



Review of Noise Metric Sensitivities for Analysis of Quiet Supersonic Overflight

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**182nd Meeting of the Acoustical Society of America
Denver, CO, USA
May 24, 2022
Session 2aPAa**



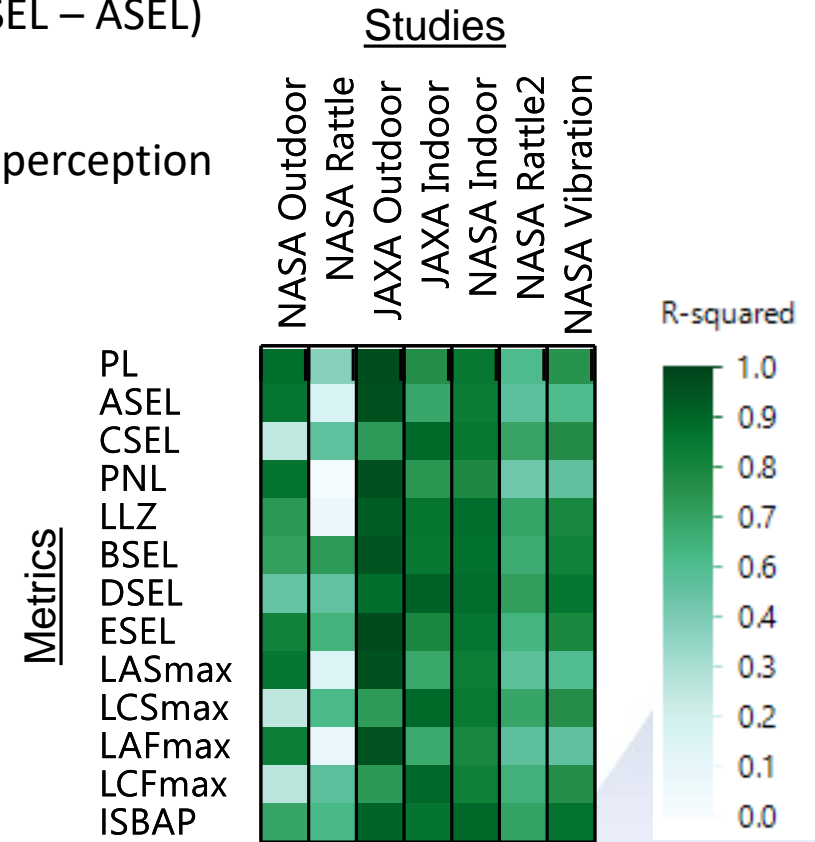
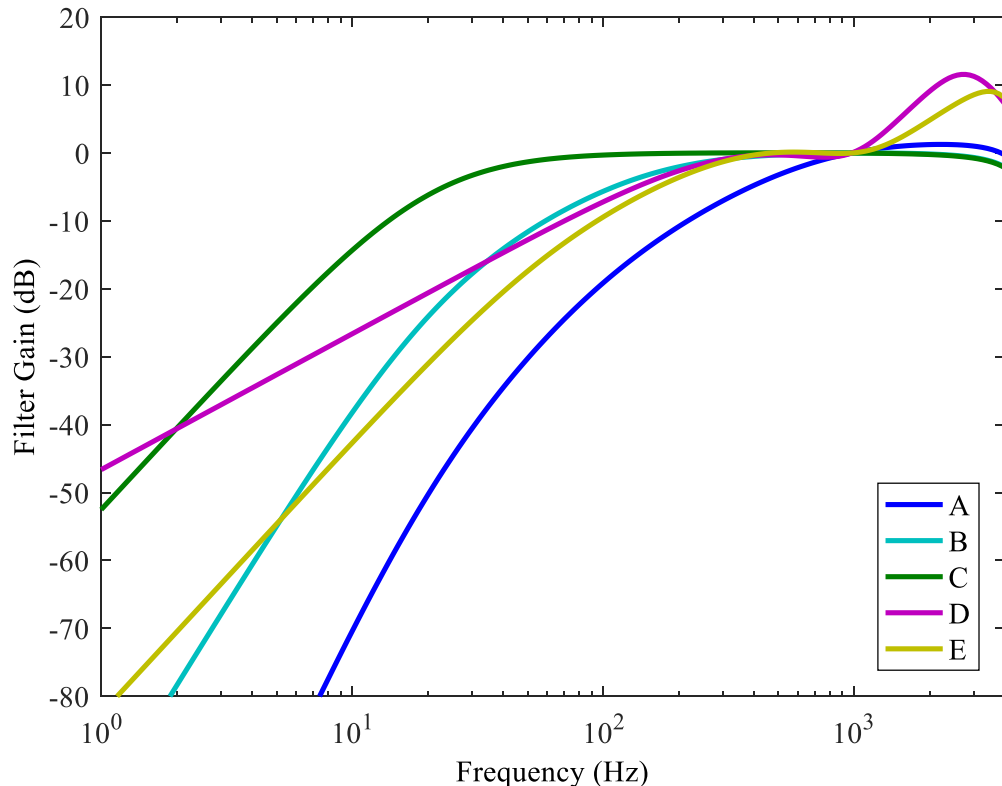
- **NASA goal to enable development of noise-based standard for commercial supersonic aircraft**
- **Two regulatory issues for civil supersonic flight**
 - Limiting airport noise during subsonic flight
 - Limiting sonic boom noise during en route supersonic flight
- **Development of international standard**
 - Noise-based certification standard for supersonic en route (sonic boom) noise
 - Certification standard would include **noise metric**, test procedures, and noise limits
- **Required characteristics of noise metric**
 - Easy to implement and well-defined
 - Predict human perception of sonic booms experienced both outdoors and indoors
 - Robust to apply in real-world situations

Sonic Boom Noise Metrics: Human Perception



➤ Six noise metrics identified in previous work^{1,2}

- ASEL, BSEL, DSEL, ESEL, PL, ISBAP
 - Indoor Sonic Boom Annoyance Predictor = ISBAP = PL + 0.4201 (CSEL – ASEL)
- No clearly preferred metric
 - PL has been used often because of good correlation with outdoor perception



Graphical representation of R² values for each experiment

¹ANSI 2020
²Loubeau 2018

Sonic Boom Noise Metrics: Human Perception

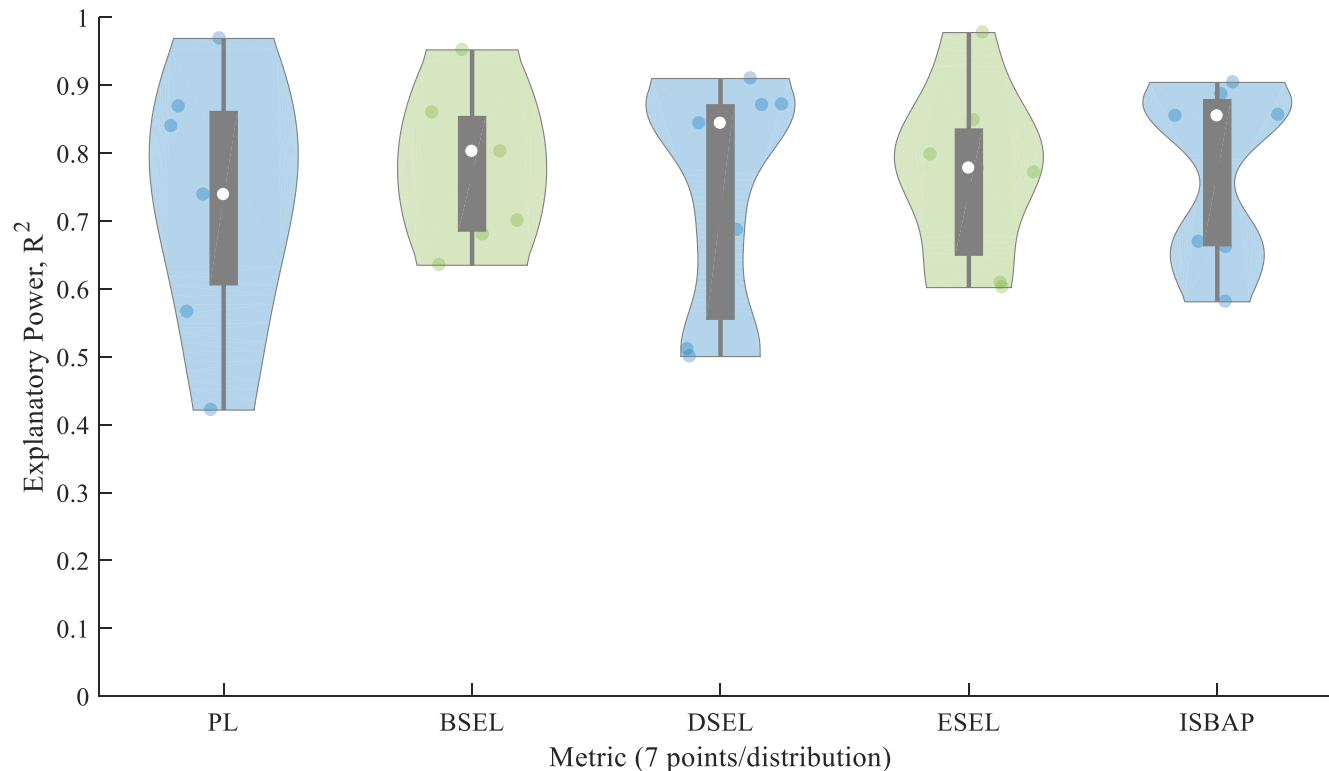


➤ Meta-analysis

- Comprehensive evaluation of metrics
- Several years of laboratory testing data (7 tests) at NASA and JAXA

➤ Five metrics correlate well with human response outdoors and indoors²

- Sixth metric (ASEL) retained for historical reasons



Sonic Boom Noise Metrics: Robustness



- **Meta-analysis did not identify a single metric that was significantly superior**
 - No internationally agreed-upon metric has been chosen for the quiet supersonic aircraft noise certification procedures currently under development
 - Current analyses apply all six metrics
- **Analyses of metric sensitivities using existing empirical and simulation datasets have shown significant differences between metrics**
- **Sources of metric variability**
 - Macro-atmospheric effects
 - Atmospheric turbulence
 - Microphone setup configurations
 - Ambient noise

Macro-atmospheric Effects



➤ Simulation study of NASA X-59 sonic thumps across the U.S.³

- 138 locations, 5 years, 4 headings
- DSEL has narrowest distribution
- ASEL and PL distributions are widest

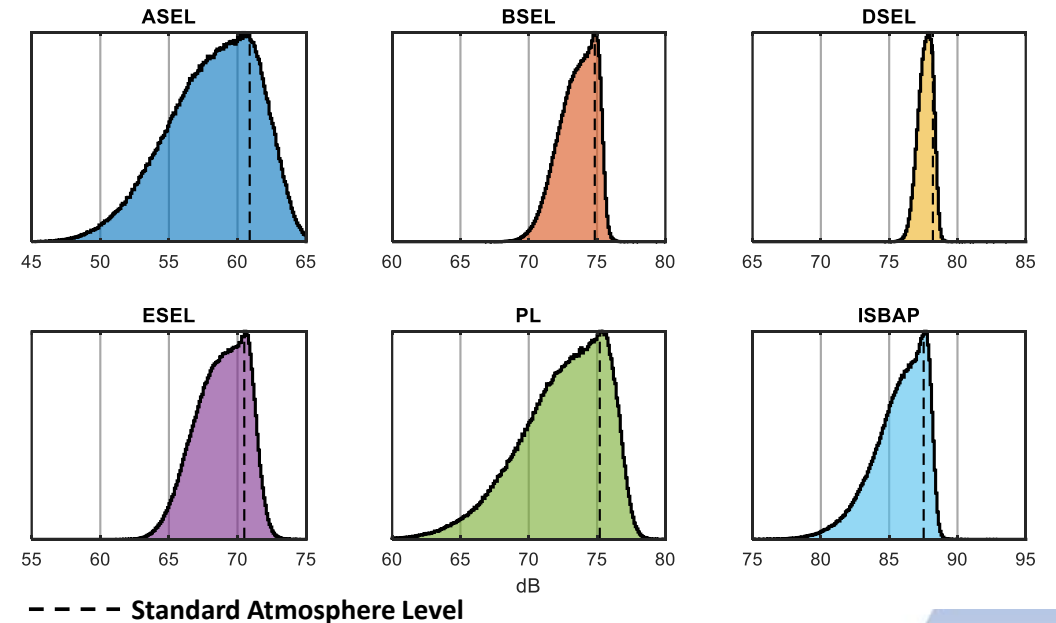
➤ Simulation study of shaped booms across the world⁴

- 666 locations, 1 year
- Confirms trends using different aircraft and locations
- PL SD is 12 dB and ISBAP SD is 8 dB

➤ Comparison to different standard atmospheres

- BSEL and DSEL show smallest differences between worldwide calculations and those with different humidity models
- PL and ASEL have more significant differences

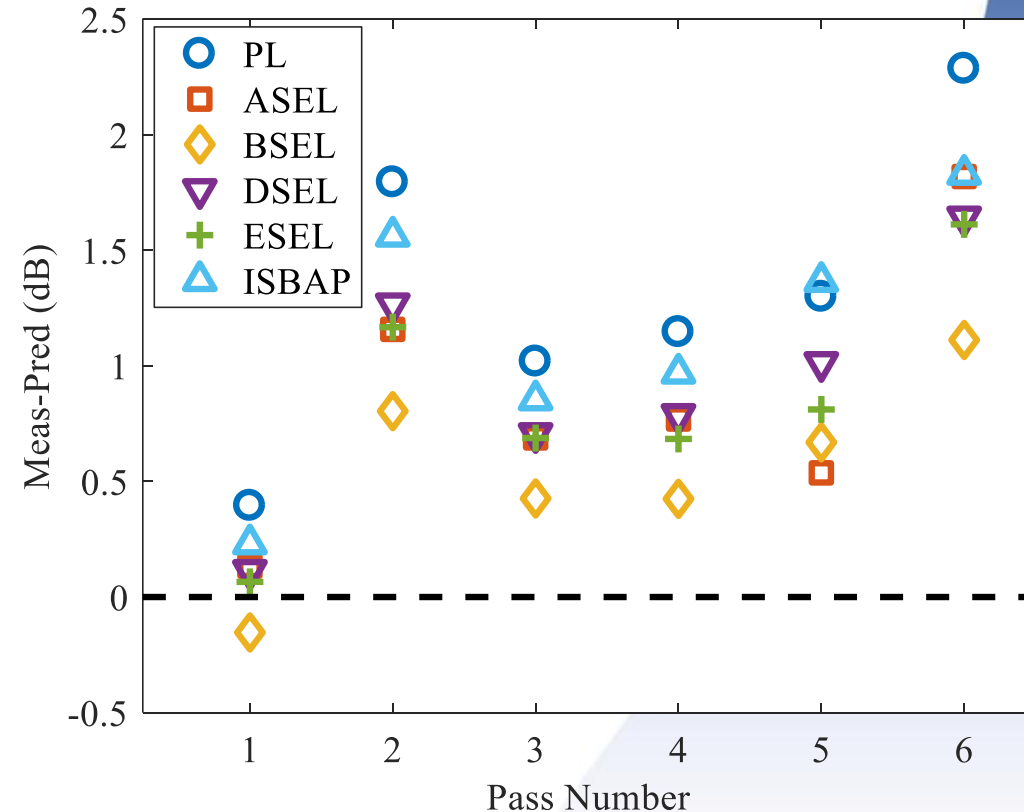
X-59 Undertrack Metrics Across U.S.



Atmospheric Turbulence

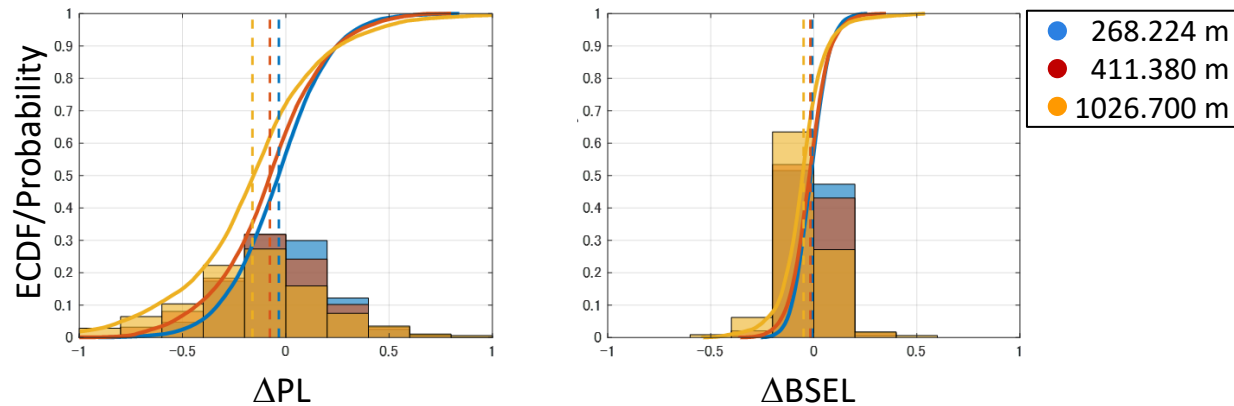


- **Measurements and simulation of atmospheric turbulence variability effects⁵**
 - N-wave simulations show lower SD for ISBAP than for PL
 - FIR filter approximation vs. full simulations
 - Errors are less for BSEL and highest for ASEL and ESEL
- **Measurements of N-waves with turbulence variations along a mic array^{6,8}**
 - BSEL and ISBAP were most “stable” and PL and ASEL were least stable
 - Similar conclusions for set of N-waves and shaped booms with turbulence filters applied⁷
- **Comparisons of predictions and measurements⁹**
 - BSEL differences are smallest and least sensitive to (low) turbulence effects



➤ Simulation datasets of shaped booms through turbulence¹⁰

- Input signature from NASA X-59 C609 design
- 3 different atmospheric boundary layer heights
- Multiple random realizations for one low/medium turbulence case
- Predictions at 4,000+ simulated microphone locations for each turbulence realization



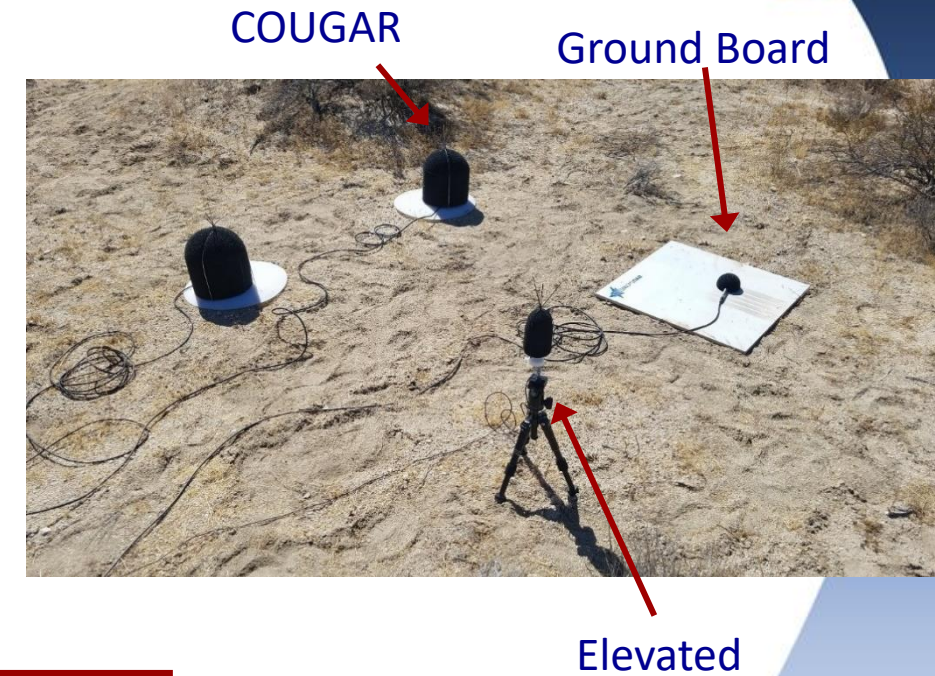
- As expected, some metrics like BSEL have less variability
 - 90% confidence intervals on means are smaller

Microphone Setup Configurations



➤ Effect of elevating microphone above ground¹¹

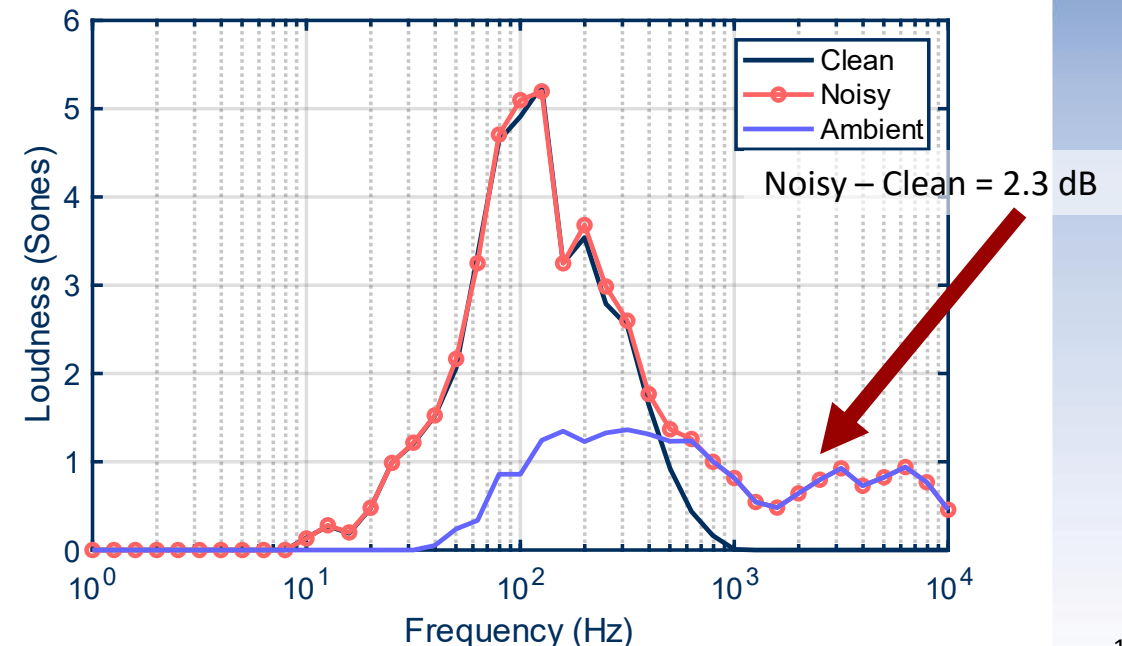
- Microphone elevated 0.5 m above ground
- Largest measured mean differences for ASEL, ESEL, and PL
- Due to dip in spectra of about 8 dB around 500 Hz
- Trends confirmed through modeling¹²



Mean Differences Relative to COUGAR Configuration

	PL	ASEL	BSEL	DSEL	ESEL	ISBAP
COUGAR	-	-	-	-	-	-
Ground-Board	-0.04	-0.2	-0.3	-0.2	-0.2	-0.02
Elevated	-2.1	-3.4	-1.4	-1.3	-2.2	-0.8

- Low loudness sonic boom levels may be difficult to recover in field measurements without ambient noise corrections
- Simulations of X-59 signatures combined with real measurements of ambient noise
- Signal-to-noise ratio is poor above a few hundred Hz
 - One option is to filter the signal
 - Another option is to correct the loudness levels or spectra in each band according to SNR
- Metrics affected by signal bandwidth limitations¹³
 - More uncertainty in final metric result for PL and ASEL than for BSEL





- **Small group of sonic boom metrics exist that correlate well with human perception**
 - Metrics apply different low-frequency weighting shapes
- **Reviewed prior studies that show differences in metric robustness**
 - Considered atmospheric effects, microphone configurations, and ambient environment
 - Included measurements and simulations for N-waves and shaped low booms
 - Similarity in findings across studies

**BSEL and DSEL are most robust
while PL and ASEL are least robust**

- **Additional studies are ongoing as analyses continue with the six metrics**
- **Differences in metric robustness could aid in further downselection for certification procedures**

References



1. ANSI/ASA S1.42-2020.
2. Loubeau et al. J. Acoust. Soc. Am., 144: 1706, 2018.
3. Doebler et al. e-Forum Acusticum, 2020.
4. Normand et al. ECCOMAS 2020.
5. Bradley et al. NASA/CR-2020-220509.
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8. Loubeau et al. J. Acoust Soc. Am., 146: 2780, 2019.
9. Loubeau & Doebler. J. Acoust Soc. Am., 145: 1899, 2019.
10. Loubeau et al. J. Acoust. Soc. Am. 149(4): A102, 2021.
11. Gee et al. J. Acoust. Soc. Am. 149(4): A102, 2021.
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13. Anderson et al. J. Acoust. Soc. Am. 149(4): A103, 2021.



Backup Slides

Calculation Steps for Perceived Level (PL)



1. Calculate Sound Pressure Level of signal in 1/3-octave bands
2. Apply frequency weighting for loudness of individual bands
 - where loudness of 1 sone is referenced to 1/3-oct band of noise at 3150 Hz at 32 dB
3. Apply summation rule for total loudness

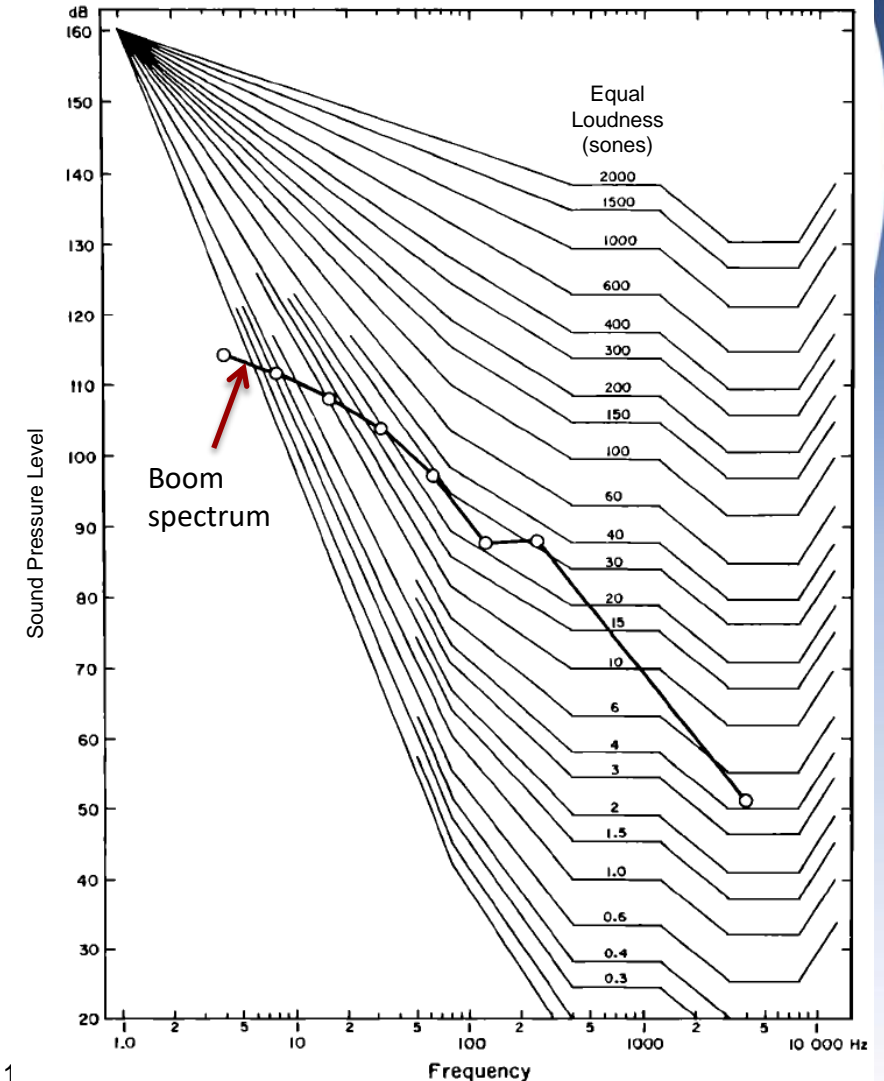
$$S_t = S_m + F(\Sigma S - S_m)$$

where

- S_t = total loudness
- S_m = loudness of loudest band
- ΣS = sum of loudnesses of all the bands
- F = fractional factor based on S_m

4. Convert to PL in dB

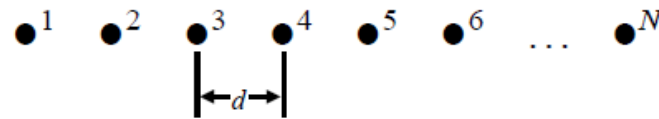
$$PL = 32 + 9 \log_2(S_t)$$



Microphone Array Layouts

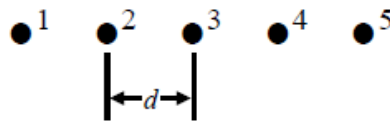


- Choice of metric affects recommendations for number of sites and number of grouped monitors at each site for a distributed array across a community
- BSEL more consistent across tests and for different array geometries
 - Less sensitive to differences for the limited datasets



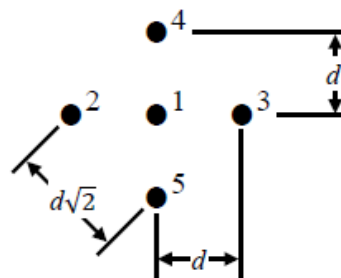
a)

Linear array



b)

Linear array



c)

Cross array