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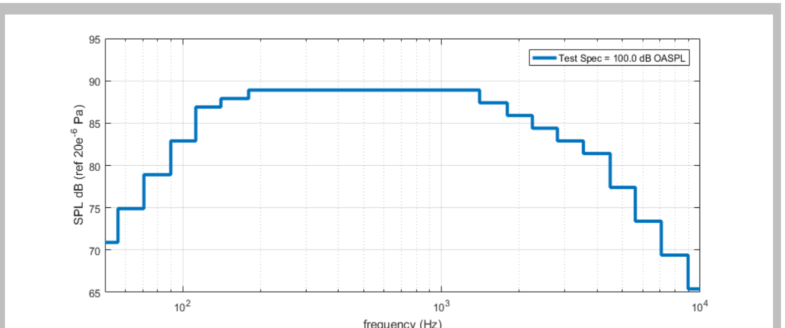

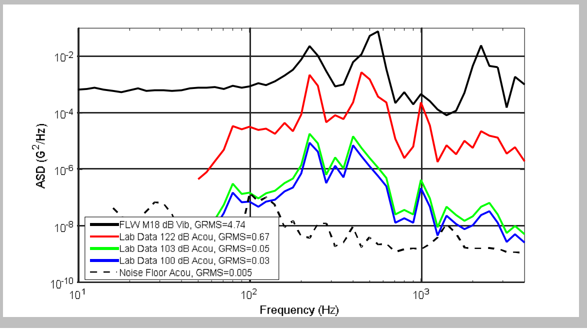

Predicting Flight Environments with a Small-Scale Direct-Field Acoustic Test Facility

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Sandia National Labs

U.S. DEPARTMENT OF ENERGY NNSA National Nuclear Security Administration

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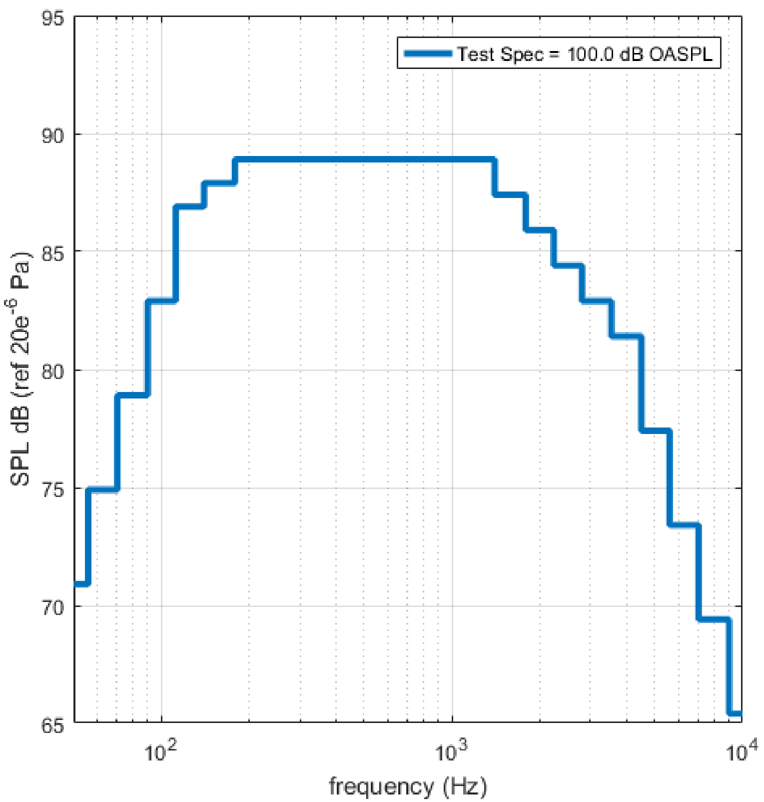
Introduction & Motivation

- Desire to develop a more realistic definition of the flight line environment for Ground Support Equipment (GSE).
- Acoustic excitation performed with using small-scale, direct-field acoustic test (DFAT) laboratory with multi-input multi-output (MIMO) closed-loop control.
- Resulting acoustic data, along with vibration test data, used to derive a shaker table test environment for future testing.
- Details of the small-scale laboratory setup and test method is discussed in detail as well as the process used to predict flight environments for the GSE.

Test Item and Specification

- Ground Support Equipment (GSE)
  - 12-in × 8-in × 6-in
  - Approximately 20-lbs
  - Internal accelerometers
- Test Specification
  - Generic spectra for aircraft-induced acoustics
  - Reference: MIL-STD-810G
  - Scaled to 100 dB OASPL (overall sound pressure) based on maximum approved levels for short duration exposure per OSHA.
  - Performed for 30 second duration



Small-Scale Acoustic Test Details

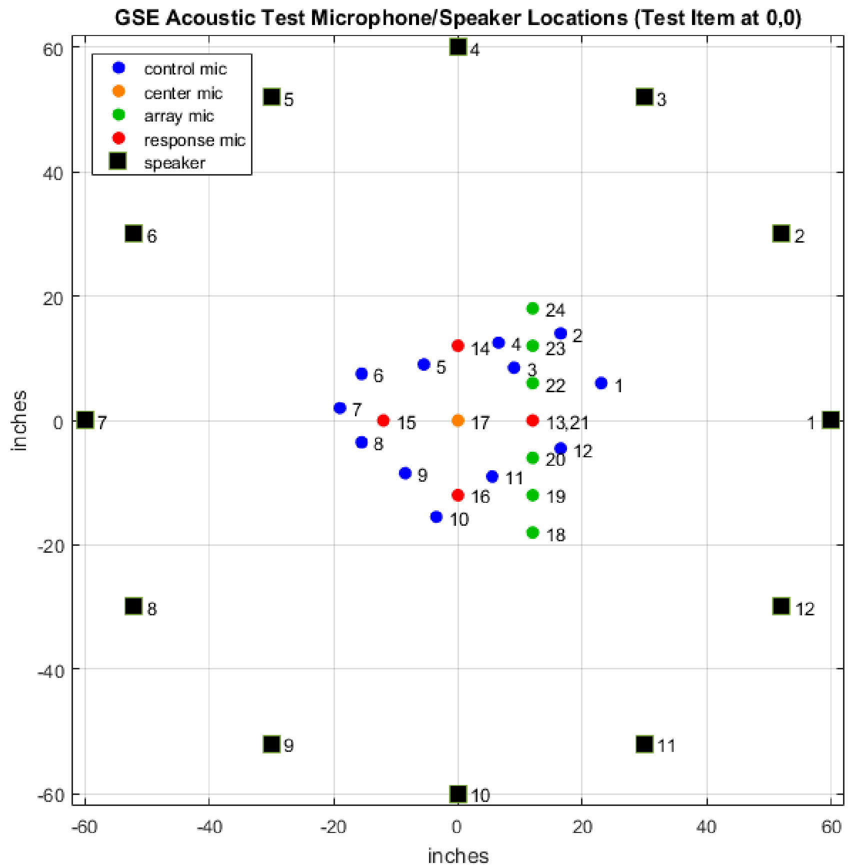
- Direct-Field Acoustic Test Method
  - GSE placed at speaker-circle center
  - Closed-loop control system drives speakers using control microphones
- MIMO Control System
  - 12 independent drives
  - 12 control mics randomly-placed
  - Define phase and coherence
- Monitor Speakers
  - Relatively flat frequency response and phase for all frequencies
  - Consists of 5.25-in and 1-in drivers
  - Doubled-up to increase sound level (24 total speakers)

Typical DFAT test: from *DFAT Recommended Practice*, Larkin, P., Goldstein, B., 2011.

Typical Monitor Speaker: from music-group.com

Small-Scale Acoustic Test Lab

- Acoustic Test Frame
  - Covered with sound-attenuating blankets.
  - Provided quiet inside and quieter outside
  - 10-ft × 10-ft × 8-ft tall
- Microphones
  - ¼-in diameter, 12 mV to 0.9 mV/Pa
  - Control microphones (Ch 1-12) placed randomly in field (12 mV)
  - Response mics (Ch 13-16) placed at GSE
  - Response mic Ch 17 4-in above GSE
  - Response microphones array (Ch 18-24)
- Speaker circle diameter = 10-feet
- Test plane = 4-feet above floor



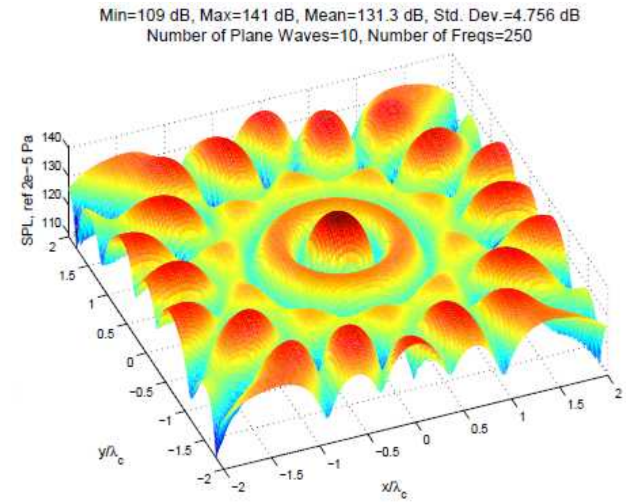
Speakers = black
Control = blue
Array = green
Response = red/orange

Small-Scale Acoustic Test Lab

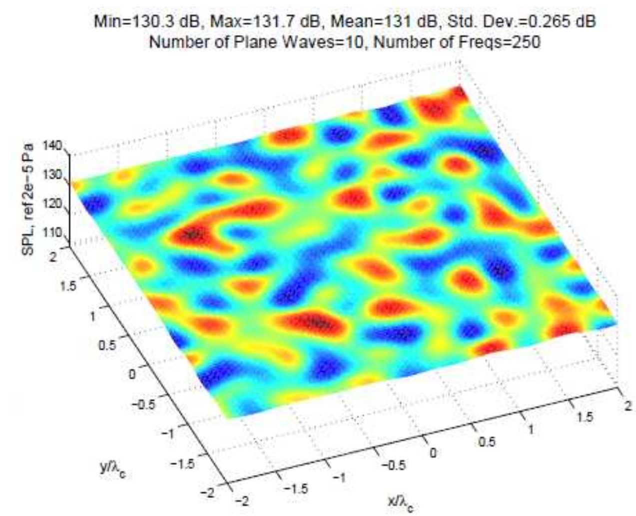
MIMO Control Details

- MIMO Control - Multiple Input, Multiple Output.
  - Independent input/output.
  - Test specification (magnitude) defined for each control input.
  - Define Phase and Coherence between input locations.
  - High Coherence = system will attempt to meet desired Phase
  - Low Coherence = system will ignore (randomize) Phase.
  - Allows for field tailoring and/or reduction of spatial variability.

*Rouse, Jerry W., et al., "Analytical Modeling of the Acoustic Field during a Direct Field Acoustic Test," *26th Aerospace Testing Seminar,* The Aerospace Corporation, Los Angeles, CA, March 2011.



Equal Phase, High Coherence SPL (σ = 4.75)*



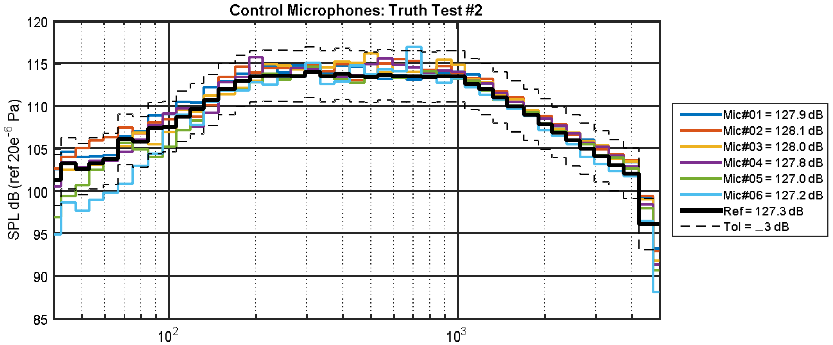
Random Phase, Low Coherence SPL (σ = 0.27) *

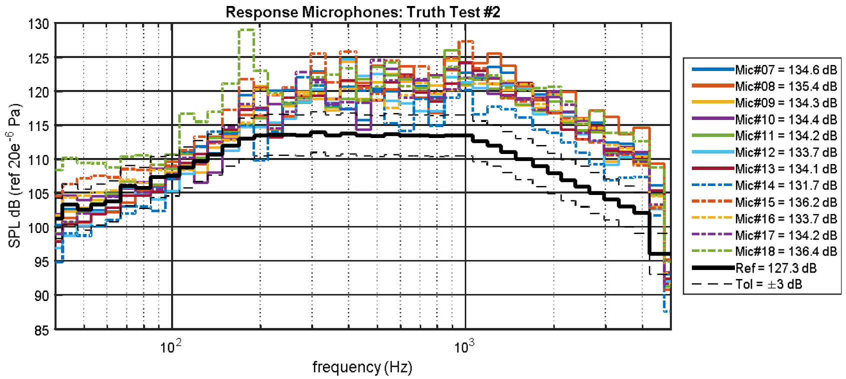
Typical SISO Test

Test Plan

- Past DFAT MIMO results showed accurate local control with increased global response [Stasiunas, IMAC 2016].
- Low coherence desired = random phase = diffuse field (theory)
- Therefore, run desired test spec at -12 dB with low coherence (0.1)
- Perform test runs with low and high coherence (0.1 and 0.9).
- Adjust array -4-in, 0-in, +4-in

*Stasiunas, IMAC 2016

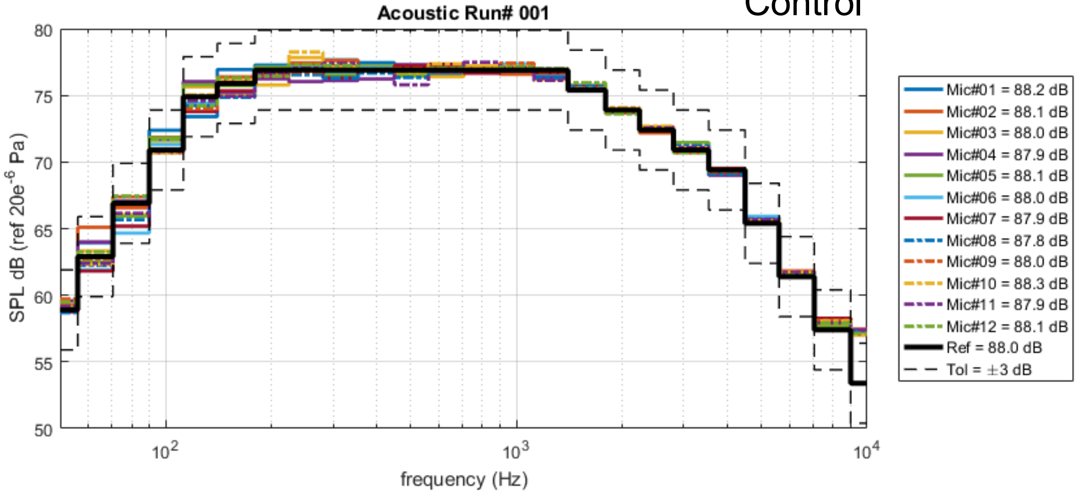




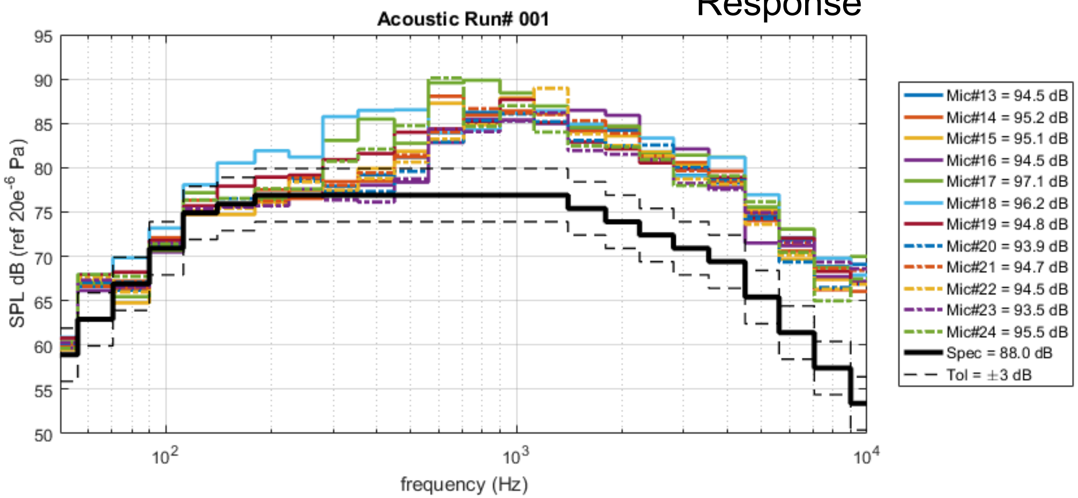
Results – Test Specification (-12 dB)

- Control OASPL = 88 dB
- Control mics displayed accurate local control
- Response mics
  - Well-grouped together
  - Increasing SPL > 250 Hz
  - Outlier responses = center mic above GSE (#17) and outside array mics (#18 and #24)
- Control and response difference expected, but not well understood; appears to be function of frequency wavelength

Control

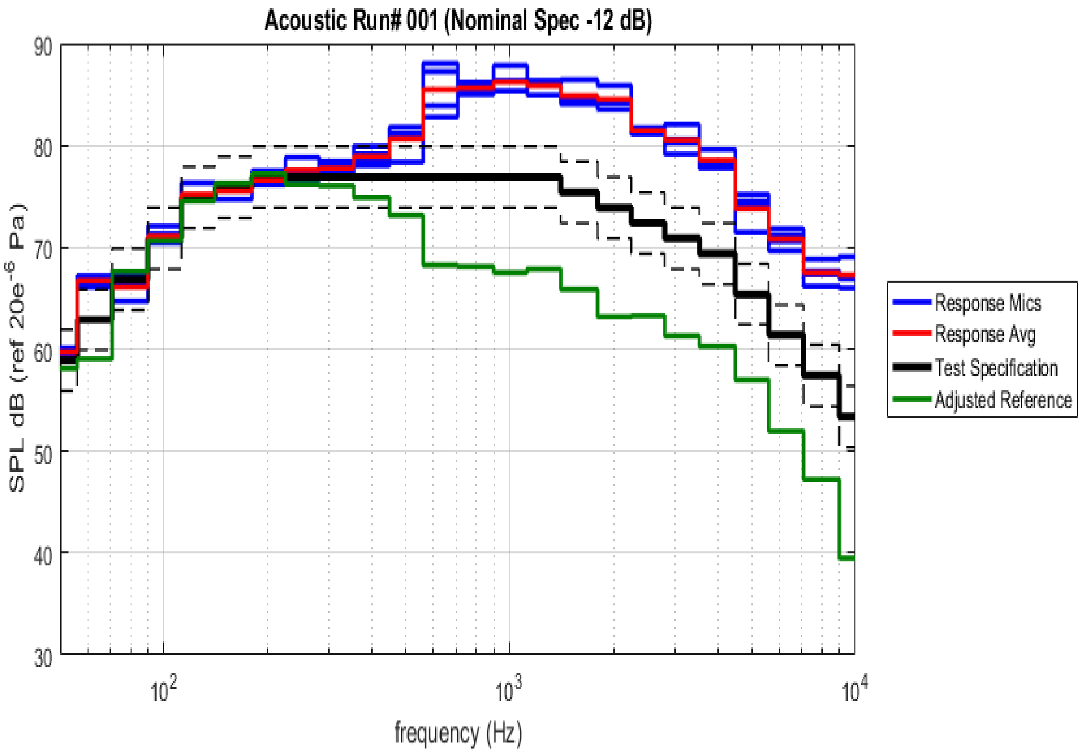


Response



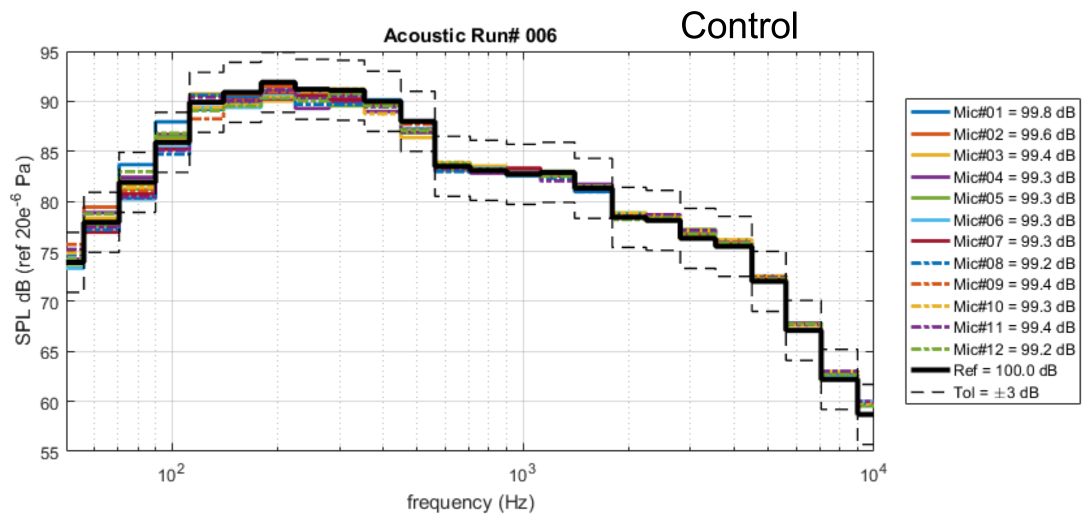
Adjusting Reference Specification

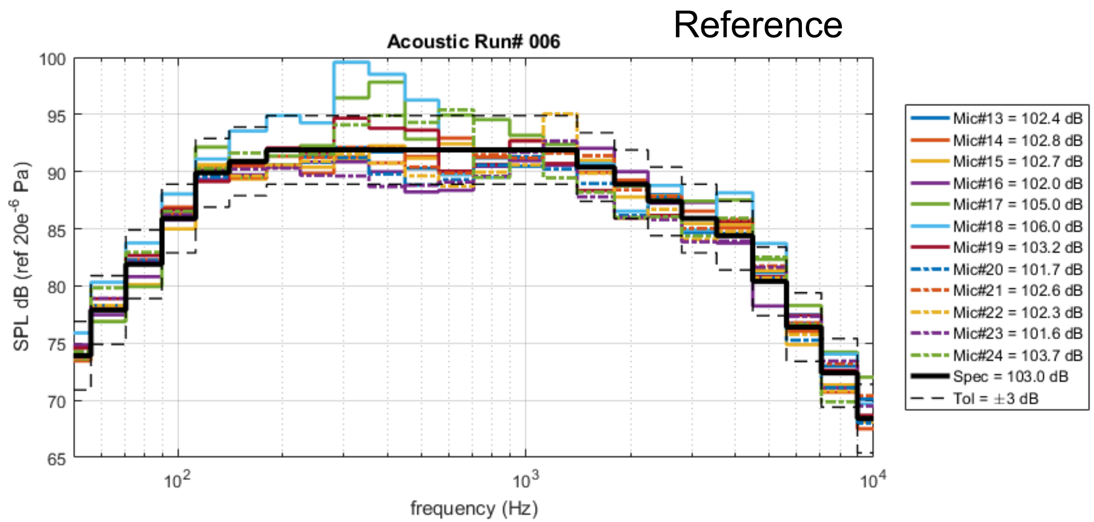
- Adjusted Test Reference Calculation:
  - Response Mic #13-16 located near GSE (blue)
  - Subtract test spec (black) from average of Mic #13-16 SPL (red)
  - Subtract this difference from test spec (black)
  - Adjusted ref (green)
- Found consistent levels at adjusted reference = 100 dB OASPL
- Response microphones = 103 dB OASPL.



Test Results – Adjusted Ref, Low Coh

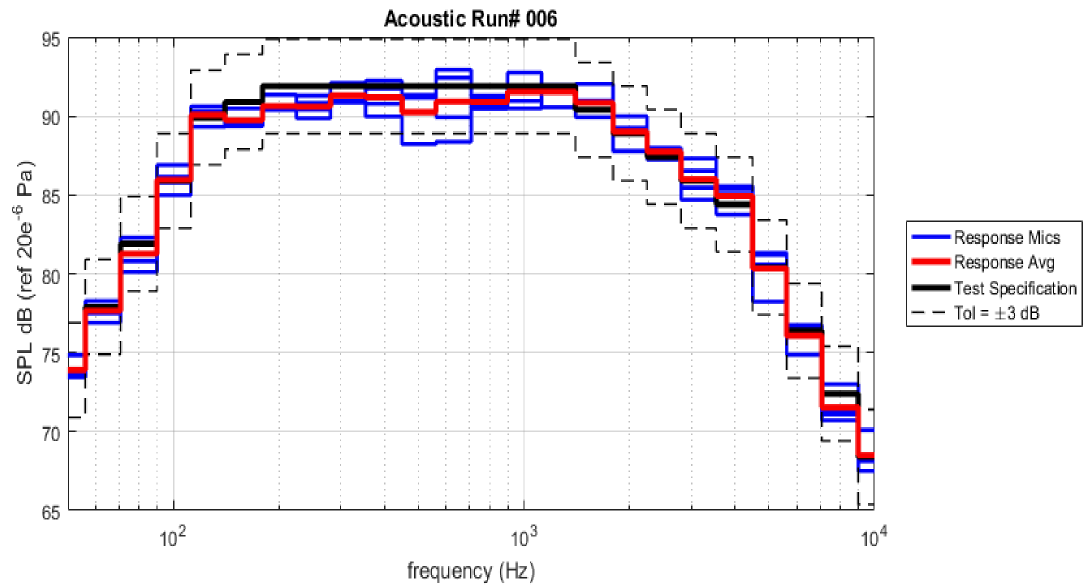
- Control microphones = 100 OASPL; accurate local control
- Response microphones = 103 OASPL
  - Well-grouped together
  - Deviates from tolerance at a few freq bands
  - Outlier responses = center mic above GSE (#17) and outside array mics (#18 and #24).
- Good accelerometer response (above noise floor).





Test Results – Adjusted Ref, Low Coh

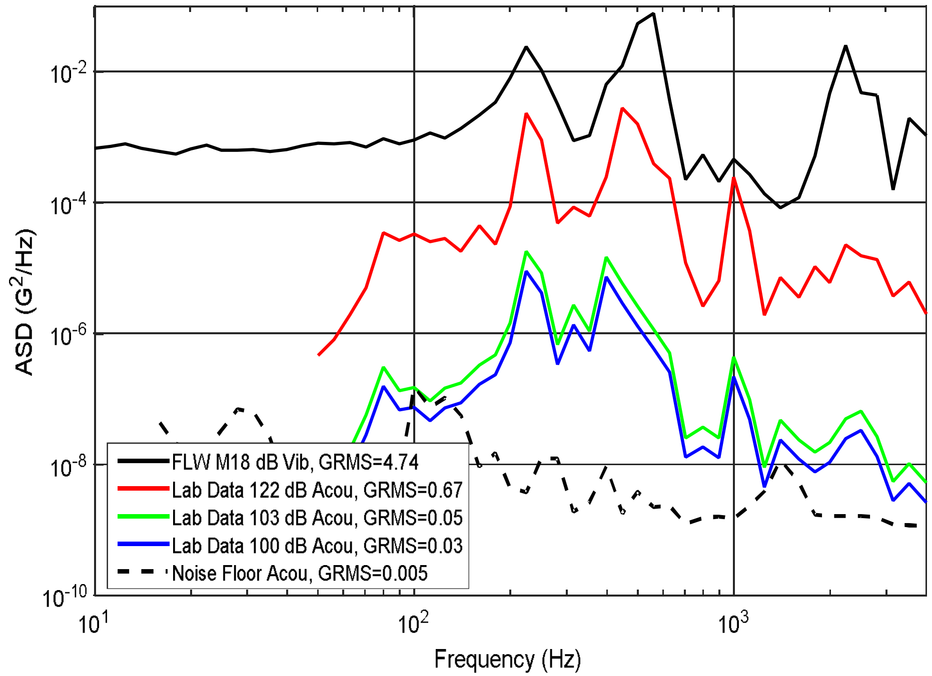
- Goal of testing was to simulate flight line acoustic input for test spec derivation.
- Required one SPL spec for scaling purposes.
- Therefore, use average of four response mics (#13-#16) for prediction method.
- Average (red) a bit lower than test specification.
- Hindsight: increase adjusted test ref at low frequency bands.



Predicting Flight Level Predictions

- Need to quantify what vibration test level envelopes acoustic flight-line response.
- Scale averaged acoustic input (Ch #13 - #16) up to 122 dB OASPL for highest short term OSHA levels allowed.
- Scale measured GSE response data corresponding amount.
    - Small-scale data (green).
    - Scaled up to 122 dB (red).
- Using MIL-STD-810G vibration shaker test data, scale down vibration GSE acceleration responses (black) to envelope acoustic responses.
- Decibel Formula used for scaling

$$dB = 10 * log_{10}(\frac{P2}{P1})$$



- Flight Line Workmanship now a shaker vibration test reference that represents acoustic environment seen on flight-line.

Conclusion

- Multiple small-scale, acoustic tests were performed on ground support equipment.
- Twelve pairs of commercial off-the-shelf monitor speakers were used for acoustic excitation, enclosed in acoustic blanket frame.
- Direct-field acoustic method with multi-input multi-output control used to apply drives.
- A reasonable diffuse environment of 103 dB OASPL was obtained with low coherence.
- Control system reference was adjusted to account for difference between control and response microphone measurements.
- Scaling up acoustic responses to input of 122 dB OASPL, and scaling down vibration test data to envelope these responses resulted in new Workmanship Flight-Line vibration test spec.