Toward Development of Standard Practices in Direct Field Acoustic Testing

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The Aerospace Corporation

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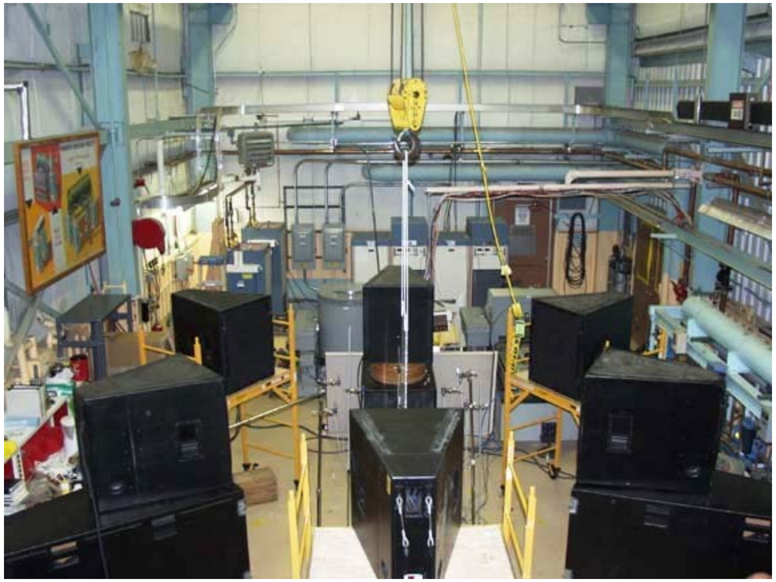
Objectives

- Illustrate need for developing industry standard practices for direct field acoustic testing
- Highlight work done by Aerospace
- Solicit feedback and call for industry participation

Direct Field Acoustic Testing

- Acoustic testing that relies primarily on the control of the direct sound field from acoustic sources with the objective of exposing a test article to specified average test levels
  - Compared to reverberant chamber testing that relies on controlled excitation of the characteristic reverberant response of a chamber to achieve specified test levels

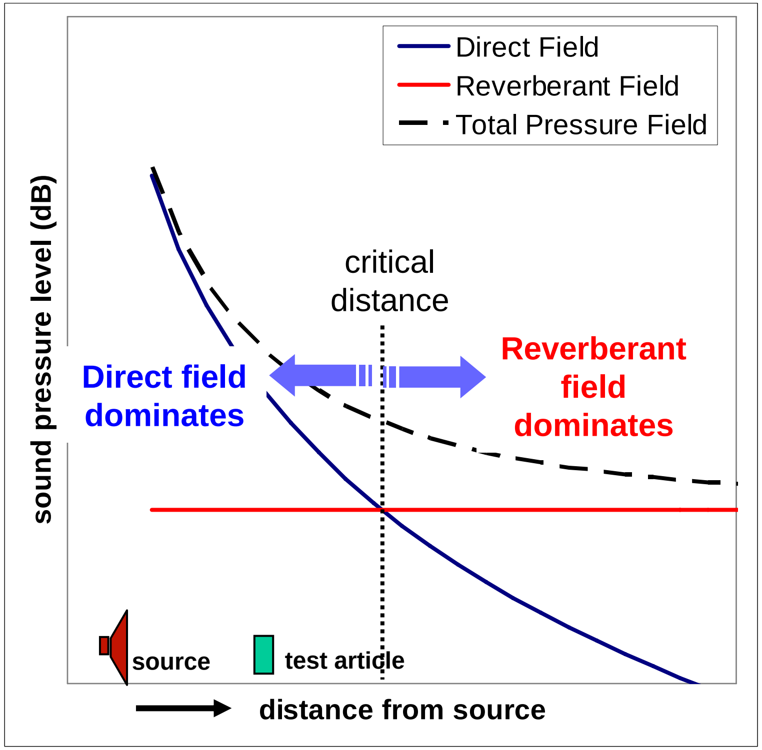


- Usually implemented with array of electrodynamic loudspeakers surrounding test article

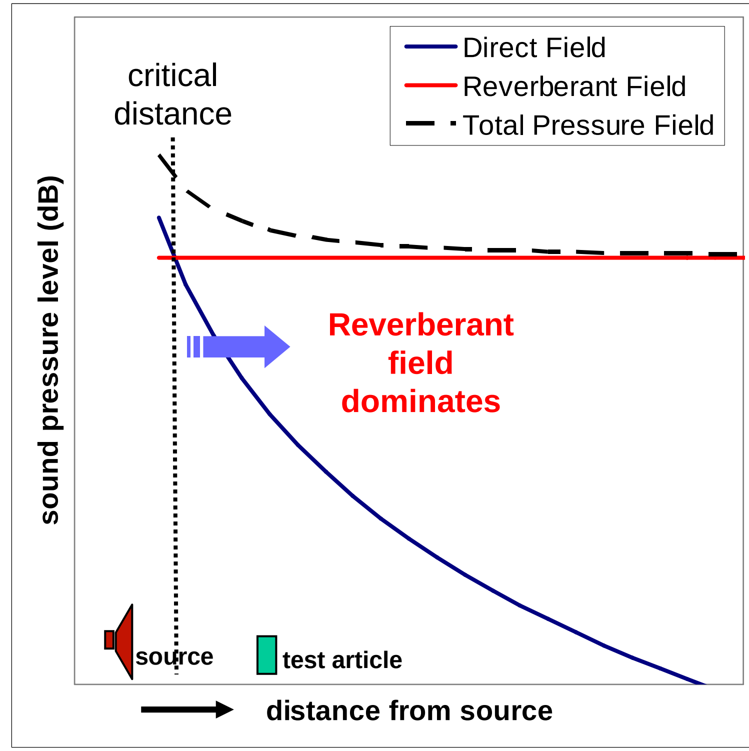
Attractive Features of Direct Field Acoustic Testing

- Test can be performed in variety of test spaces
  - Reason: Less dependence on room characteristics to achieve desired levels
  - Portable test equipment
  - Test equipment can be configured to accommodate test article and space
- "*In situ*" testing minimizes issues related to transportation
- Eliminates logistic, safety issues associated with use of nitrogen (typically used in chamber testing to reduce attenuation of high frequency waves)
- Minimal number of personnel needed to operate test
- Testing can be performed by vendor if no equipment/expertise available
- Easy to make many test iterations for investigative, experimental testing
- Enables non-conventional test capabilities for specific purposes
  - Simulation of spatial sound gradients
  - Non-stationary acoustic testing
  - Narrowband control of sound spectrum (Larkin, Smallwood, 2003)

Relative Influence of Direct and Reverberant Fields on Test Article



Case 1: Room With Low Reverberance*



Case 2: Room With High Reverberance*

- Test article lies in region dominated by direct field
- Test article lies in region dominated by reverberant field

*** Frequency Dependent**

Sensitivity of Direct Field Acoustic Testing to Test Configuration

- **Achievable sound levels dependent on proximity, number of sources**

- **Spatial distribution of direct acoustic field non-uniform and dependent on**
  - Loudspeaker placement and orientation with respect to test article
  - Directivity of sound source
    - Directivity effect increases where half-wavelength < driver diameter
  - Control microphone placement
    - e.g., mic placed in acoustic minimum can cause over-test, *visa versa*
  - Test article size and geometry (scattering characteristics)
  - Correlation and phasing between source loudspeakers

Sensitivity of Direct Field Acoustic Testing to Test Configuration

- **Acoustic waves impinge on test article at discrete incidence angles** (vs. random incidence angles reverberant chamber diffuse field)
  - Dependent on source orientation and location
  - Affects vibroacoustic response and transmission loss of test structures
    - Difference in panel response to normal vs. diffuse incidence noted previously (Larkin, et al, 1999, Anthony, et al, 1999)

- **All of the above considerations are frequency dependent**

Research Efforts by Aerospace

- **Immediate objective**
  - Develop in-house direct field acoustic testing capability
    - Initial phases – Testing at Sandia National Laboratories
    - Follow-on phase – purchase equipment and demonstrate mobile test capability

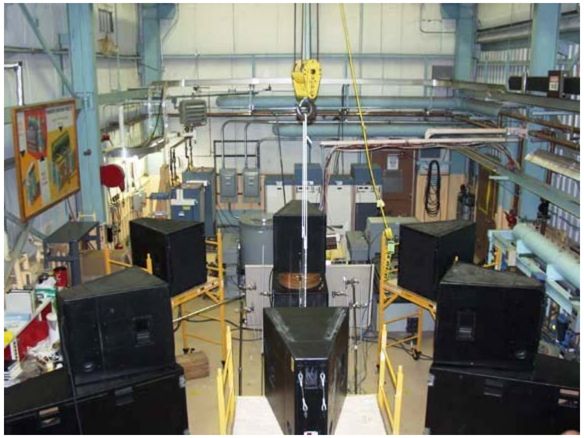
- **Long term objectives**
  - Customer support using test capability
    - Portable characterization testing, vibroacoustic anomaly resolution
  - Actively participate in developing industry best practices

Current Research Activities

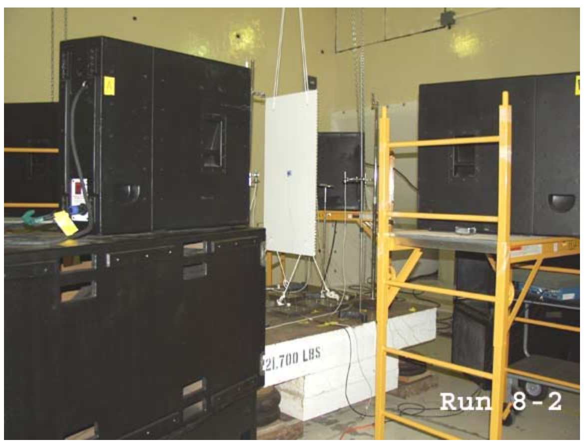
- **Performed testing at Sandia National Laboratories facility***
  - Validated equipment suite as prototype for Aerospace portable direct acoustic testing laboratory
    - To be used for characterization testing of small to mid-sized test articles
    - Achieved 132 dB overall SPL in direct field dominant test space (highbay)
  - Collected initial data sets for characterizing direct acoustic testing
    - Comparison between two test spaces
      - Highbay – low reverberance (T60 < 1 sec), direct field dominates at test article
      - Reverberant Chamber – high reverberance (T60 ~ 10 sec) reverberant field dominates
    - 52 test runs using various configurations
      - Loudspeaker configuration
      - Control microphone number and placement
      - Test article orientation
    - 24” x 48” x ½” aluminum honeycomb panel for nominal test article

*Tests conducted by SNL using SNL equipment

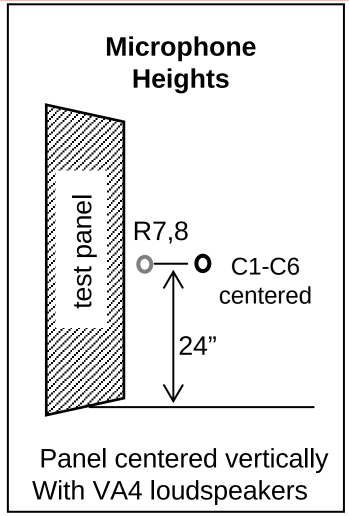
Example Test Configuration

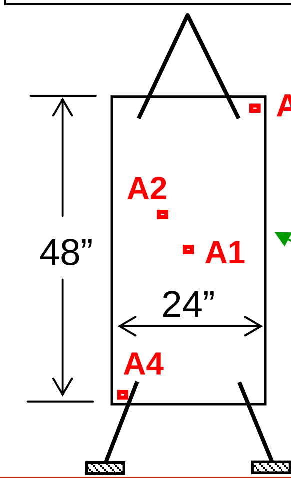


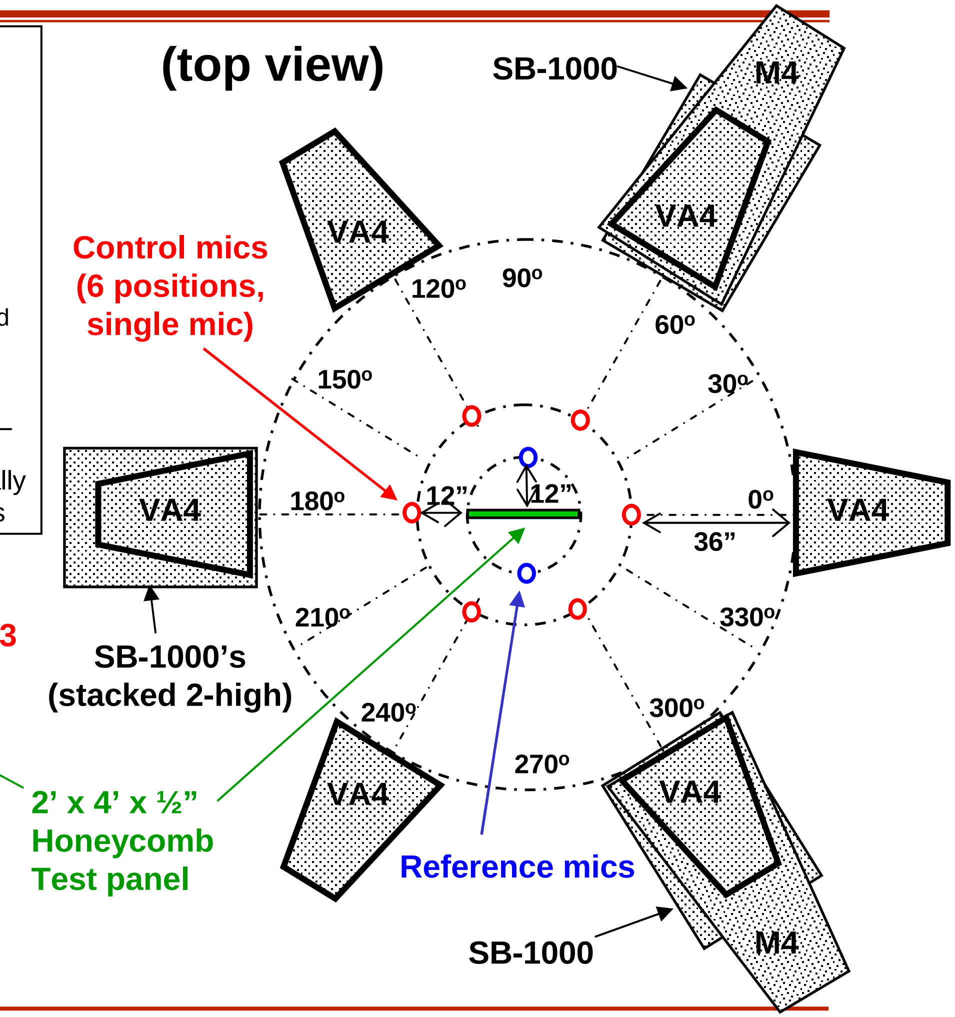
Setup in Highbay



Setup in Reverberant Chamber

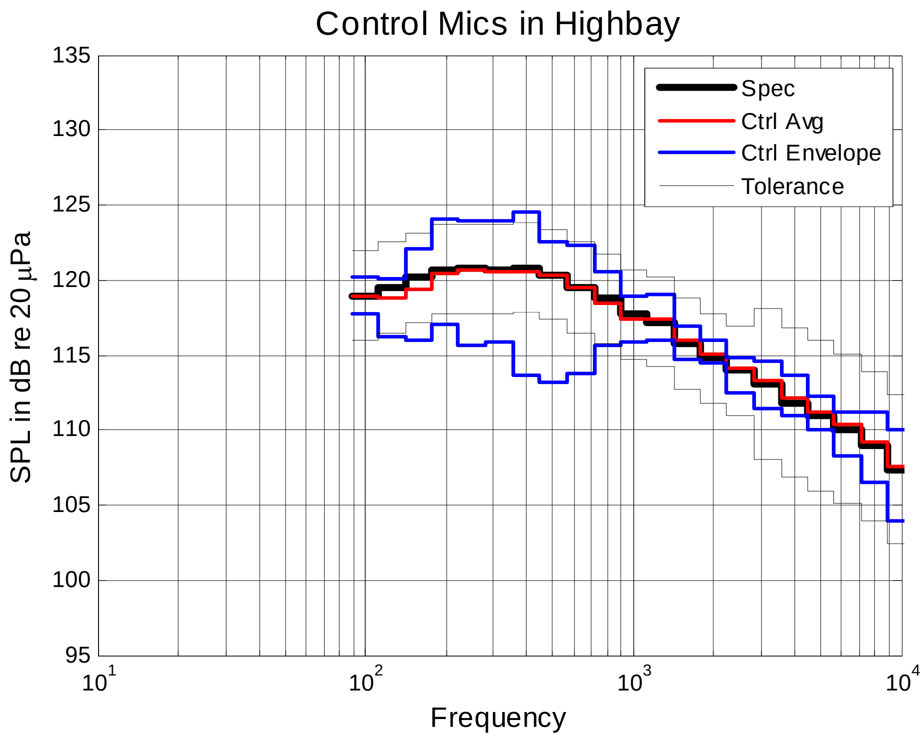


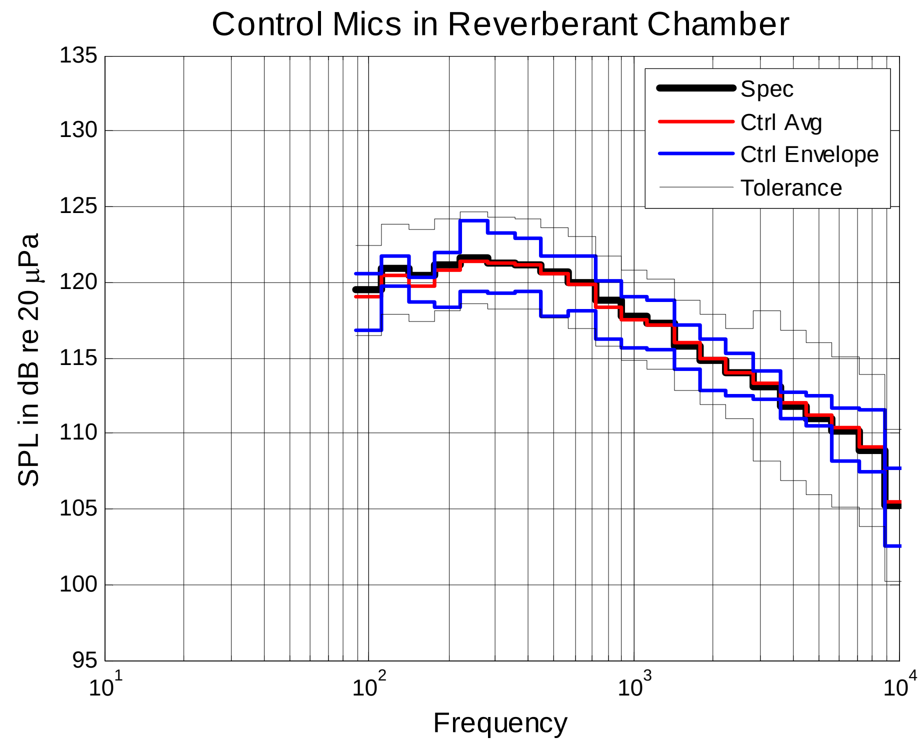




Test Control – Highbay vs. Chamber

Example test configuration – diagram on previous chart

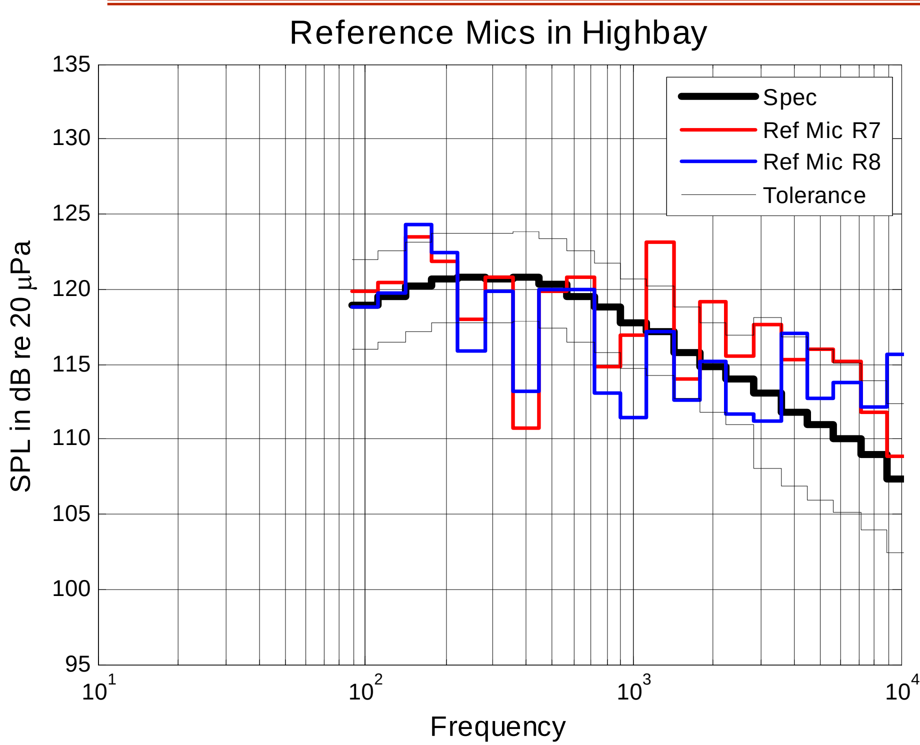


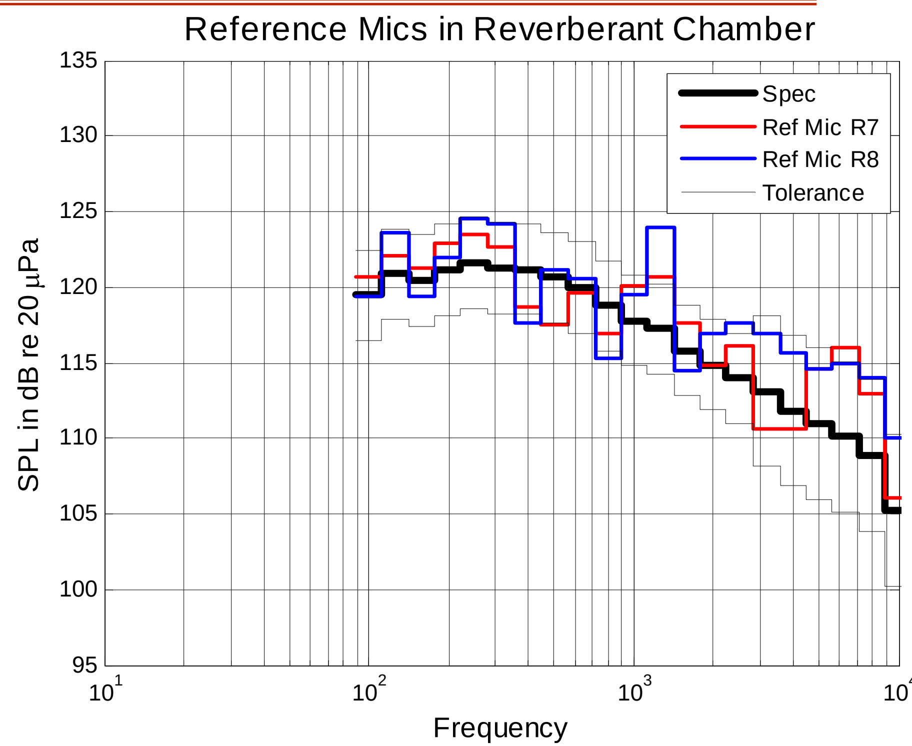


- Control mic average well within tolerance for both highbay and chamber test spaces
- Spatial variability between control mics more pronounced in mid-frequency range for direct field dominated highbay test space (shown by envelope of control mic max and min)

Reference Mics – Highbay vs. Chamber

Example test configuration

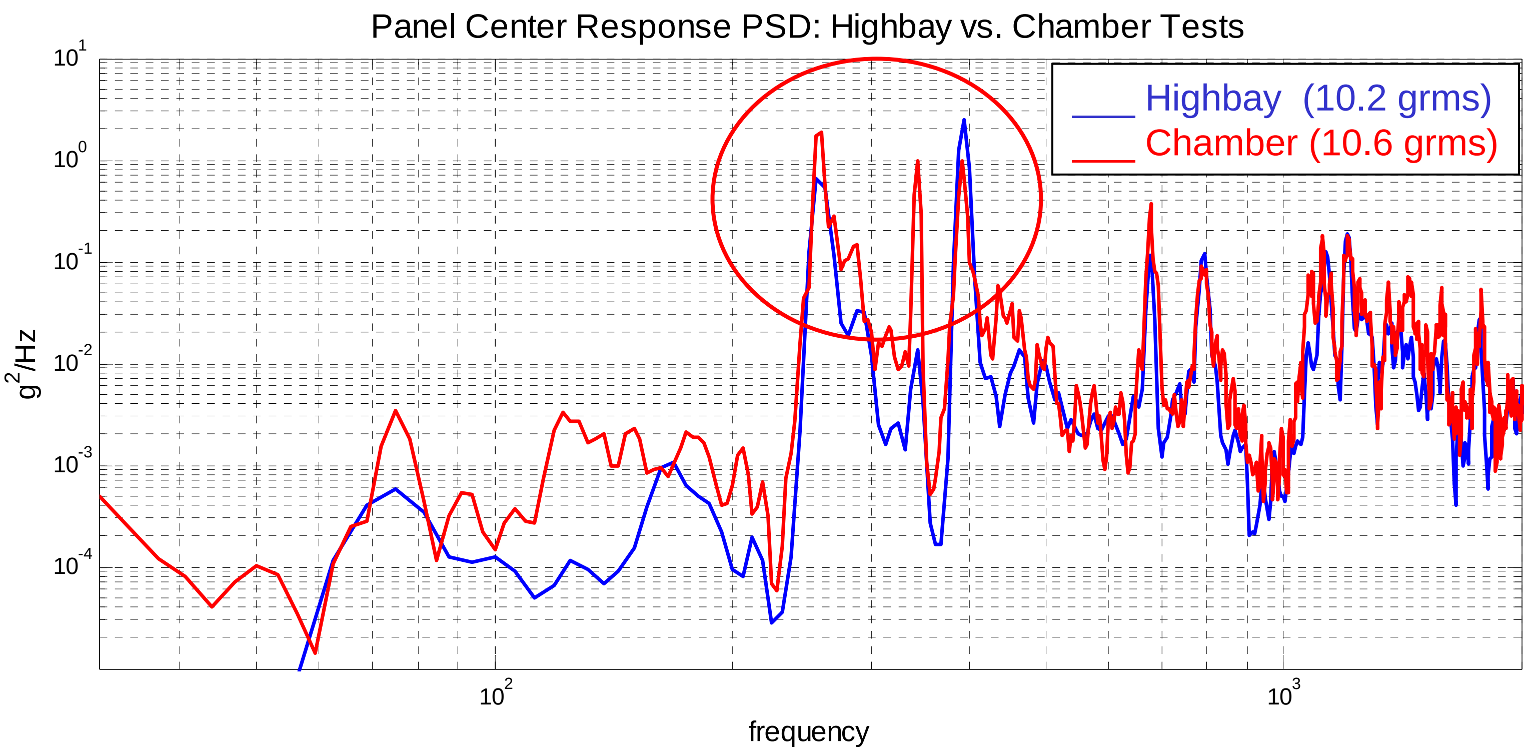




- Reference mics not in control loop – purpose to measure sound field near test article (12" from center)
- Frequency response variance from nominal spec more pronounced in highbay test space (direct field dominated)

Panel Response – Highbay vs. Chamber

Example test configuration (Response at panel center)

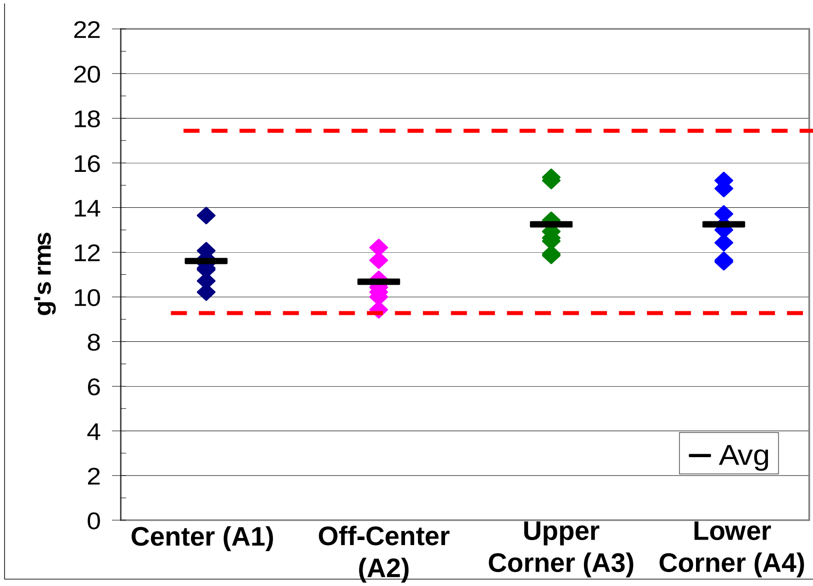


- Primary differences noted in major panel mode responses
- Overall grms response is comparable for this particular configuration

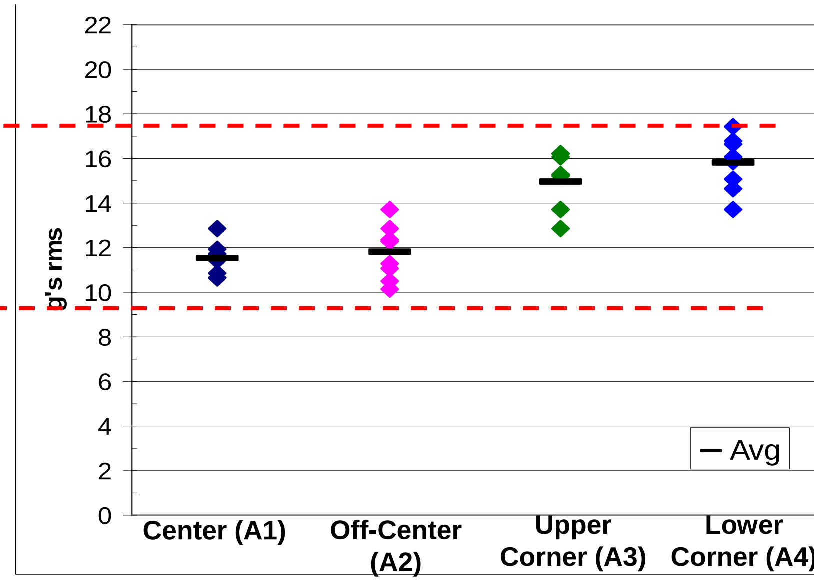
Panel Response Comparison

Selected Configurations

Highbay (dominant direct field)
Panel Response Variability for Different Test Configs

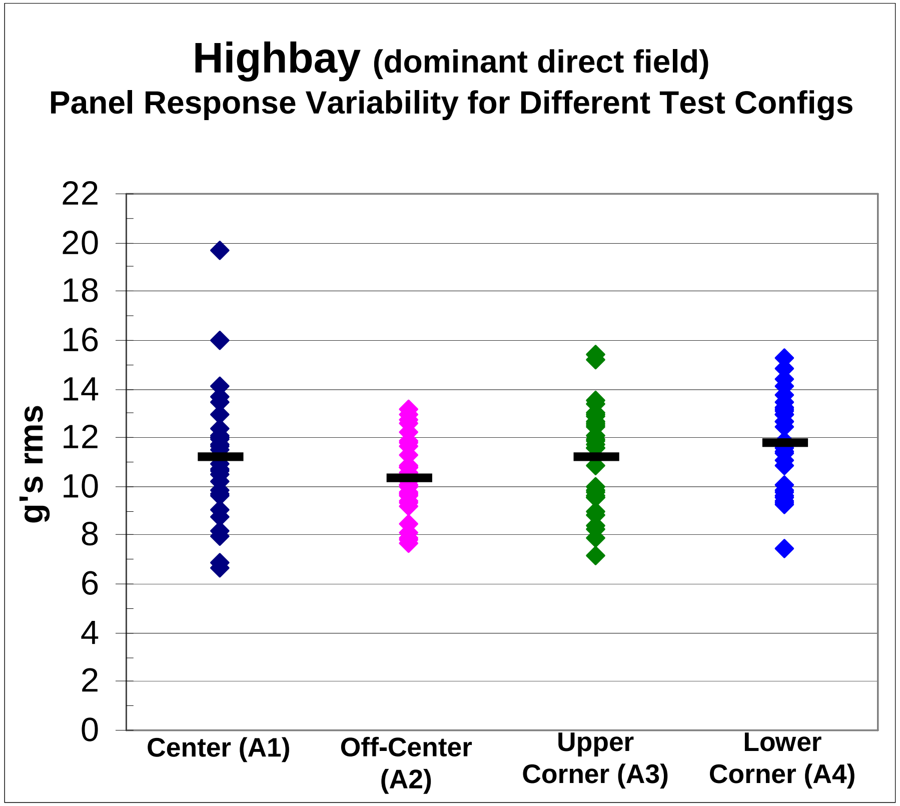


Chamber (dominant reverberant field)
Panel Response Variability for Different Test Configs



- Variations on example test configuration
  - Fixed test article and loudspeaker placement - VA4's placed at 60 deg
  - 3 control mics @ 120 deg, 6 control mics @ 60 deg, clocking of control mics
- Response variation between configurations comparable between highbay and chamber. Overall responses slightly higher for runs in reverberant chamber test space

Highbay Test Space: Panel Response vs. All Test Configurations



- **31 runs performed in highbay with different test configurations**
  - Loudspeakers spaced @ 120 deg vs. 60 deg.
  - Test article orientation (clocking) with respect to loudspeakers
  - Control mic number, placement
- **Measure of panel response shows significant scatter around mean**
  - Changes in loudspeaker spacing and test article orientation contributed significantly to scatter
- **Note: results highly repeatable for any single configuration**

Initial Observations from Testing

- Test specification with overall SPL = 132 dB achieved well within tolerance with equipment used
- Spatial variability of sound field more pronounced for highbay test space (direct sound field dominant) than for chamber (reverberant sound field dominant)
- Panel response comparable between highbay test space and chamber test space for similar selected test configurations
  - Differences pronounced in comparison of response of major modes
- Wide variability of panel response noted between different configurations in highbay test space (dominated by direct field)

General Observation

- **Direct field acoustic testing prone to variability in results, depending on test configuration**
  - Lends itself to wide variation of test configurations, while particularly sensitive to test configuration
  - "Achieving spec" with control mic average does NOT guarantee consistent test results
    - No direct control of entire sound field at test article
    - Structural response, sound transmission and scattering also dependent upon angle of incidence and spatial correlation – not indicated by control SPL
- **Industry-wide acceptance of direct field acoustic testing calls for development of an industry standard practice**
  - Based on experience and theoretical/experimental investigation
  - Current IEST Recommended Practice for High-Intensity Acoustic Testing (see bibliography) contains brief description of typical practices for direct field acoustic testing – can act as starting point

Suggested Areas for Development

- **Characterization of direct sound field**
  - Acoustic spatial variability, diffuse vs. discrete incidence, statistical uncertainty, etc.

- **Optimization of test configuration and control parameters to achieve desired acoustic power, sound field characteristics**

- **Characterize response and sound transmission of structure as function of defined direct sound field characteristics**
  - Develop means of comparison with reverberant chamber testing and flight

- **Guidelines for meeting safety and environmental regulations**

Next Steps

- **Convene industry experts in the field**
  - Assess current state-of-the-art, discuss concepts, methodologies
  - Chart course toward accepted industry standard practices

Acknowledgements

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Call for Discussion

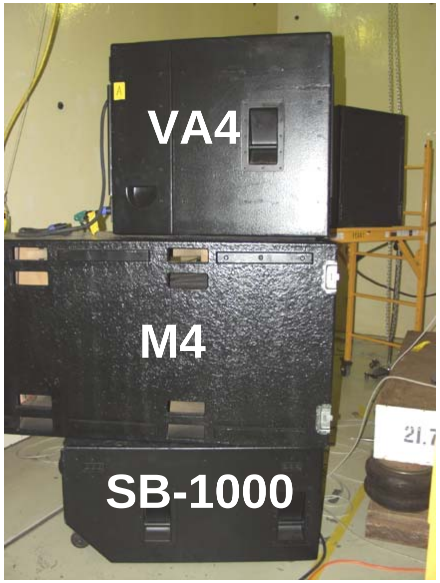
Backup

Test Equipment – Sound System

- **Loudspeakers**
  - 6 VA4 full range (Maryland Sound)
    - contain high, mid and low drivers
  - 4 SB1000 sub bass (Maryland Sound)
    - Each contain 2 18” woofers
  - 2 M-4 mid-bass horn (JBL)
    - Supplement acoustic power near 250 Hz

- **Amplifier rack**
  - 5 Crown MT5002VZ
    - 5 kW (2.5 kW/chan)
    - w/ programmable input processor module
  - 1 Crown MT2402
    - 2.5 kW (1.25 kW/chan)
    - w/ programmable input processor module
  - IQPIP-USP2 computer control system

- **PC-based digital amplifier control**
  - Control parameters set over ethernet
  - Set driver crossover frequency
  - Set voltage limits for protection
  - Monitor power draw and thermal



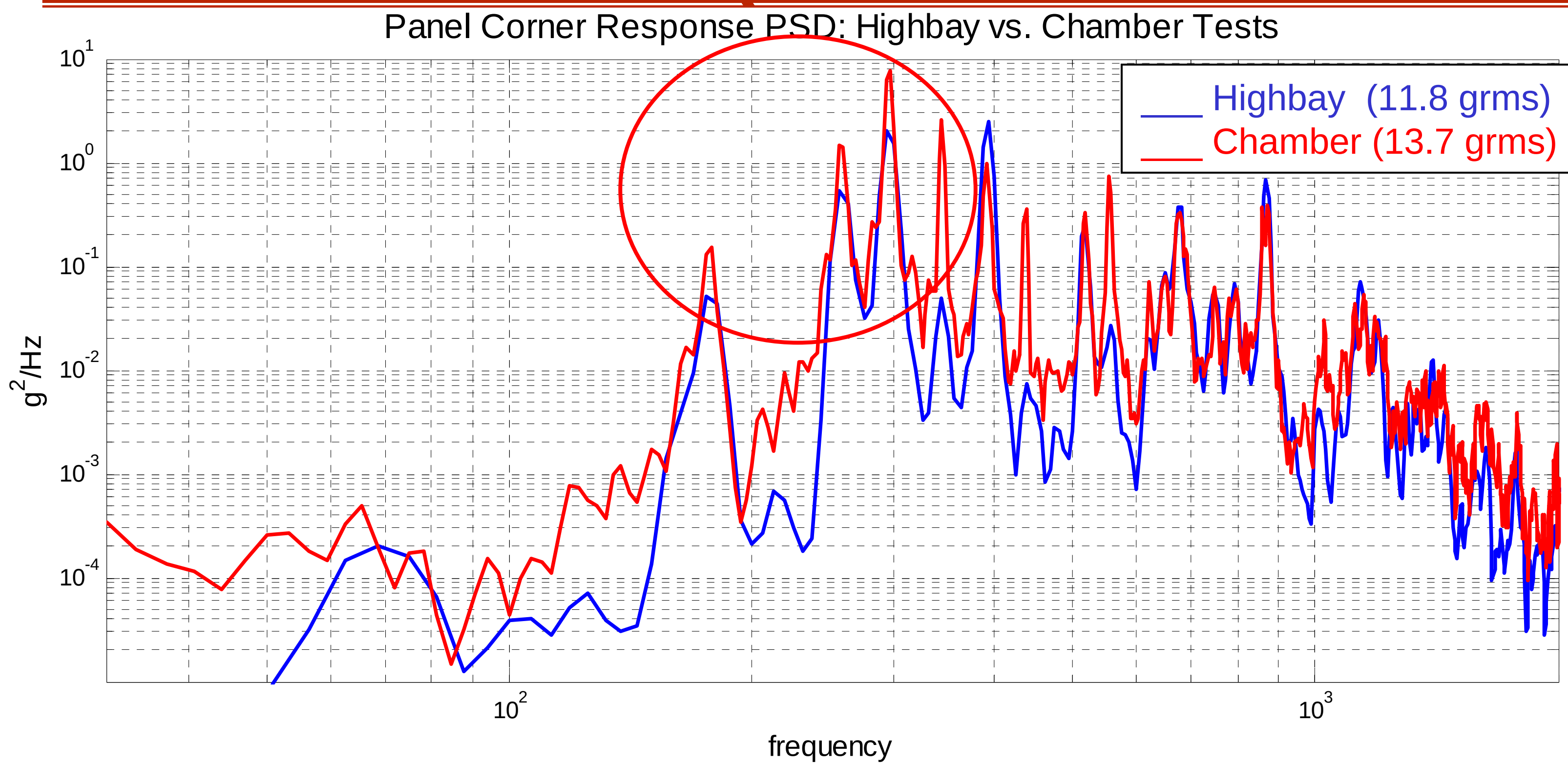
Test Equipment - Control

- **Random controller and data acquisition**
  - Spectral Dynamics Jaguar Acoustic Control & Analysis
    - Same HW as used for random vibration closed loop control
    - SW modified for random acoustic control and analysis
    - Data acquisition and data reduction (spectral analysis)
  - SCSI drive
    - Real time data streaming and storage

- **Remote communication interface for Jaguar**
  - Sun workstation

Panel Response (cont.)

Example configuration (Response at panel free corner)



- A number of modes more readily excited in chamber space test than in highbay test
  - May possibly be effect of support boundary conditions at corners

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