
Mean Time Between Failures	2,000,000 Hours	300,000 Hours
Operating Temperatures	0°C - 70°C	5°C - 55°C
Shock (Operating)	1500G at 0.5ms half sine wave	300 G at 2ms half sine wave
Vibration (Operating)	20 G Peak (10 - 2000Hz)	1.0 G Peak (5 - 500 Hz)
Average Sequential Read Rate	88.5 MB/s	
Average Sequential Write Rate	72.5 MB/s	
Average Access Time	4.4 ms	

Summary

BRRC BLUE RIDGE RESEARCH AND CONSULTING

- Performing NAH in the jet noise field is challenging, but has a potentially big payoff
- NAH patch and scan methodology along with an innovative test system and instrumentation design enables high fidelity characterization of jet plumes
- We can decompose sound field into “orthogonal modes” and we can determine the number of important partial fields are important in describing the source.
- NAH Data Collection System Excelled
- Data Analysis Continues

Questions?