# SBPW3: SUMMARY OF PROPAGATION WORKSHOP

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# 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 for low-booms at realistic atmospheric conditions particularly at lateral cut-offs

# Boom Propagation Workshop

- Subject today was atmospheric propagations
- 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, but ignoring atmospheric turbulence

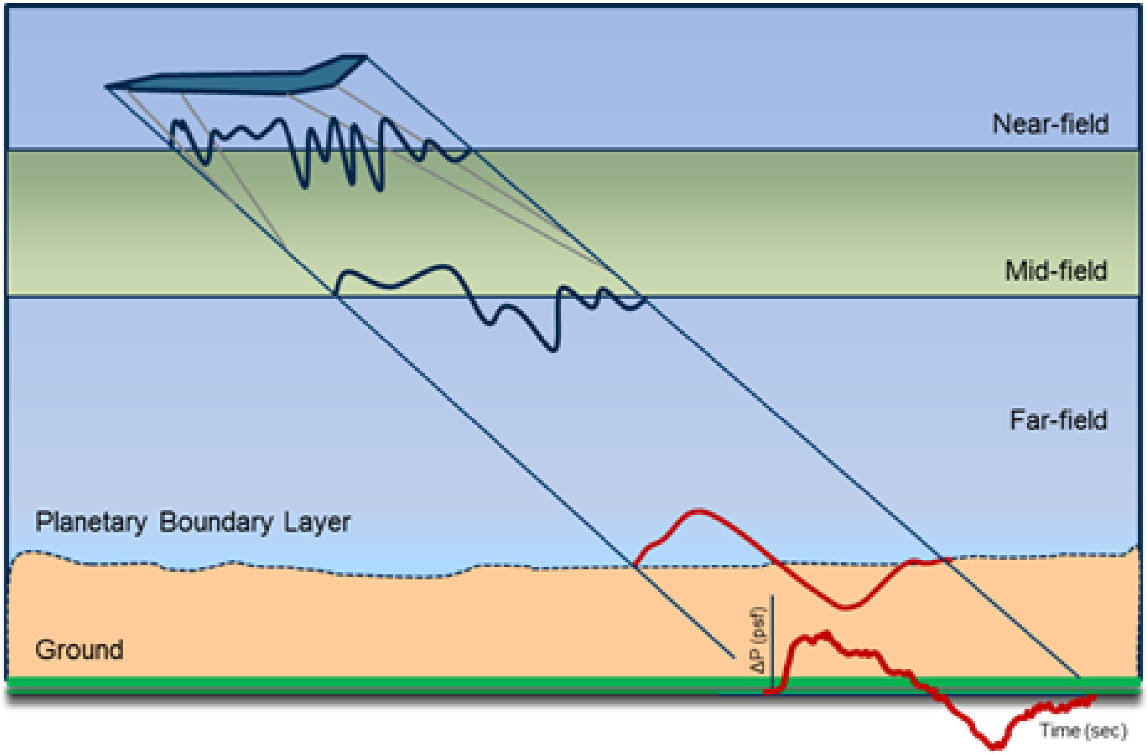



Figure Source: "Status of Certification Procedures for Quiet Supersonic Flight", Robbie Cowart, *AIAA AVIATION 2019, Dallas, TX*

# Workshop Culture

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

# Cases

- Case 1: NASA trimmed low-boom concept - C25P


- Case 2: NASA-Lockheed Low-Boom Flight Demonstrator (LBFD) Concept: A variant of the X-59 QueSST

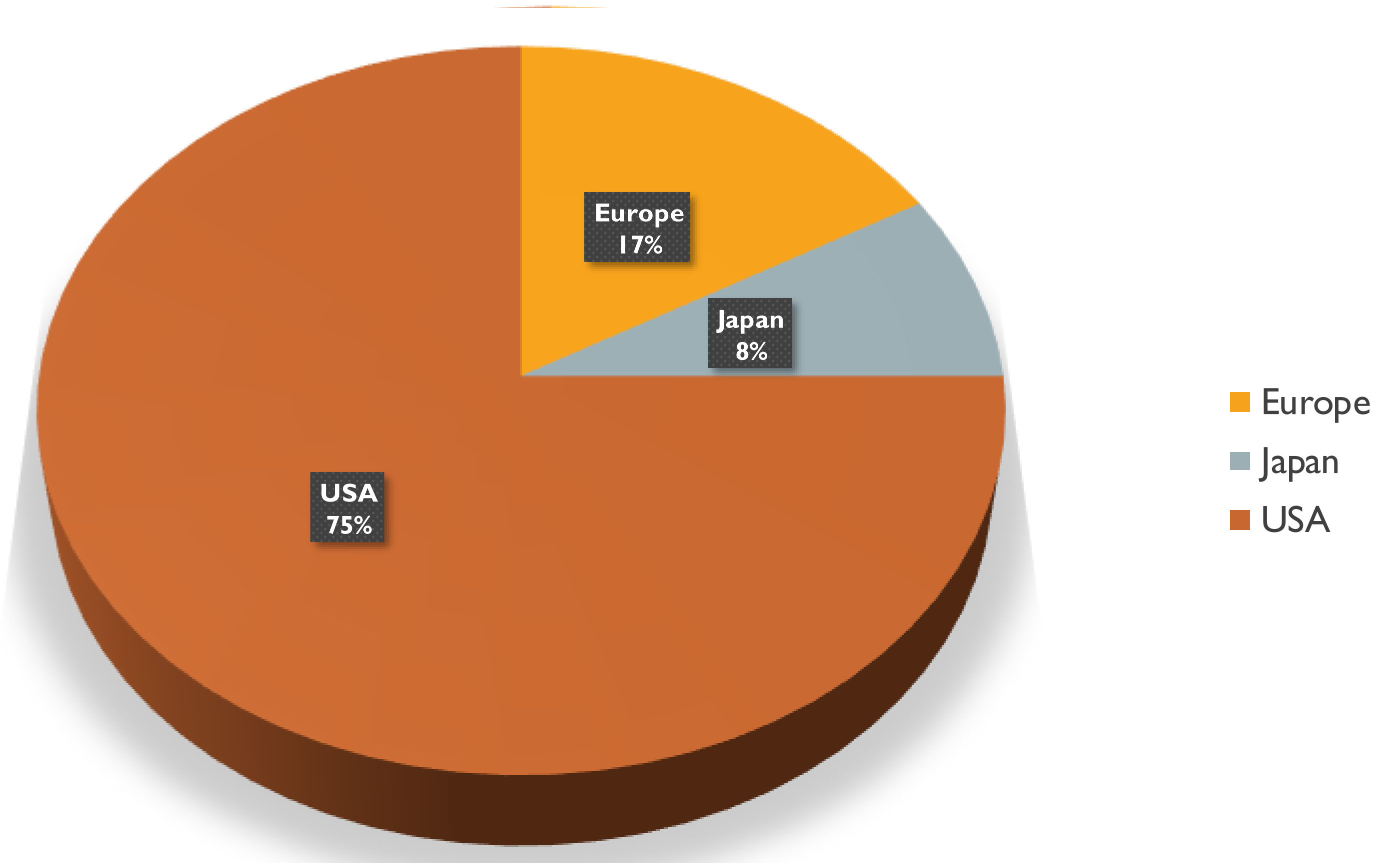
# Data Processing

- Thank You for all the submissions and participation!
- Received data via FTP or email
- Some had to be renamed, reformatted, zero padded, or sorted
  - Some submissions did not follow the provided template
  - Some submissions had non-zero pressure difference in ambient conditions
  - Some submissions had missing data at some azimuthal angles
- Contacted participants for clarification/update when
  - Significant or unexpected differences between submissions was observed with respect to other submissions
  - Data missing

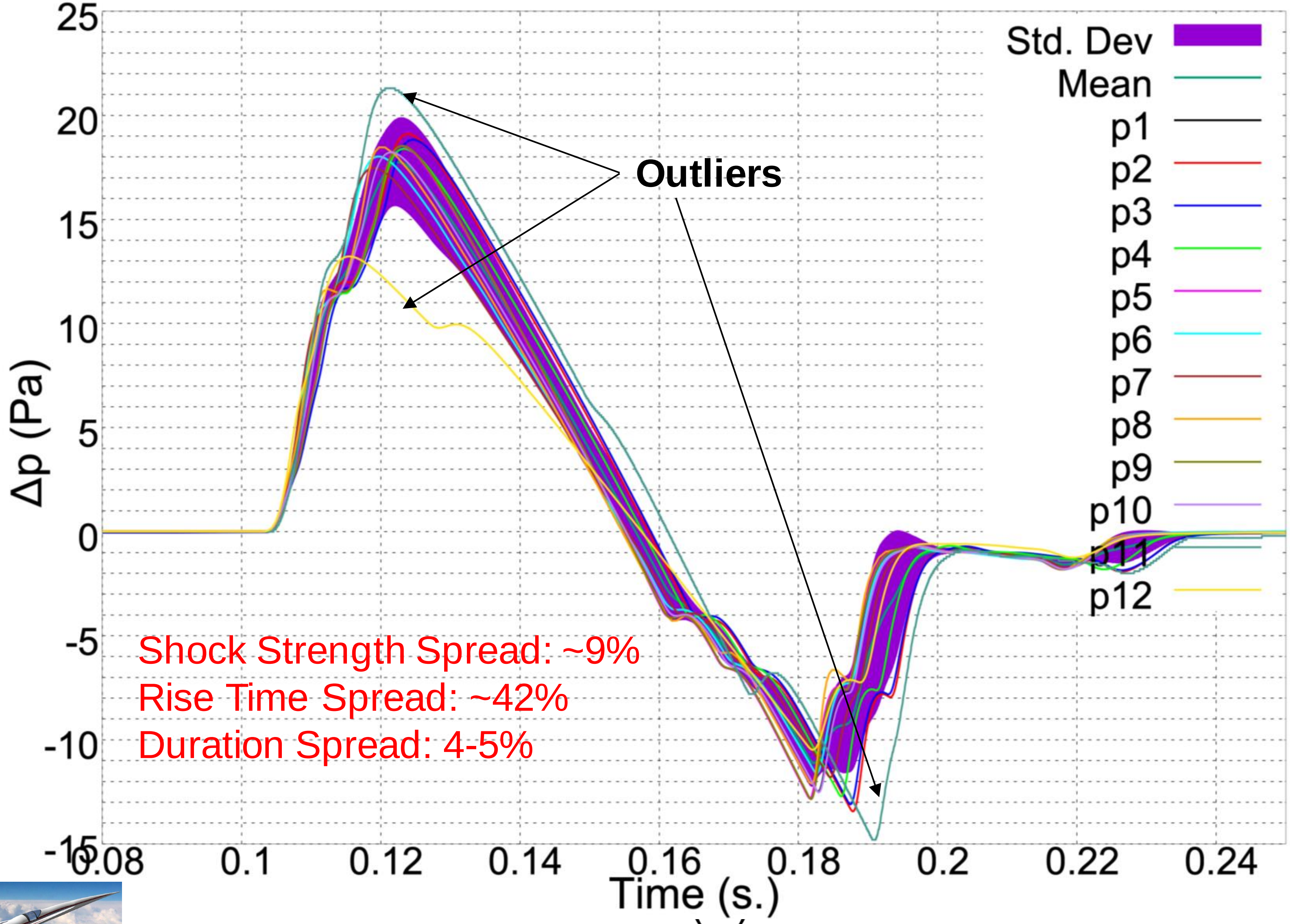
NOTE: The atmospheres were intentionally chosen to produce large carpets. Most of the time, the carpet widths using measured/realistic atmospheres are more or less similar compared to Standard Atmosphere

# Submissions

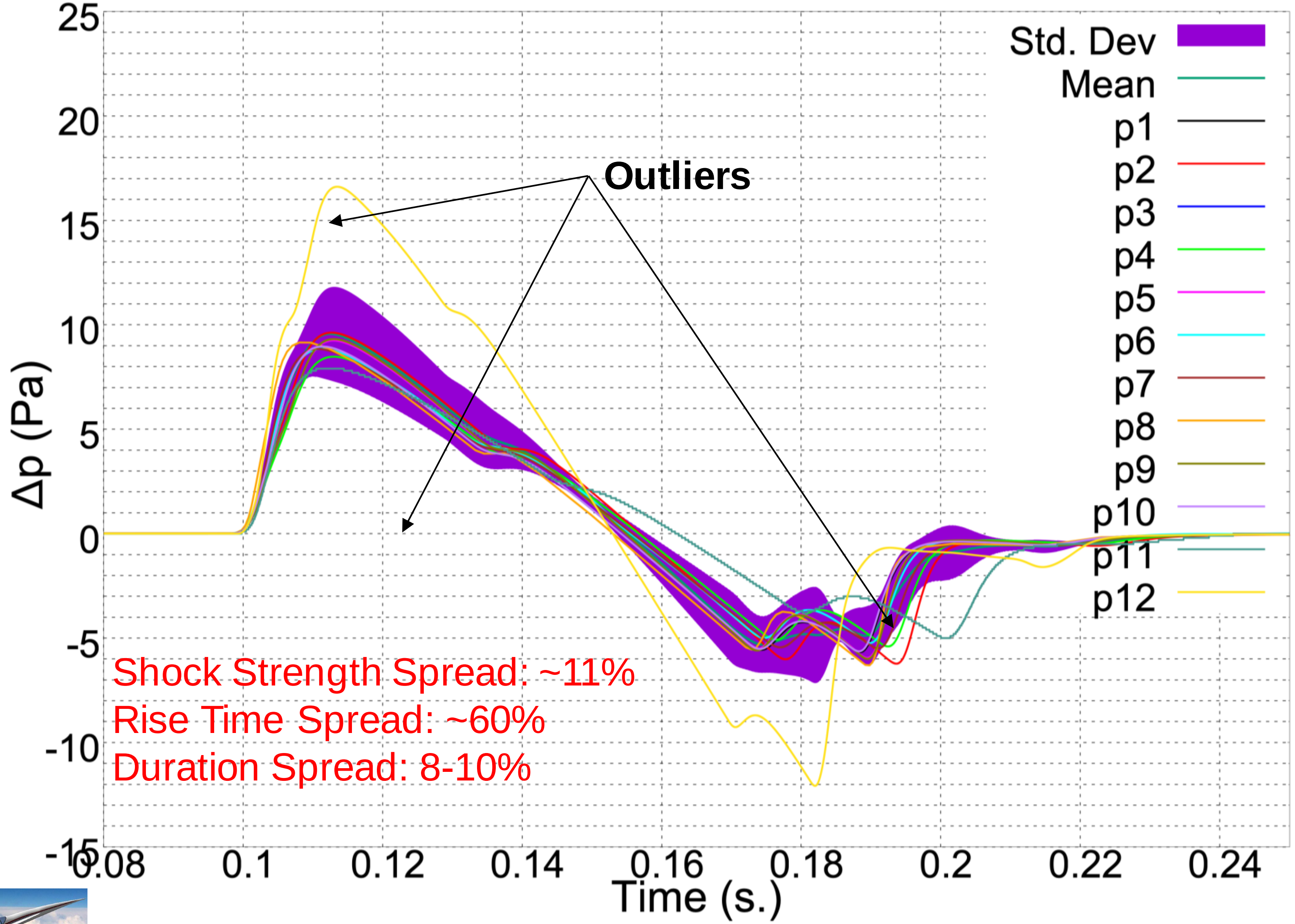
- 12 separate submissions: P1 – P12



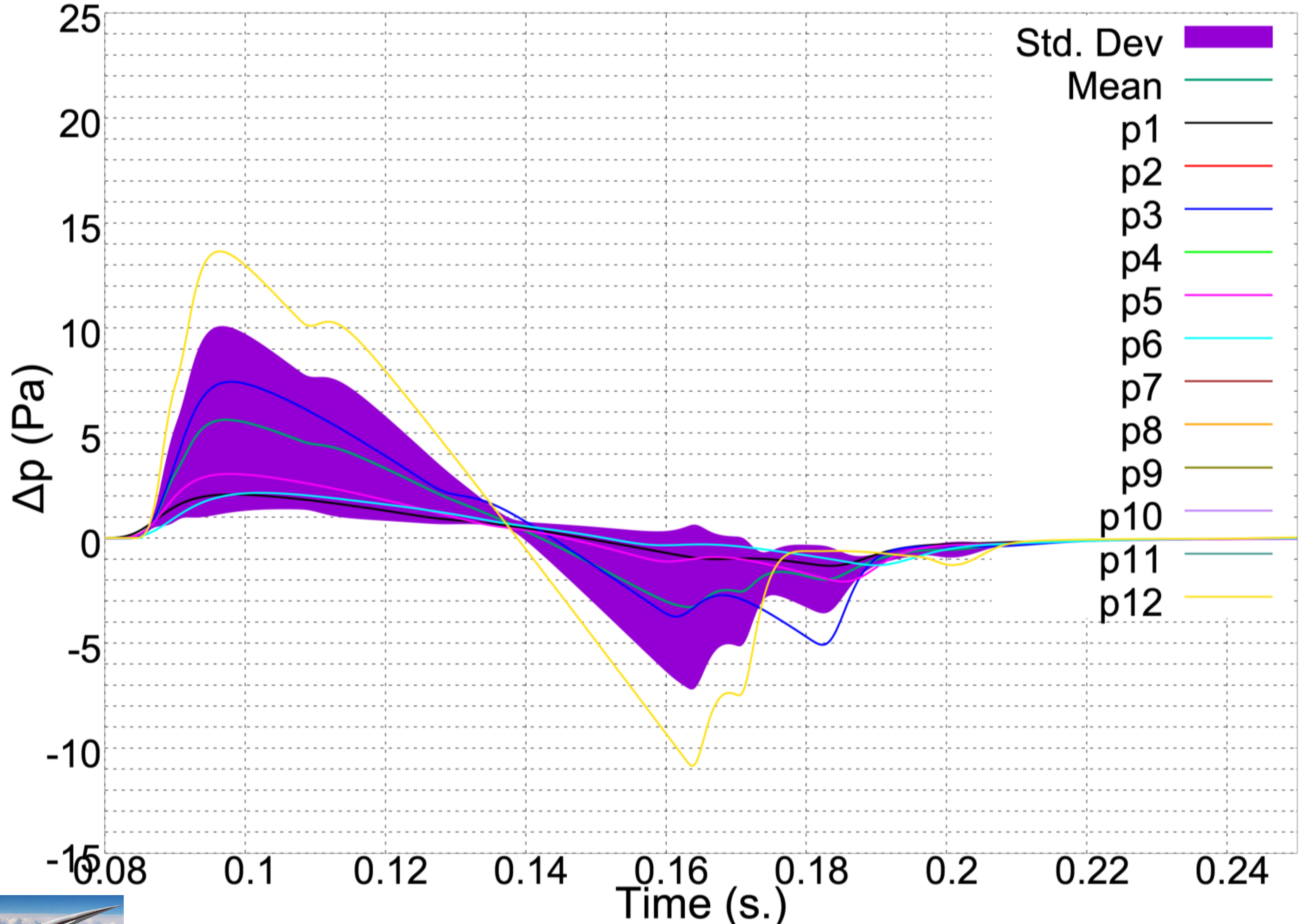
# Case1 – Required Case, Phi=$0^0$



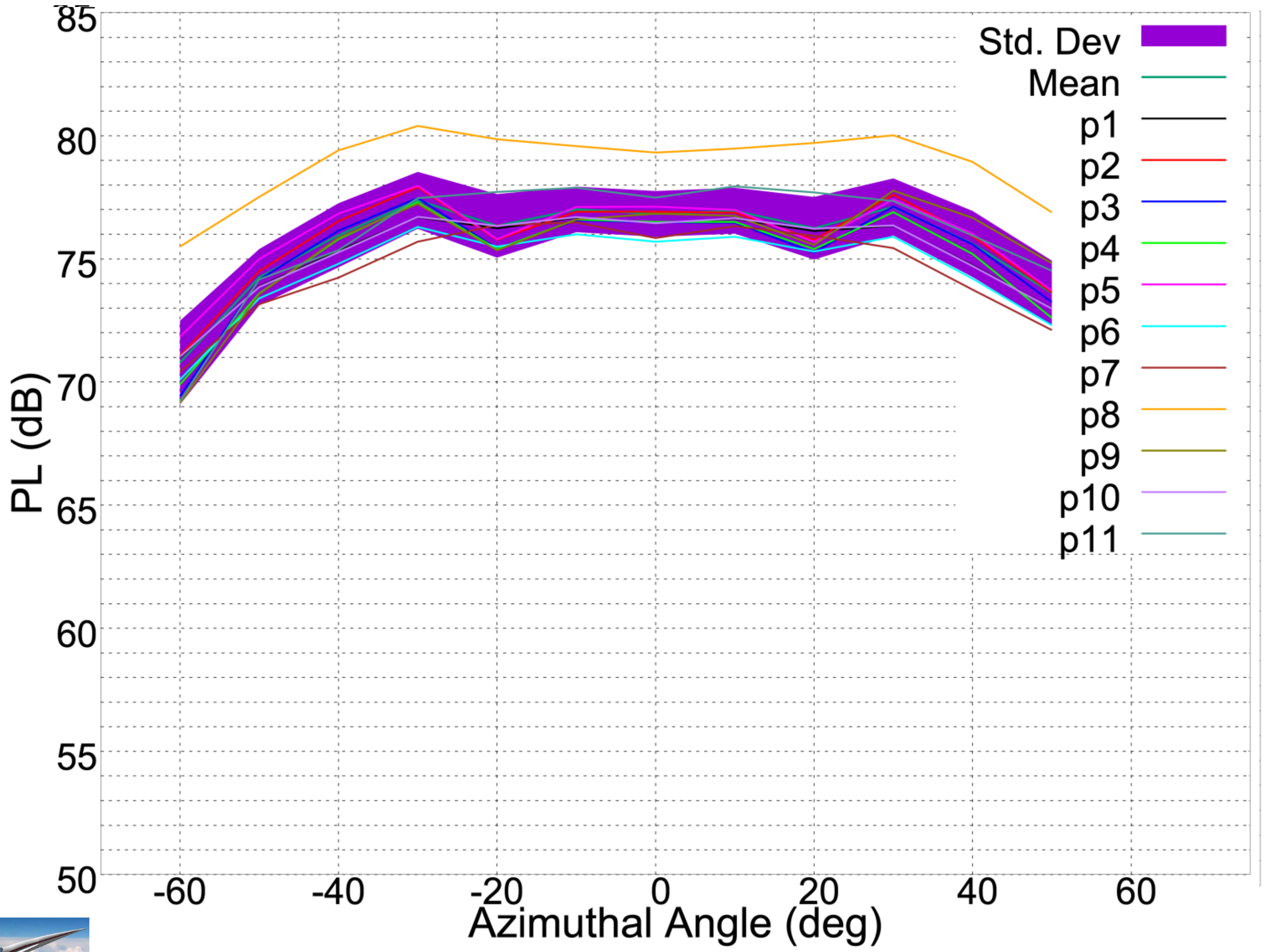

# Case1 – Required Case, Phi=$60^0$




# Case1 – Required Case, Negative Cut-off

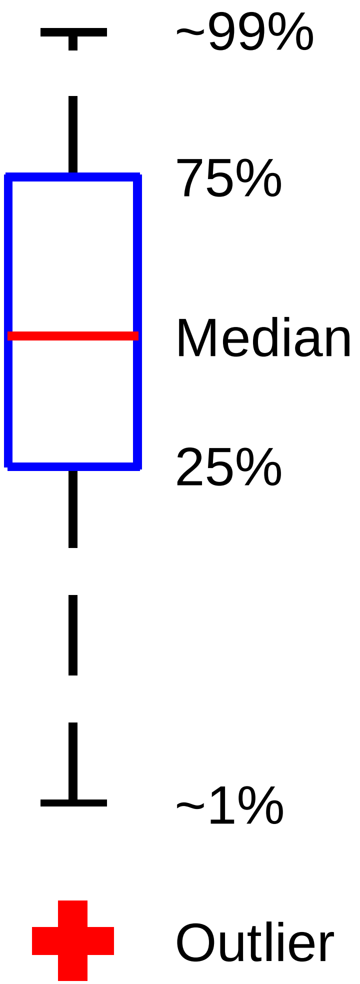



# Case1 – Carpet Loudness



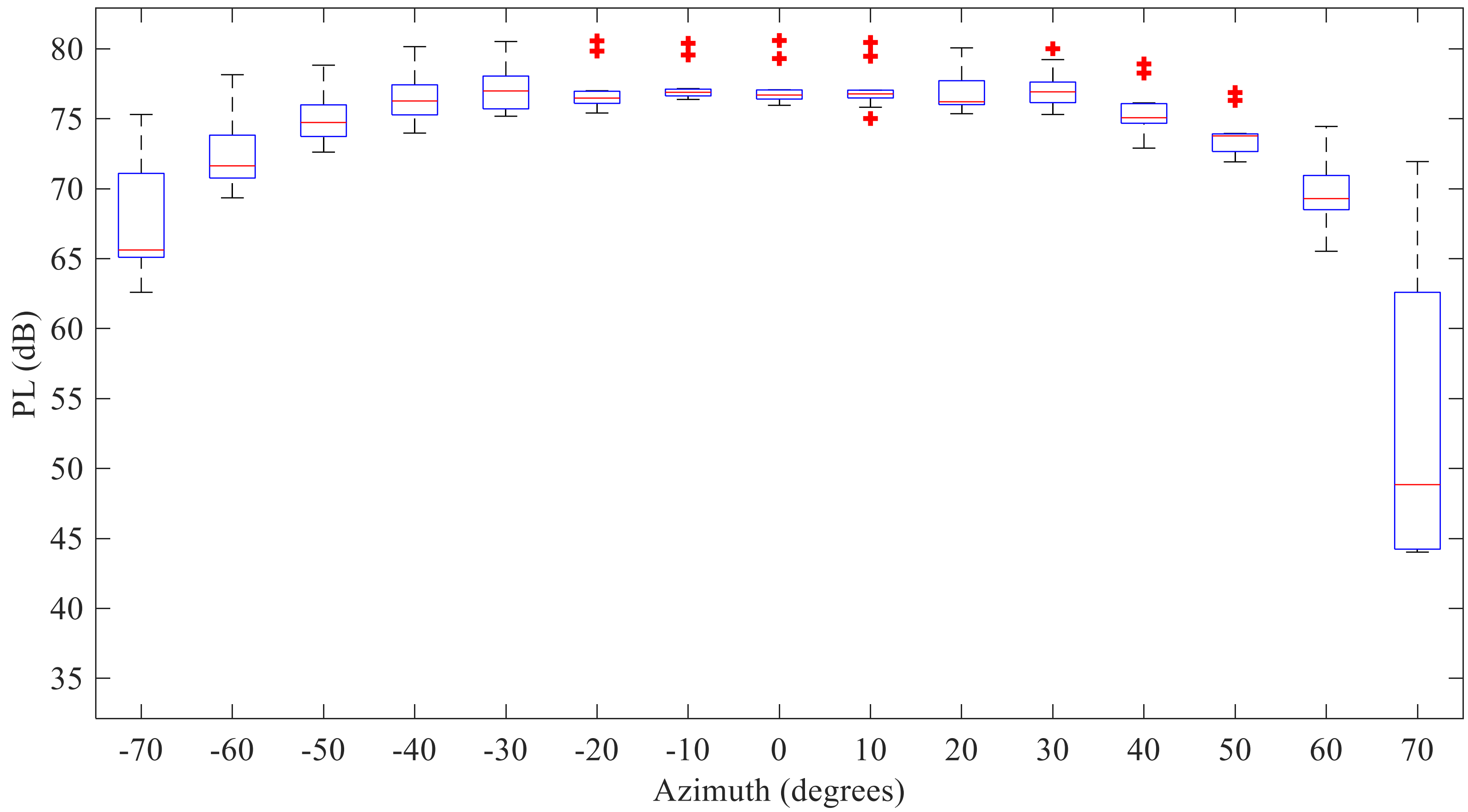

# Box Plot Analysis

- Six noise metrics were calculated from each participant's submitted signatures
  - 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*
- Box plots show summary statistics of carpet loudness
  - Only 12 points per box plot (1 per participant)
  - Box covers half of the data
  - Whiskers cover ~99% of data (for a normal distribution)
  - Outliers are beyond ± 2.7$\sigma$
- Some metrics exhibit greater variability



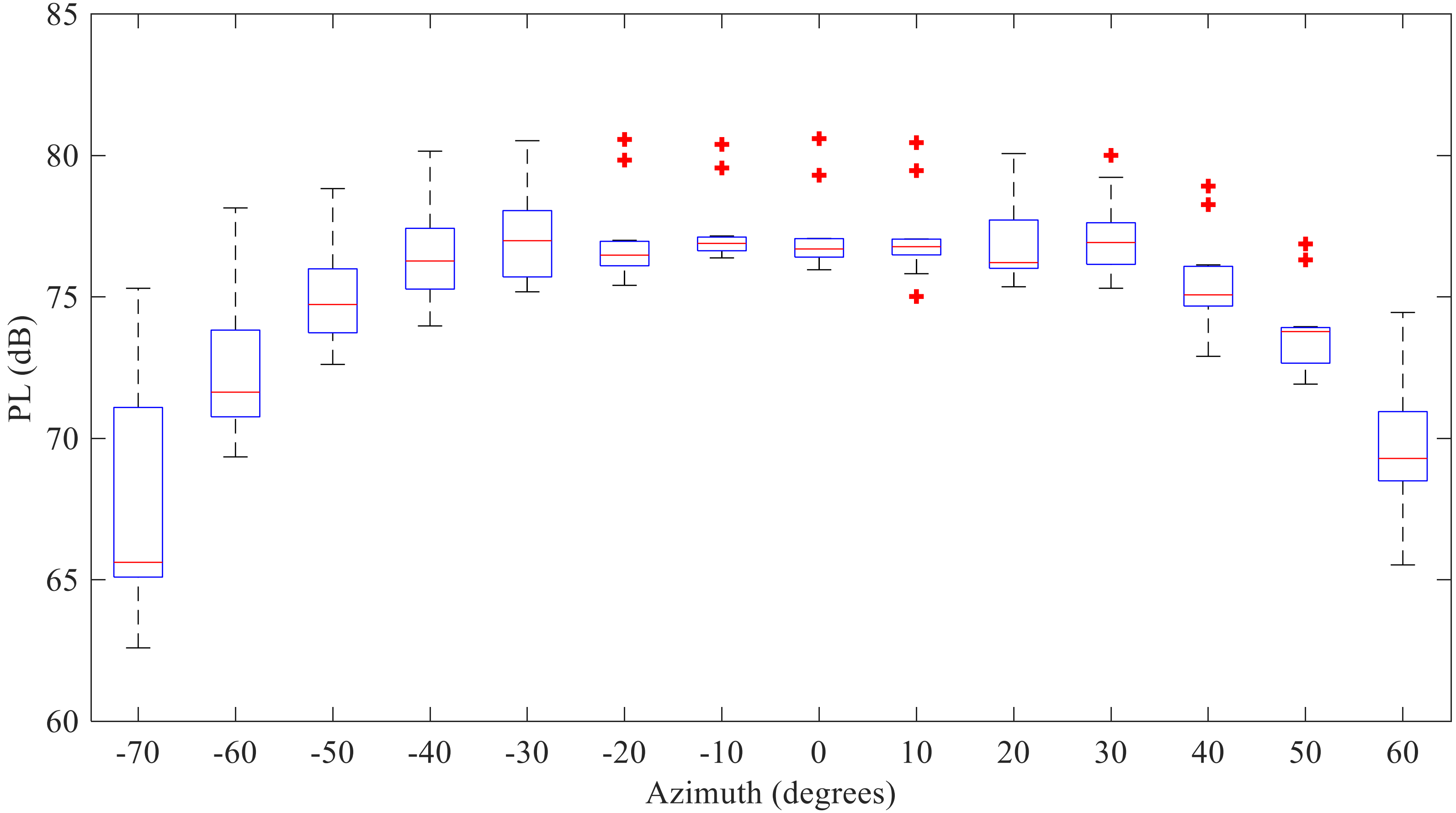

*A. Loubeau, S. Wilson, and J. Rathsam. Updated evaluation of sonic boom noise metrics. J. Acoust Soc. Am., 144: 1706, 2018.

# Case1 –Carpet Loudness (PL)

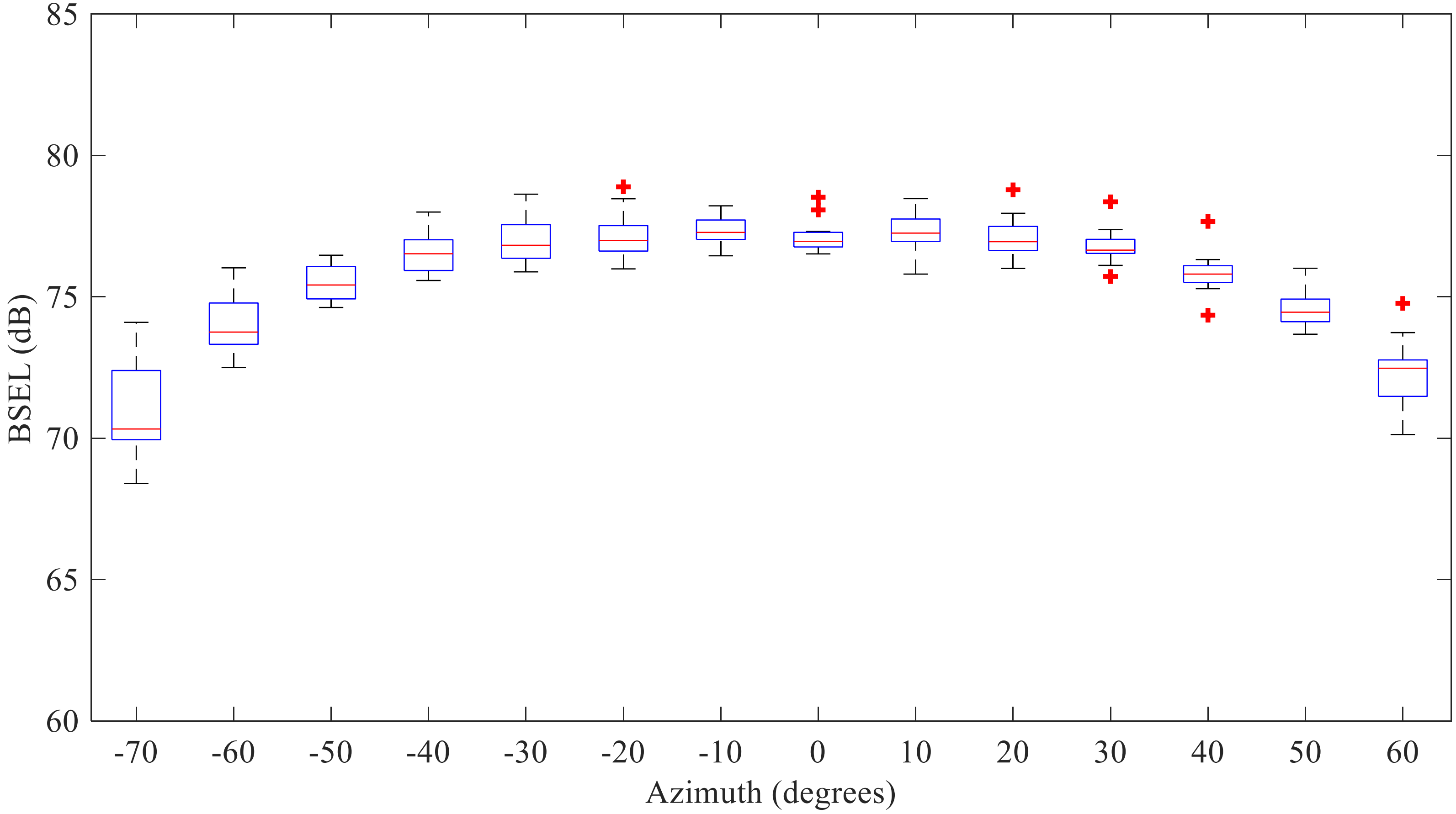



# Case1 –Carpet Loudness (PL)

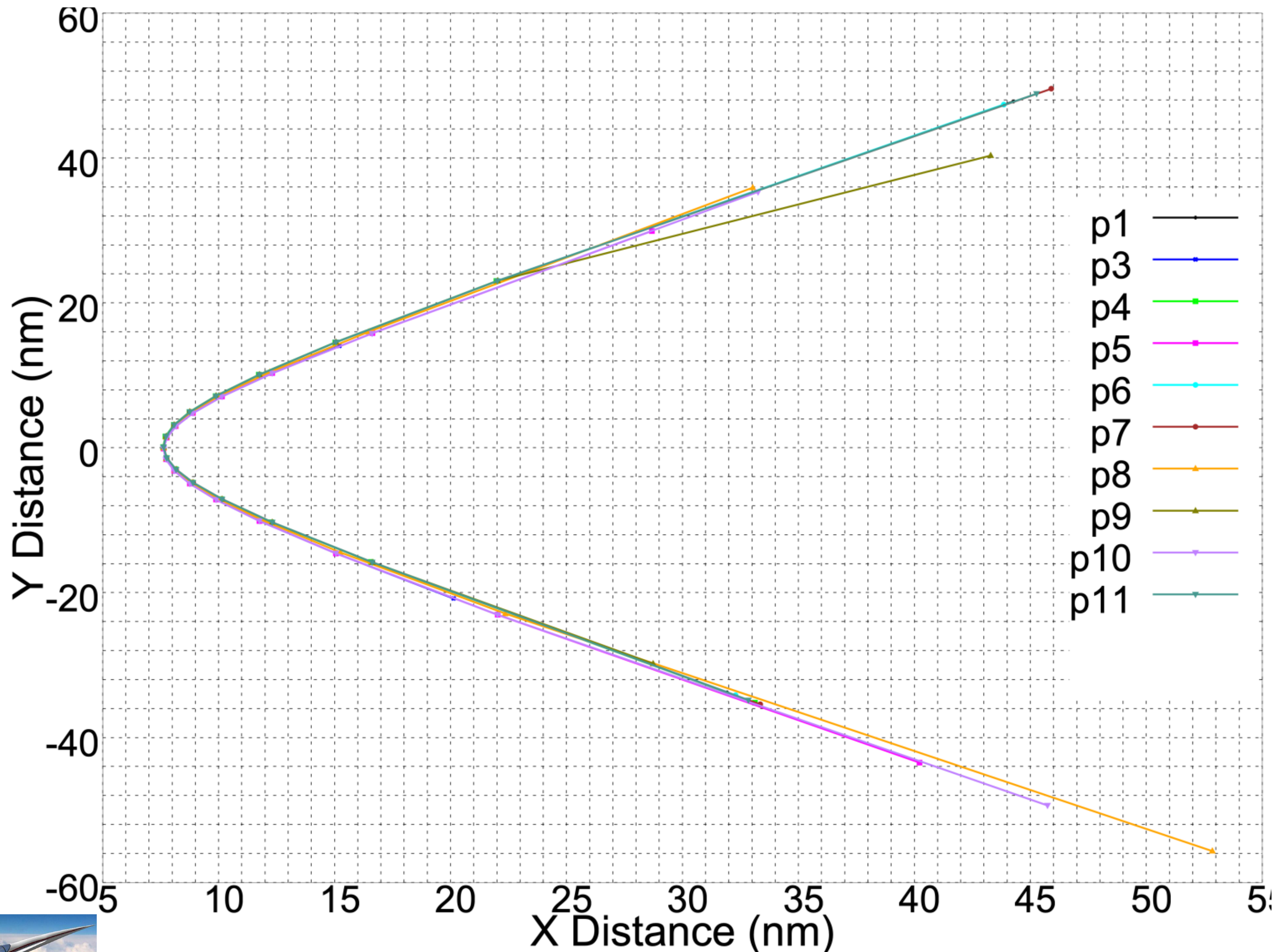
Remove +70 degree results to zoom in



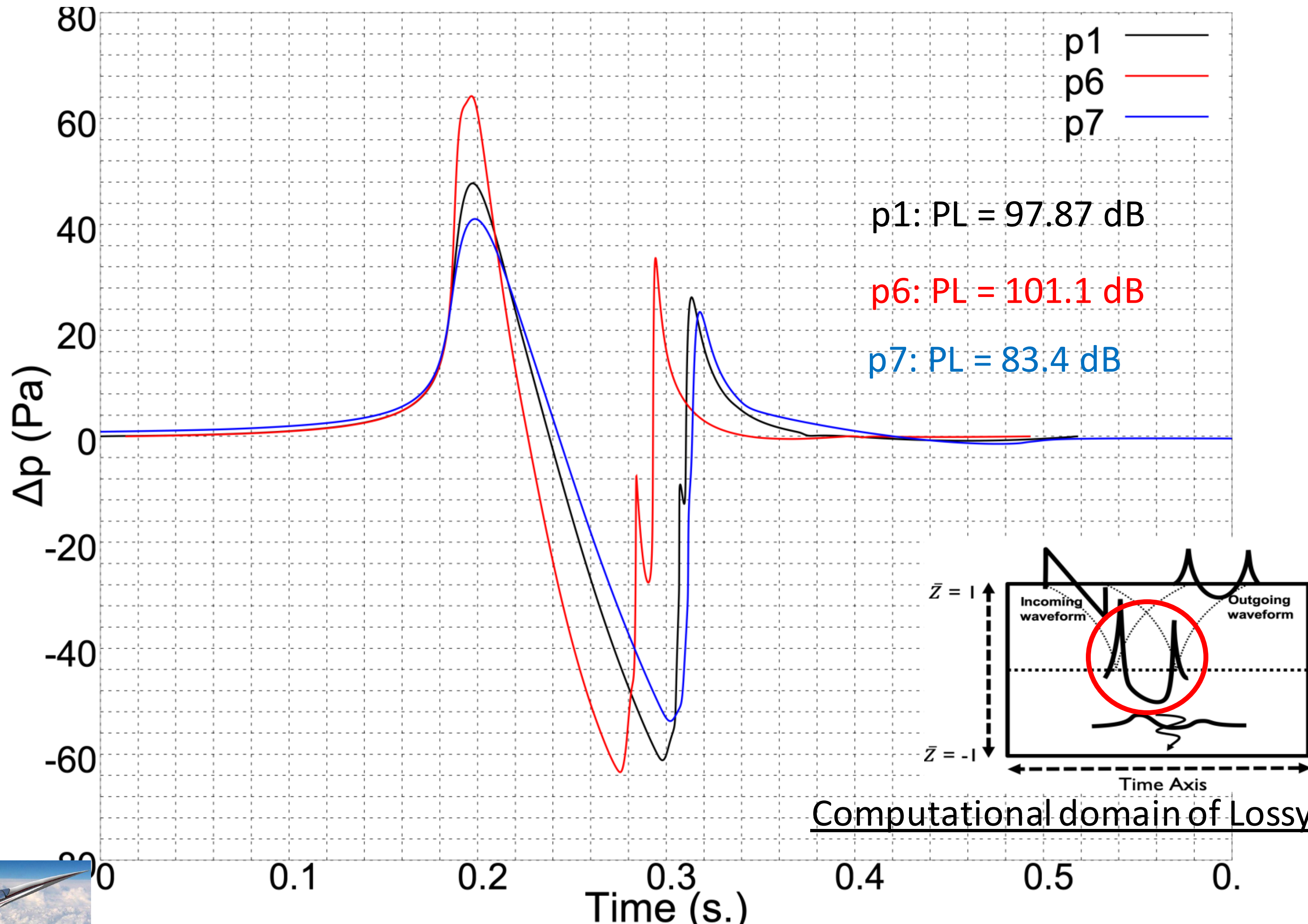

# Case1 –Carpet Loudness (BSEL)




# Case1 – Extent of Carpet

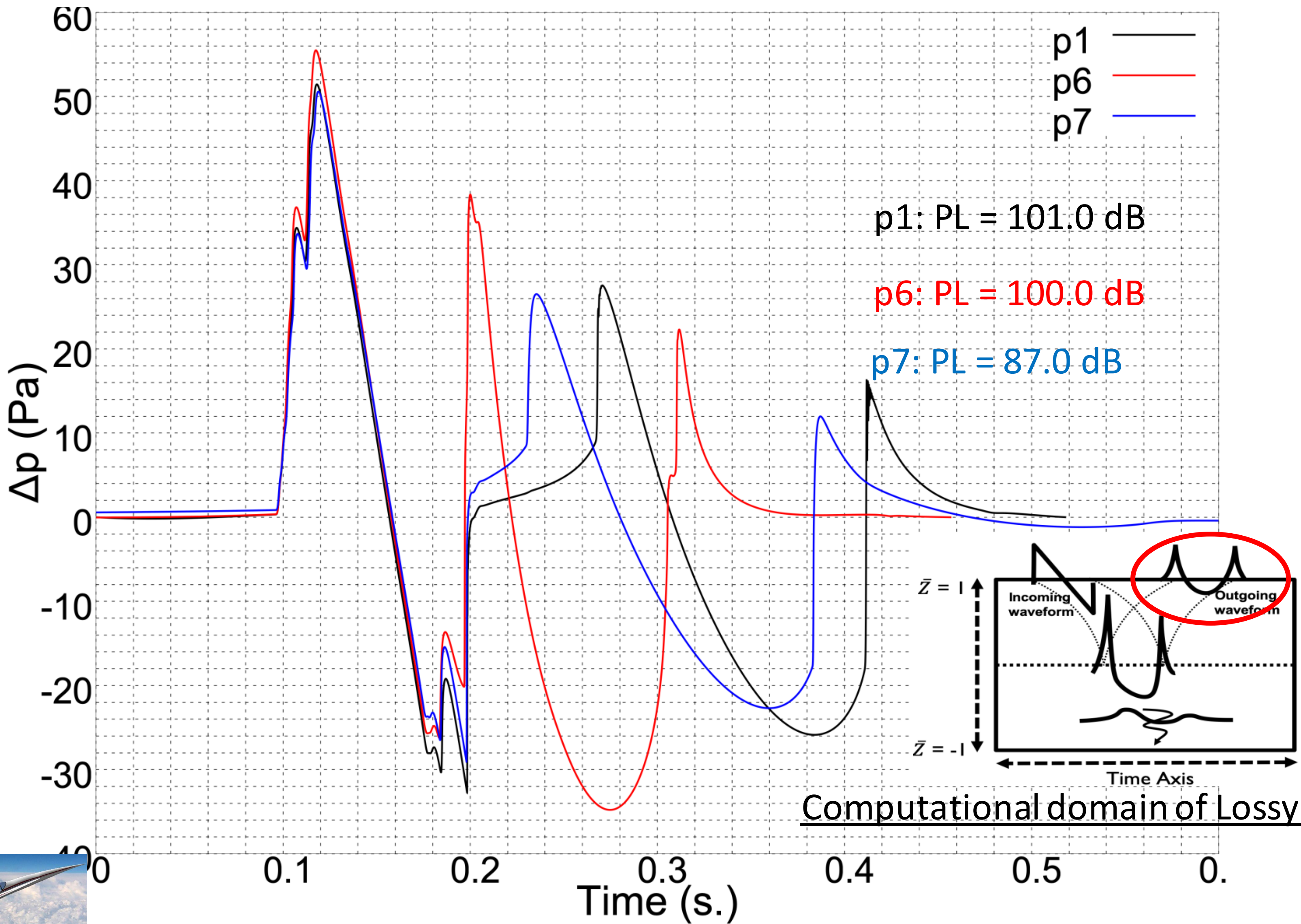



# Case1 – Optional Focus Case, $\bar{Z}$ =0.0



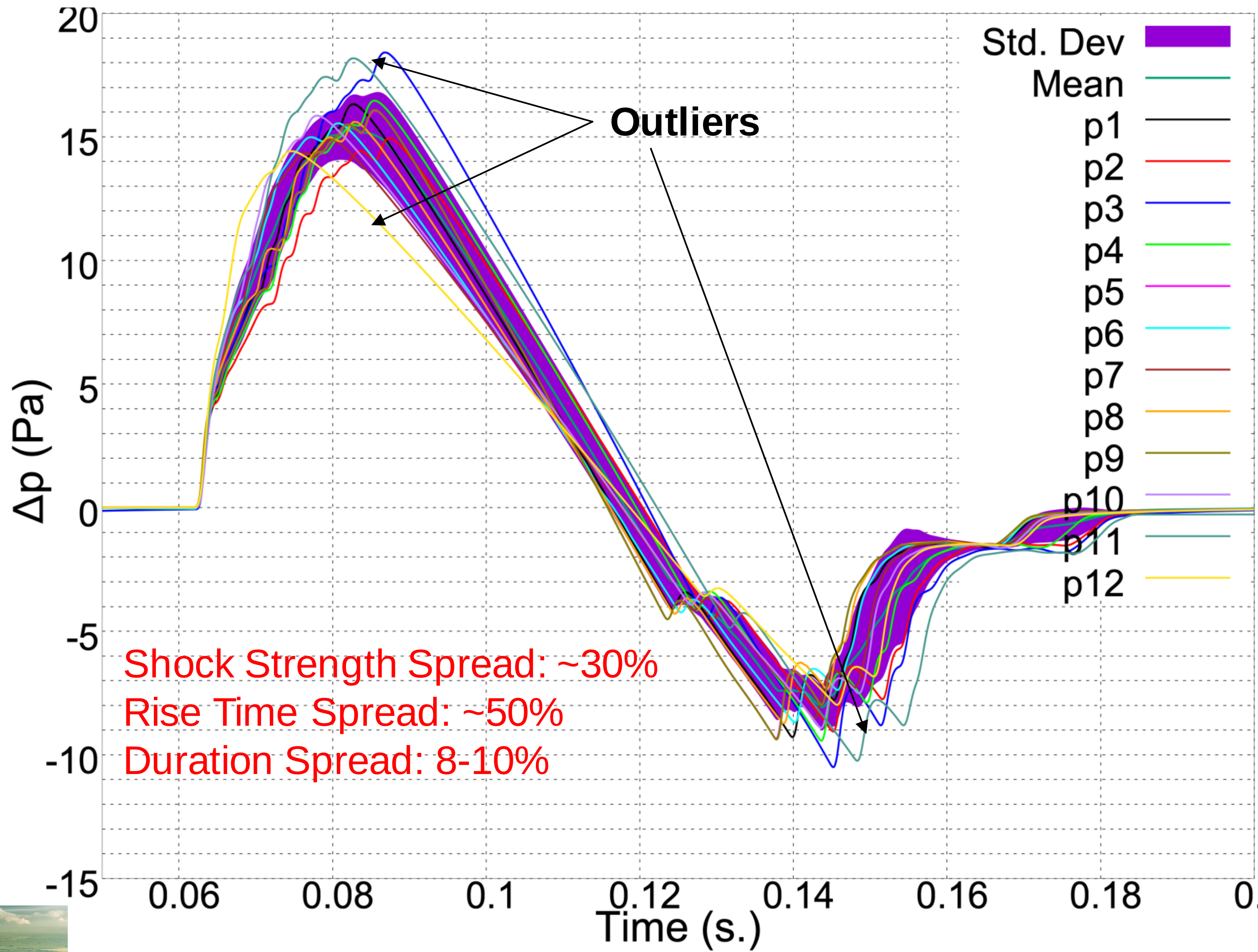

Computational domain of Lossy NTE

# Case1 – Optional Focus Case, $\bar{Z}$ =1.0

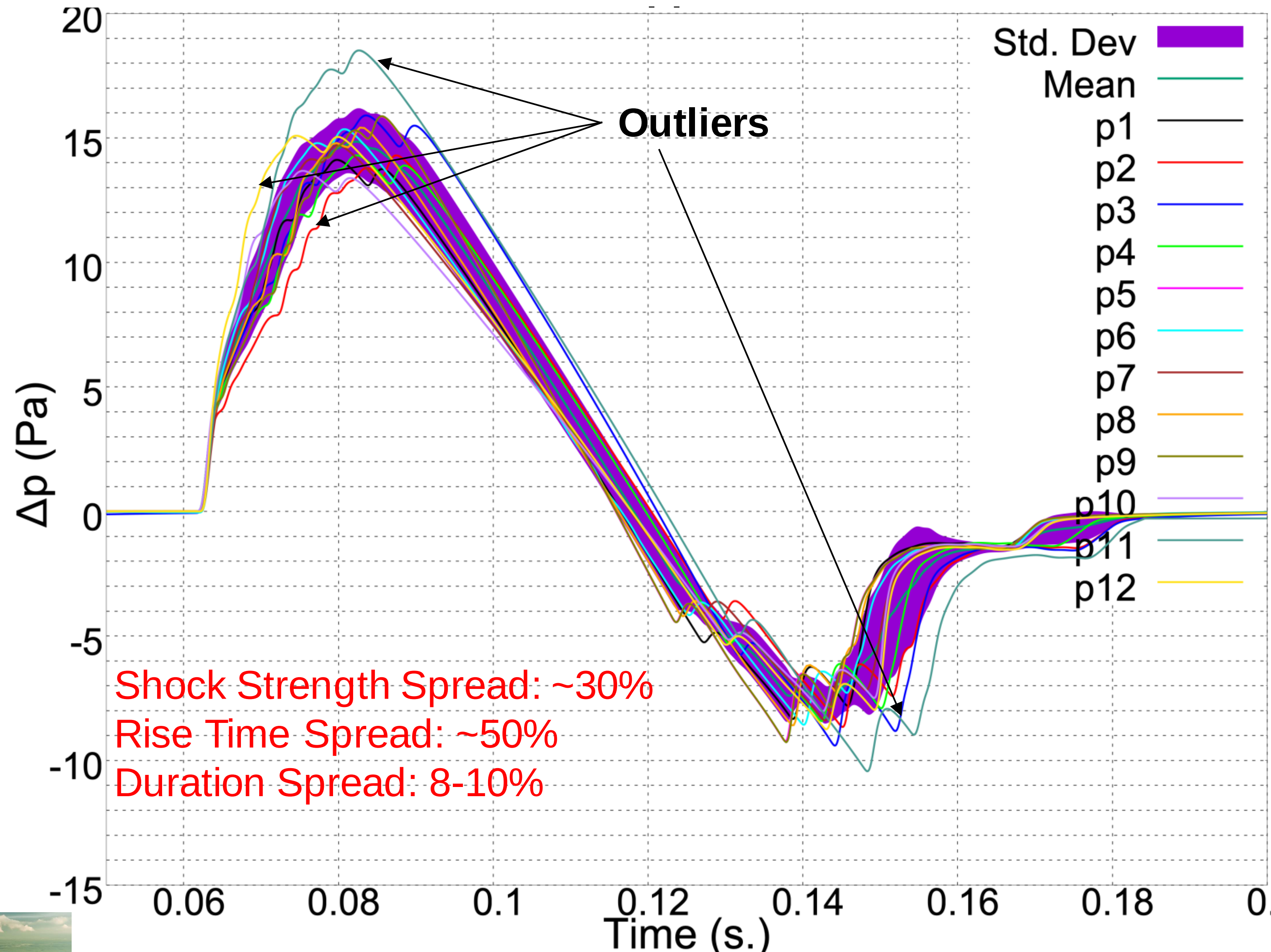



Computational domain of Lossy NTE

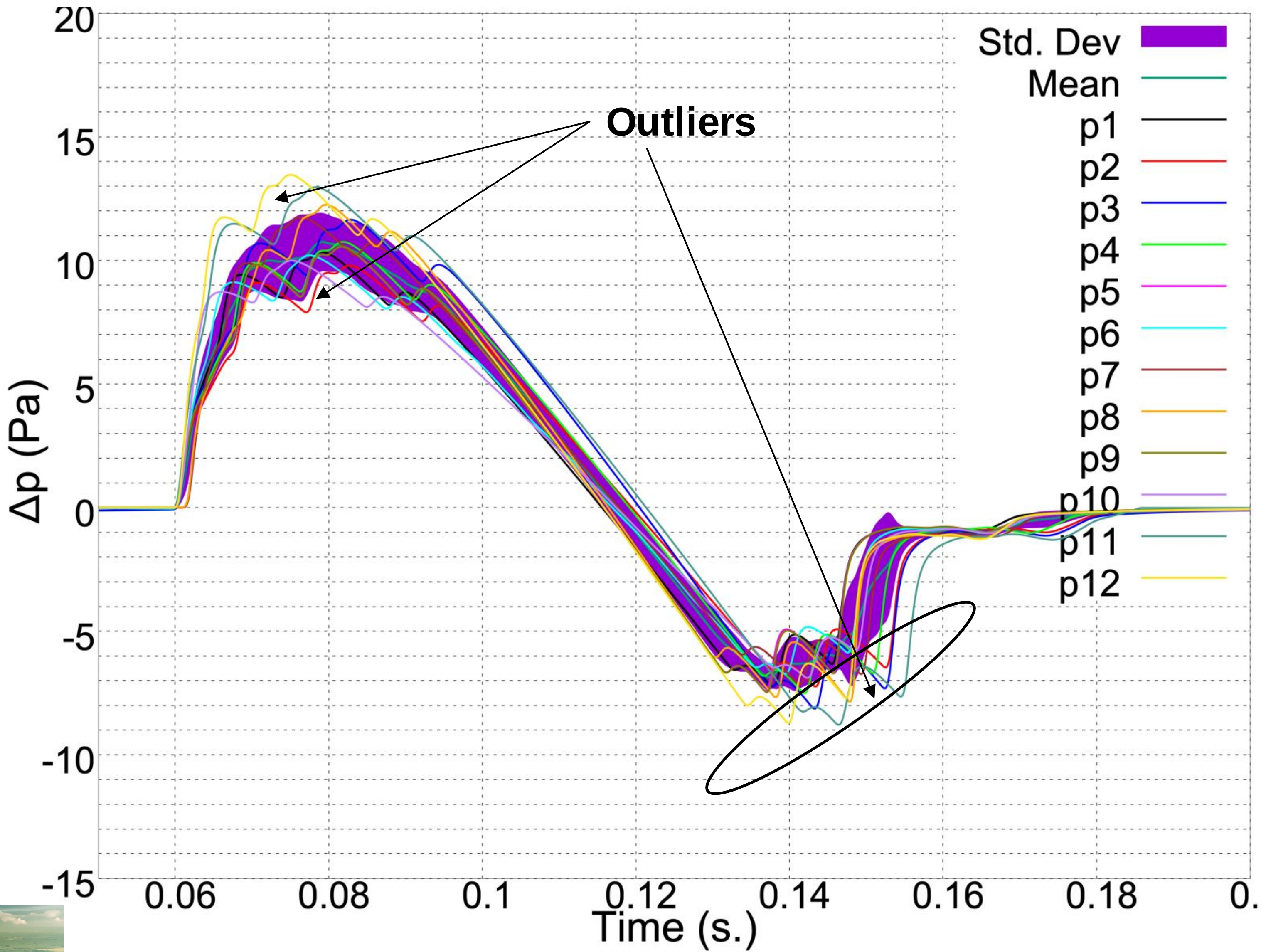
# Case2 – Required Case, Phi = 0.0



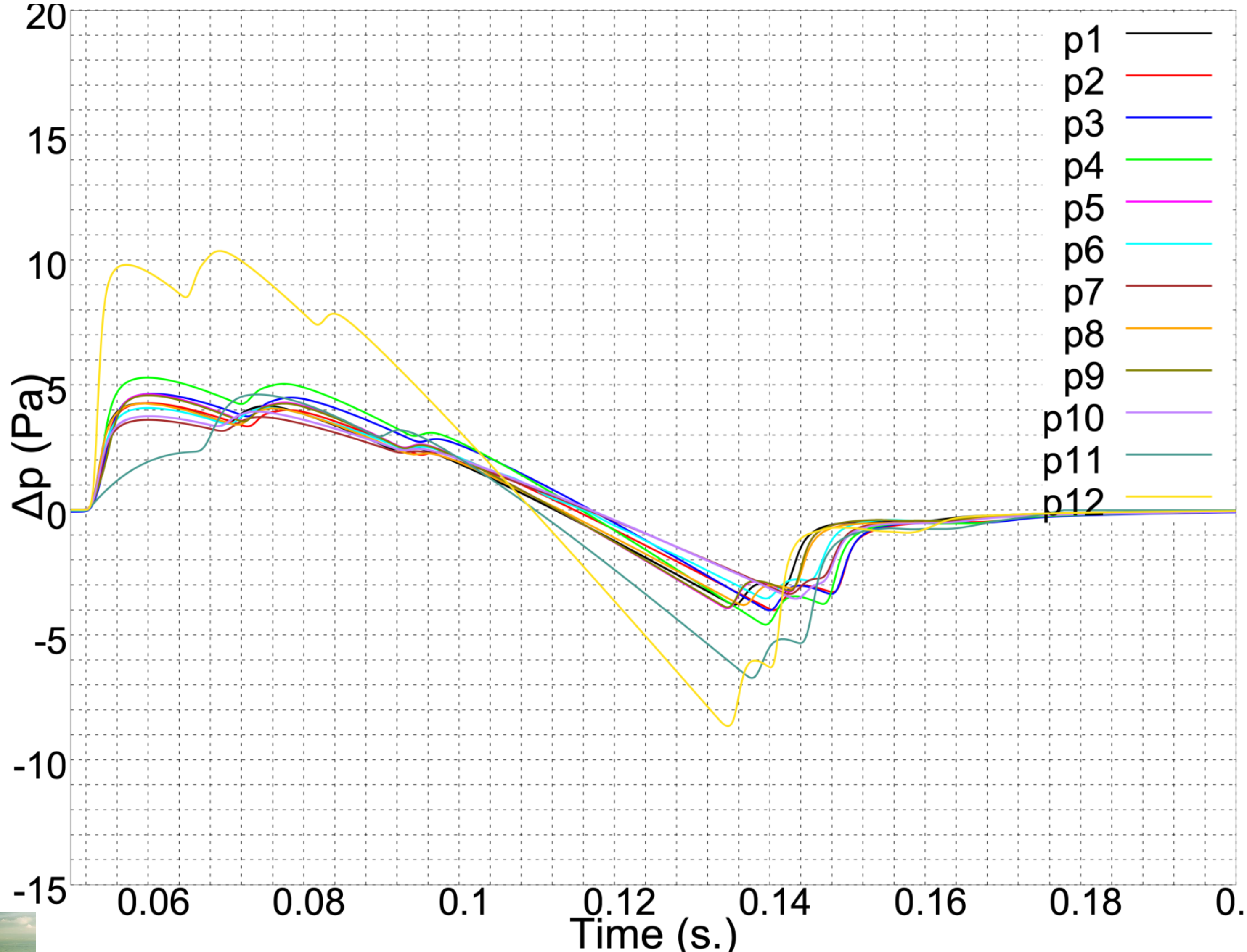

# Case2 – Required Case, Phi = -20.0



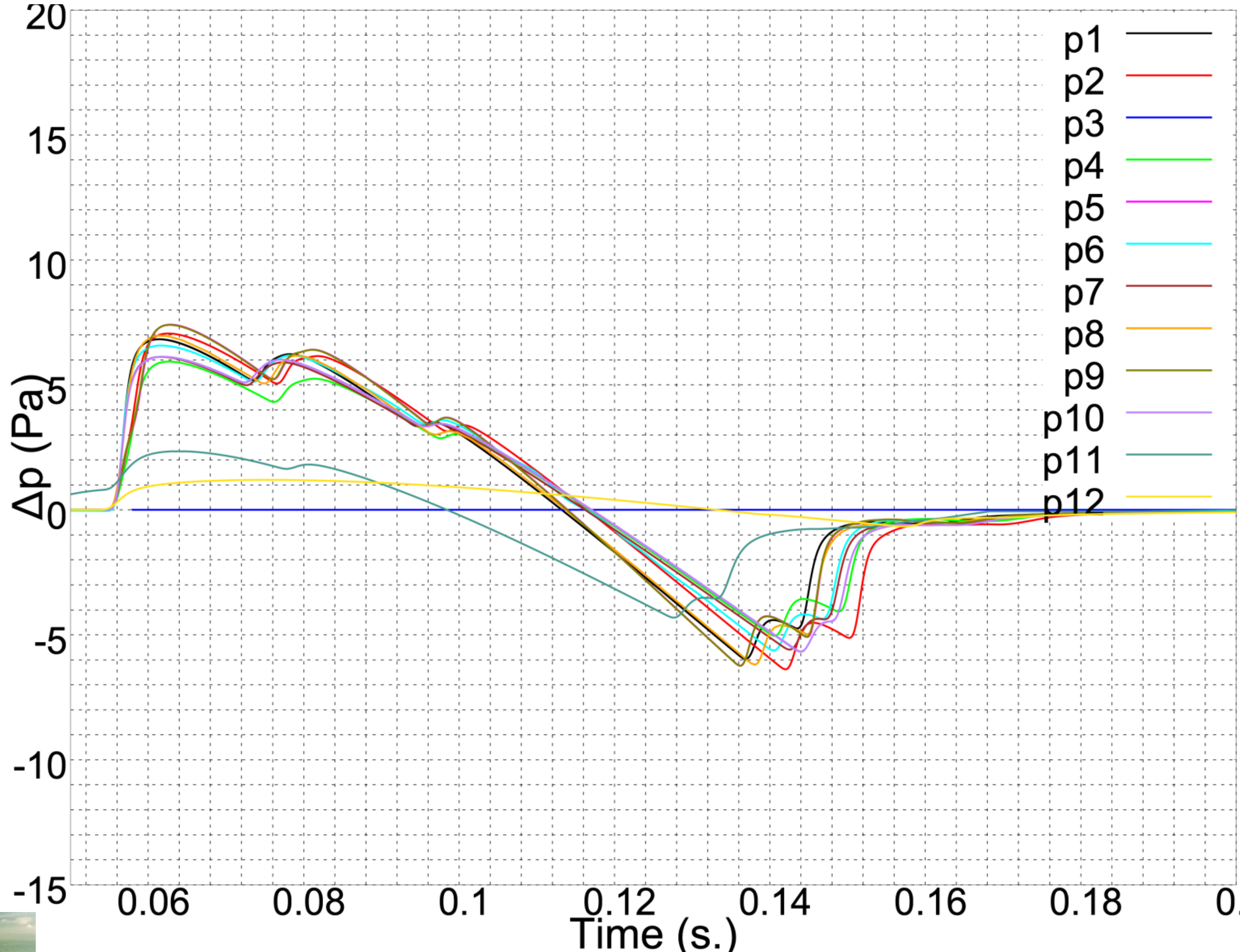

# Case2 – Required Case, Phi = -40.0



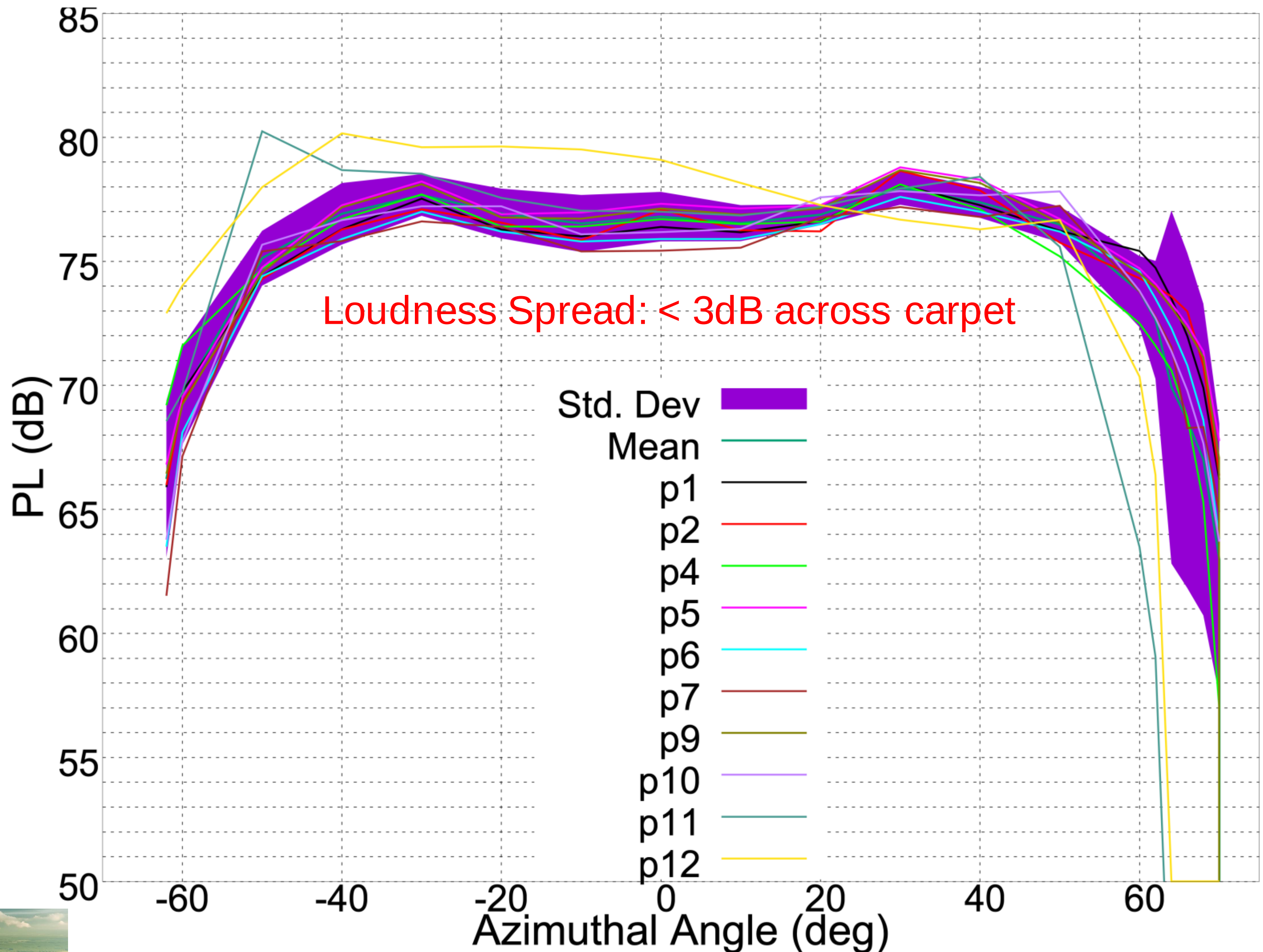

# Case2 – Required Case, Phi = -60.0



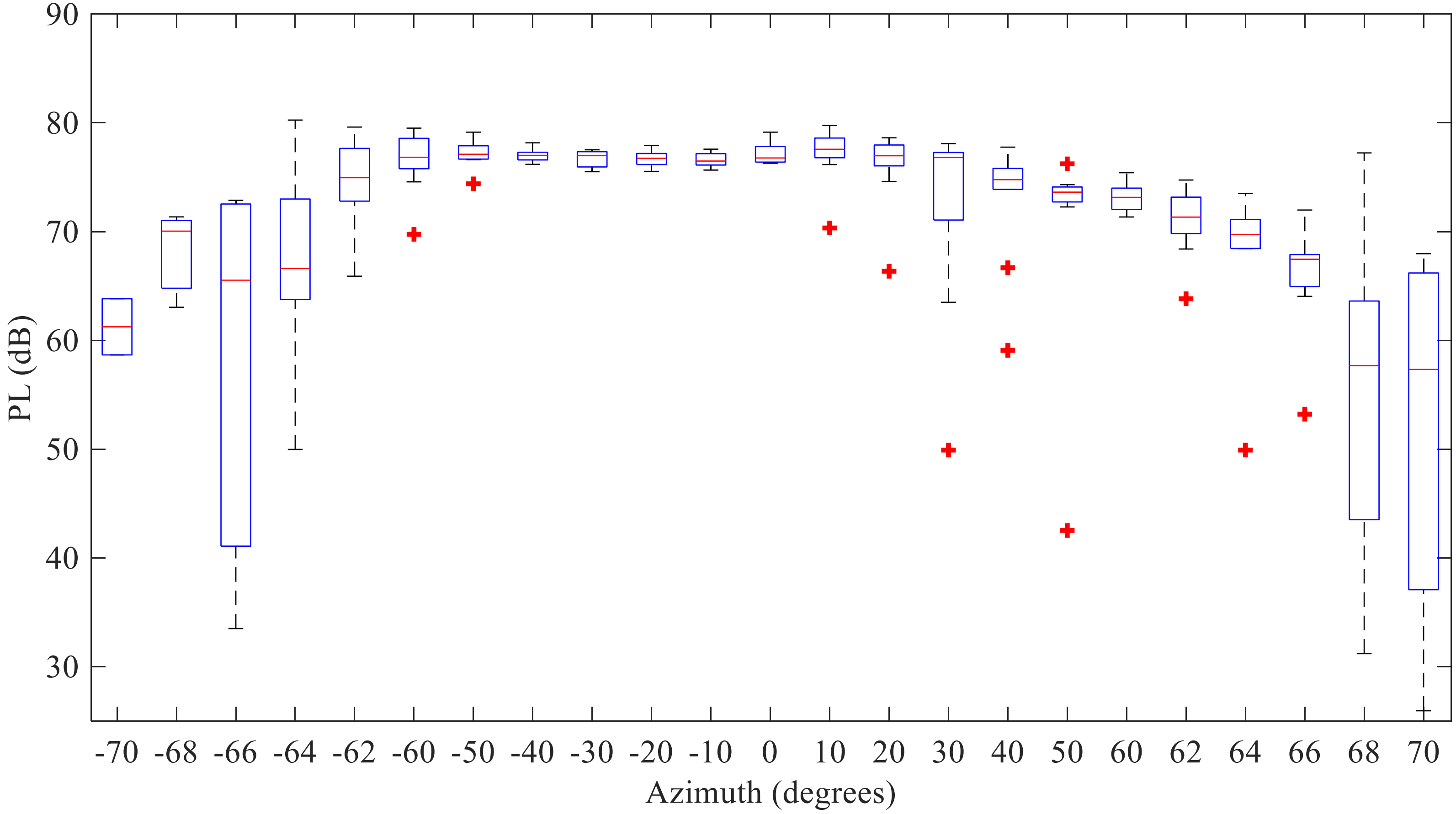

# Case2 – Required Case, Phi = 60.0



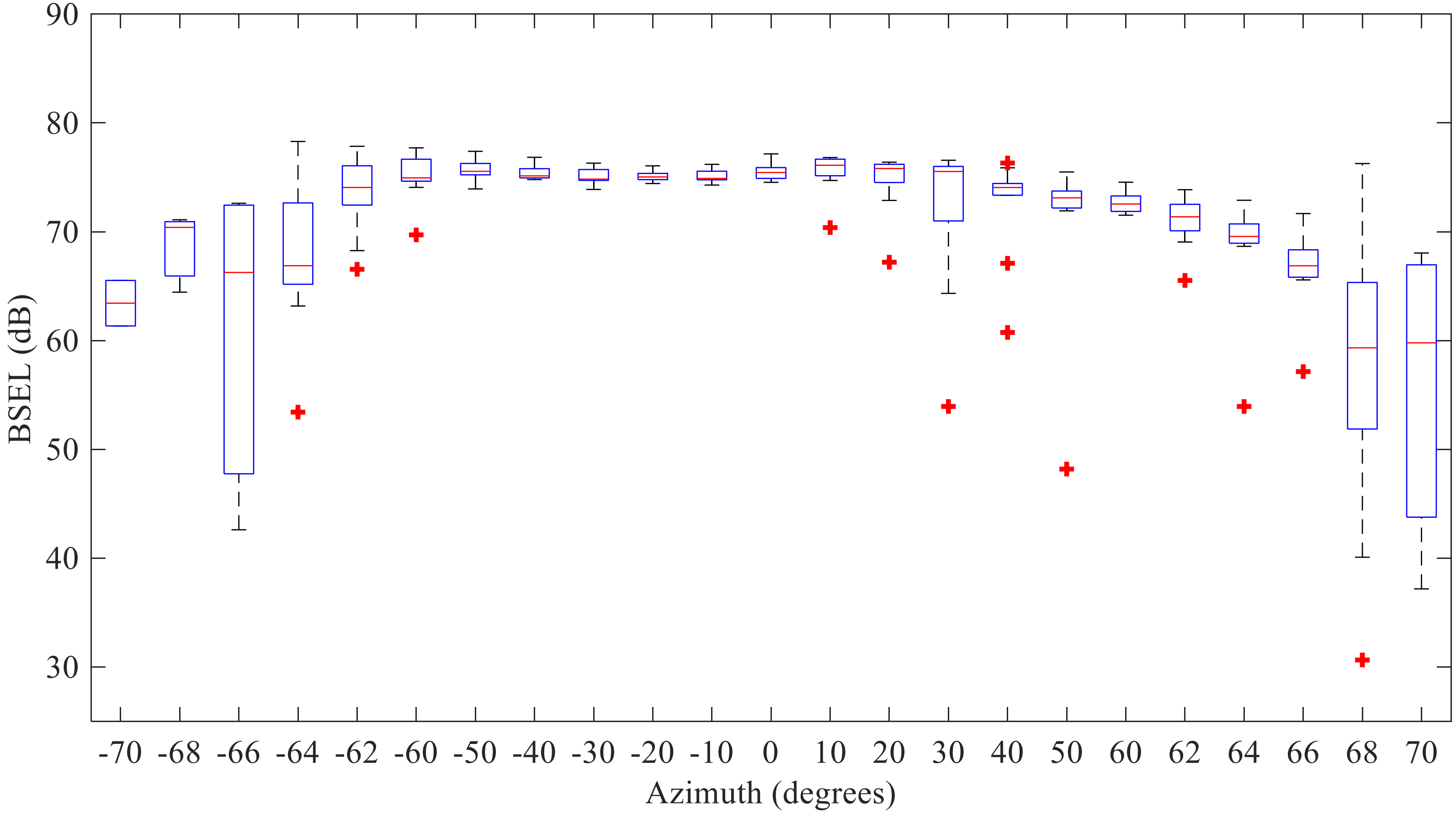

# Case2 – Carpet Loudness




# Case2 – Carpet Loudness (PL)




# Case2 – Carpet Loudness (BSEL)




# Summary

- Ray paths generally very consistent between different implementations
  - The cases where there are discrepancies also perhaps stem from improper conventions
- Most loudness predictions are tightly spaced across the primary carpet
- Spread increases as the predictions move off-track
  - Loudness predictions questionable near edges of the lateral carpet
  - Standard deviation between submissions increases away from under-track
- Significant spread in focus predictions
  - Most likely attributed to differences in input waveform computation

# Acknowledgments


- All participants
- NASA Commercial Supersonic Technology (CST) project
- Boom prediction workshop organizing committee and participants

# Next Steps

- Participant submission updates (10-FEB-2020)
- Please provide your presentations so we can post them to the LBPW server
- AVIATION Papers and AIAA Journal of Aircraft Special Section
    - Can provide ensemble data to authors for independent analysis, as requested

# Discussion

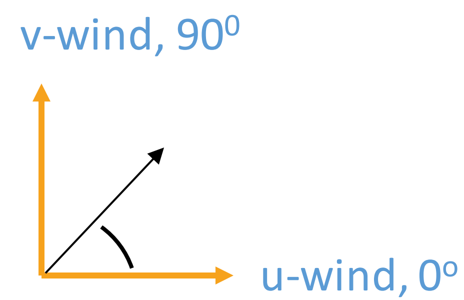
- Age parameter, Blokhintzev invariant
- Lateral cut-off analysis
- Loudness metrics recommendations: BSEL vs PL
- Atmospheric turbulence modeling
- More detailed focus boom analysis
- Vertical winds
- Secondary booms
- Mach cut-off

# SBPW3 Wind Conventions

- In the workshop atmospheric profiles, X-WIND corresponds to u-wind and Y-WIND corresponds to v-wind
- We following the convention of **Meteorological Vector Winds**

Example: Consider air particles moving from the south west to the north east represented by the black arrow ↗

**Meteorological Vector Winds**




$$\Theta_{met\ vect} = 45^o$$

| | |
|---|---|
| 0º | Positive u-wind: air particles moving from west to east |
| 90º | Positive v-wind: air particles moving from south to north |

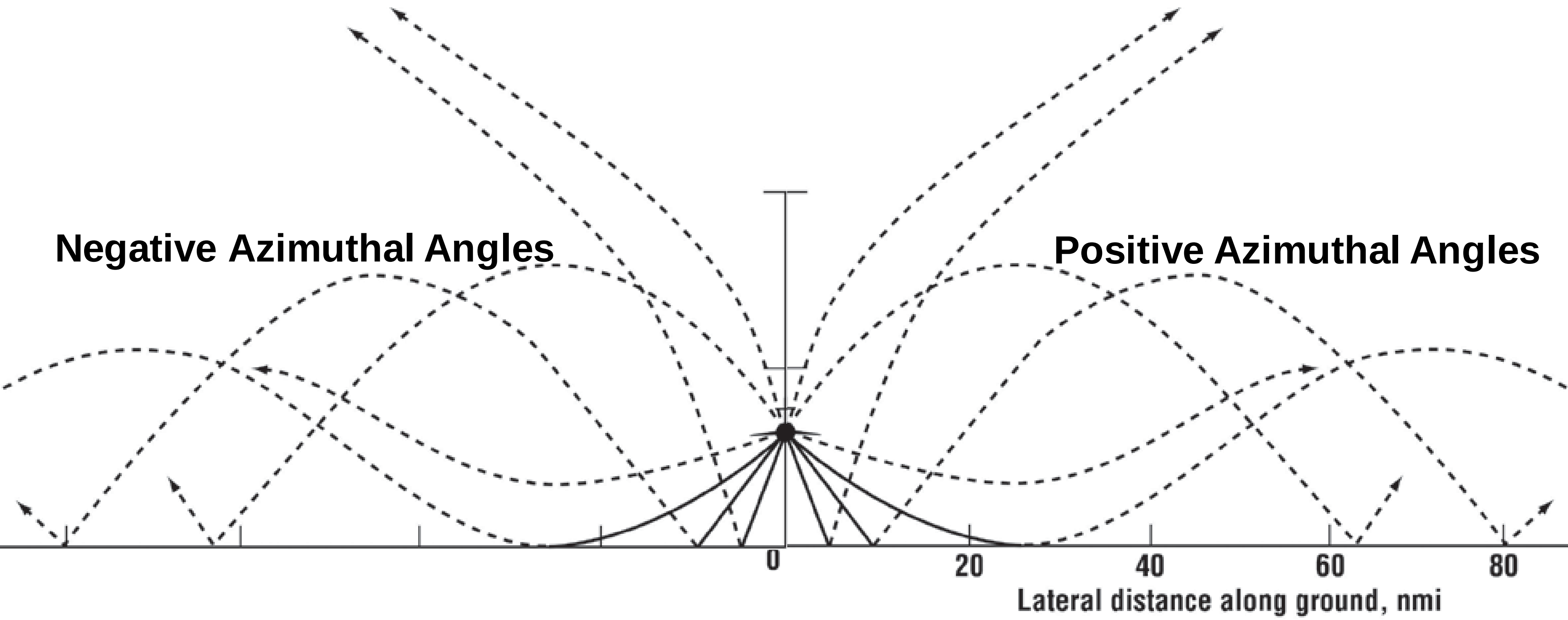
Modified from original developed by Will Doebler (william.j.doebler@nasa.gov)
NASA Langley Research Center

# SBPW3 Azimuthal Angle Conventions

Assume aircraft is flying into the plane of the paper

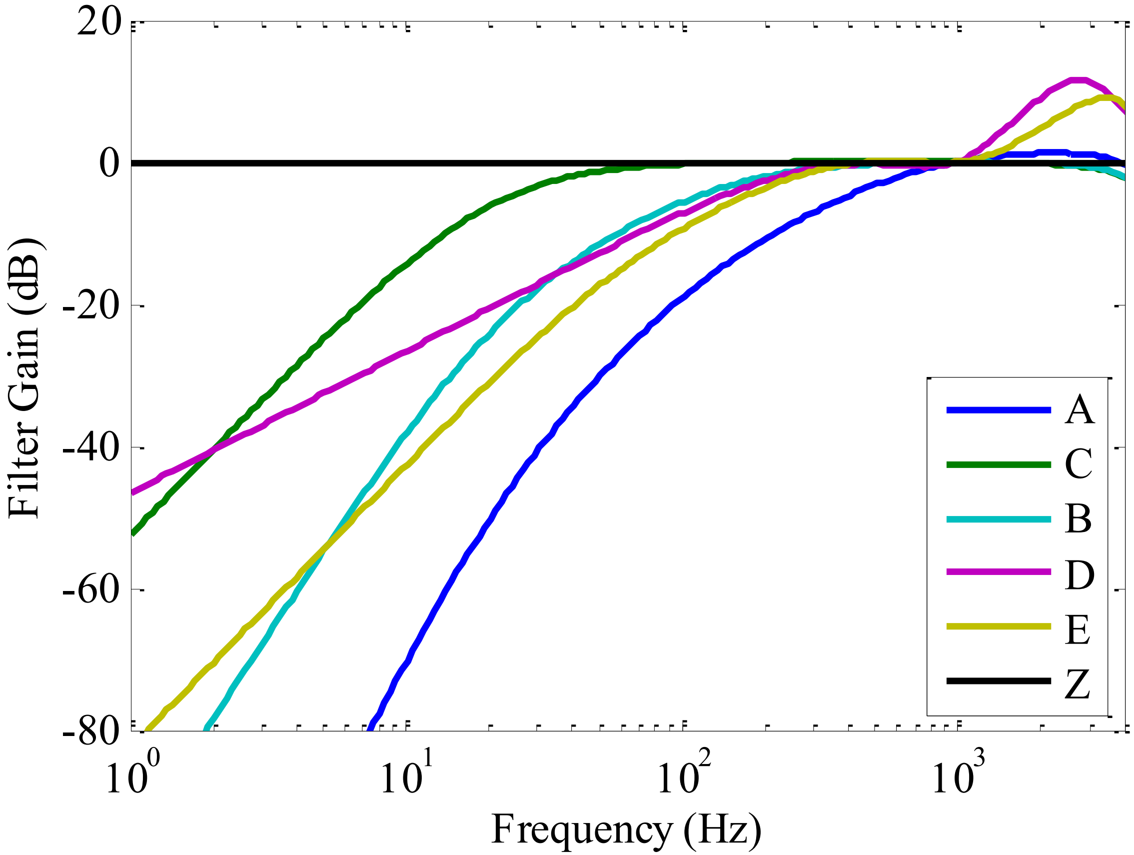
**Negative Azimuthal Angles**

**Positive Azimuthal Angles**



# Loudness Calculation

- Several weighting functions exist that can be applied to Sound Exposure Levels (SEL): A/B/C/D/E/Z weighting
- Each has different weighting at low frequencies, in the range important for sonic booms

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# 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

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)

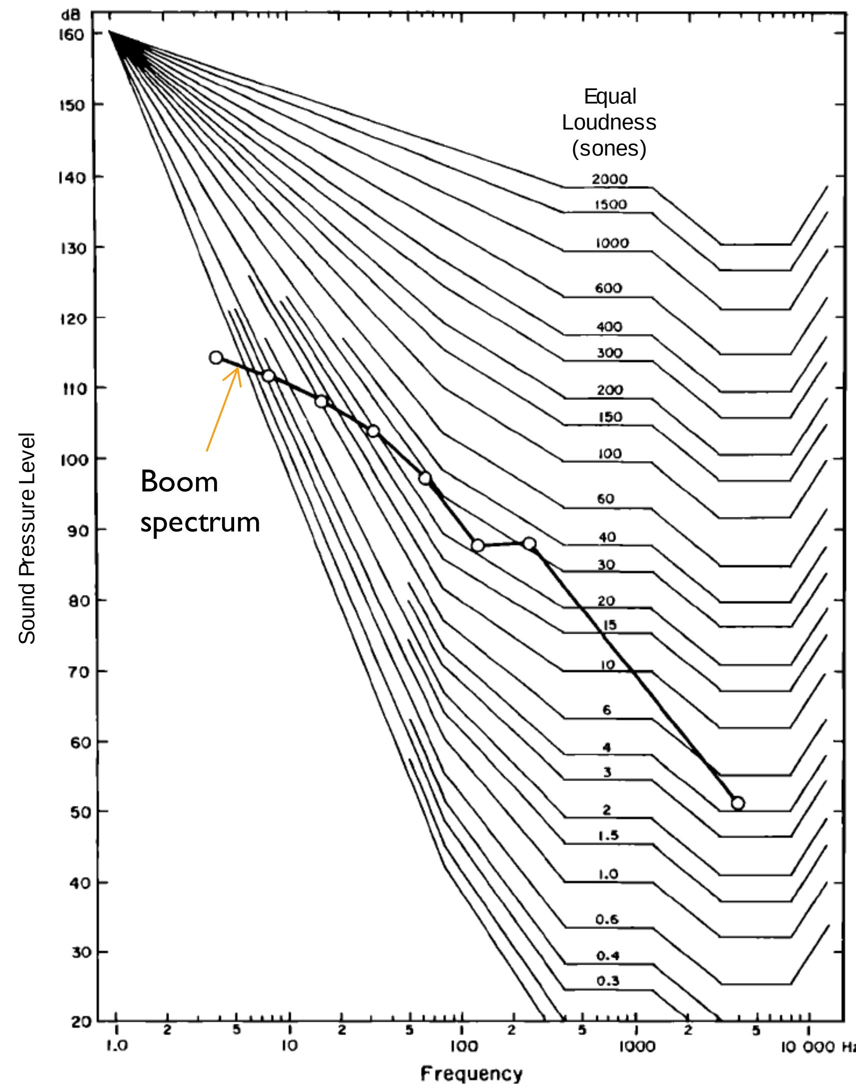
1. Calculate Sound Pressure Level of signal in 1/3-octave bands
2. Apply frequency weighting for loudness of individual bands
   - where loudness of 1 sone is referenced to 1/3-oct band of noise at 3150 Hz at 32 dB
3. Apply summation rule for total loudness

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

where
$S_t$ = total loudness
$S_m$ = loudness of loudest band
$\Sigma S$ = sum of loudnesses of all the bands
$F$ = fractional factor based on $S_m$

4. Convert to PL in dB

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

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