2nd AIAA Sonic Boom Prediction Workshop
Sponsored by the Applied Aerodynamics Technical Committee

The World's Forum for Aerospace Leadership

January 7-8, 2017
Weekend Preceding
AIAA SciTech 2017
Grapevine, Texas

Summary of Propagation Cases of the Second AIAA Sonic Boom Prediction Workshop

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Structural Acoustics Branch

NASA Langley Research Center

Motivation and Goals

Motivation:

- Impartially compare propagated signatures from multiple teams/codes under standard and non-standard atmospheric conditions
- Understand the state of current boom prediction methods across the international sonic boom community
- Explore the effect of the atmosphere on the evolution of shaped sonic booms

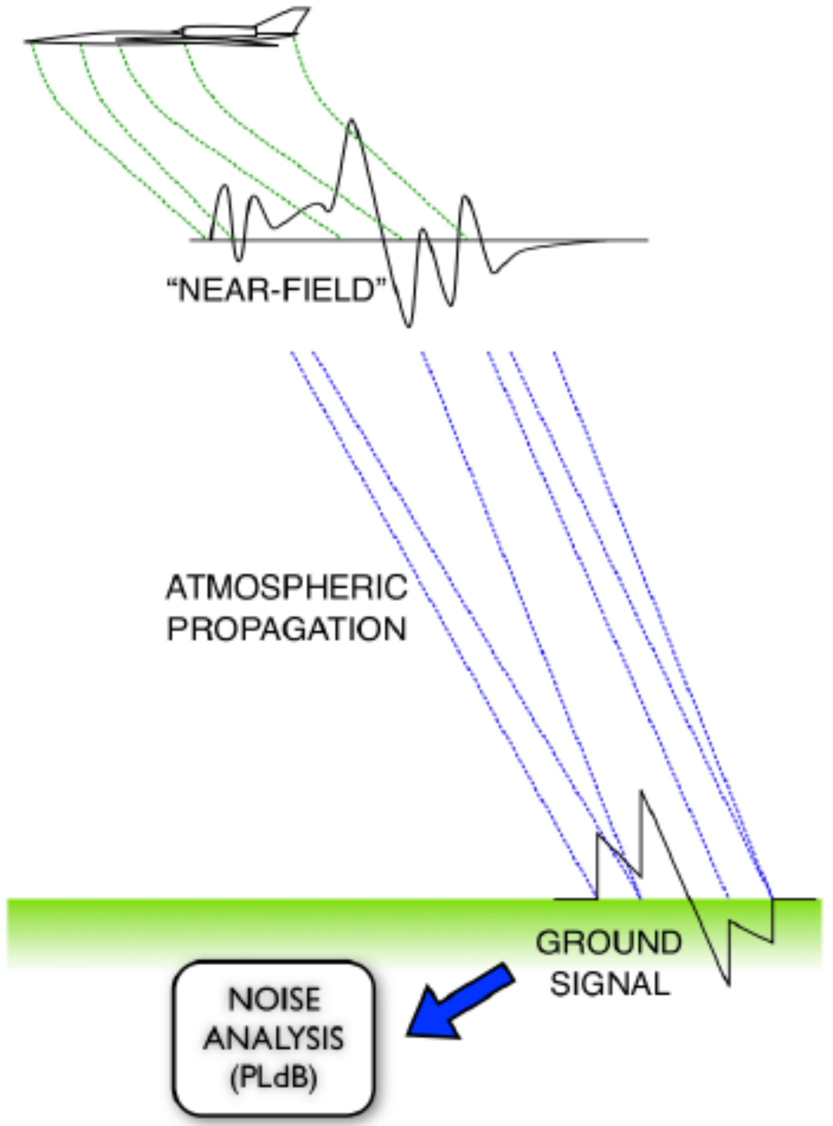
Goals/Objectives:

- Aid in supersonic aircraft noise certification process
- Verify analysis techniques within multiple codes across international teams
- Understand modeling gaps, if any
- Improve awareness of sonic boom physics at realistic atmospheric conditions particularly at lateral cut-offs

Boom Propagation Workshop

- Assumption: The input pressure waveform is sufficiently far away from the aircraft so the 3D effects are fully resolved

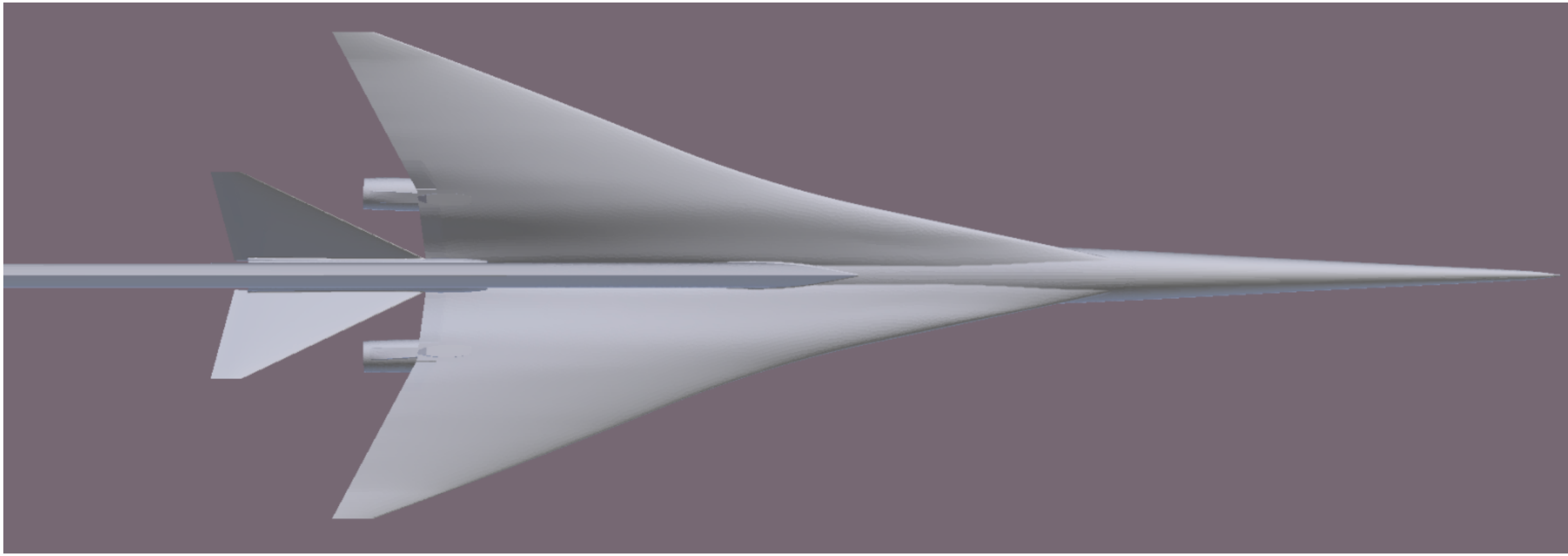
- Asked participants to use their best practices to predict ground signatures and their corresponding loudness values and ground intersection locations:
  - At several azimuthal angles, including lateral cut-offs
  - Under realistic atmospheric conditions including winds
  - Standard atmosphere assumed as U.S. Standard Atmosphere (1976) with humidity guidance from ANSI S1.26-2014 Annex C

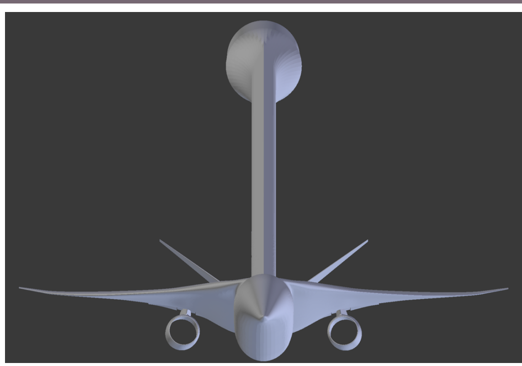


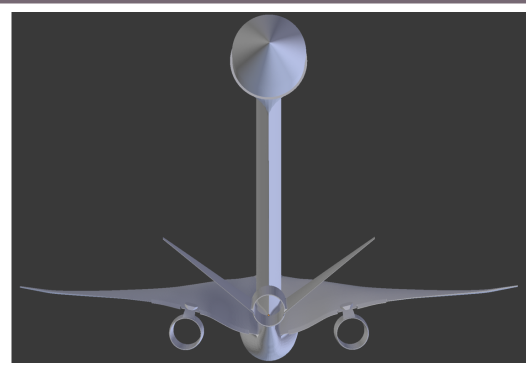
Wintzer AIAA 2015-2260

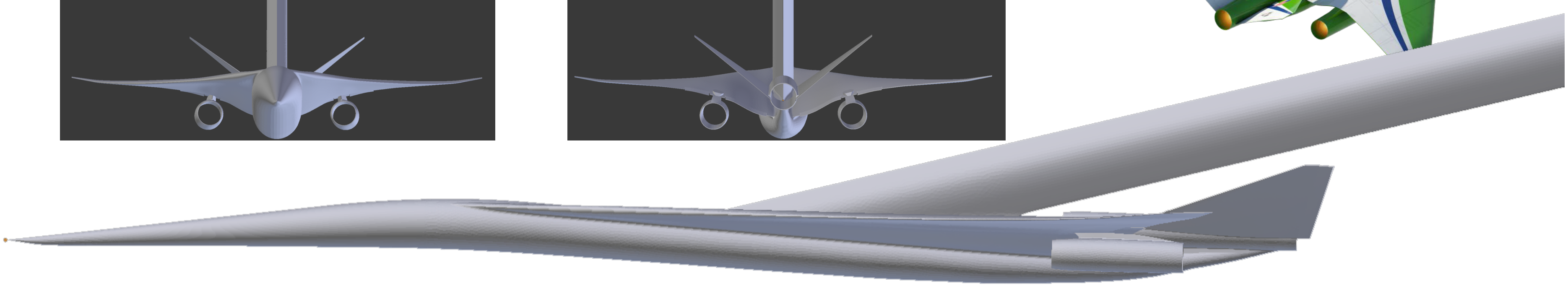
WORKSHOP CASES

Case 1: LM1021









Images from Aftosmis, Nemec; SBPW1 Presentation

Case 1: LM1021

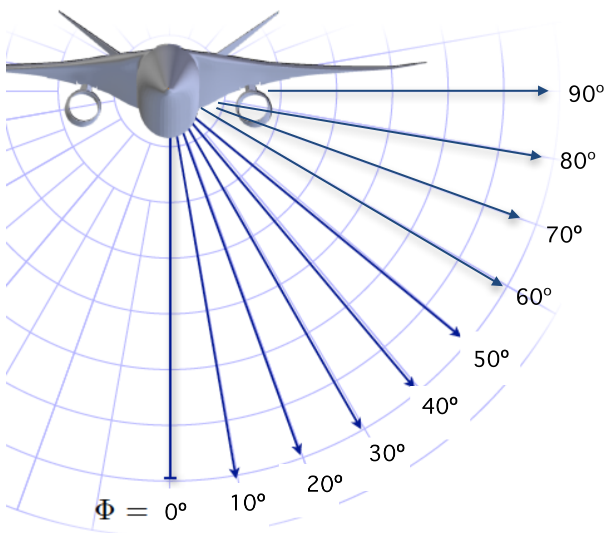
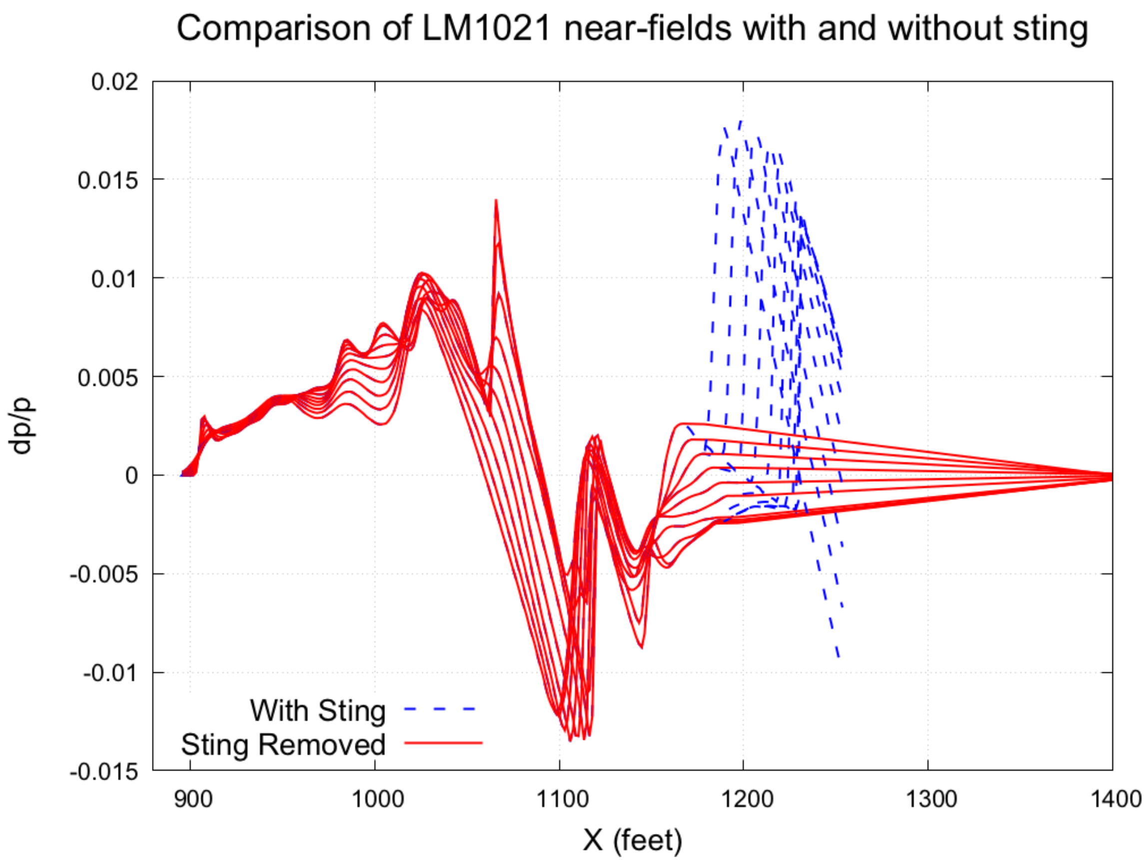
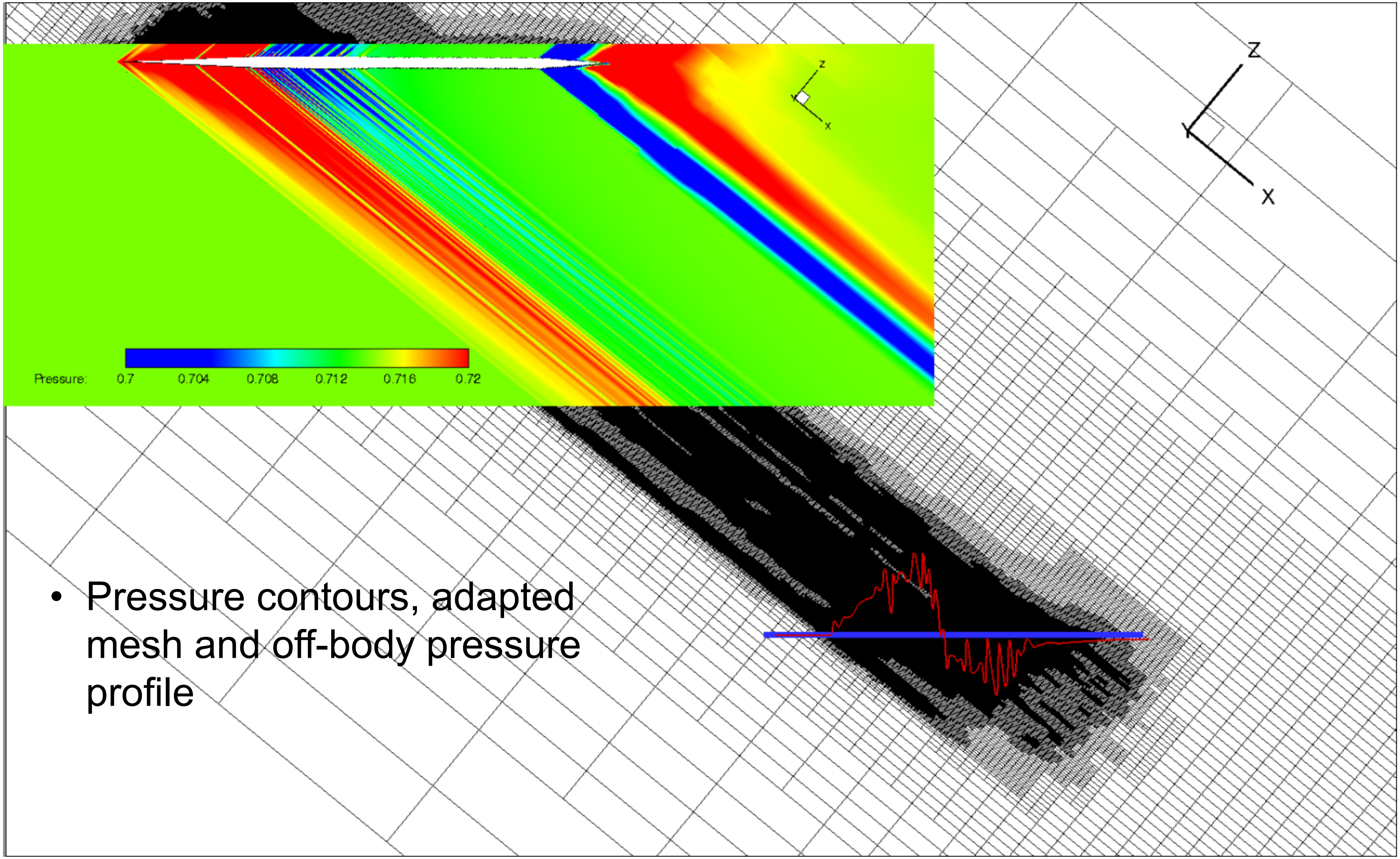


Image modified from Aftosmis, Nemec; SBPW1 Presentation

- Near-field pressure profiles contained dp/p at 10^0 intervals as shown, including the sting
  - Removed the sting contribution
  - Closed-out linearly to ambient pressure conditions



Case 2: Axi-Symmetric Body of Revolution



- Pressure contours, adapted mesh and off-body pressure profile

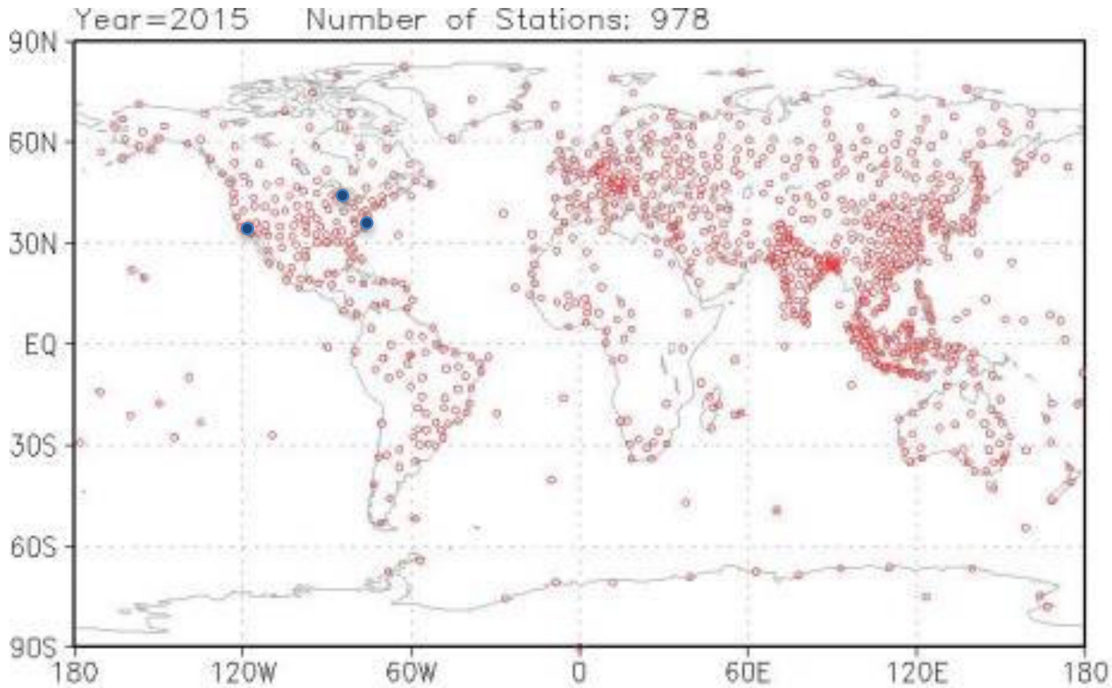
Atmospheric Profiles

Objective:

- Obtain realistic atmospheric data that can provide a “large-enough” variation in loudness metrics

Approach:

- NOAA’s Integrated Global Radiosonde Archive (IGRA[1]) contains a database of measured soundings at 978 active sites; a diverse population of observed upper-air measurements
- Offers a way to model geographical and seasonal variations in sonic boom metrics
- For this study three locations were chosen: Wallops Island (VA), Edwards AFB (CA), Green Bay (WI)

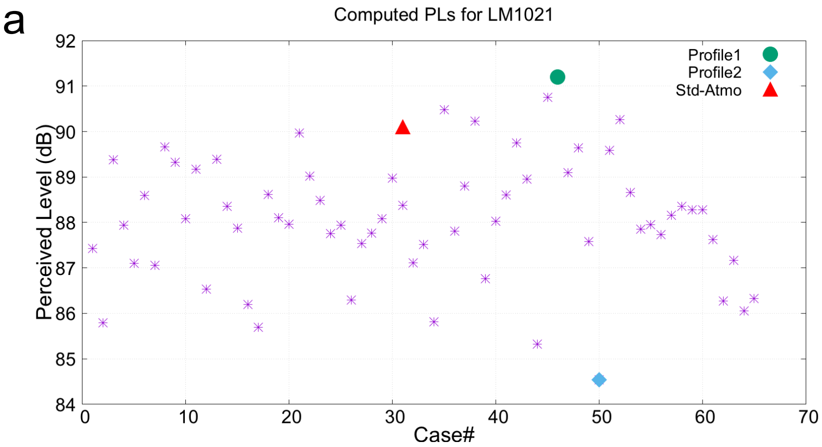


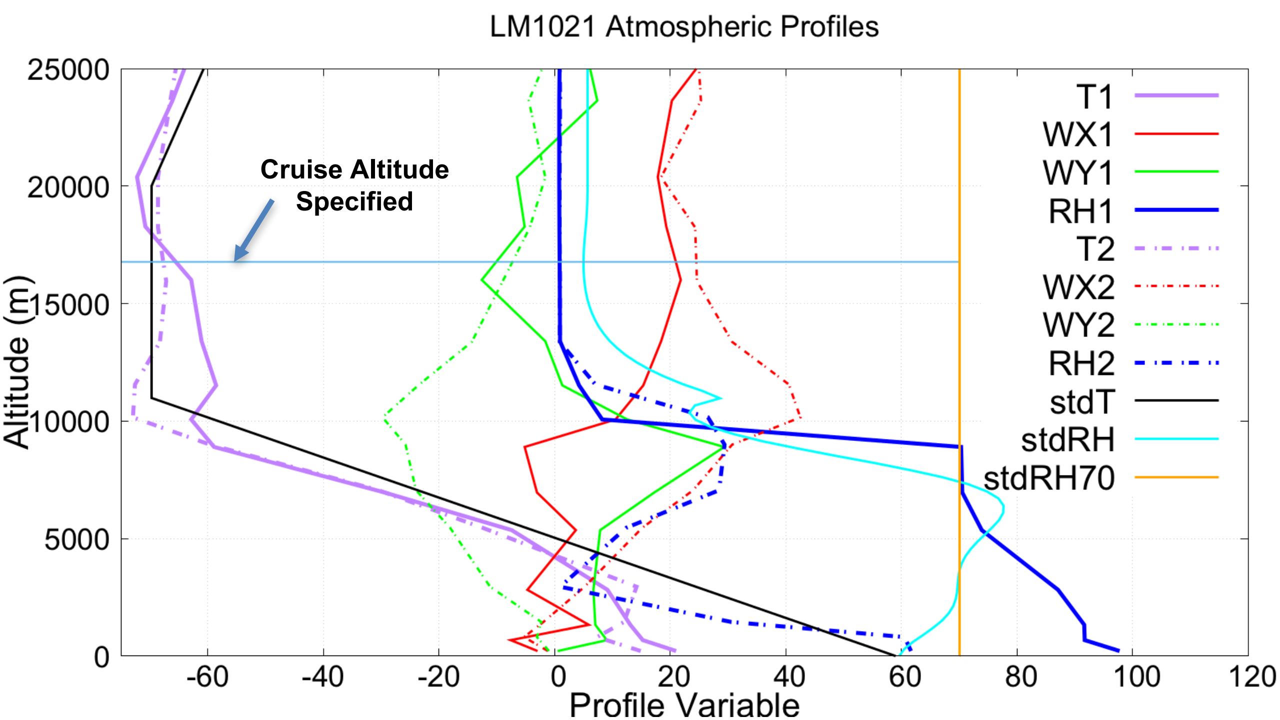
[1]https://www.ncdc.noaa.gov/data-access/weather-balloon/integrated-global-radiosonde-archive

CASE 1 Profiles

Approach:

- Took all valid profiles at the three chosen locations in a winter month (February, 2013)
- Propagated LM1021 near-field to the ground-level at the corresponding location and computed loudness metrics for each atmospheric profile
- Picked two profiles that generated the best and worst loudness
- Only under-track loudness used in profile selection



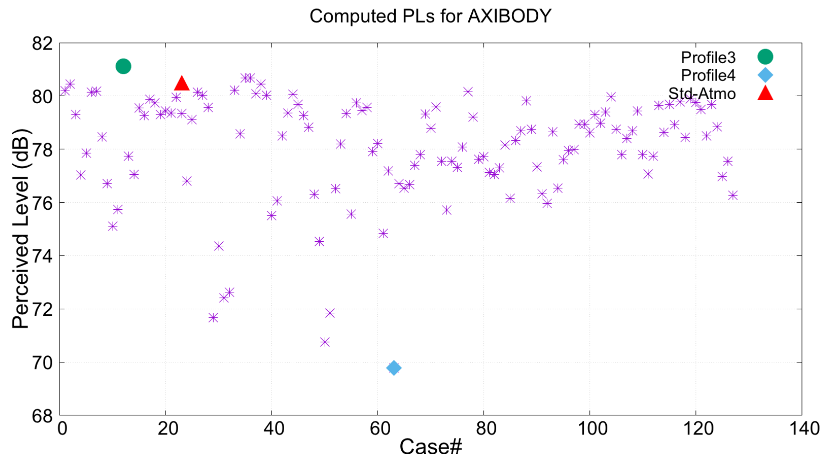


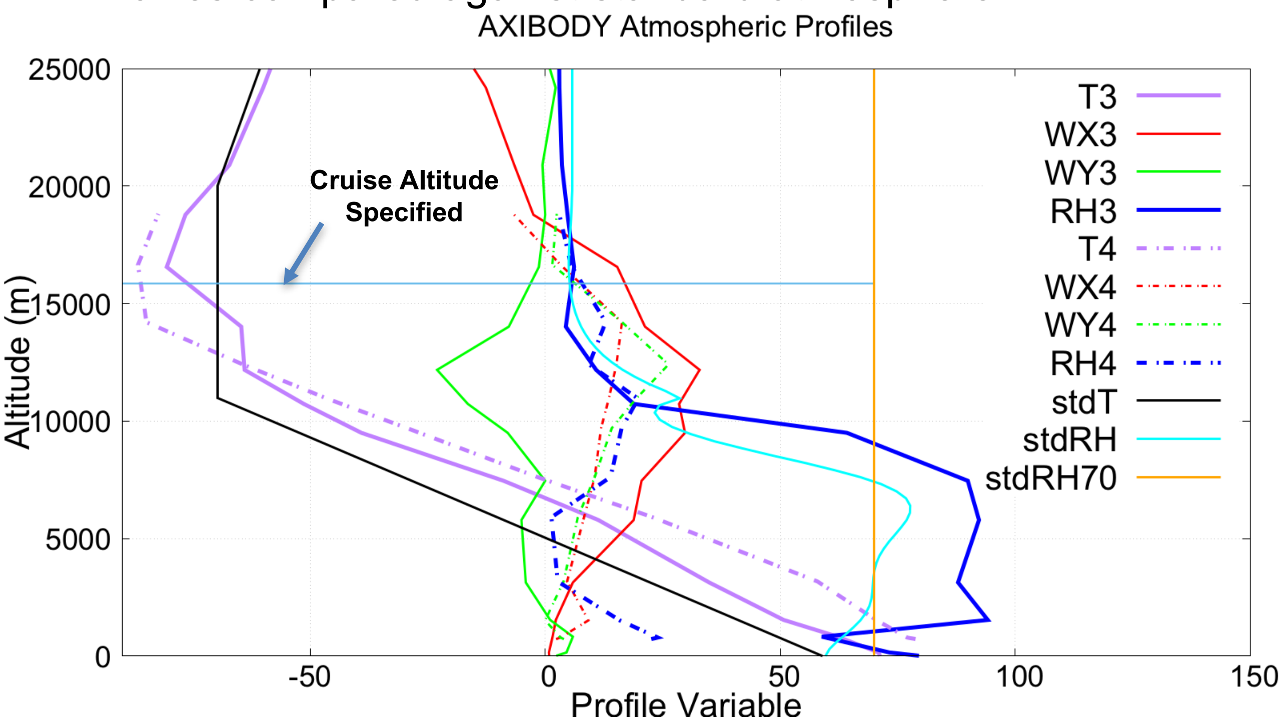
- Both profiles were from Green Bay, WI on consecutive days, February 17th and 18th
- Profile 1 has one of the highest PL, and profile 2 has one of the lowest PL

CASE 2 Profiles

Approach:

- Took all valid profiles at the three chosen locations in a summer month (August, 2012)
- Propagated Axi-Symmetric body near-field to the ground-level at the corresponding location and computed loudness metrics for each atmospheric profile
- Picked two profiles that generated the best and worst loudness
- Profiles compared against standard atmosphere





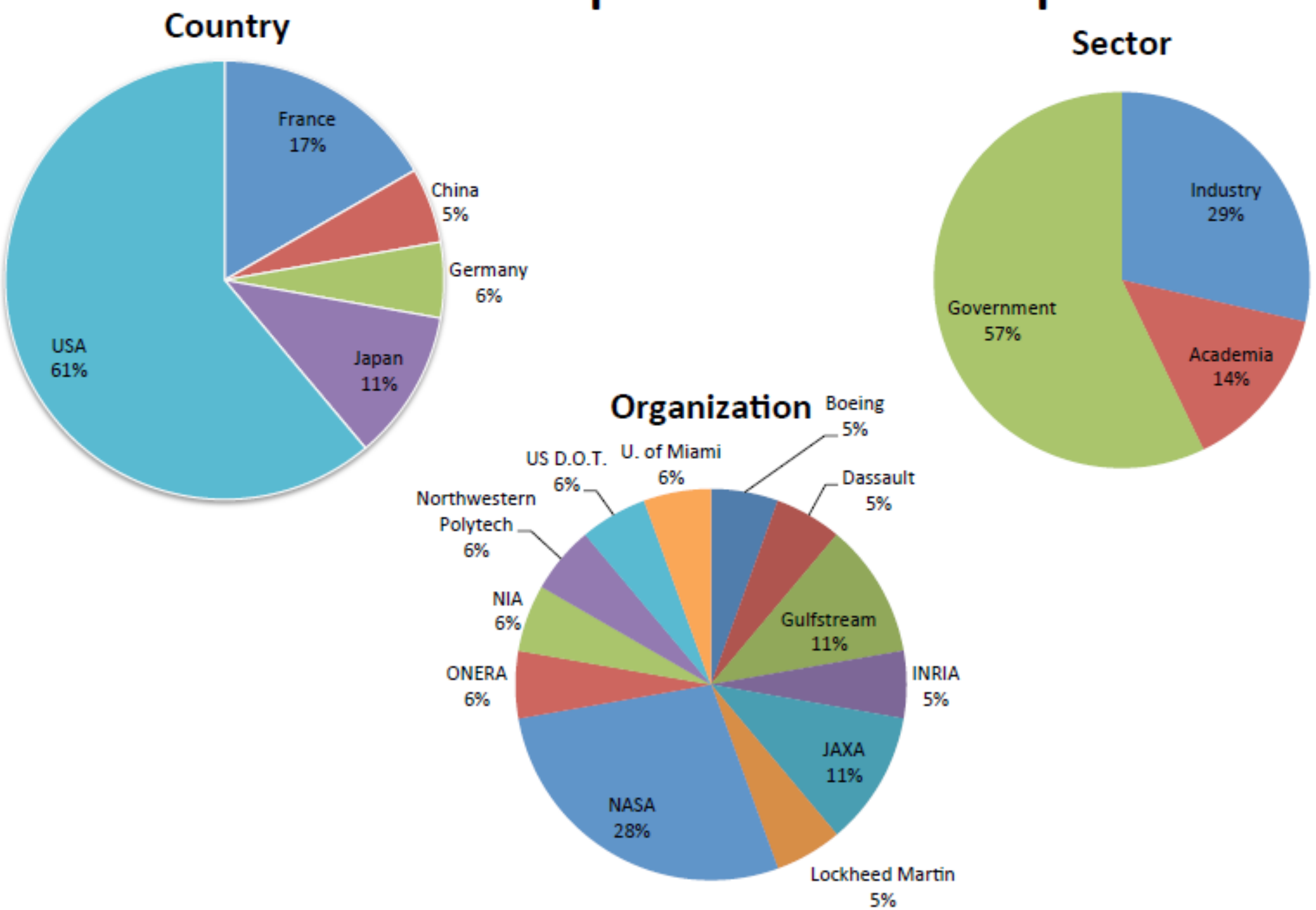
- Profile 3 (Higher PL) is measured at Wallops, on August 1, and 5PM
- Profile 4 (Lower PL) is measured at Edwards AFB, on August 6 at 12 PM

Overview of Cases

- Flow Conditions:
  - LM1021: M=1.6, Altitude = 55000 ft., R/L = 3.1299, L = 233.33 ft.
  - AxiBody: M=1.6, Altitude = 52000 ft., R/L = 3.0, L = 141.0 ft.
- Heading East
- Required/Optional Runs:
  - LM1021
    - Extrapolate at roll angles of -30^0, 0^0, and 30^0 for all atmospheric profiles
    - Profile1: Required
  - AxiBody
    - Extrapolate at roll angles of -45^0, 0^0, and 45^0 for all atmospheric profiles
    - Profile3: Required
- Required Data:
  - Ground signatures and sampling frequencies
  - Lateral cut-off angles on both sides of the carpet
- Optional data:
  - Compute ground signatures corresponding to the lateral cut-off angle
  - Loudness metrics (PL, ASEL) corresponding to all the ground signatures reported
  - Loudness convergence history

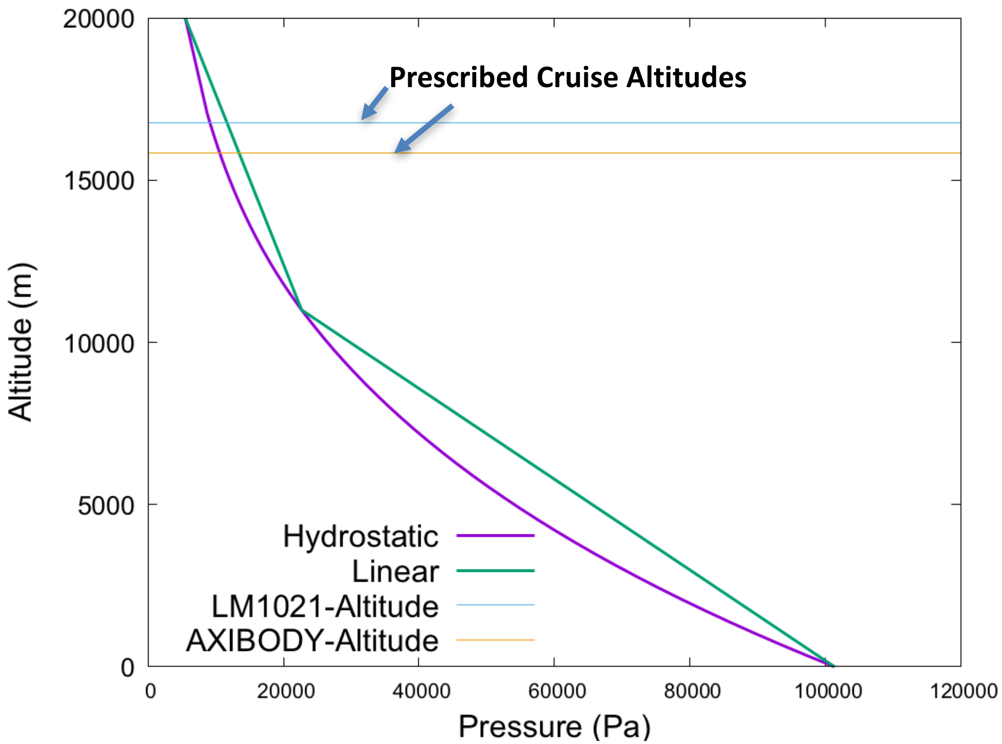
Information on Participants

2nd Workshop: 18 Participants



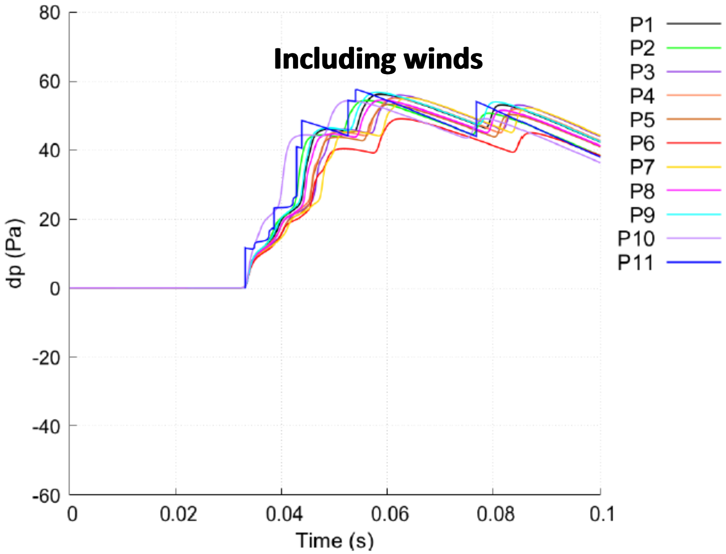
Atmospheric Pressure Interpolation

- Specified atmospheric pressure, but originally failed to specify interpolation scheme, assumed everyone would use hydrostatic
- During first submissions, some participants used linear interpolation
  - Mainly affects the conversion from dp/p to dimensional units (~20-30% difference)
  - Sent out an email (November 15) to resubmit if possible
  - Included a finer resolution of all pressure profiles for participants to use

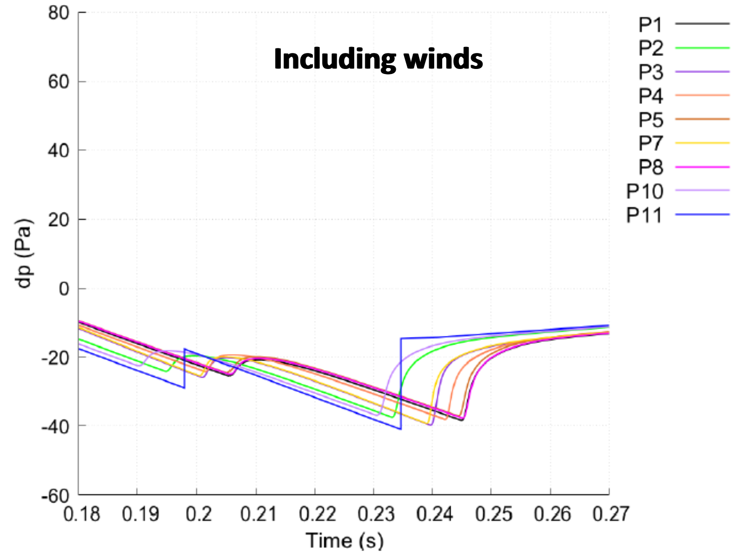


RESULTS

Ground Signatures: LM1021

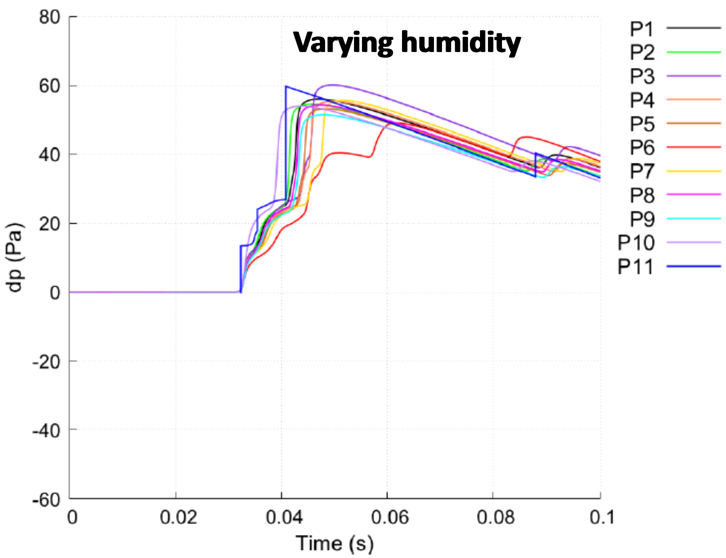


(a) **Front shock system for Roll Angle =0°.**

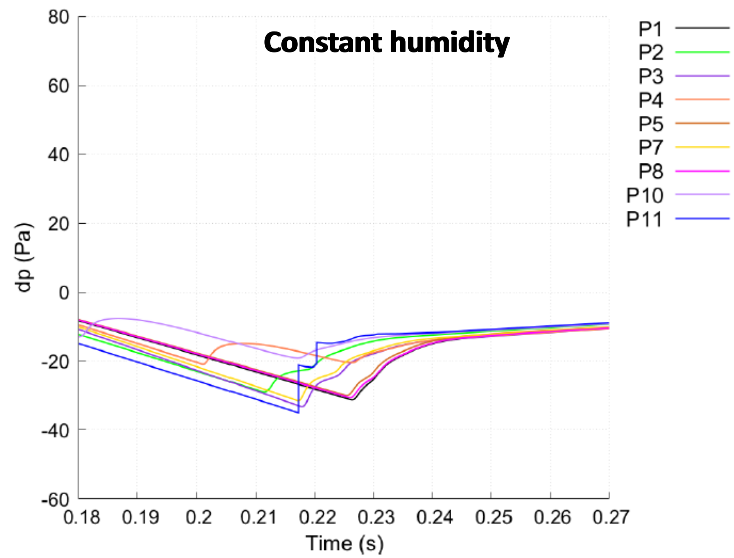


(b) **Aft shock system for Roll Angle =0°.**

For Profile1

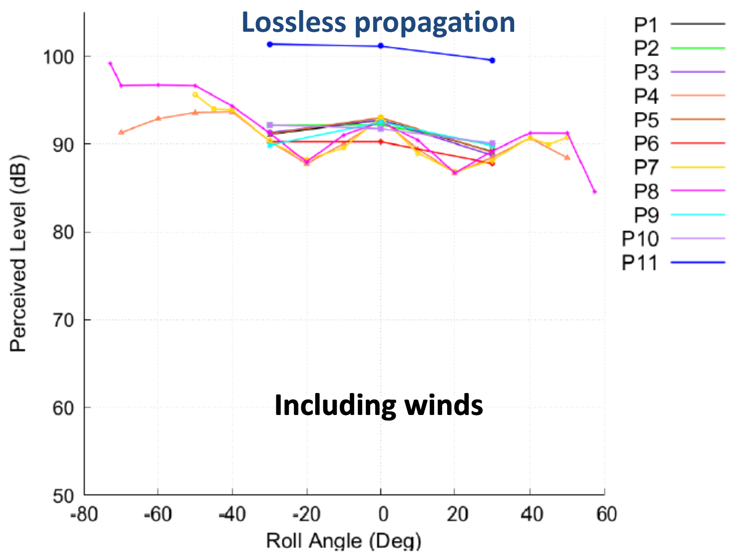


(c) **Front shock system for Roll Angle =−30°.**



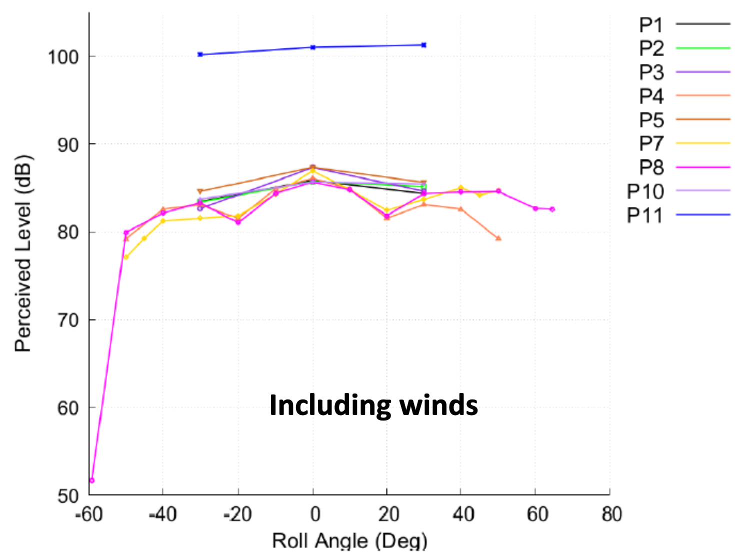
(d) **Aft shock system for Roll Angle =−30°.**

Loudness Levels: LM1021

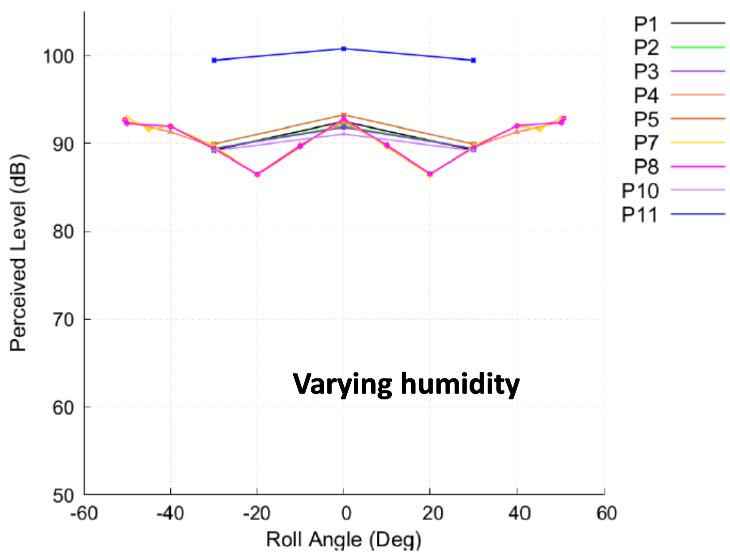


(a) **Profile1 (Required).**

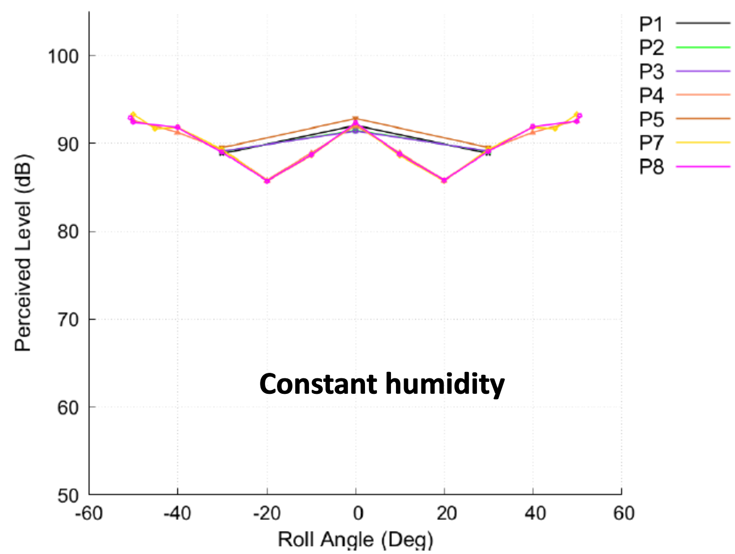
Calculated Loudness Levels



(b) **Profile2 (Optional).**

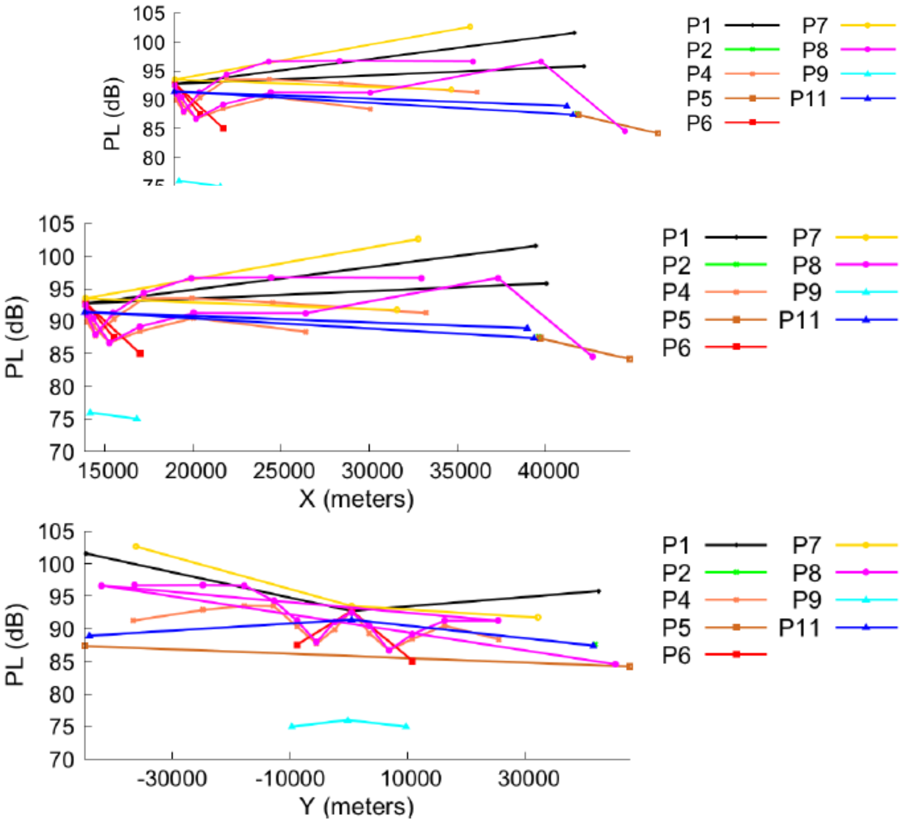


(c) **Standard Profile (Optional).**

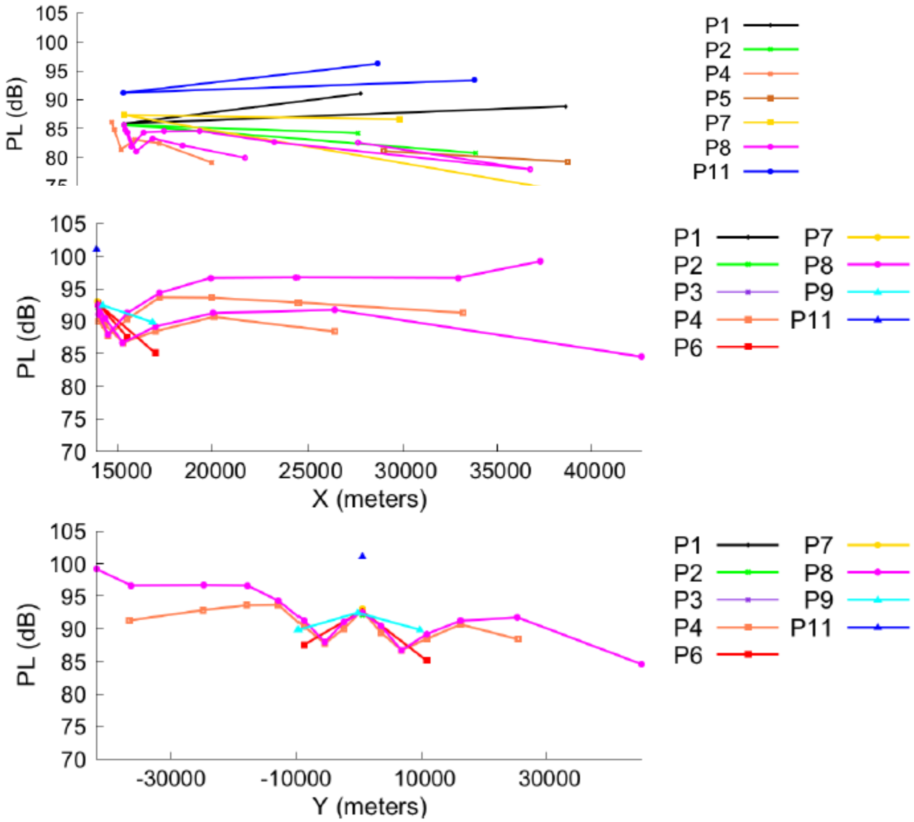


(d) **Standard Profile w/ RH=70% (Optional).**

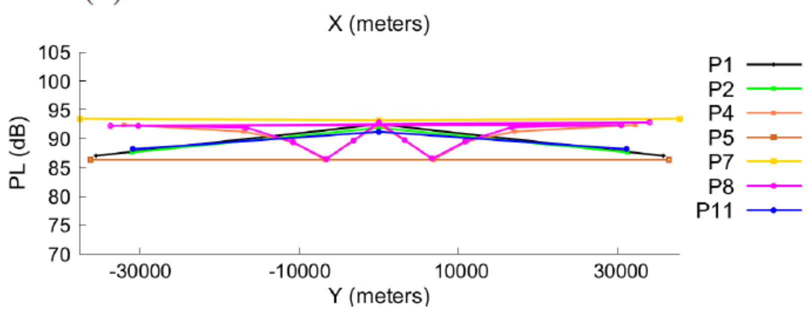
Loudness - Ranges: LM1021



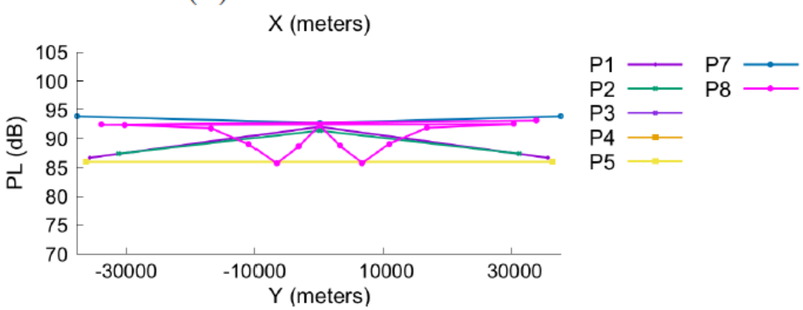
(a) **Profile1: Submitted loudness.**



(b) **Profile1: Calculated loudness.**



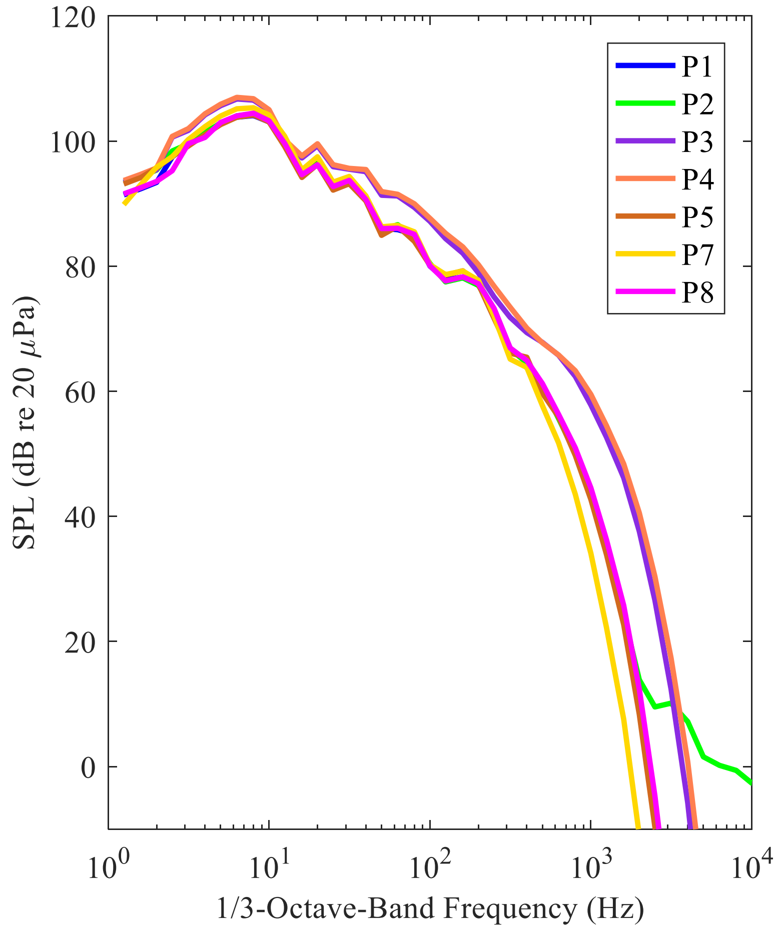
(c) **Standard Profile (Optional).**



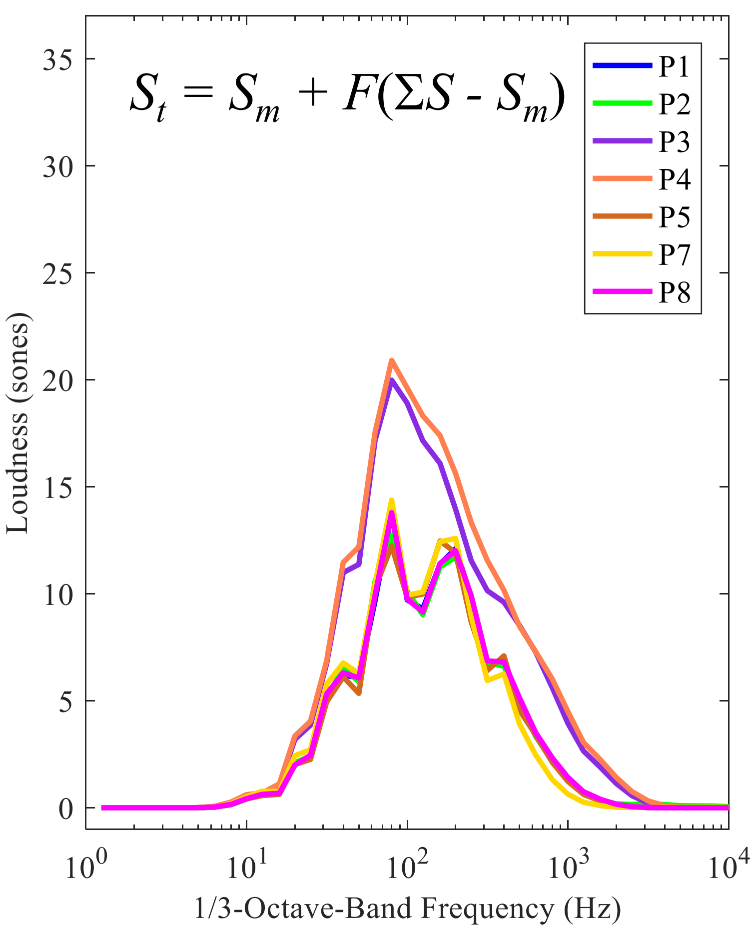
(d) **Standard Profile w/ RH=70% (Optional).**

1/3-Octave-Band and Loudness Spectra

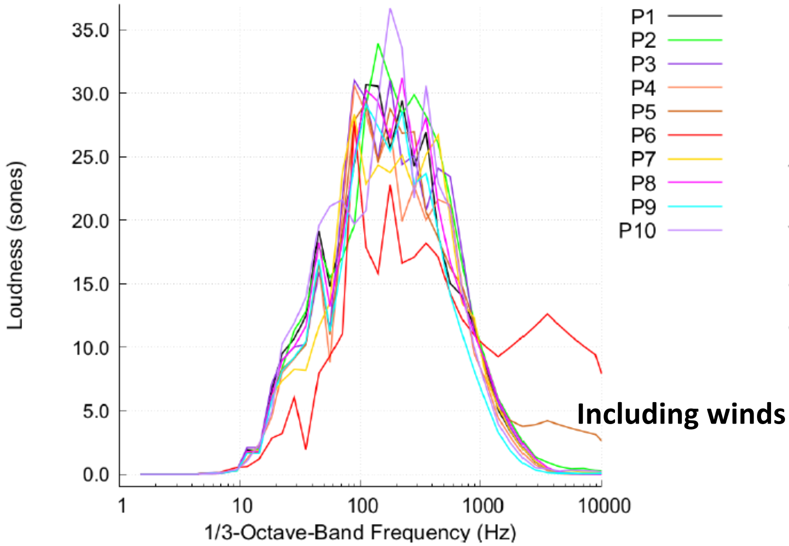
Spectra indicate the energy in different 1/3-octave frequency bands



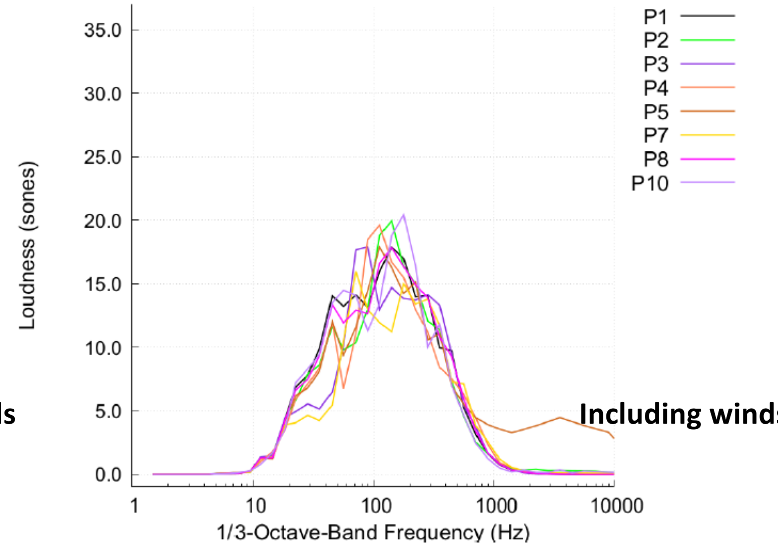
Loudness spectra indicate the frequency bands which are most important to the calculation of PL (which approximates the sensitivity of human hearing)



Loudness Spectra: LM1021

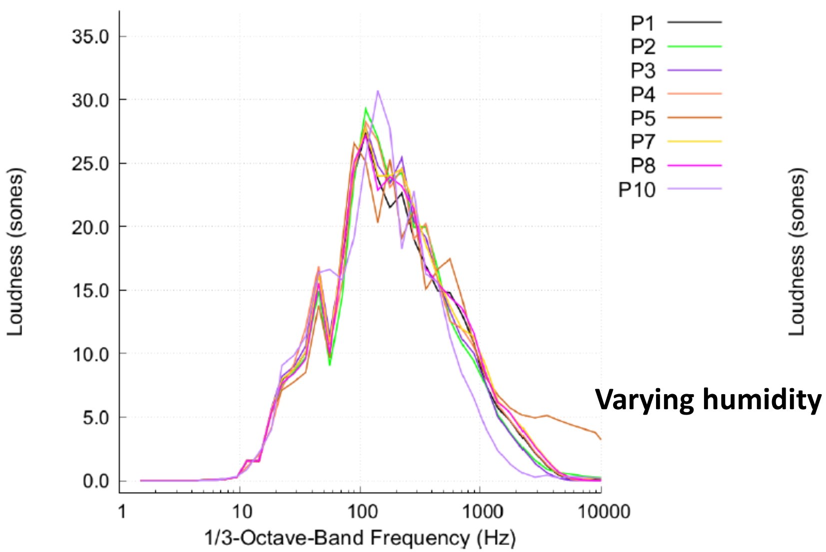


(a) **Profile1 (Required).**

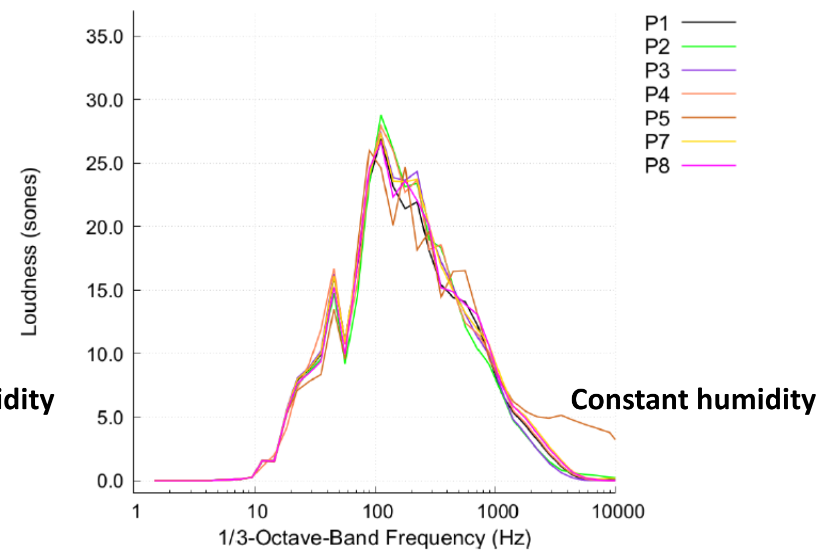


(b) **Profile2 (Optional).**

Phi = -30°

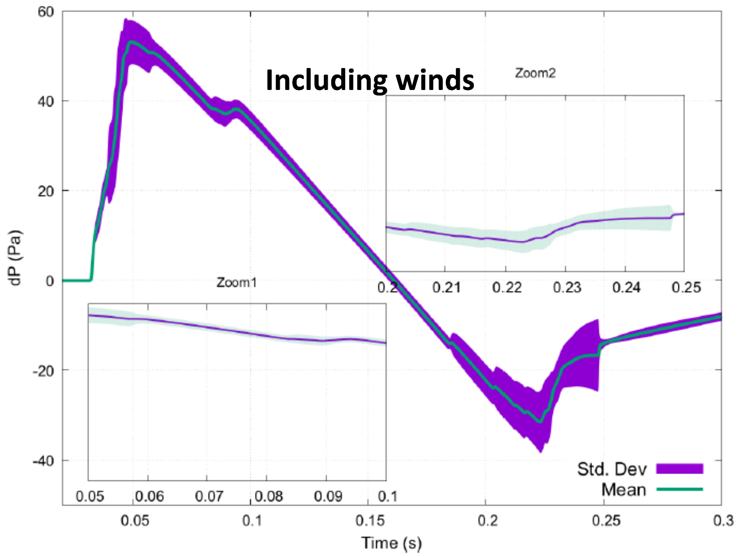


(c) **Standard Profile (Optional).**



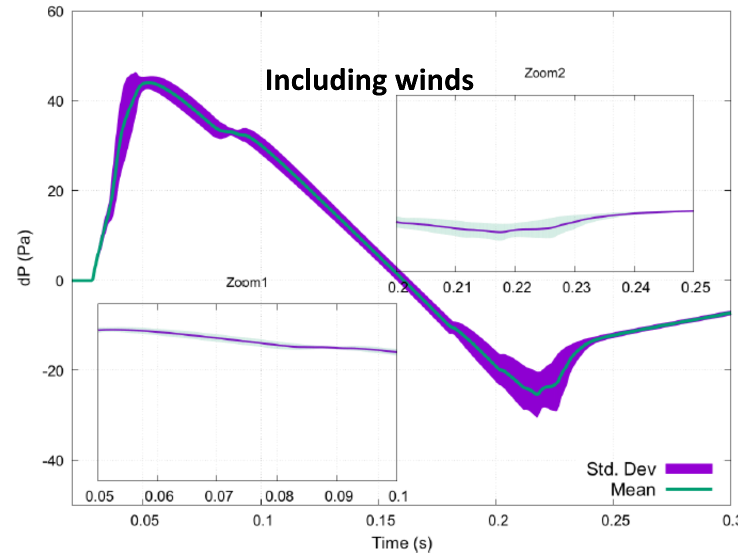
(d) **Standard Profile w/ RH=70% (Optional).**

Standard Deviations: LM1021

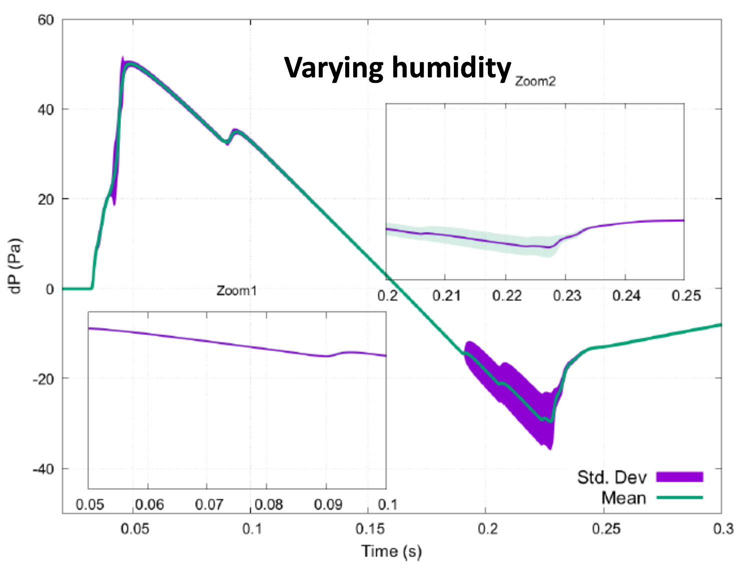


(a) **Profile1 (Required).**

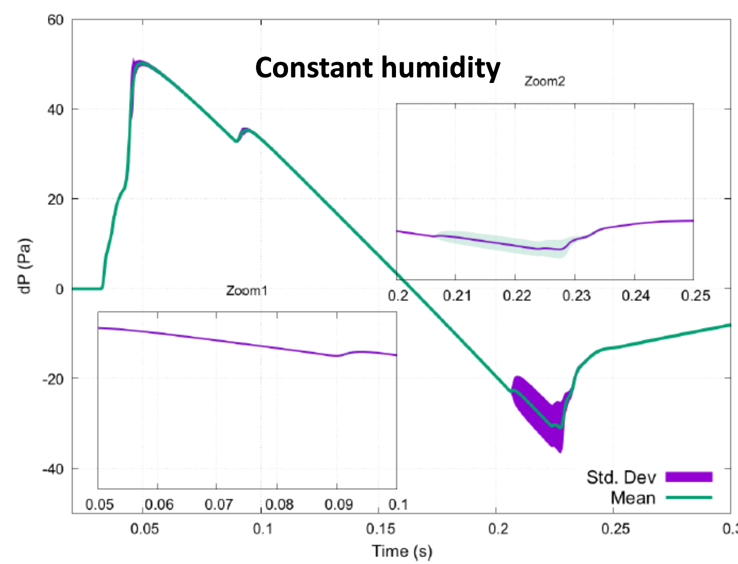
Phi = -30°



(b) **Profile2 (Optional).**



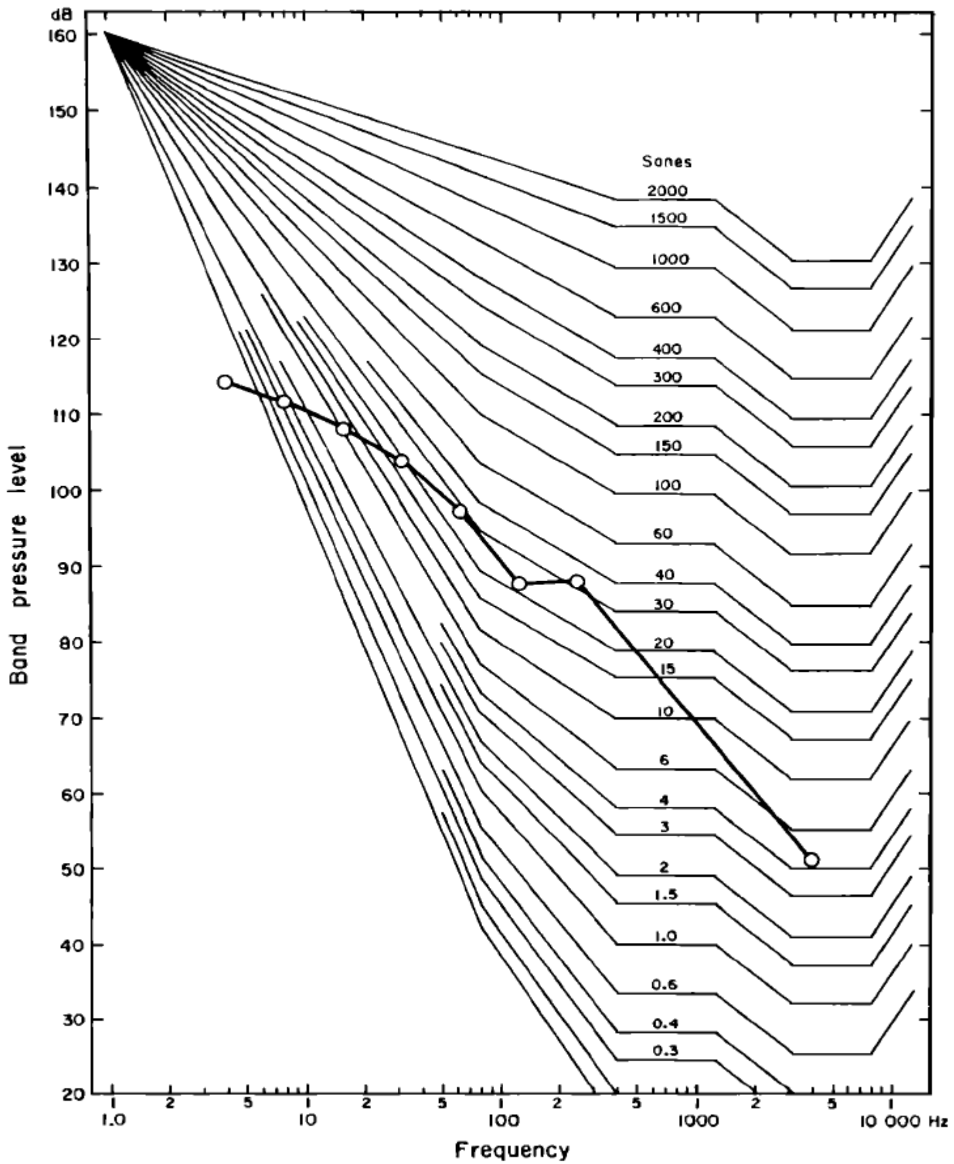
(c) **Standard Profile (Optional).**



(d) **Standard Profile w/ RH=70% (Optional).**

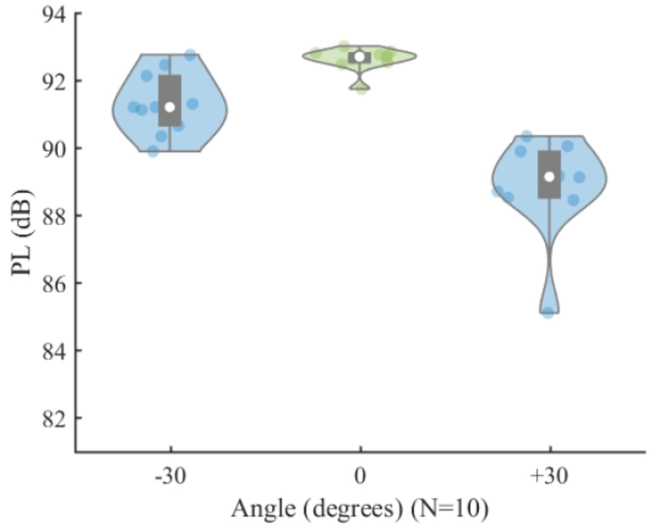
Noise Metrics Analysis

- Six noise metrics were calculated
  - PL
  - ASEL, BSEL, DSEL, ESEL
  - ISBAP = PL + 0.4201(CSEL-ASEL)
- These metrics have been found to correlate well with human annoyance (indoors and outdoors)
  - Based on meta-analysis of a variety of laboratory studies*
- Violin plots show distribution of data in addition to summary statistics

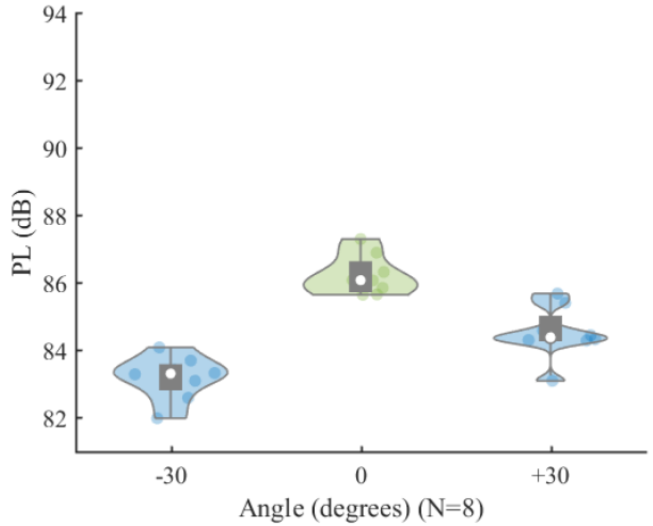


*A. Loubeau, Y. Naka, B. G. Cook, V. W. Sparrow, and J. M. Morgenstern. A new evaluation of noise metrics for sonic booms using existing data. 20th International Symposium on Nonlinear Acoustics, 2015.

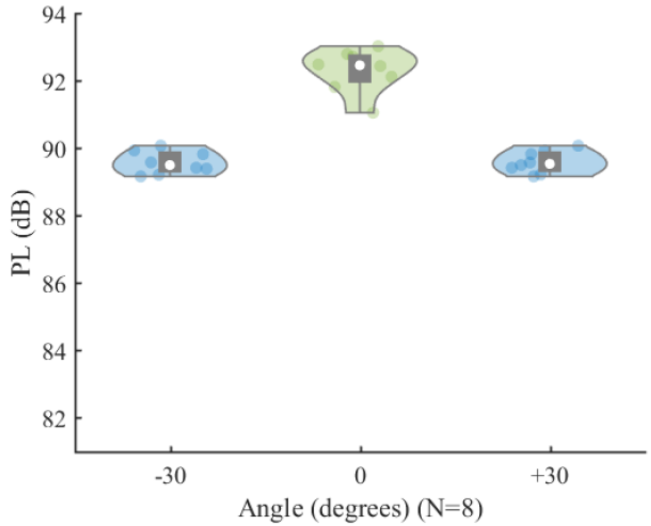
Violin Plots: LM1021



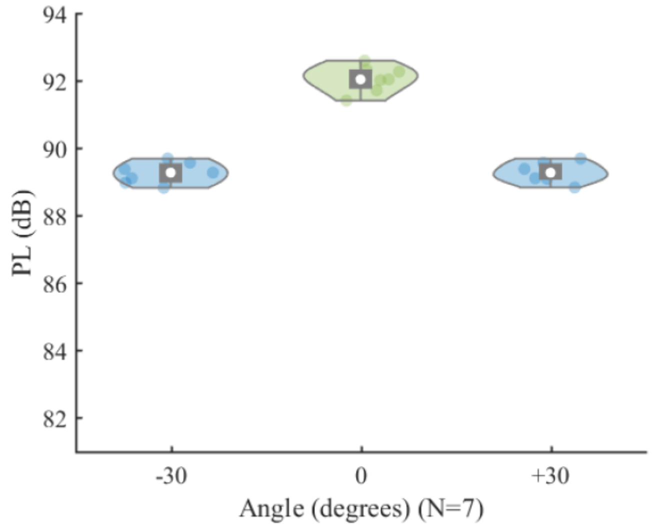
(a) **Profile1 (Required).**



(b) **Profile2 (Optional).**



(c) **Standard Profile (Optional).**



(d) **Standard Profile w/ RH=70% (Optional).**

Summary

- Most results match under-track in terms of ground signatures
- Comparisons similar between LM1021 and AxiBody concepts
    - AxiBody showed larger PL spread
- The discrepancy seems to increase for off-track roll angles, particularly near lateral cut-offs
- The PL calculation was inconsistent between participants
- Atmospheric pressure interpolation scheme has a significant impact on the propagated signatures
- There seems to be a discrepancy in the wind convention used by different participants – need to make this consistent
- Realistic atmospheric profiles have a significant impact on the propagated signatures, carpet ranges and loudness metrics

Future Work

- Work in a smaller group to closely match a few (2-3) independent implementations for data relevant to this sonic boom community
- Develop cases and ideas for future workshops
- Make baseline cases available for PL calculation and propagation

- *Acoustics'17, Boston, June 2017: Paper presentation on lessons learned, and progress made between the workshops and an informal propagation comparisons done in 2013*

QUESTIONS?

- Acknowledgments
  - NASA Commercial Supersonic Technology (CST) project
  - Boom prediction workshop organizing committee and participants
  - Mike Park for sharing relevant data and information from previous workshops

EXTRAS

2nd Boom Prediction Workshop Flyer

The World's Forum for Aerospace Leadership

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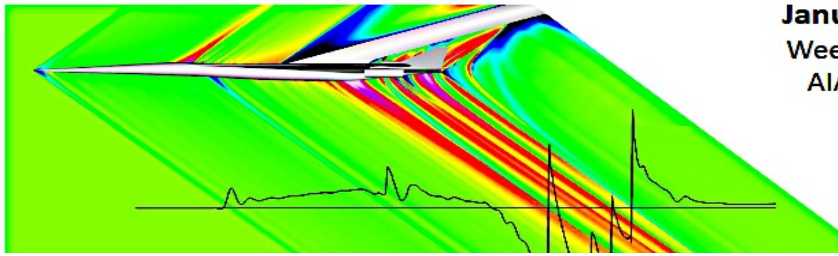
Sponsored by the Applied Aerodynamics Technical Committee



January 7-8, 2017
Weekend Preceding
AIAA SciTech 2017
Grapevine, Texas

Second Sonic Boom Prediction Workshop:

The two part workshop will cover both the state-of-the-art for predicting near field sonic boom signatures with CFD as well as propagation of the near field pressures to the ground. Participants are encouraged to apply their best practices for computing solutions for the provided cases. There is particular interest in exploring refinement techniques including grid adaptation and alignment with flow characteristics.

- Low Boom Body-of-Revolution (required).
- Wing-Body (required).
- Full Airplane with Flow Through Nacelles (req.)
- Full Airplane with Powered Nacelles (optional).

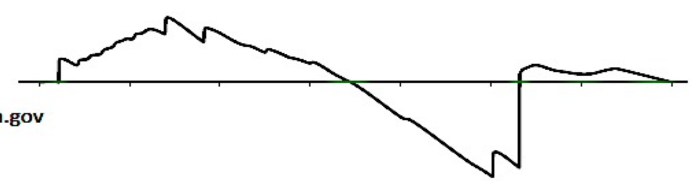
Important Dates:

April 30, 2016:	Notice of Intent Due from Participants.
May 31, 2016:	Acceptance Notification from Committee.
Sept. 30, 2016:	Participant Data Submittal Deadline.
January 7-8, 2017:	**2nd Sonic Boom Prediction Workshop**

Sonic Boom Prediction Workshop Organizing Committee:

Kenrick Waithe	*Boom Technology*
Mike Park, Alexandra Loubeau, Lori Ozoroski, Linda Bangert & Alaa Elmiligui	*NASA Langley*
Susan Cliff	*NASA Ames*
Don Howe	*Gulfstream Aerospace*
John Morgenstern	*Lockheed Martin*
Todd Magee & Eric Adamson	*Boeing*
Yoshi Makino	*JAXA*
Jean-Luc Hantrais-Gervois	*ONERA*
Gecheng Zha	*Univ. of Miami*
Claudio Pita & Erick Gantt	*Pointwise*

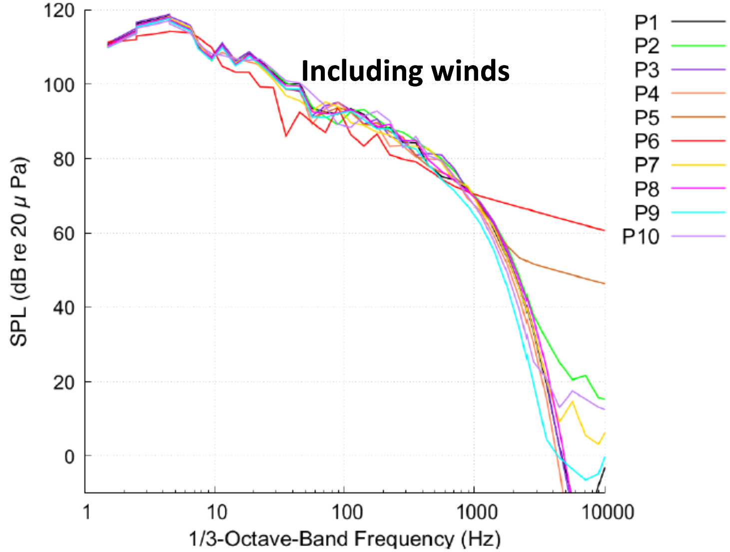
For more information:
http://lbpw.larc.nasa.gov/
aiaa-boompw-committee@lists.nasa.gov



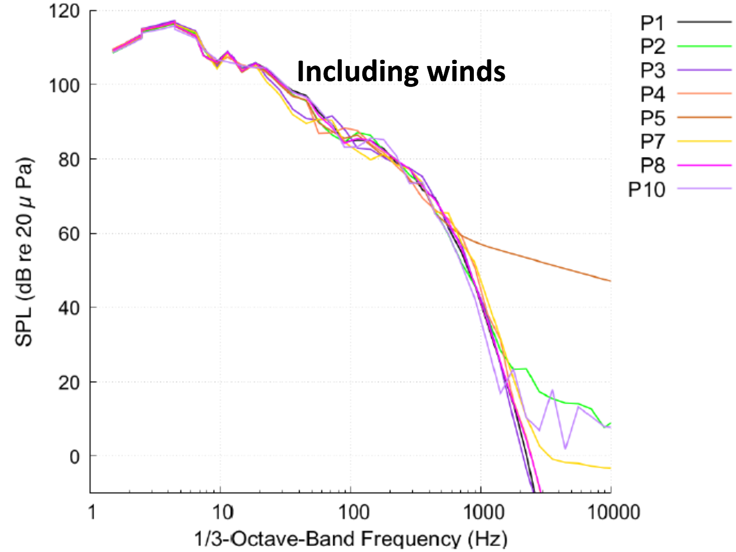
Workshop Culture

- Adjectives such as good, bad, right, and wrong oversimplify issues and should be avoided
- Focus on describing observed differences and communicate why things are different

1/3-Octave-Band Spectra: LM1021

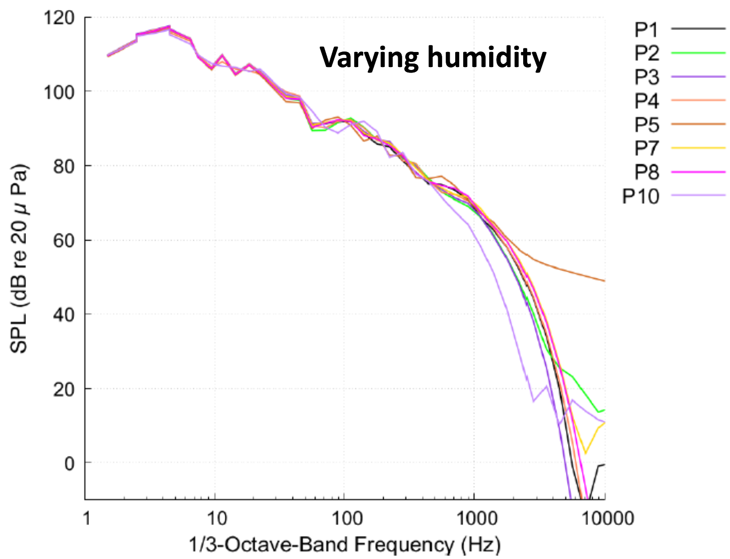


(a) Profile1 (Required).

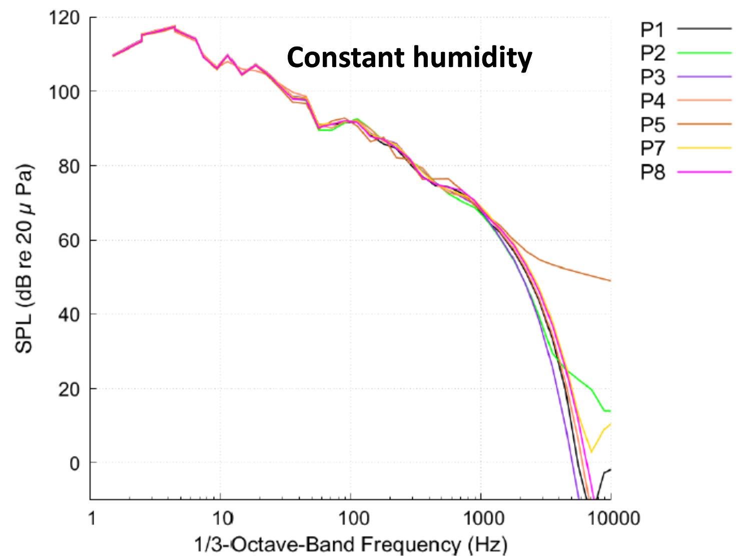


(b) Profile2 (Optional).

Phi = -30º

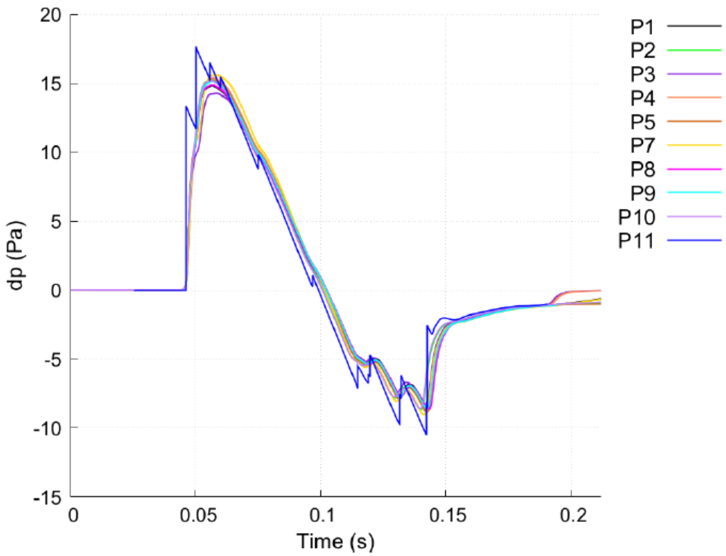


(c) Standard Profile (Optional).



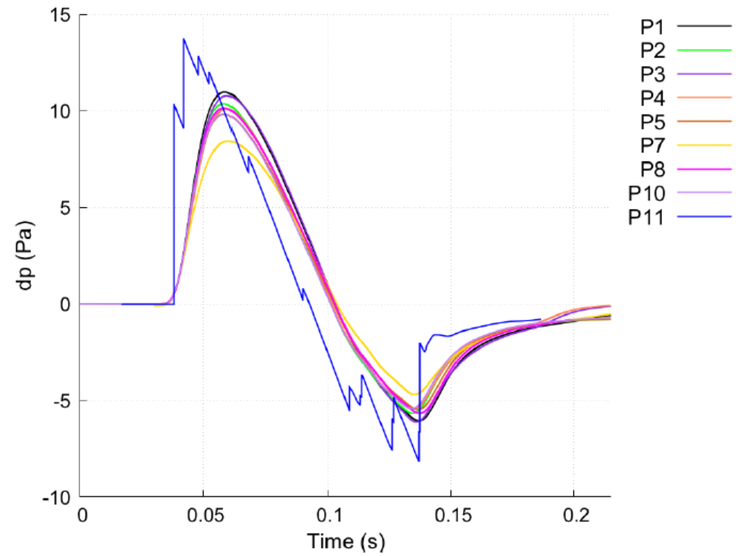
(d) Standard Profile w/ RH=70% (Optional).

Ground Signatures: AxiBody

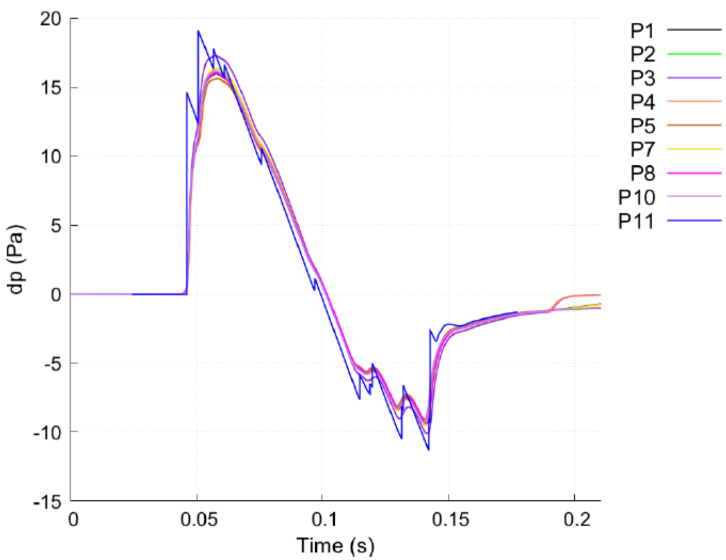


(a) **Profile3 (Required).**

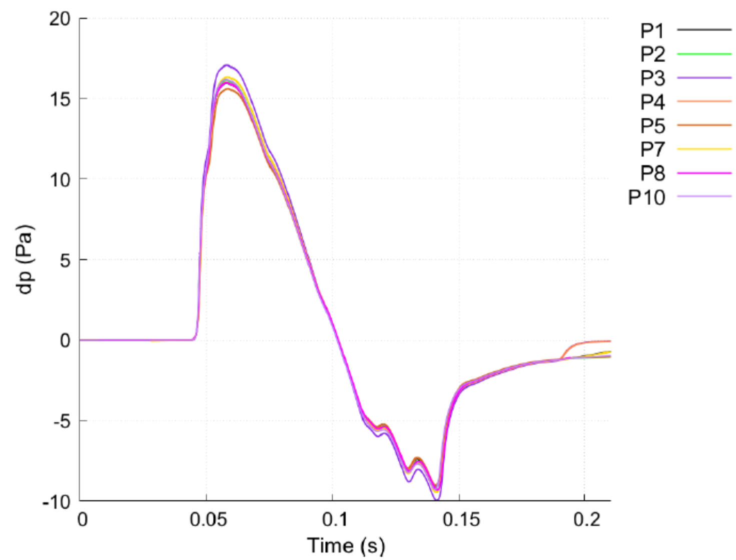
Phi = 45°



(b) **Profile4 (Optional).**



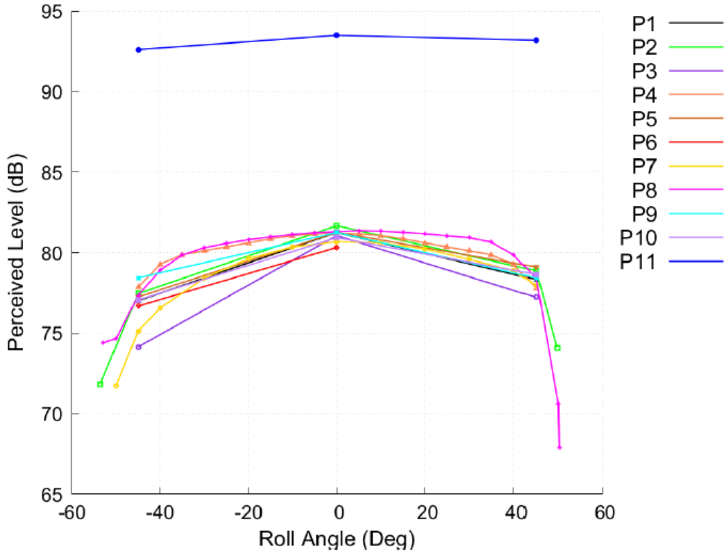
(c) **Standard Profile (Optional).**



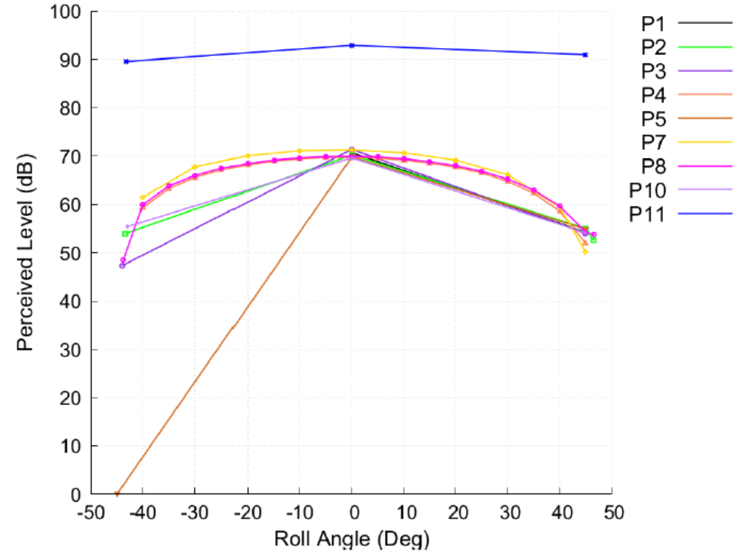
(d) **Standard Profile w/ RH=70% (Optional).**

Loudness Levels: AxiBody

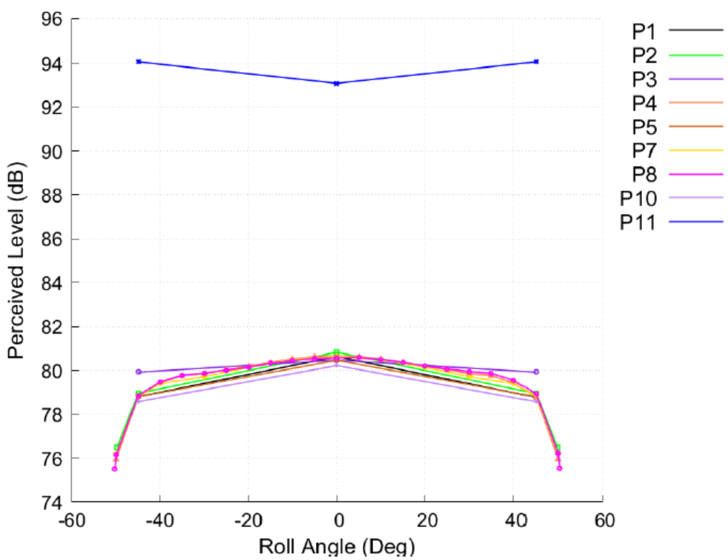
Calculated Loudness Levels



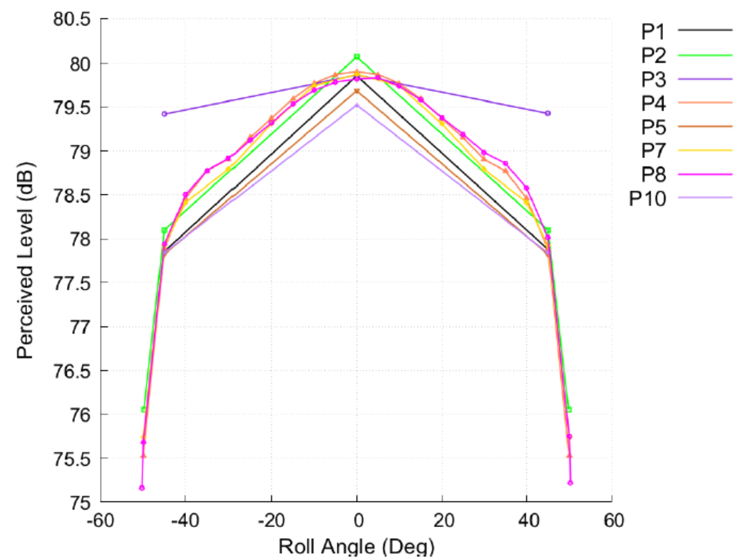
(a) **Profile3 (Required).**



(b) **Profile4 (Optional).**

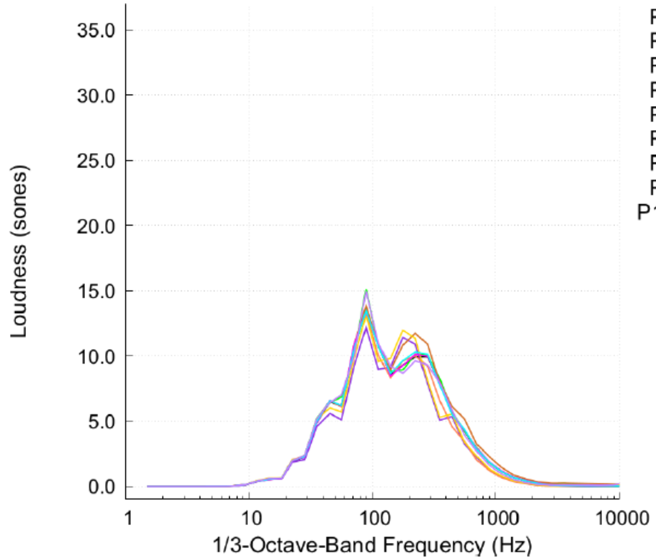


(c) **Standard Profile (Optional).**



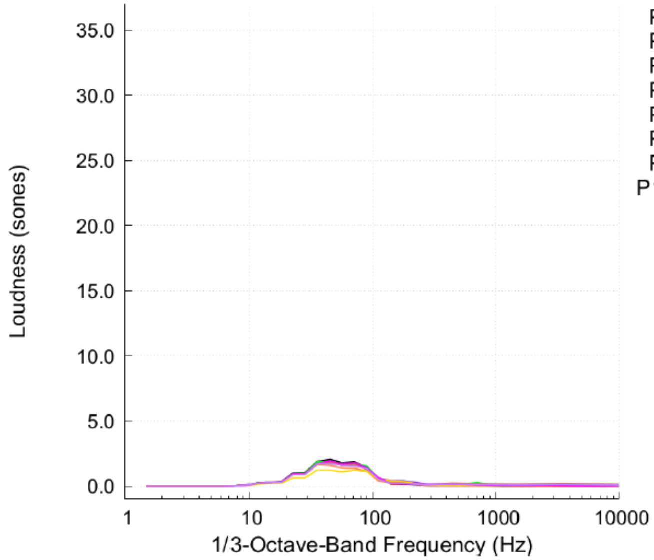
(d) **Standard Profile w/ RH=70% (Optional).**

Loudness Spectra: AxiBody

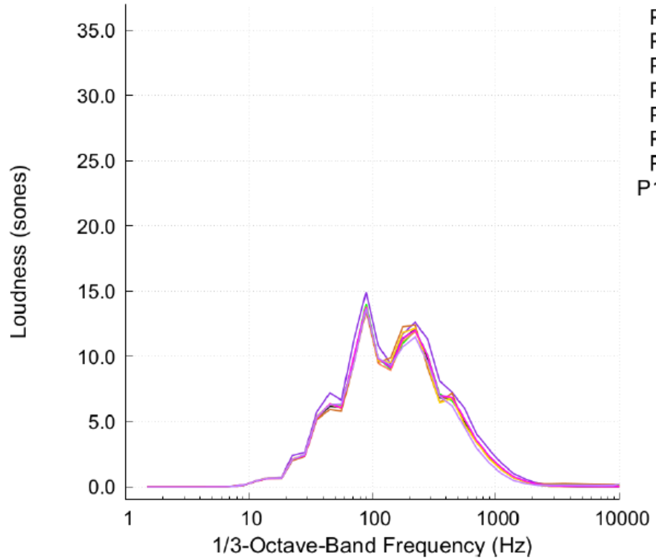


(a) **Profile3 (Required).**

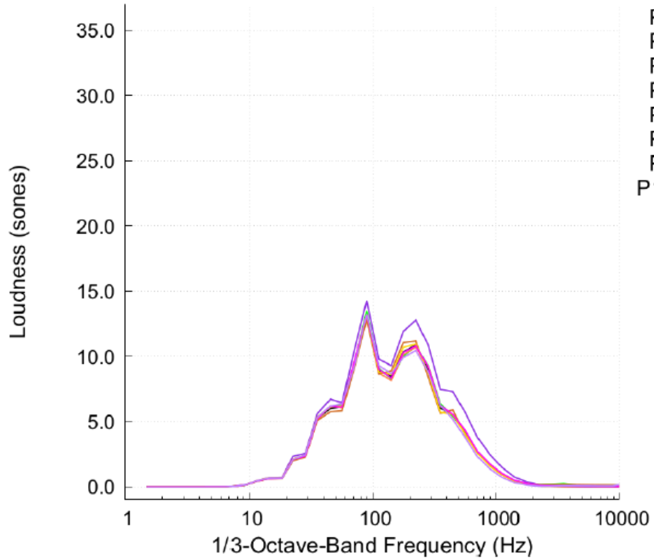
Phi = 45°



(b) **Profile4 (Optional).**

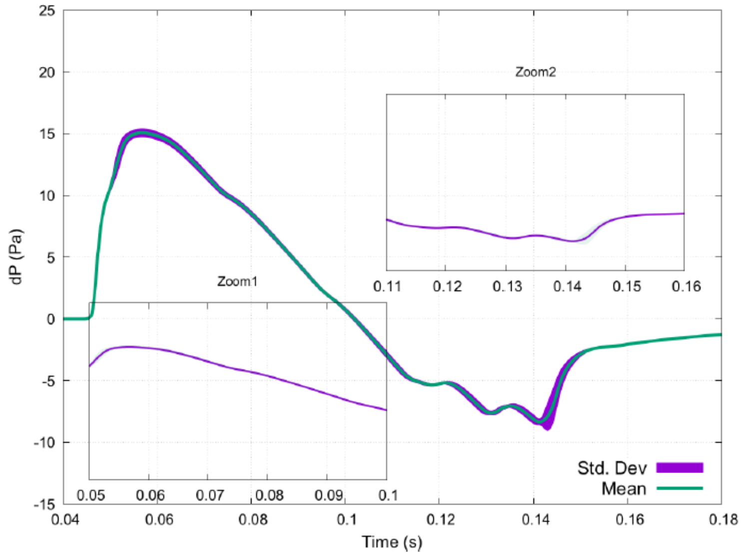


(c) **Standard Profile (Optional).**



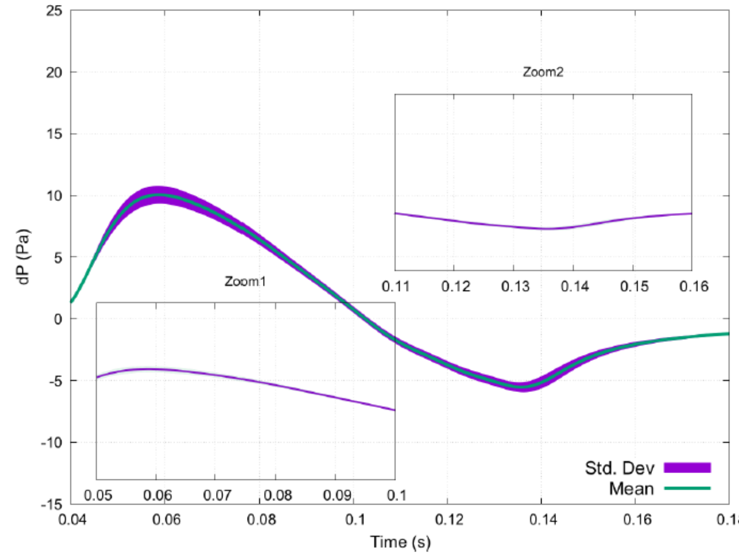
(d) **Standard Profile w/ RH=70% (Optional).**

Standard Deviations: AxiBody

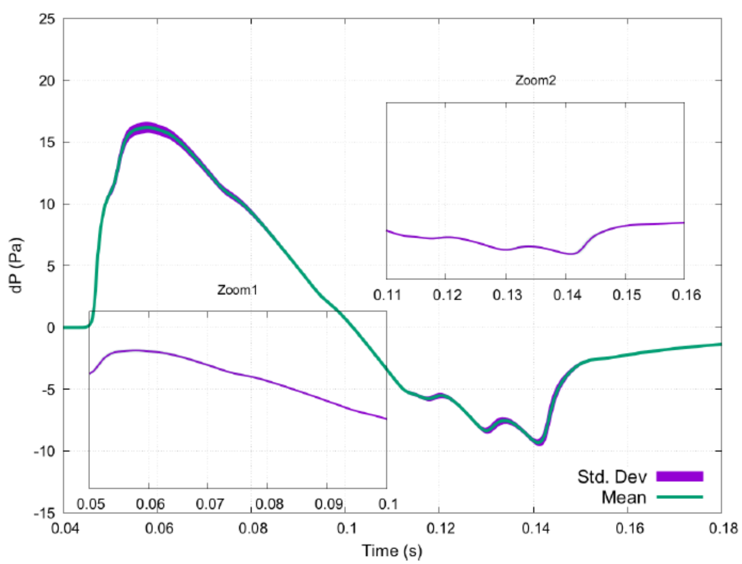


(a) **Profile3 (Required).**

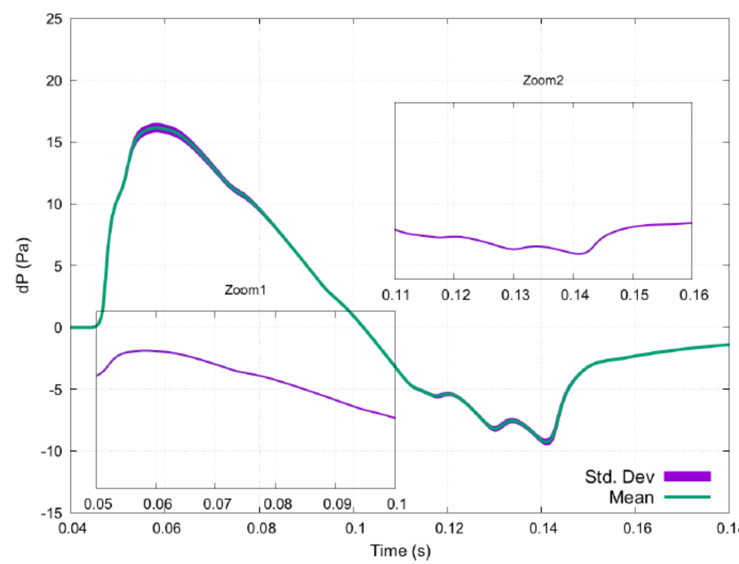
Phi = 45°



(b) **Profile4 (Optional).**

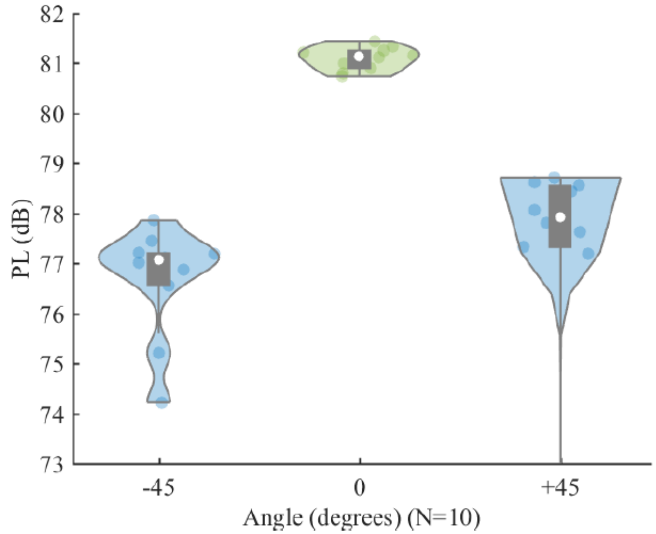


(c) **Standard Profile (Optional).**

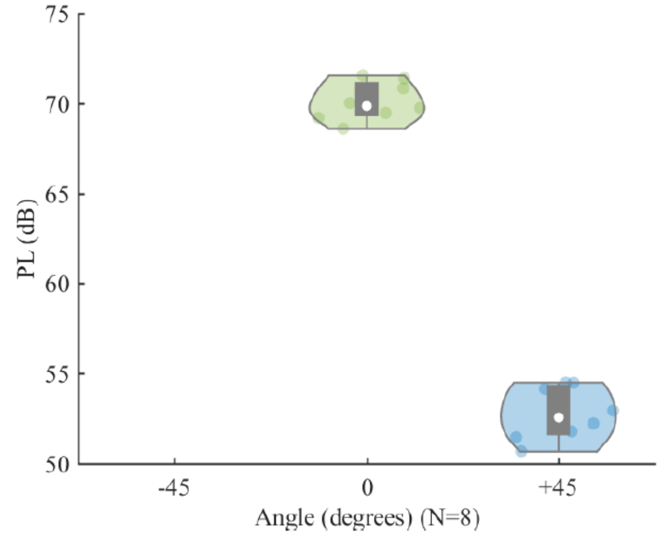


(d) **Standard Profile w/ RH=70% (Optional).**

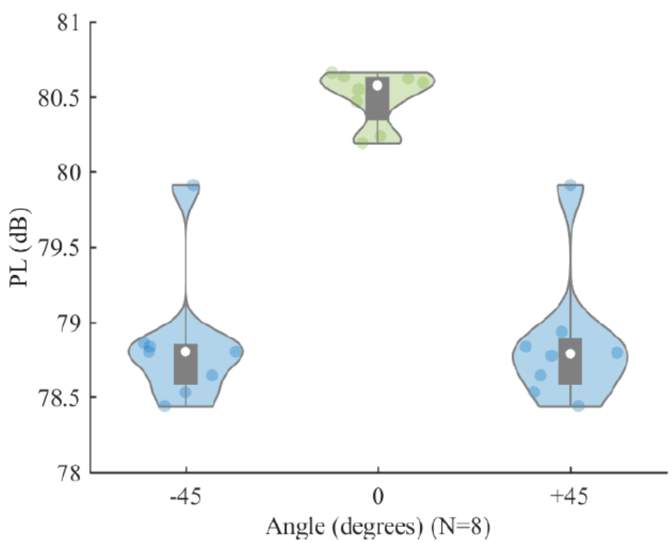
Violin Plots: AxiBody



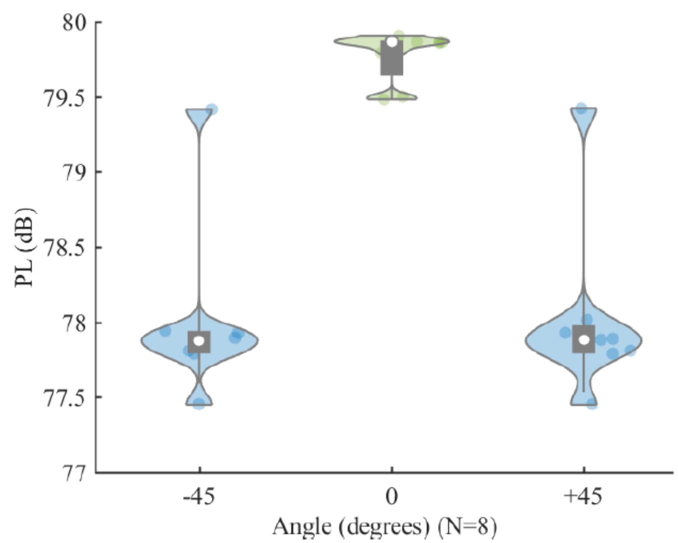
(a) **Profile3 (Required).**



(b) **Profile4 (Optional).**



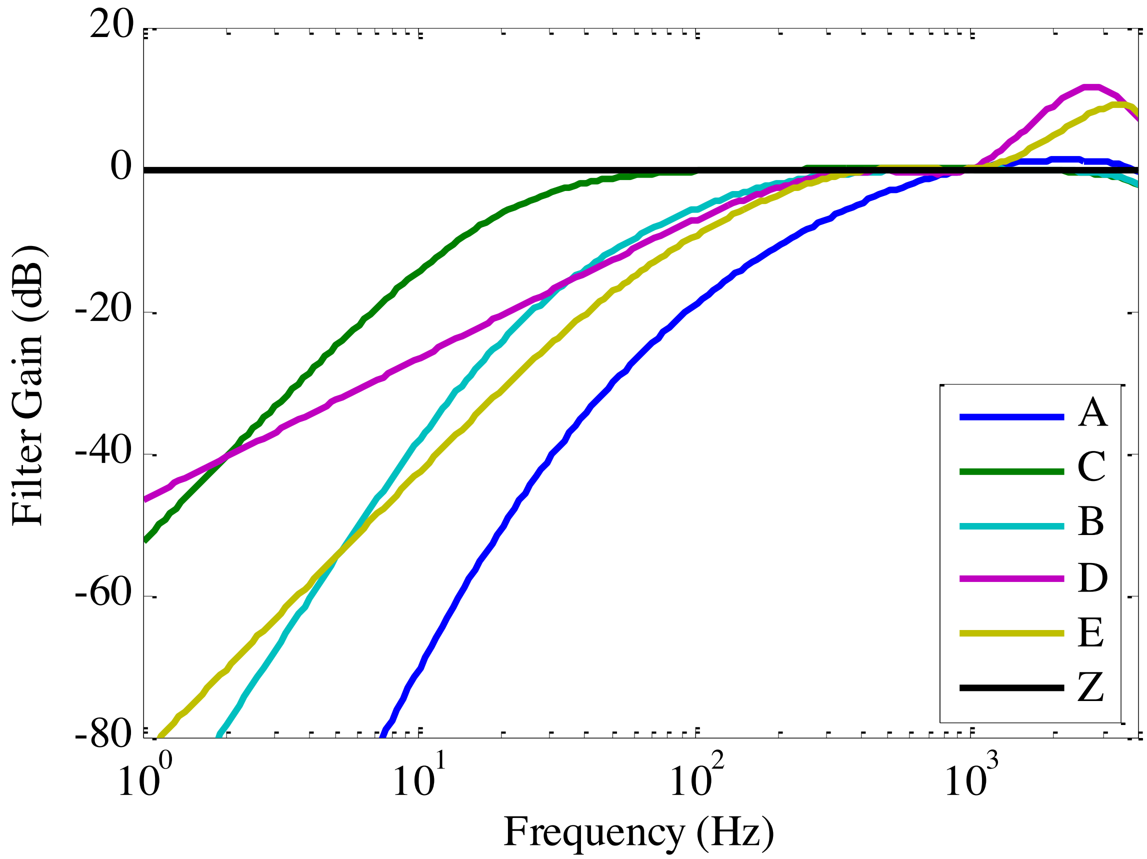
(c) **Standard Profile (Optional).**



(d) **Standard Profile w/ RH=70% (Optional).**

Noise Metrics Analysis

- Several loudness metrics are available: A/B/C/D/E/Z weighting
- Each has different weighting at different frequencies



Summary of Perceived Level (PL)

- Metric for perceived level of loudness developed by Stevens
  - Developed to predict behavior of human auditory system in response to sound
- Adapted for use with sonic booms by Shepherd and Sullivan
- PL has been shown to correlate well with human perception of sonic booms heard outdoors
  - PL is used today to evaluate supersonic aircraft designs

- Uses signal spectrum in one-third-octave bands
- Uses a set of frequency weighting contours that vary with level
  - (By contrast, A-weighting contour does not vary with level)
  - Based on equal loudness contours for bands of noise
  - Extends down to 1 Hz, but this is an approximation
- Band of highest weighted level is the most important to overall level
- PL calculated and reported here

S. S. Stevens. Perceived level of noise by Mark VII and decibels (E). J. Acoust. Soc. Am., 51(2):575–601, 1972.
K. P. Shepherd and B. M. Sullivan. A loudness calculation procedure applied to shaped sonic booms. NASA Technical Report TP-3134, 1991.

Calculation Steps for Perceived Level (PL)

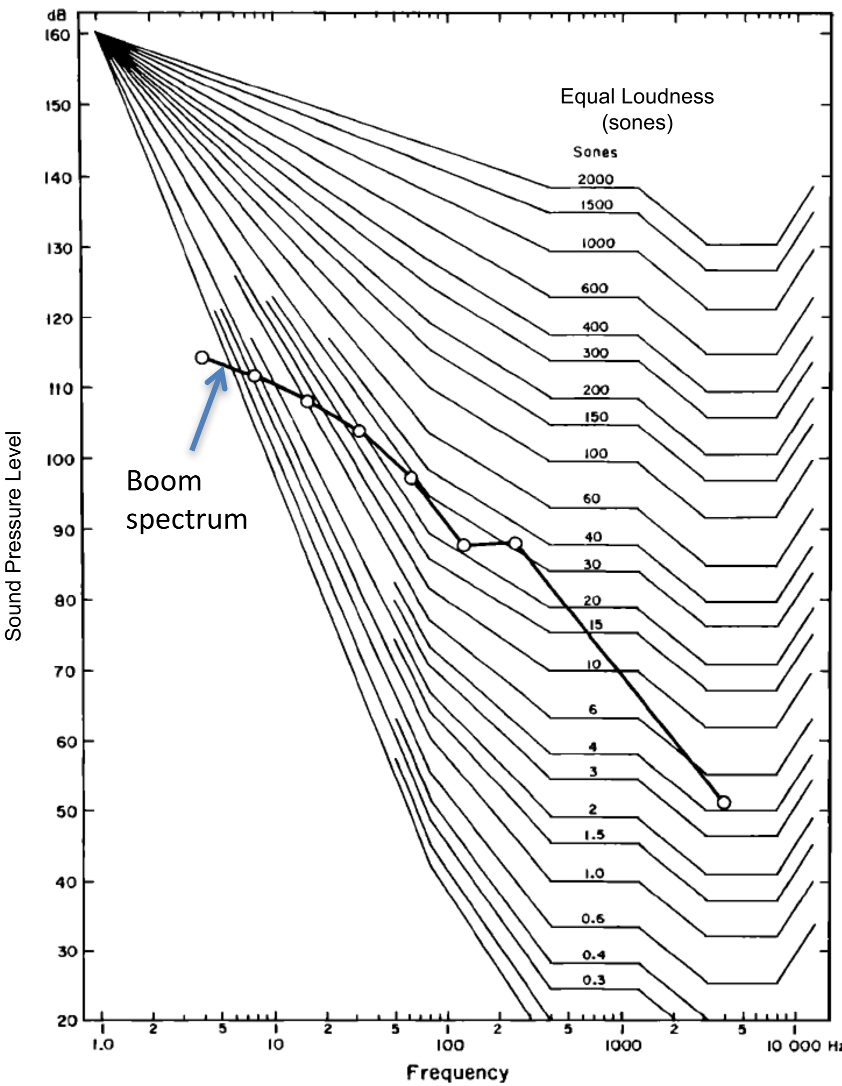
1. Calculate Sound Pressure Level of signal in 1/3-octave bands
2. Apply frequency weighting for loudness of individual bands
   - where loudness of 1 sone is referenced to 1/3-oct band of noise at 3150 Hz at 32 dB
3. Apply summation rule for total loudness

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

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

4. Convert to PL in dB

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



S. S. Stevens. Perceived level of noise by Mark VII and decibels (E). J. Acoust. Soc. Am., 51(2):575–601, 1972.

SBPW3

- Goals
- Cases
    - Need input from other participants
- Potential additional investigations
    - Maneuvers/Trajectories
    - Focus and location of caustics
    - Over-the-top secondary booms
    - Turbulence
    - Irregular terrain
    - Ground impedance
    - Curved earth effects
    - Shadow zone calculations

SBPW3

- Potential additional information to gather
  - Frequency spectra
  - Execution time (wall clock?)
  - Propagation time to ground
  - Ray tube area
- Will specify wind convention and atmospheric condition interpolation method (or provide fine resolution)

Potential Ideas for Future Workshops

- SBPW3
  - Need input from other participants
  - Potential additional investigations
    - Maneuvers/Trajectories
    - Focus and location of caustics
    - Over-the-top secondary booms
    - Turbulence
    - Irregular terrain
    - Ground impedance
    - Curved earth effects
    - Shadow zone calculations
    - Frequency spectra
    - Execution time (wall clock?)
    - Propagation time to ground
    - Ray tube area
  - Will specify wind convention and atmospheric condition interpolation method (or provide fine resolution)