2nd Boom Prediction Workshop: Summary of Propagation Cases

Sriram K. Rallabhandi
Alexandra Loubeau

NASA Langley Research Center

Motivation

- Commercial supersonic overland flight is currently prohibited
  - Supersonic overland flight is an enabler for entry into new vehicle market
- Replacing the prohibition with a certification standard requires an international effort to quantify the accuracy and reliability of prediction methods
- Deficiencies in existing methods should be noted to focus research on addressing weaknesses

Motivation

- The focus today was on atmospheric propagation
- Explore the issues
- Impartially compare:
  - Ground signatures at several azimuthal angles
    - Including lateral cut-offs
    - Under measured atmospheric conditions including winds
  - Loudness metrics
  - Primary boom carpets

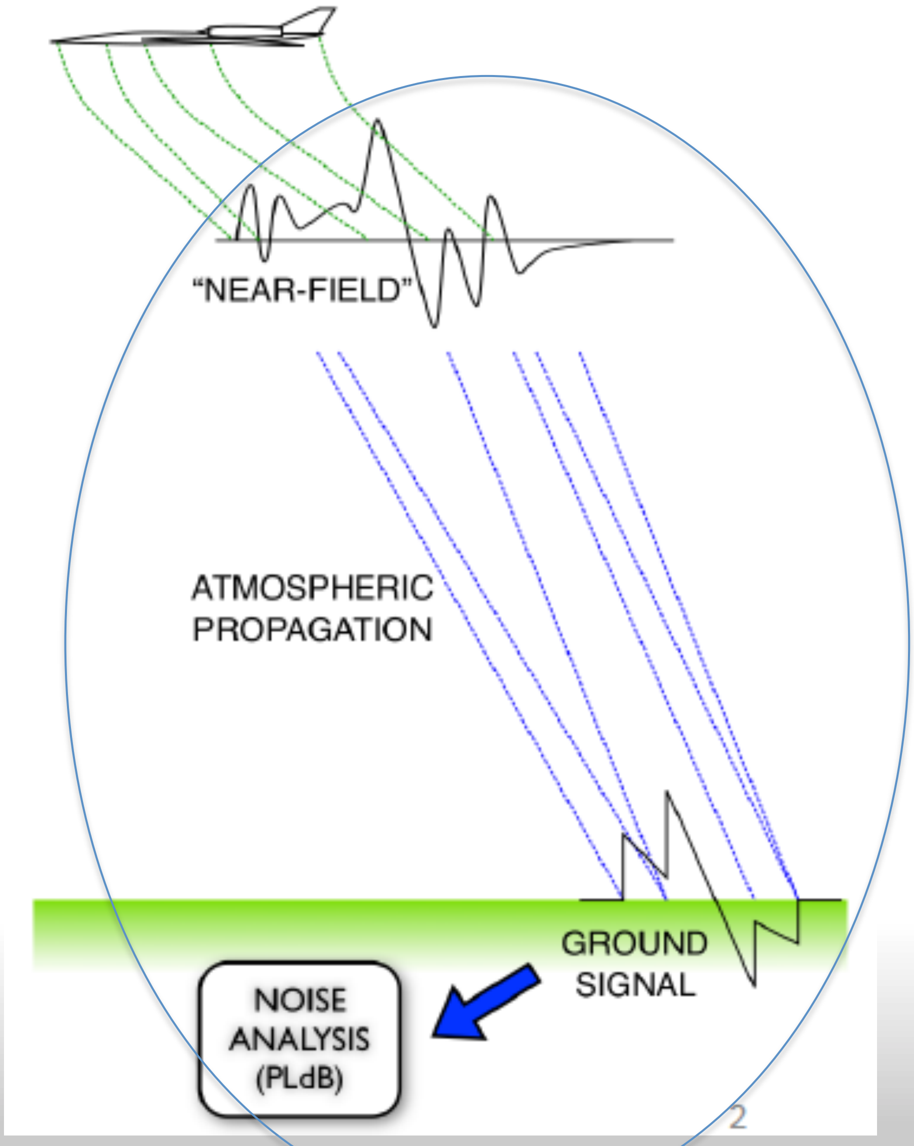


Figure Source: Mathias AIAA Paper

Sriram.Rallabhandi@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

Cases

- LM1021 – An optional cases from the 1st sonic boom prediction workshop
  - Ground signatures at -30^{o} , 0^{o} and 30^{o} roll angles for atmospheric Profile1 (Required)
  - All other data (Optional)
- Axi-symmetric body – A redesigned body of revolution that is close, in terms of the off-body pressure, to the C25F, a NASA low-Boom demonstration concept, for the near-field portion of this workshop
  - Ground signatures at -45^{o} , 0^{o} and 45^{o} roll angles for atmospheric Profile3 (Required)
  - All other data (Optional)

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
- Plotted
- Contacted participants for clarification/update when
  - Significant or unexpected differences between submissions was observed in
    - Ground signatures
    - Loudness metrics etc.
  - Data missing

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)

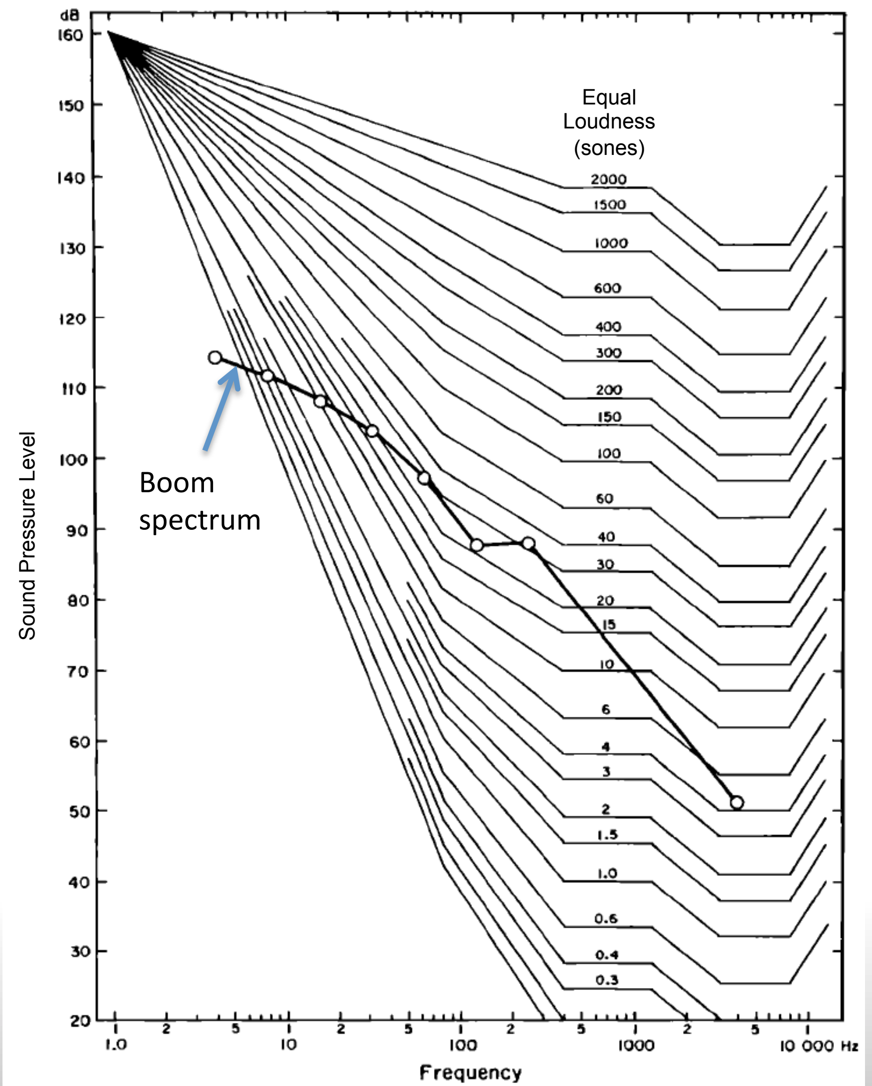
1. Calculate Sound Pressure Level of signal in 1/3-octave bands
2. Apply frequency weighting for loudness of individual bands
   - where loudness of 1 sone is referenced to 1/3-oct band of noise at 3150 Hz at 32 dB
3. Apply summation rule for total loudness

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

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

4. Convert to PL in dB

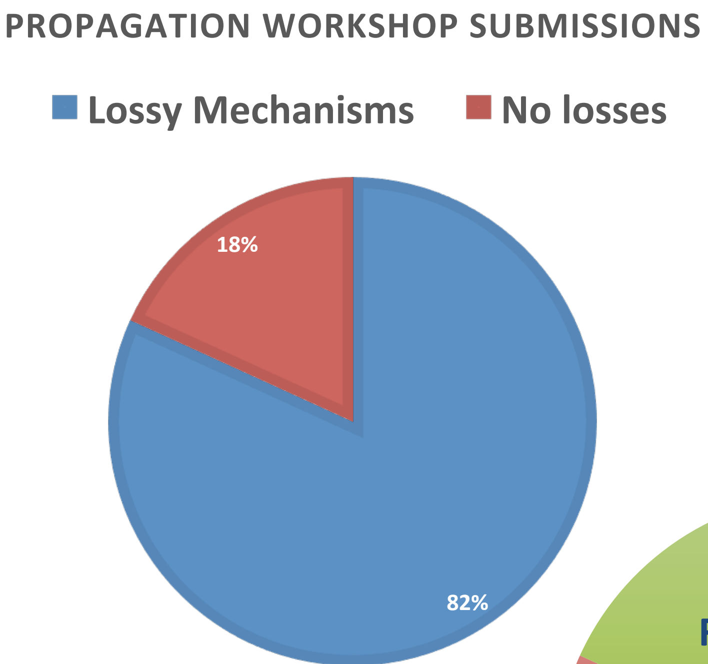
$$PL = 32 + 9\log_2(S_t)$$

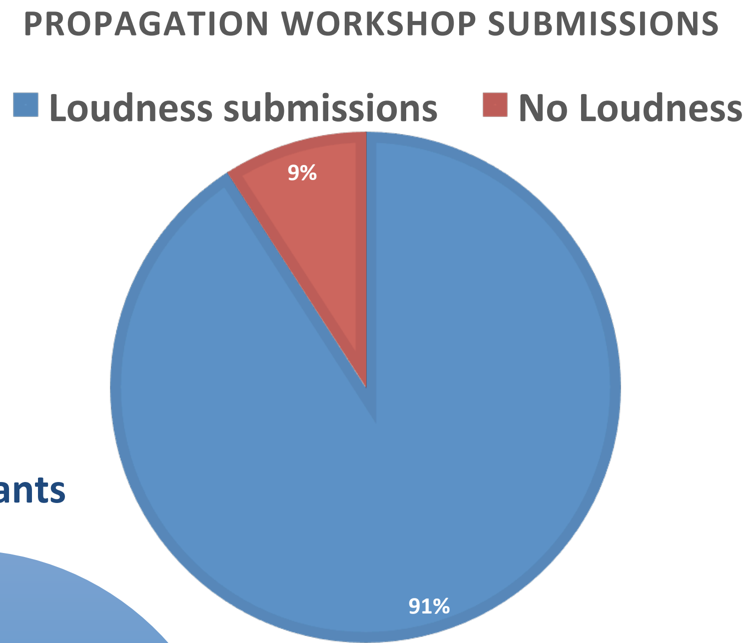


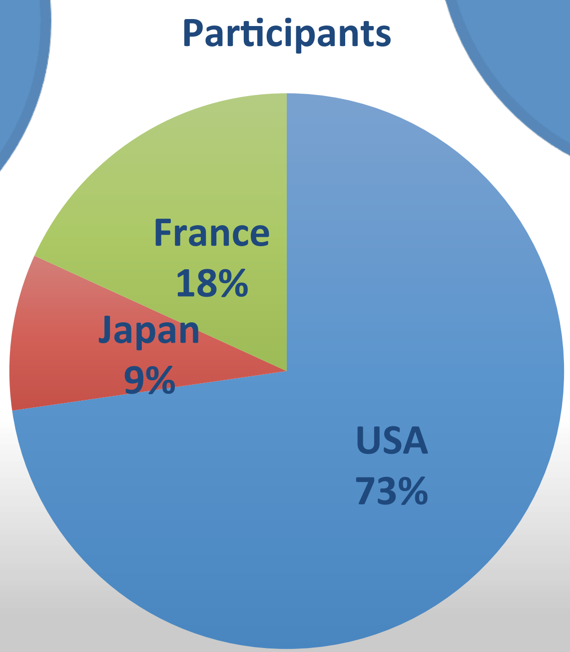
S. S. Stevens. Perceived level of noise by Mark VII and decibels (E). J. Acoust. Soc. Am., 51(2):575–601, 1972.

Submissions

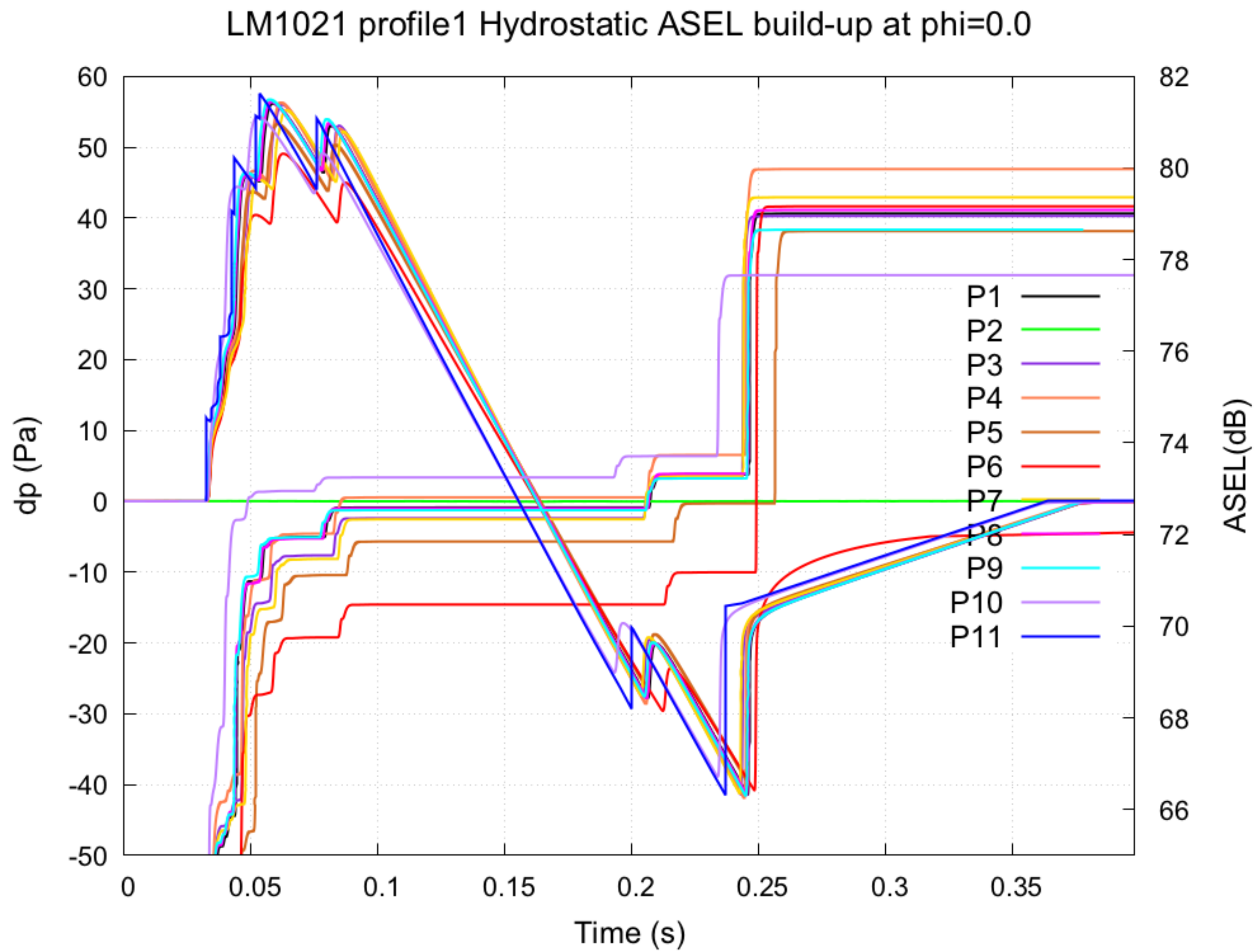
- 11 separate submissions: P1 – P11



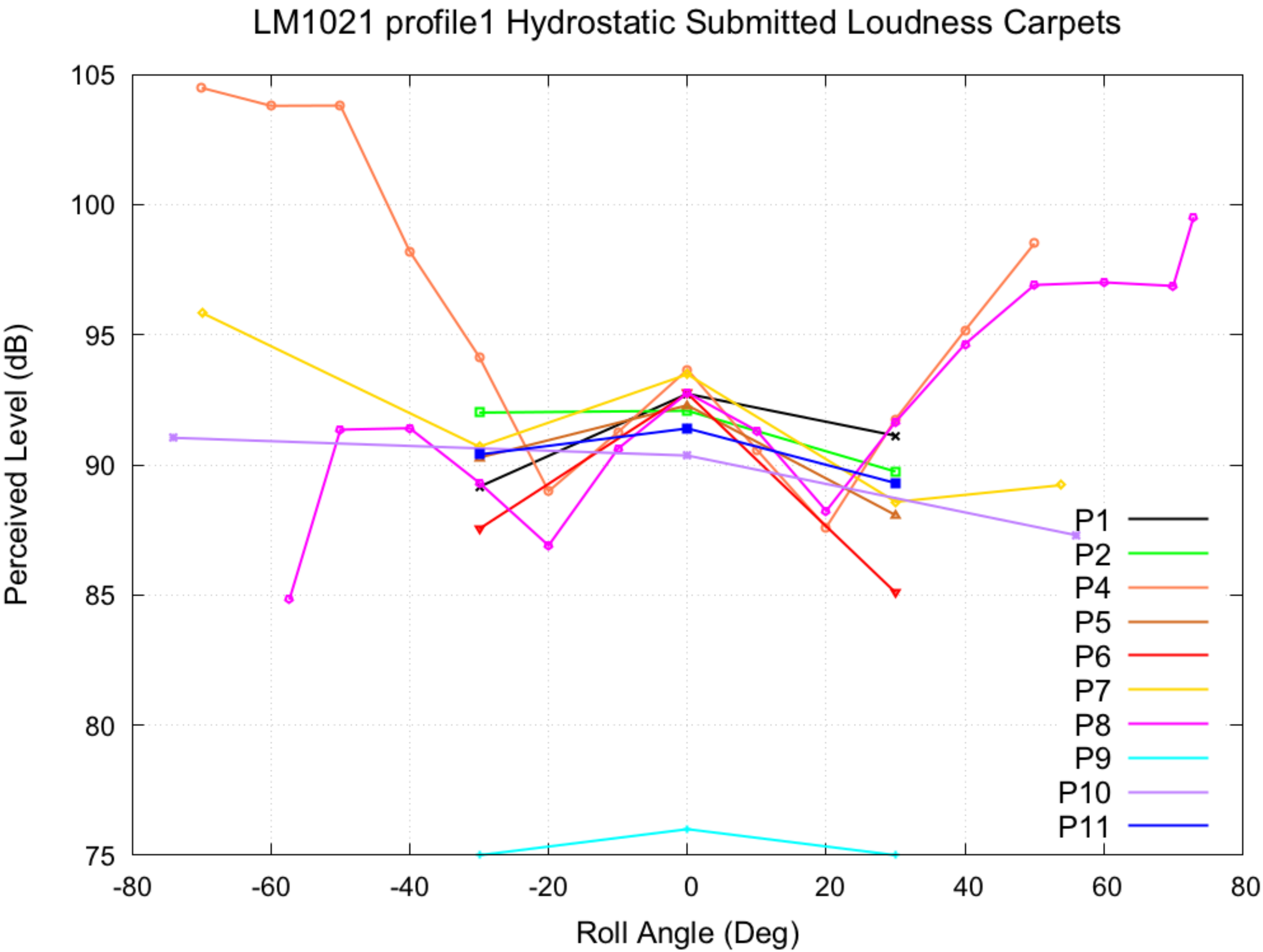




Sriram.Rallabhandi@nasa.gov

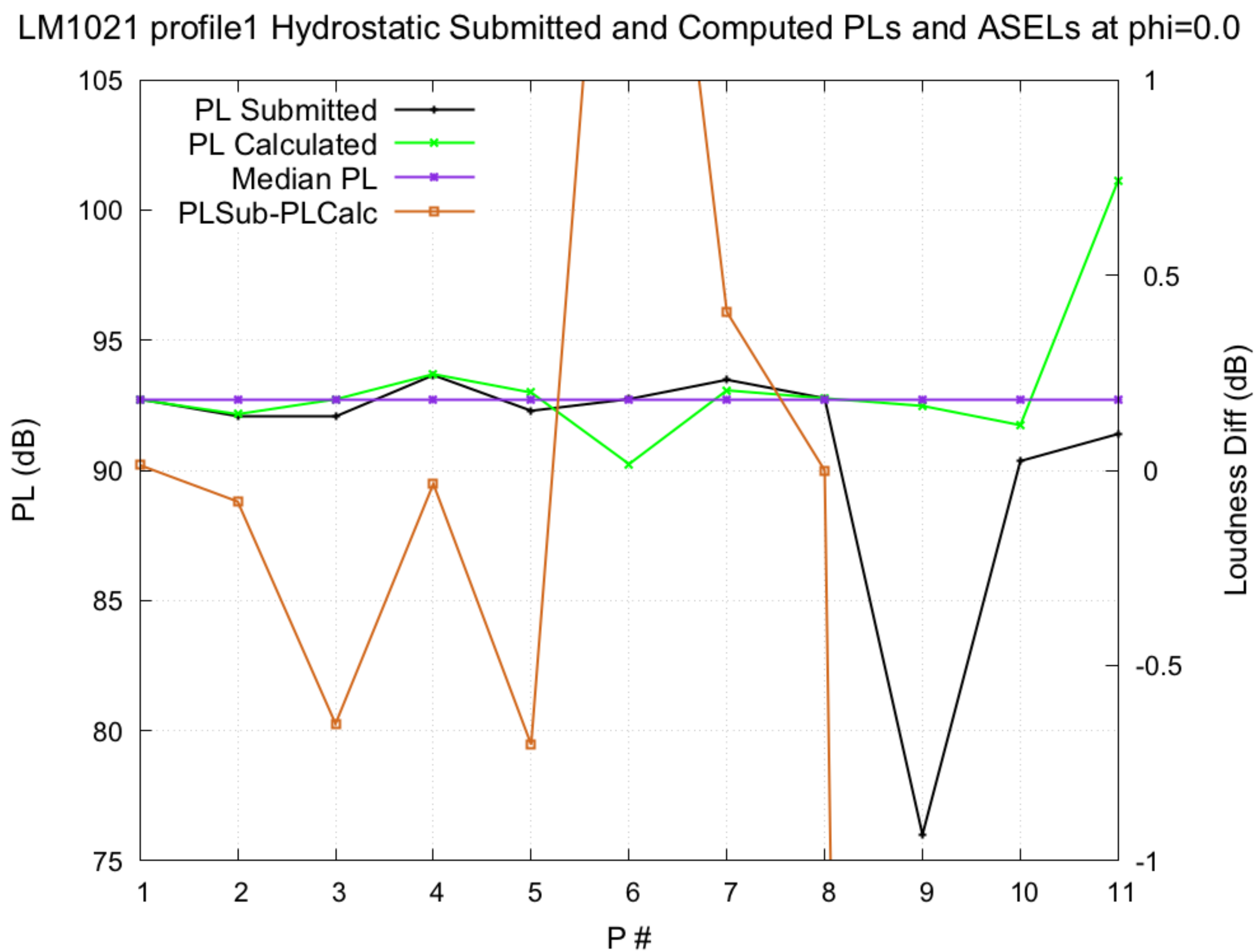


LM1021 profile1 Hydrostatic ASEL build-up at phi=0.0
dp (Pa)
ASEL(dB)
Time (s)
60
50
40
30
20
10
0
-10
-20
-30
-40
-50
82
80
78
76
74
72
70
68
66
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11



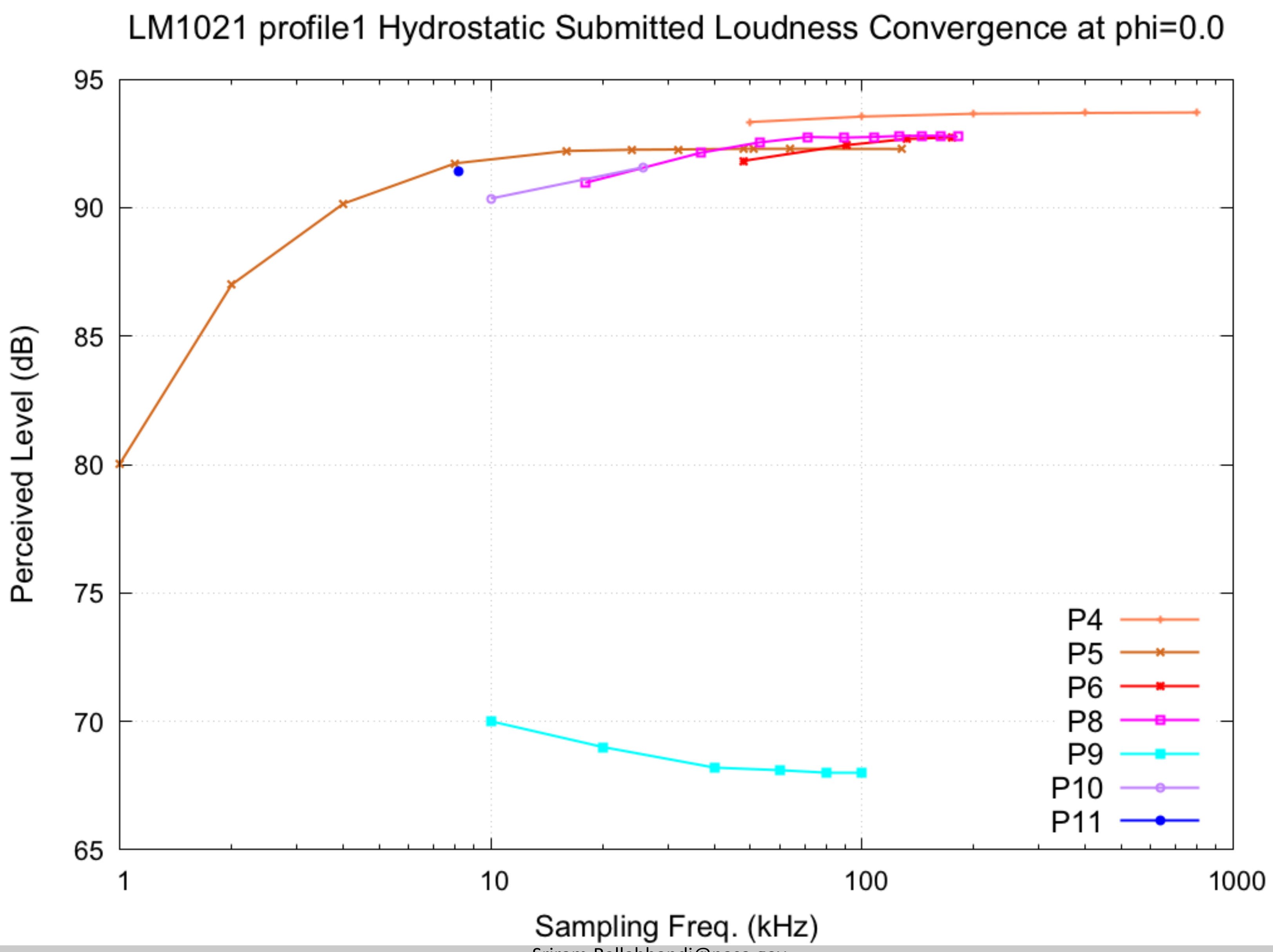
LM1021 profile1 Hydrostatic Submitted Loudness Carpets
Perceived Level (dB)
Roll Angle (Deg)
105
100
95
90
85
80
75
-80
-60
-40
-20
0
20
40
60
80
P1
P2
P4
P5
P6
P7
P8
P9
P10
P11

LM1021 – Profile1, Hydrostatic, Phi = 0˚

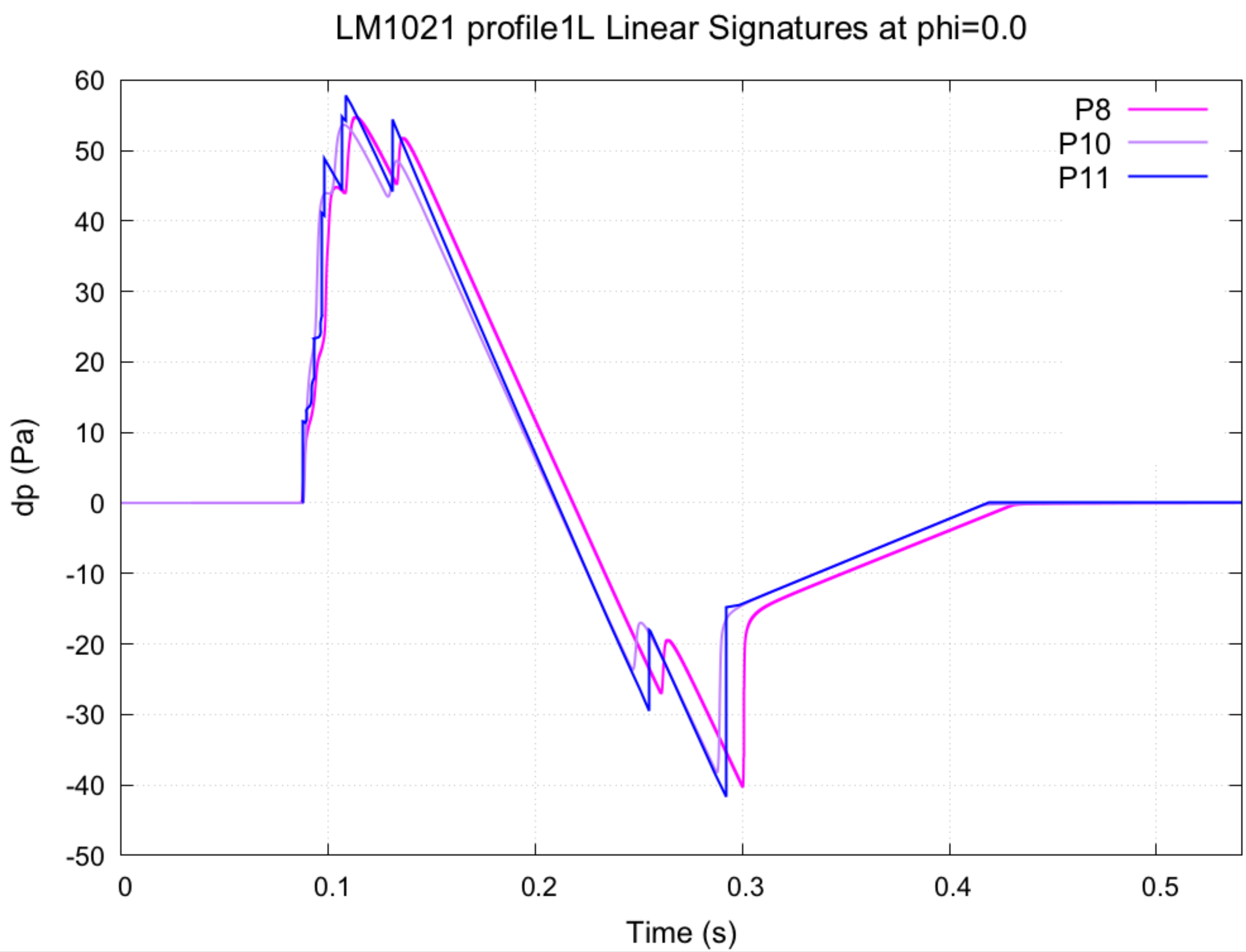


Sriram.Rallabhandi@nasa.gov

LM1021 – Profile1, Hydrostatic, Phi = 0°

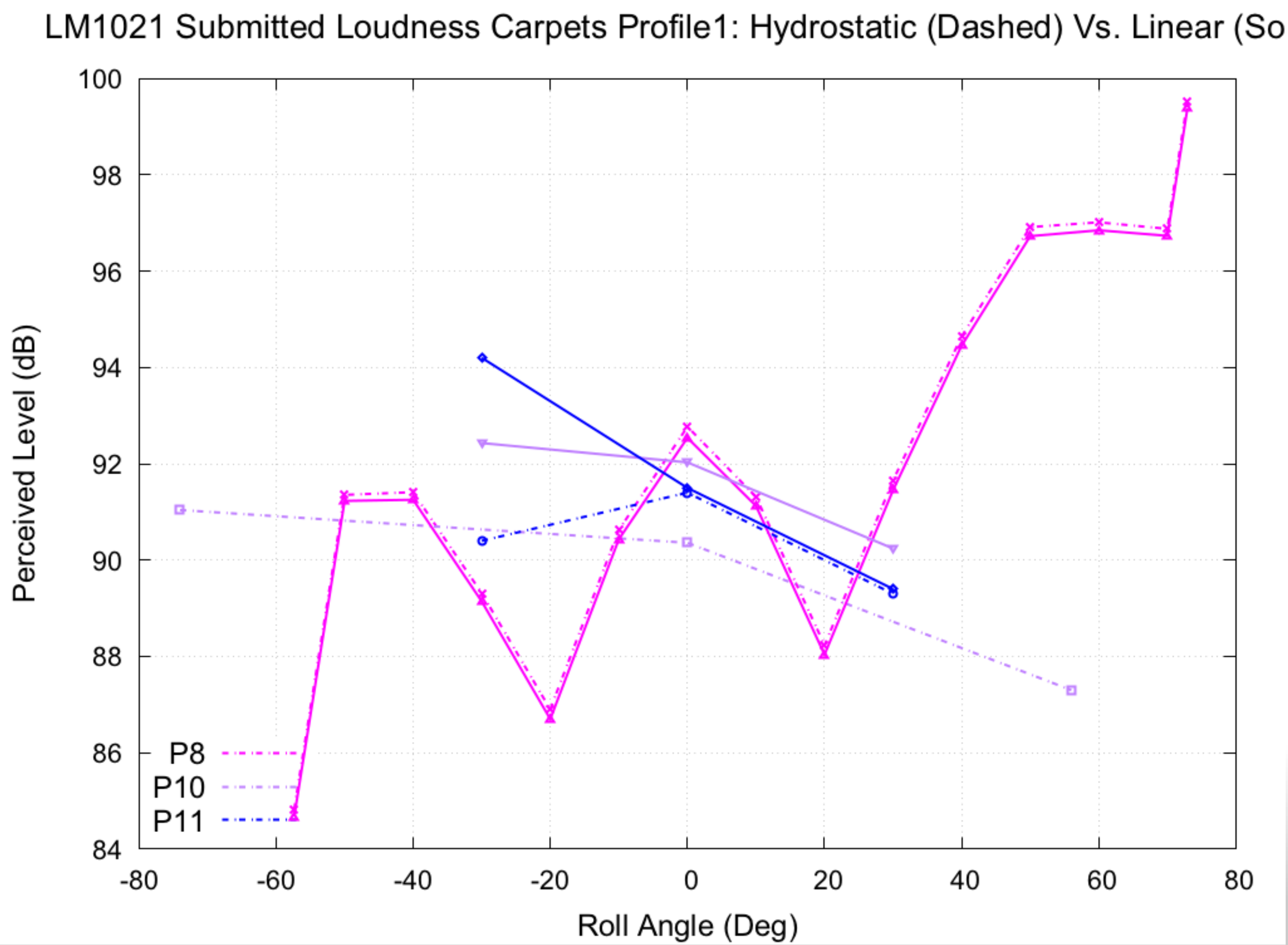


LM1021 – Profile1, Linear, Phi = 0°



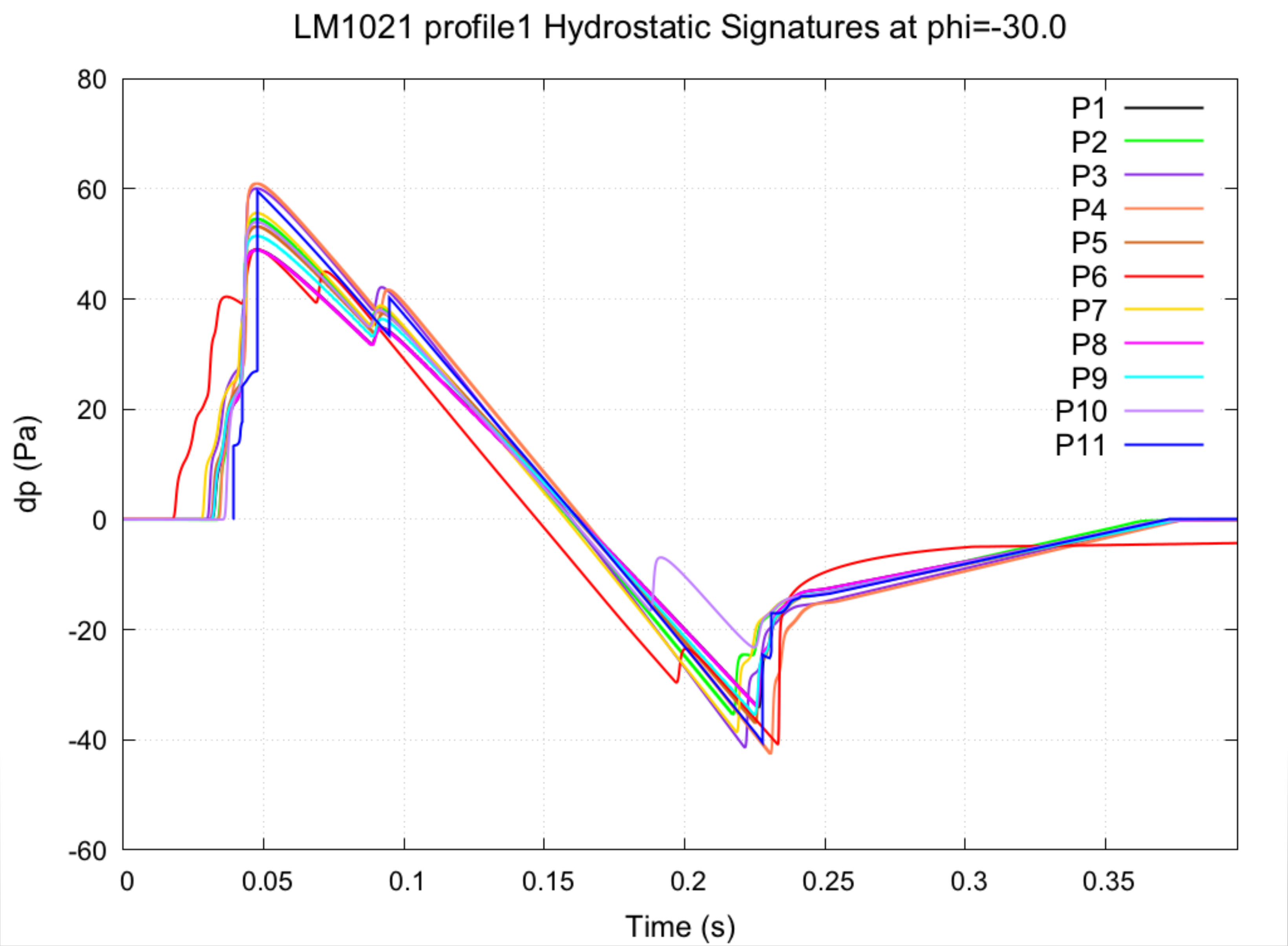
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile1, Linear, Carpet PL

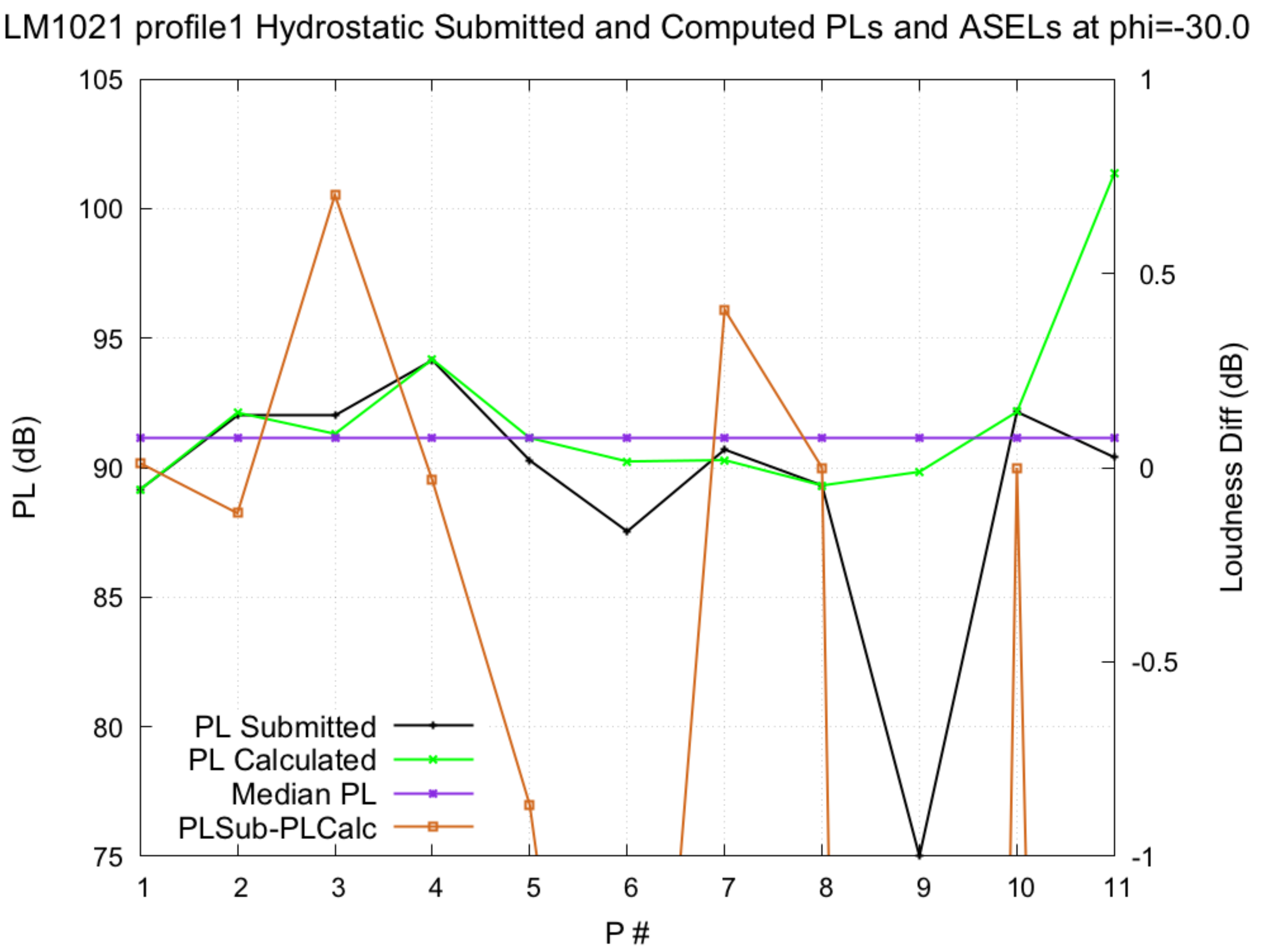


Sriram.Rallabhandi@nasa.gov

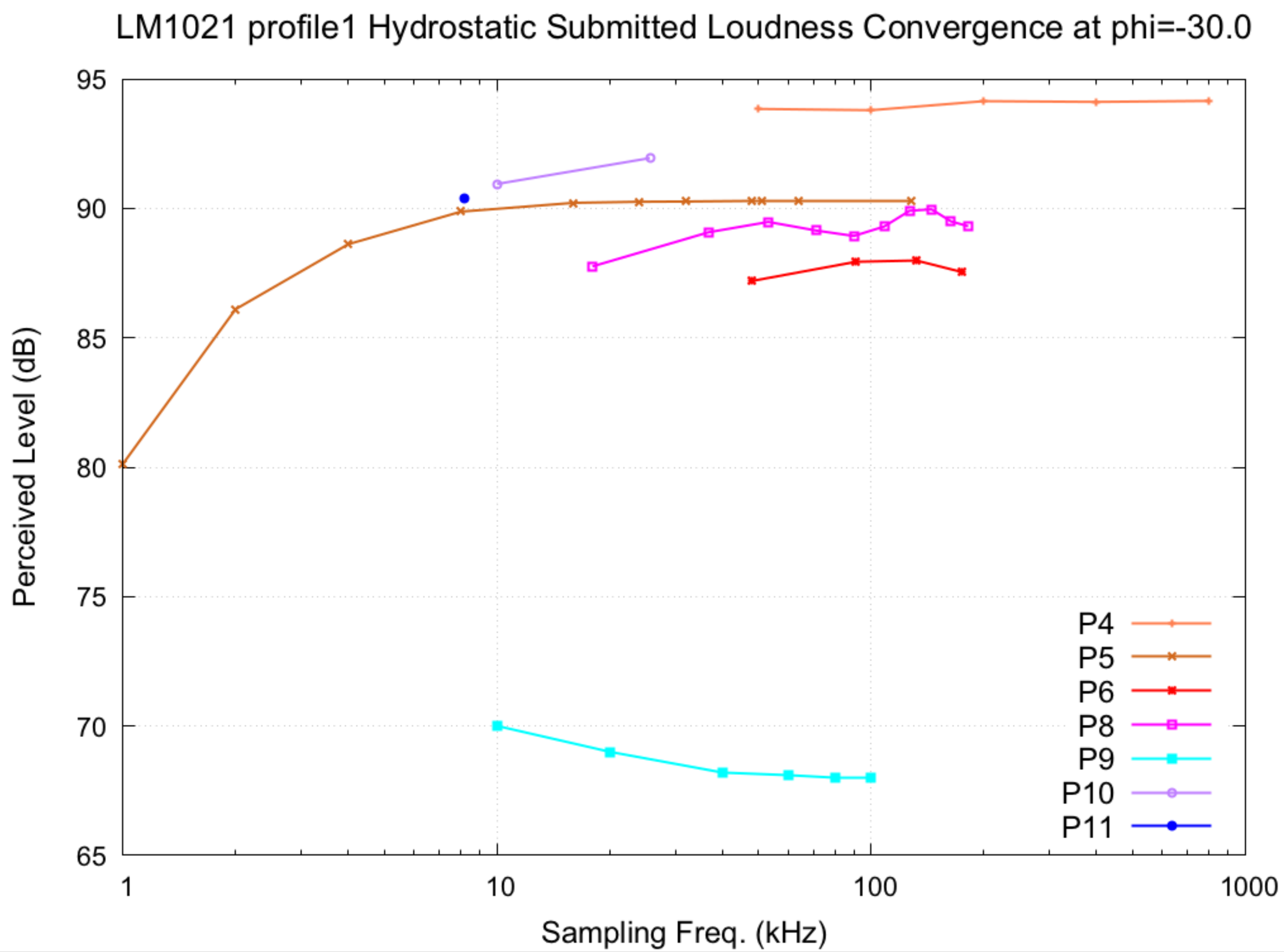
LM1021 – Profile1, Hydrostatic, Phi = -30°



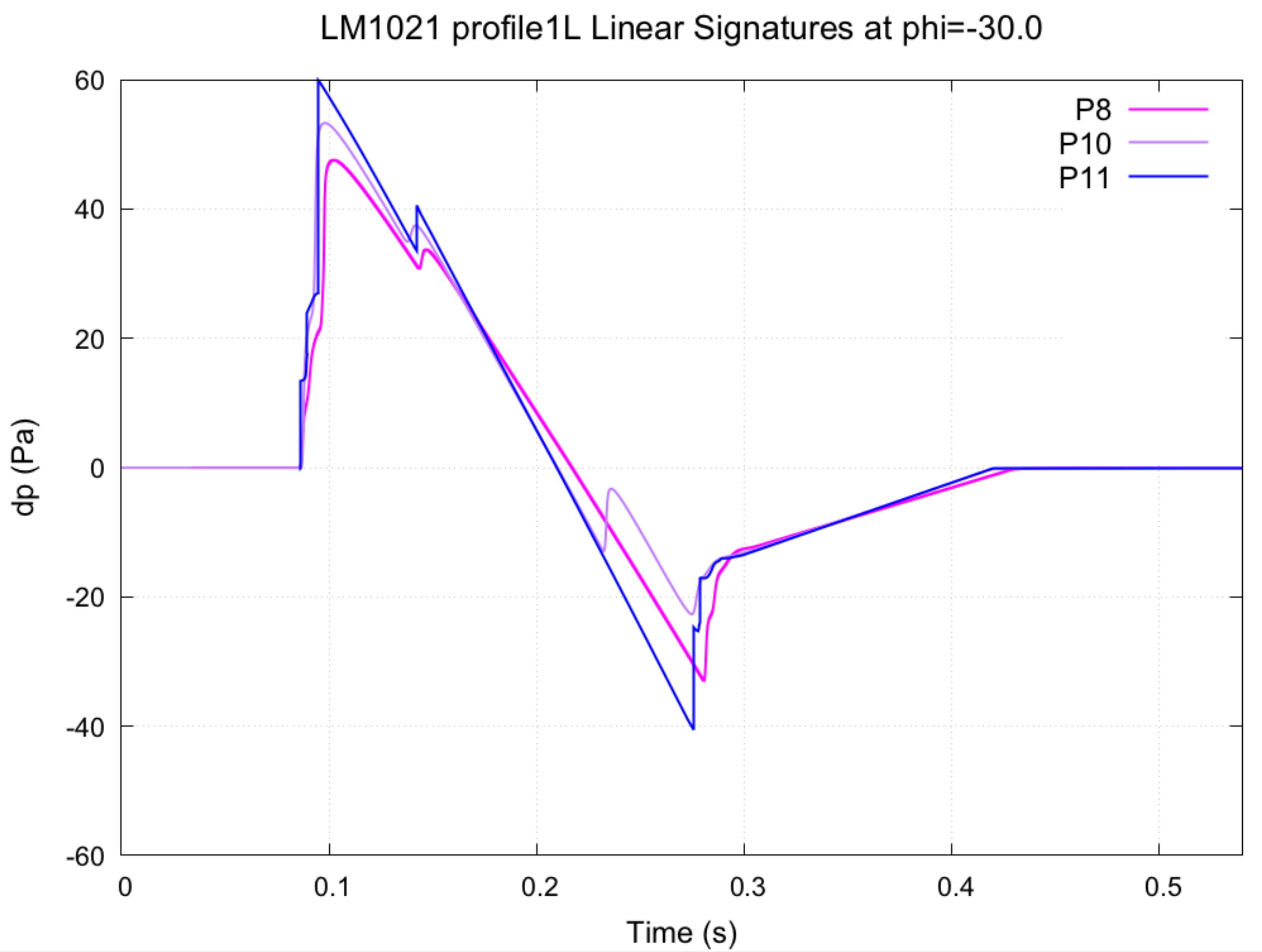
LM1021 – Profile1, Hydrostatic, Phi = -30˚



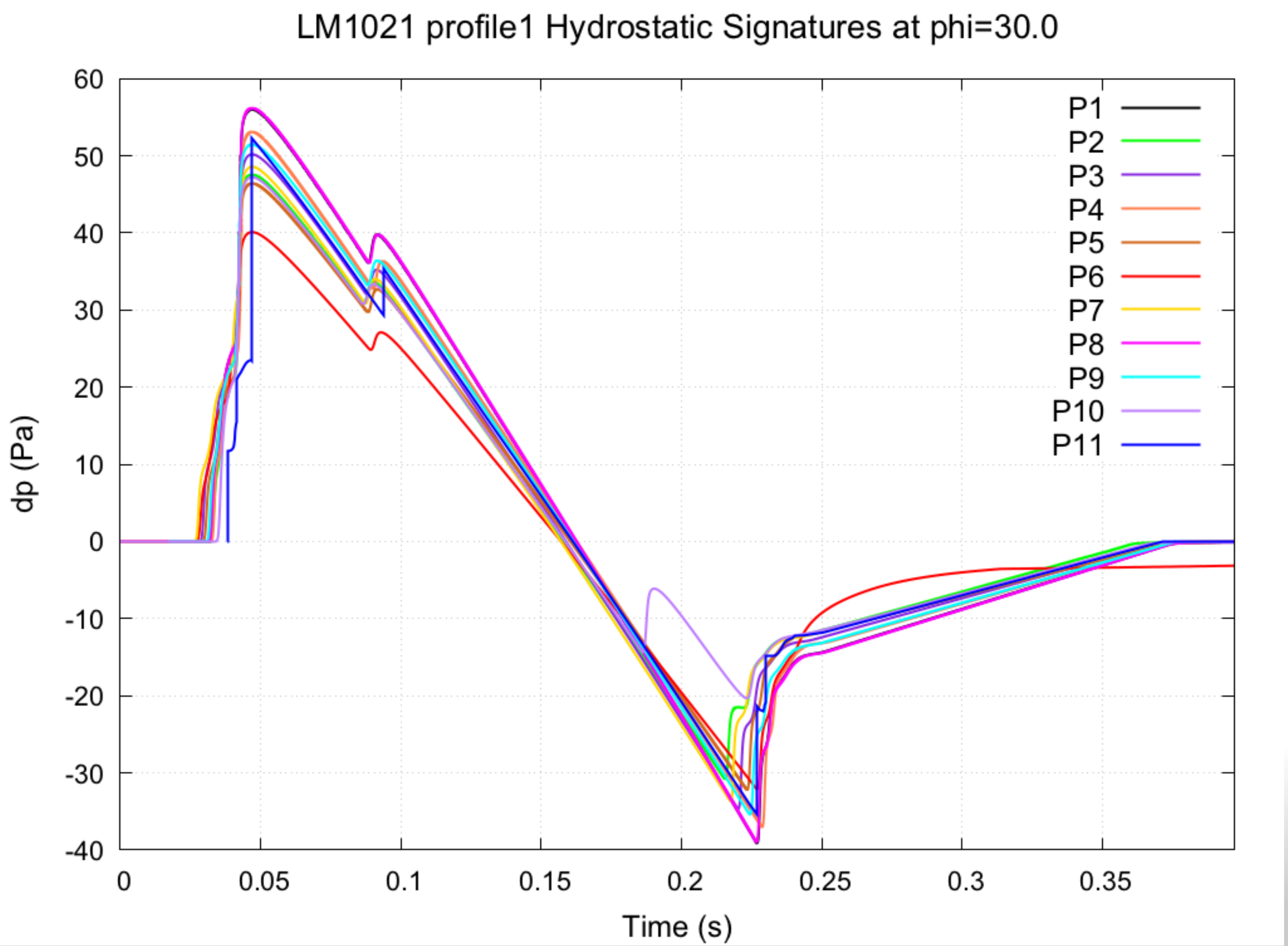
LM1021 – Profile1, Hydrostatic, Phi = -30˚



LM1021 – Profile1, Linear, Phi = -30°

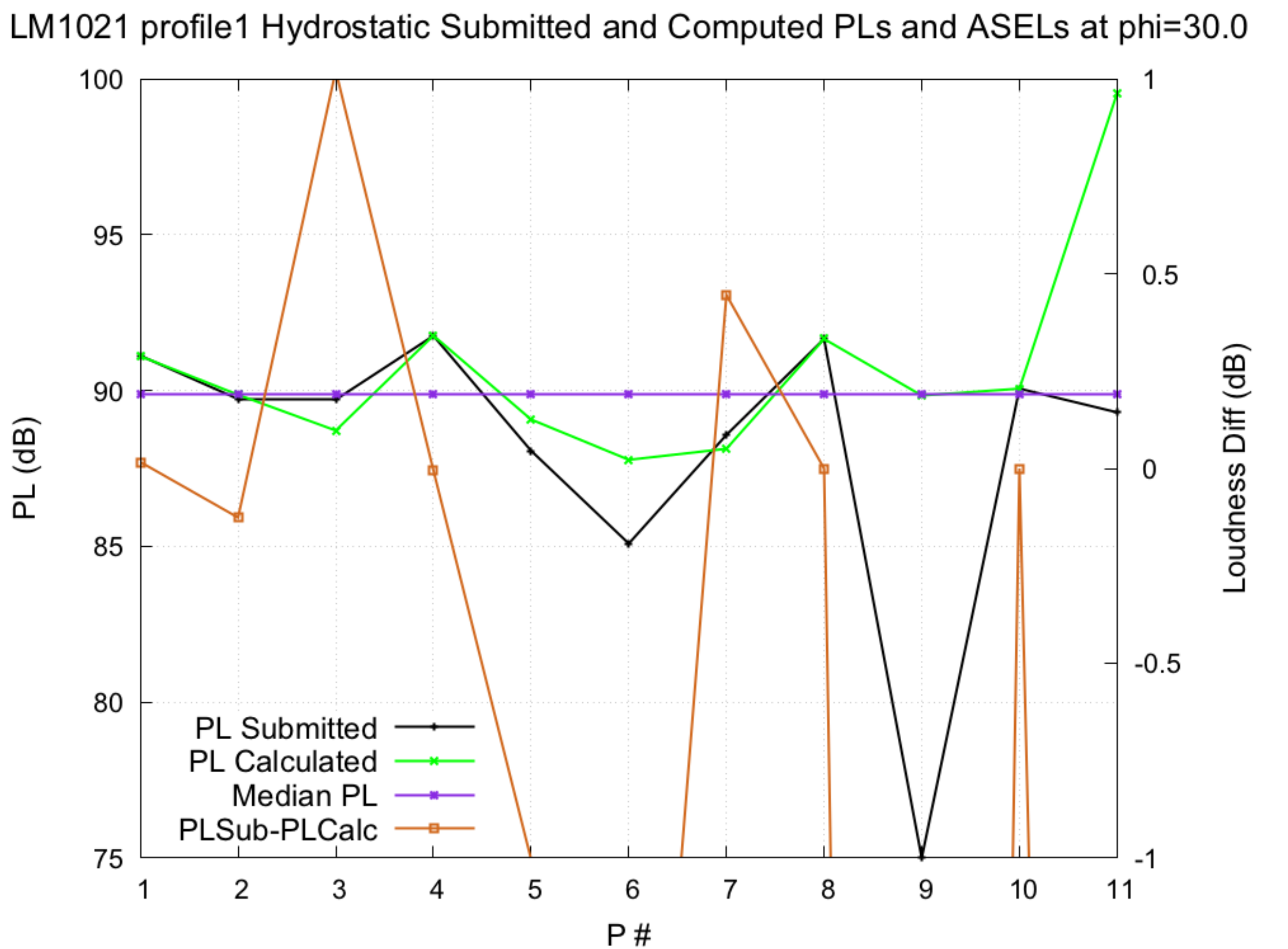


LM1021 – Profile1, Hydrostatic, Phi = 30˚

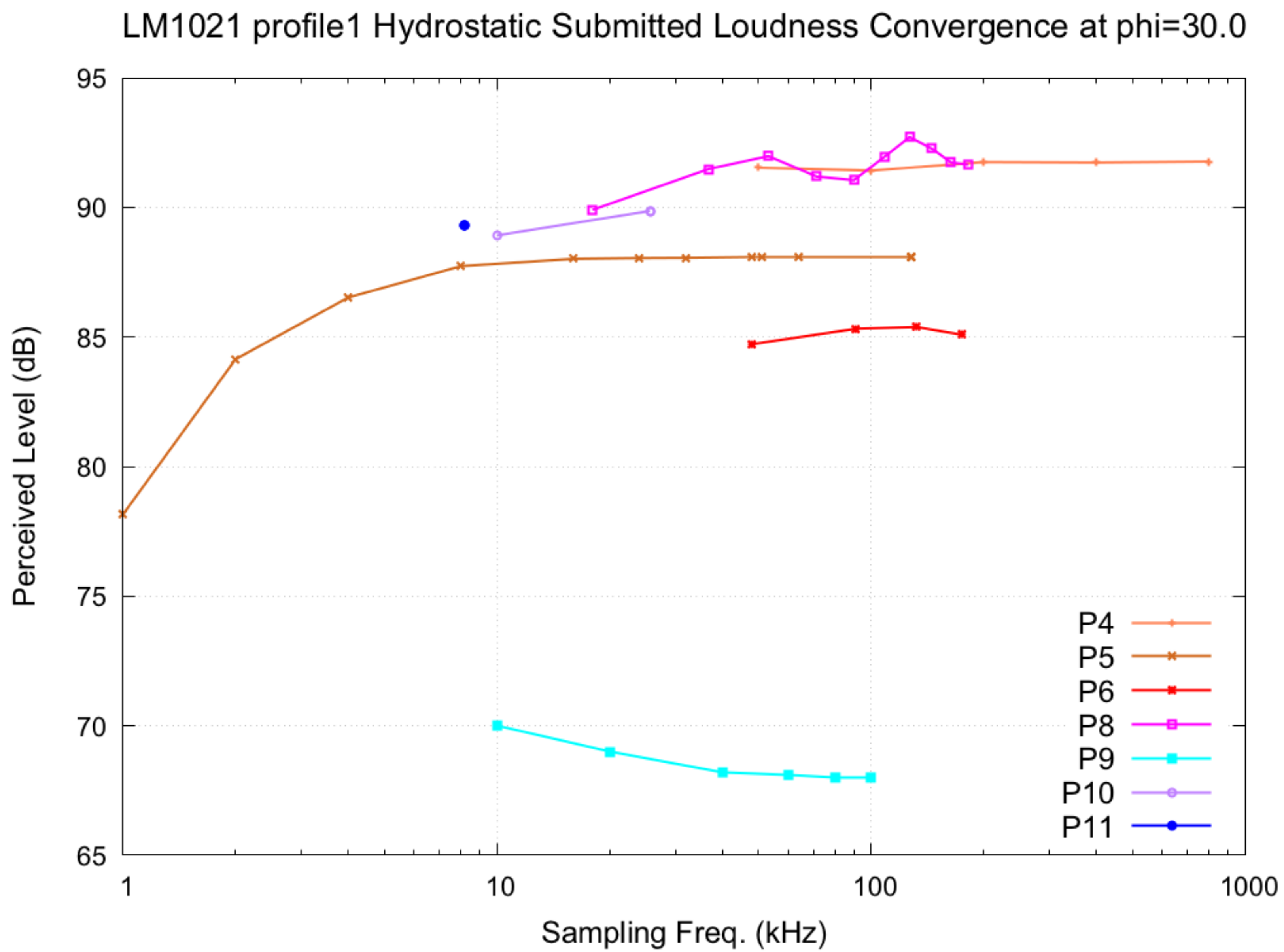


Sriram.Rallabhandi@nasa.gov

LM1021 – Profile1, Hydrostatic, Phi = 30˚

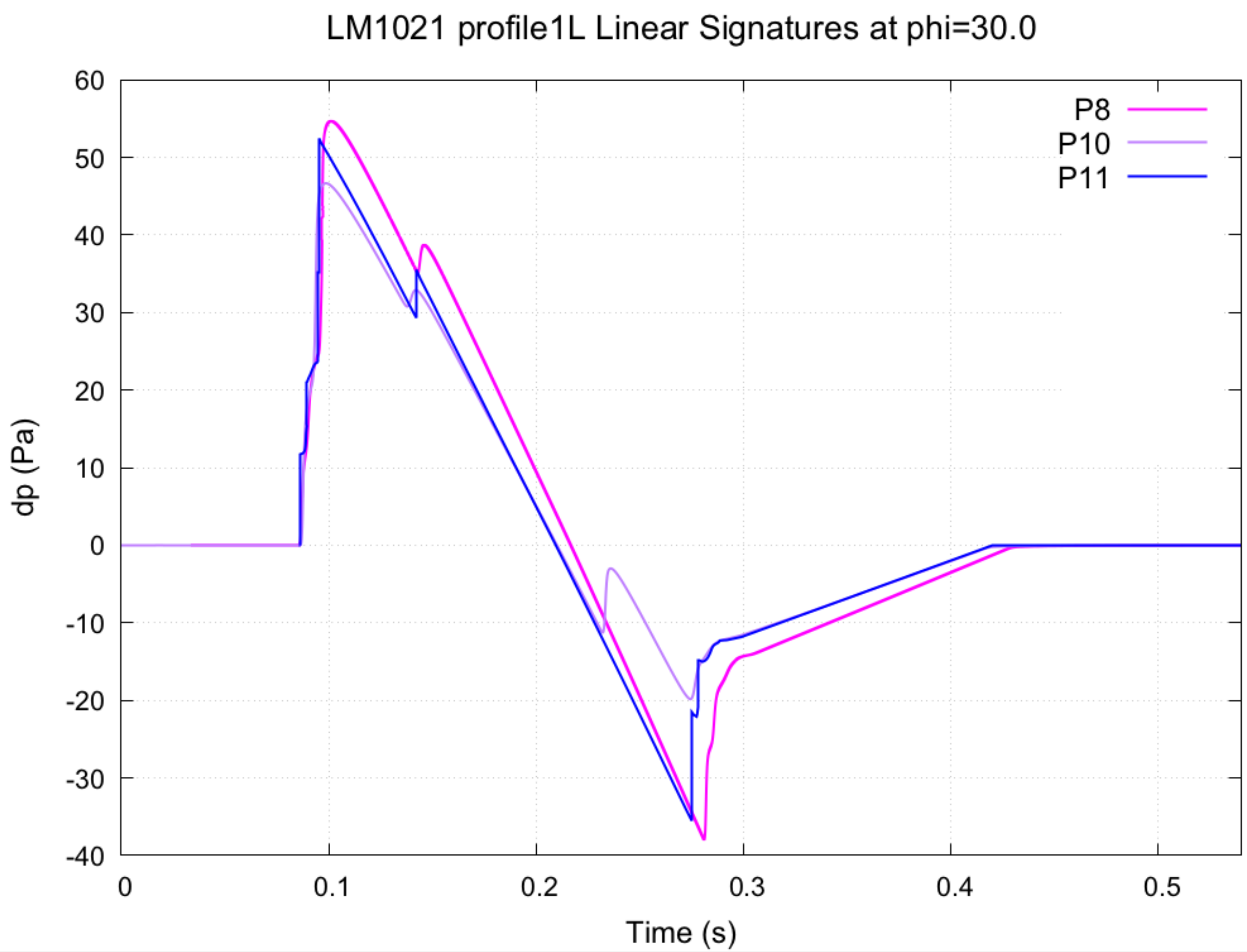


LM1021 – Profile1, Hydrostatic, Phi = 30˚



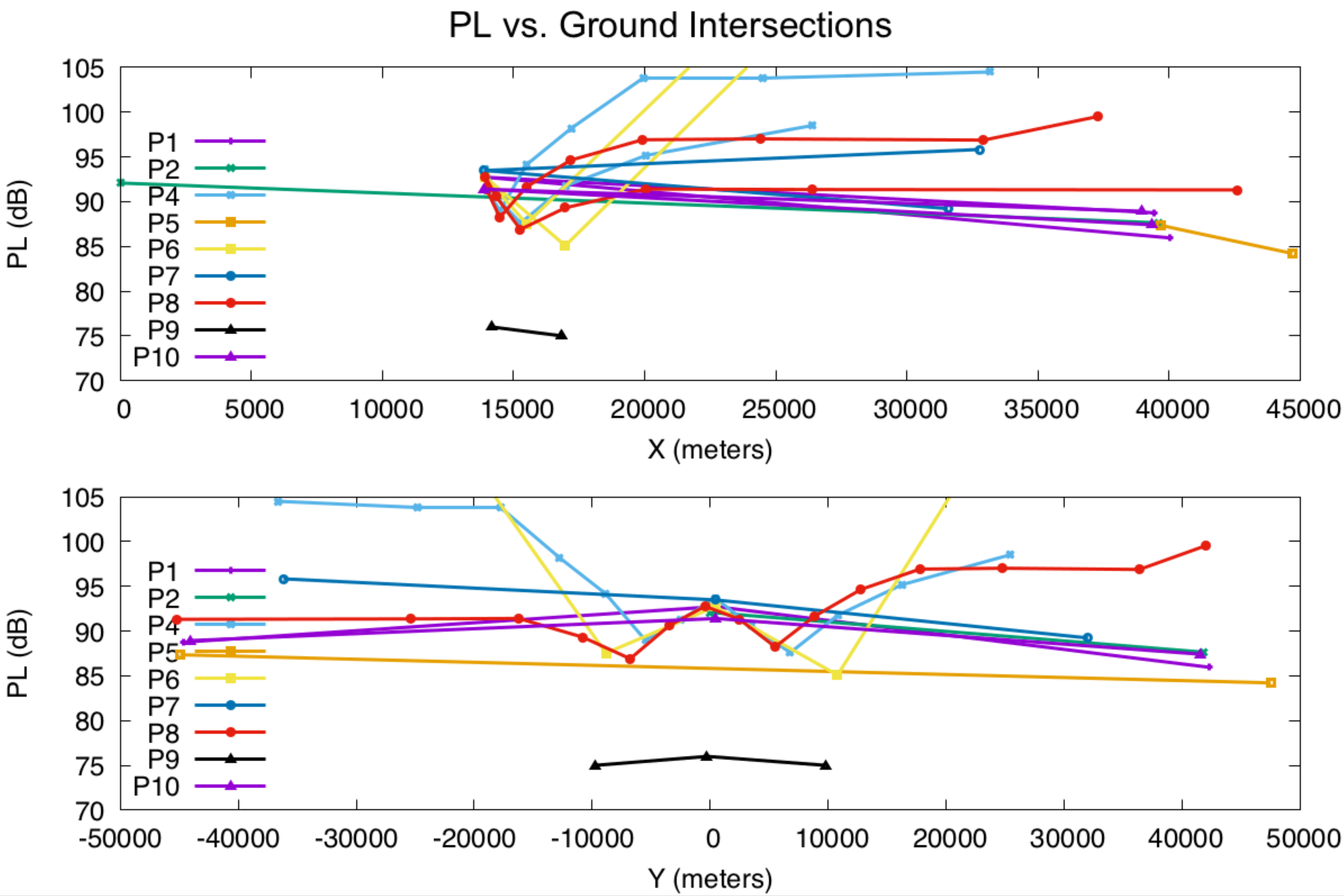
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile1, Linear, Phi = 30˚

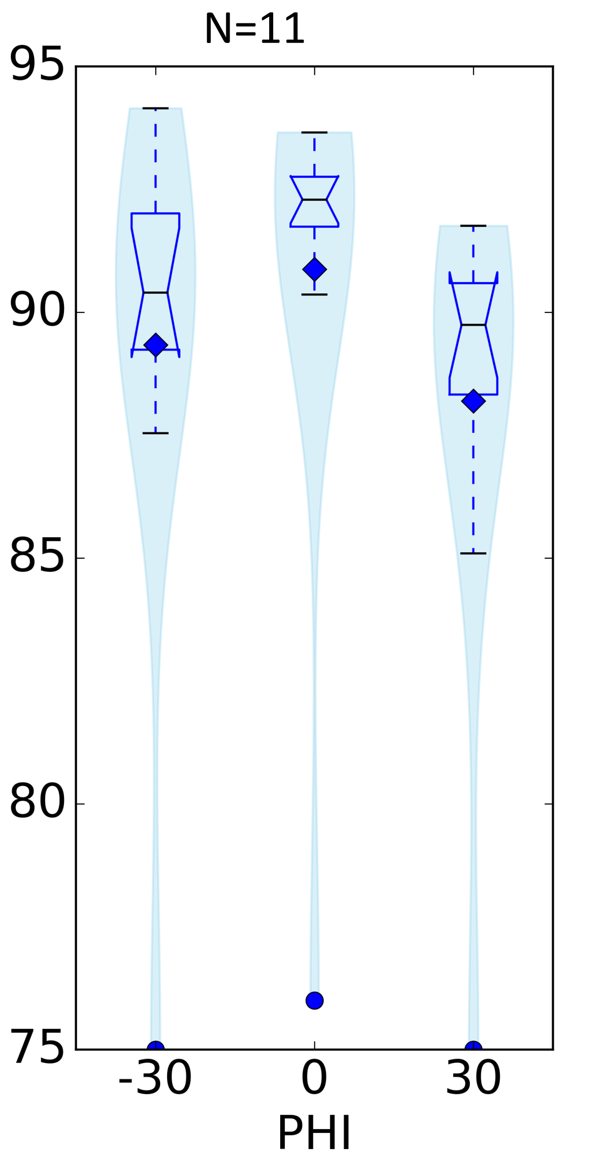


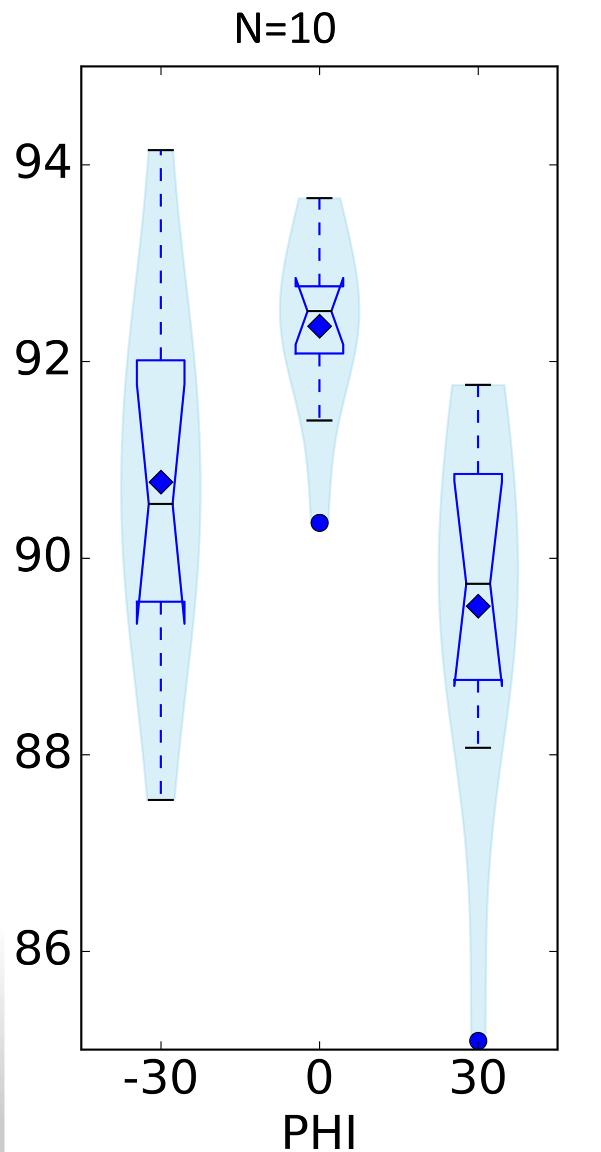
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile1, Hydrostatic, Ranges - PL



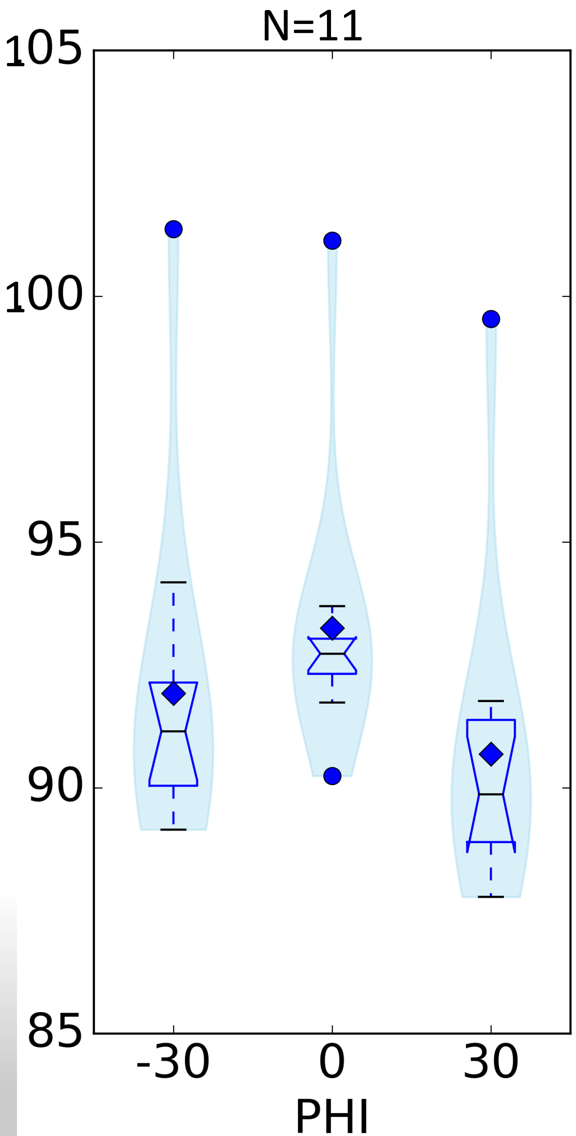
LM1021 – Profile1, PL Submitted Statistics

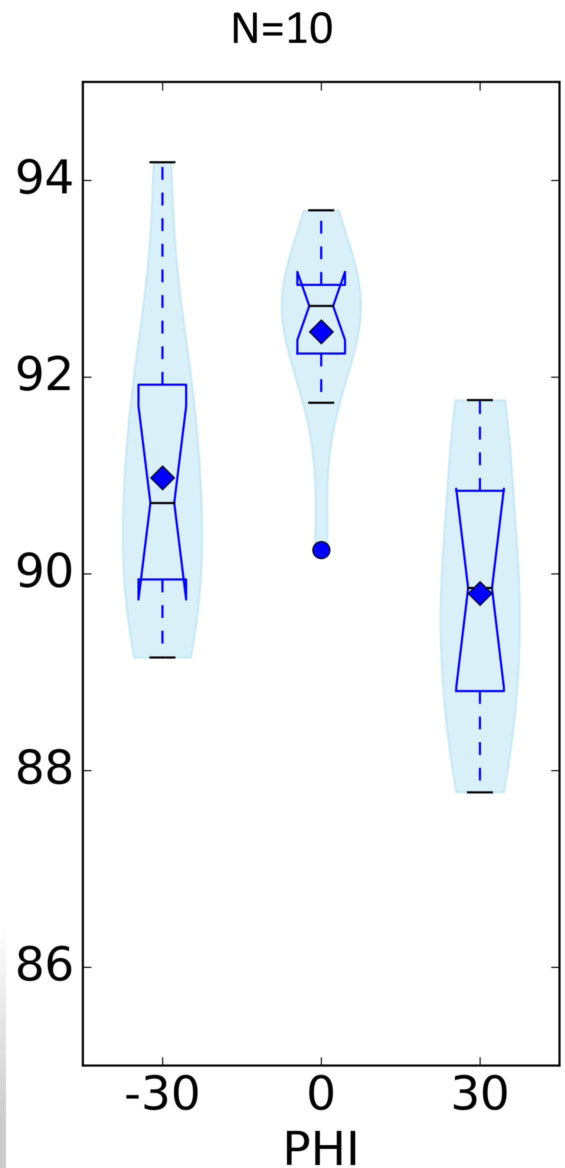




Sriram.Rallabhandi@nasa.gov

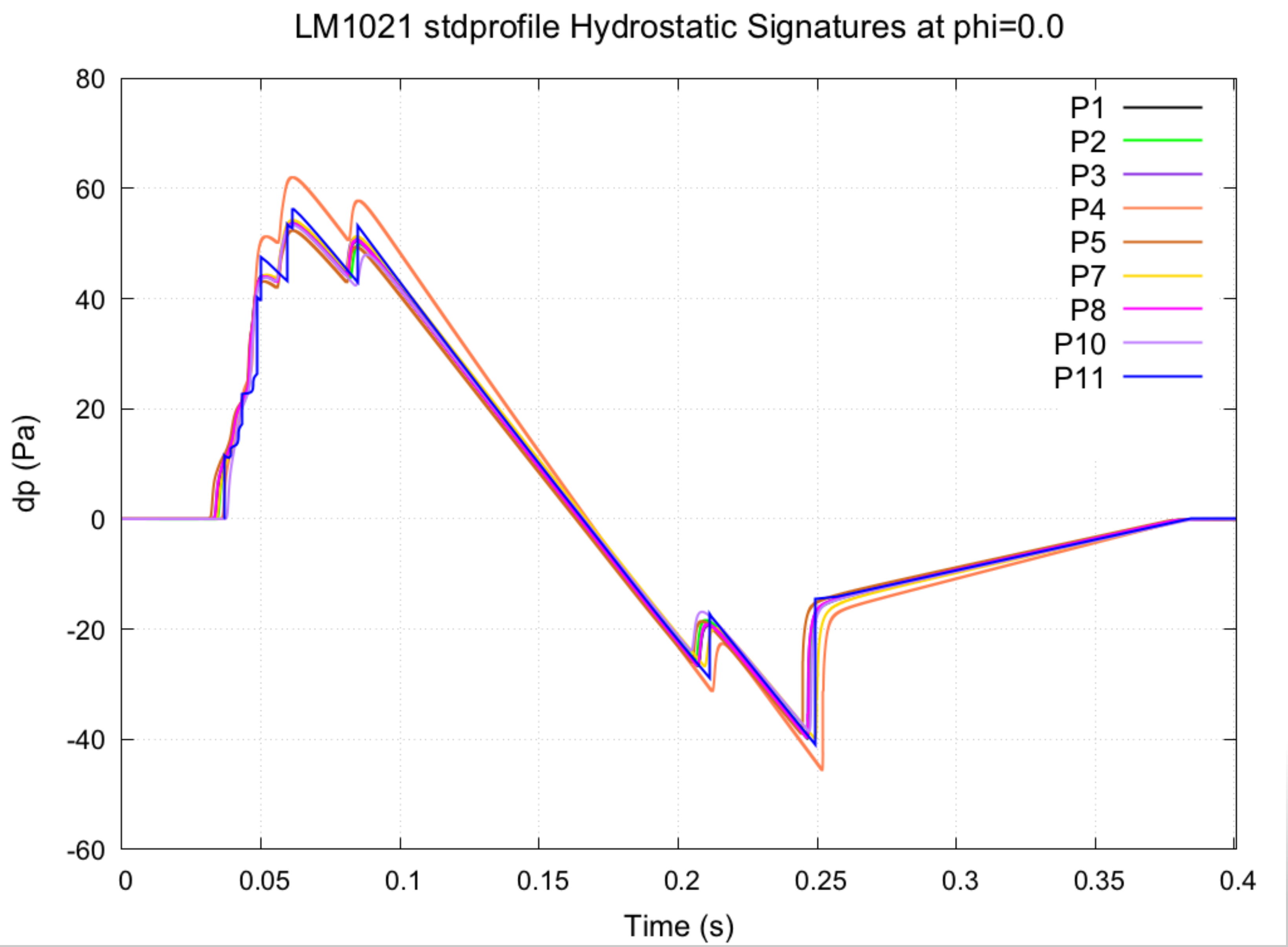
LM1021 – Profile1, PL Calculated Statistics



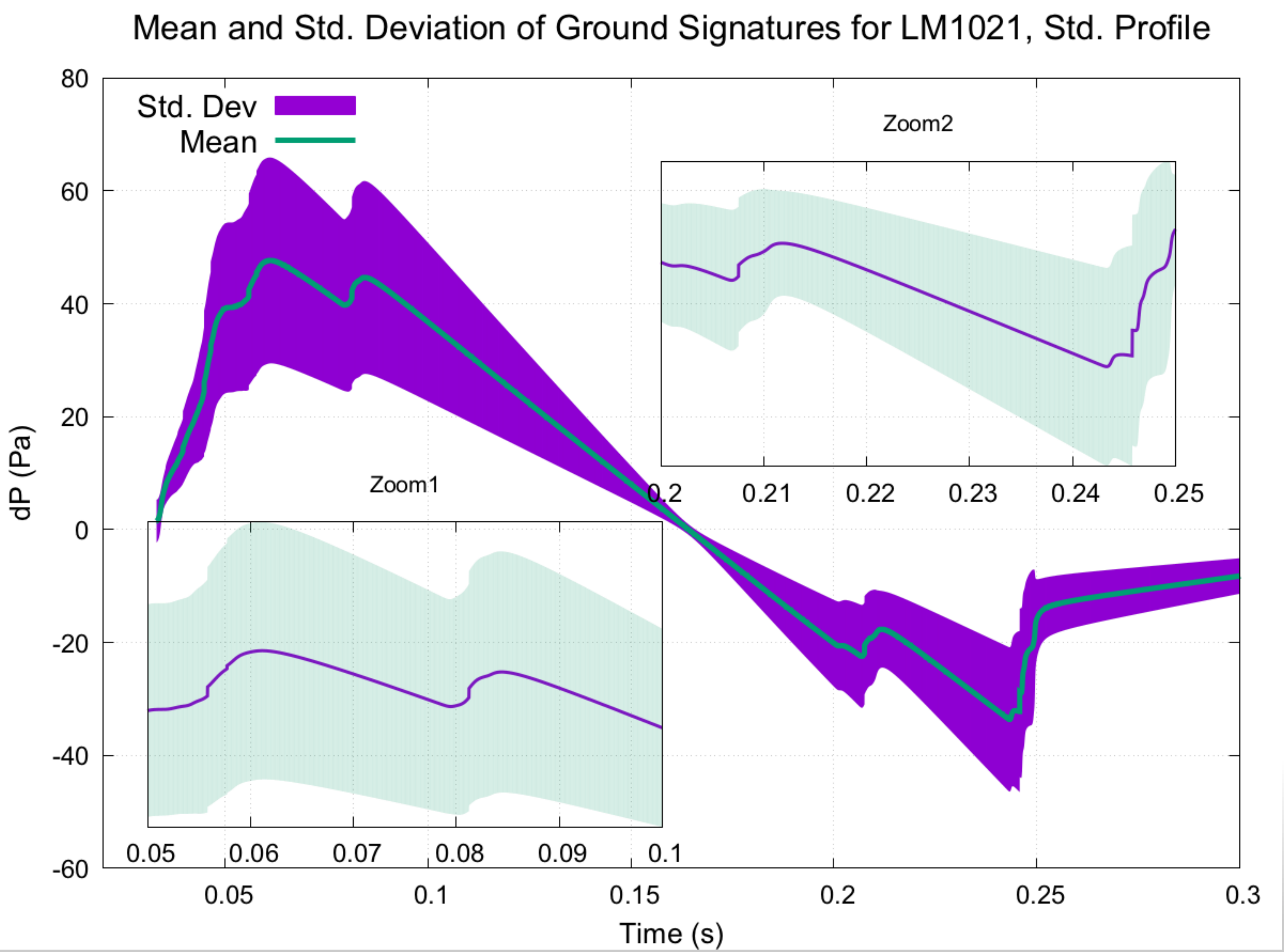


Sriram.Rallabhandi@nasa.gov

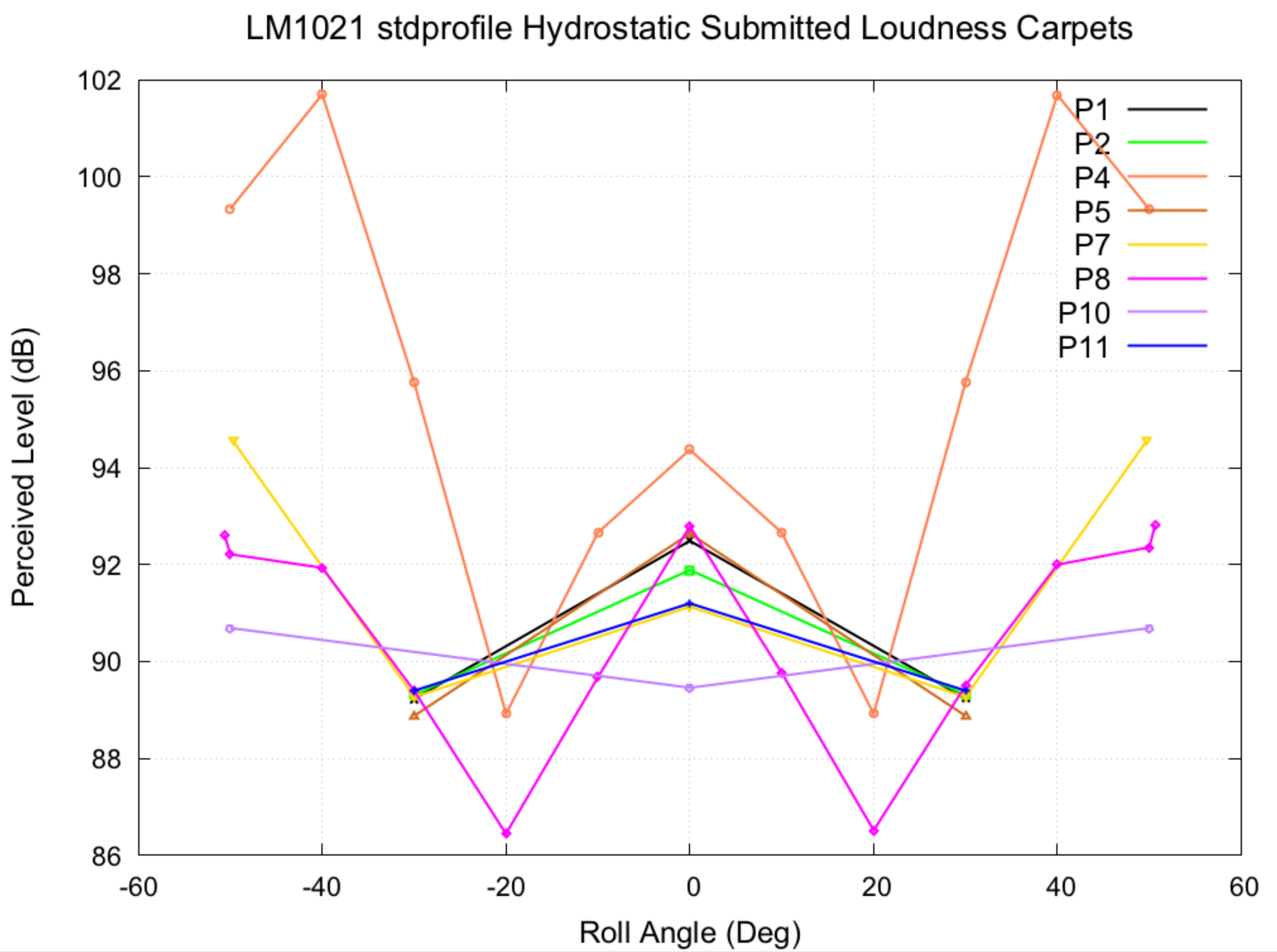
LM1021 – Std Profile, Hydrostatic, Phi = 0°



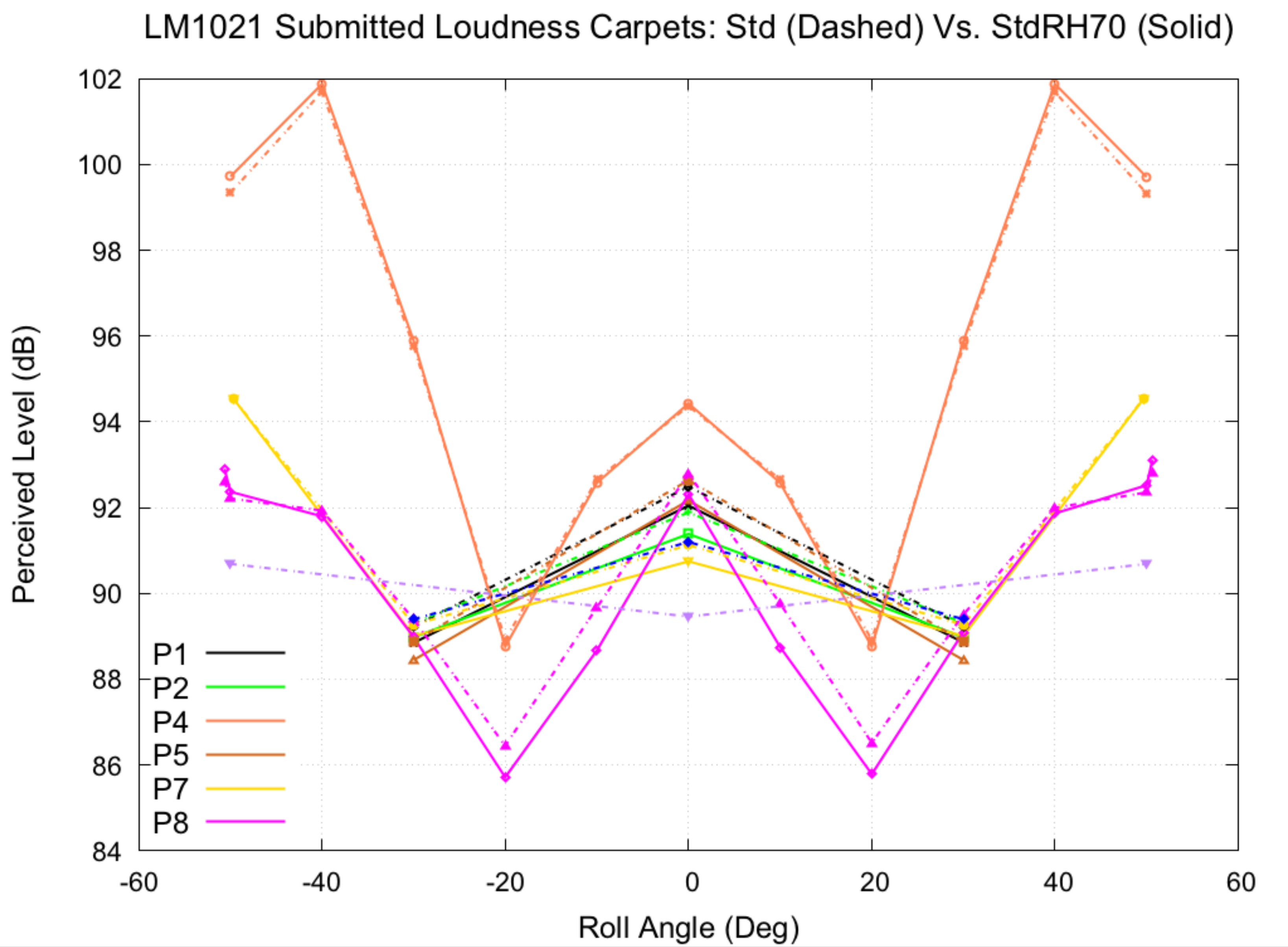
LM1021 – StdProfile, Hydrostatic, Phi = 0°



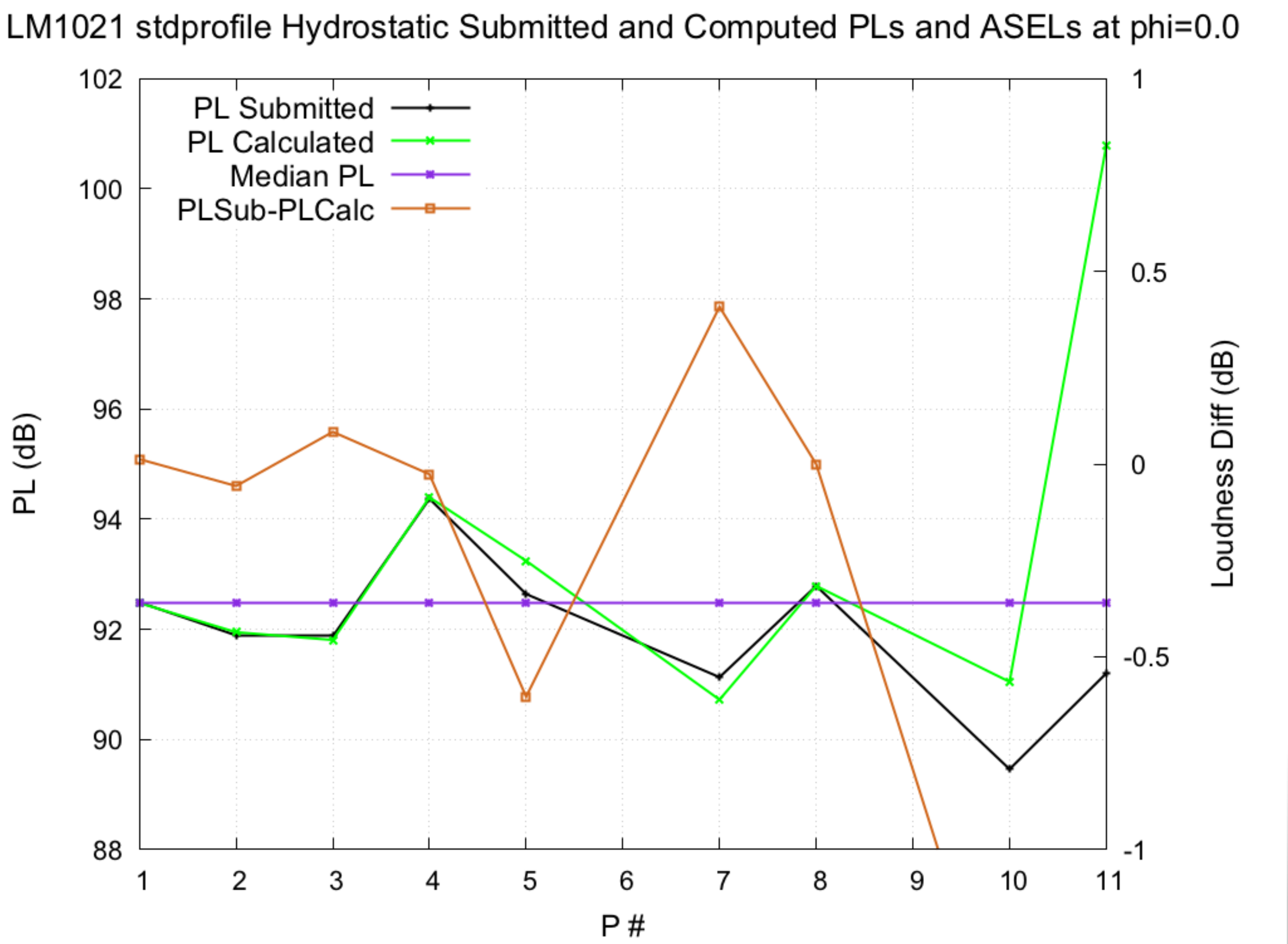
LM1021 – Std Profile, Hydrostatic, Carpet PL



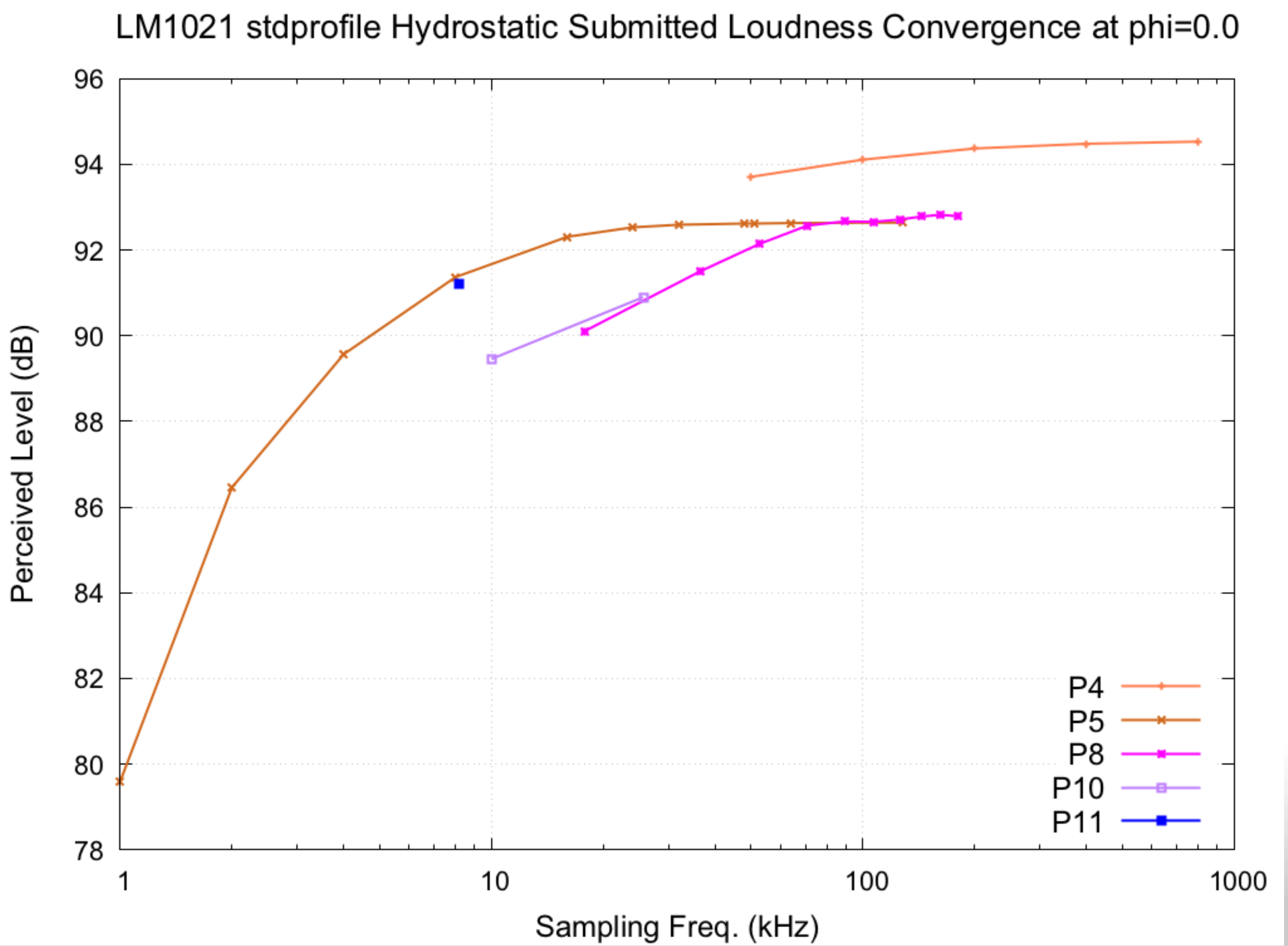
LM1021 – Std Profile, Hydrostatic, Carpet PL



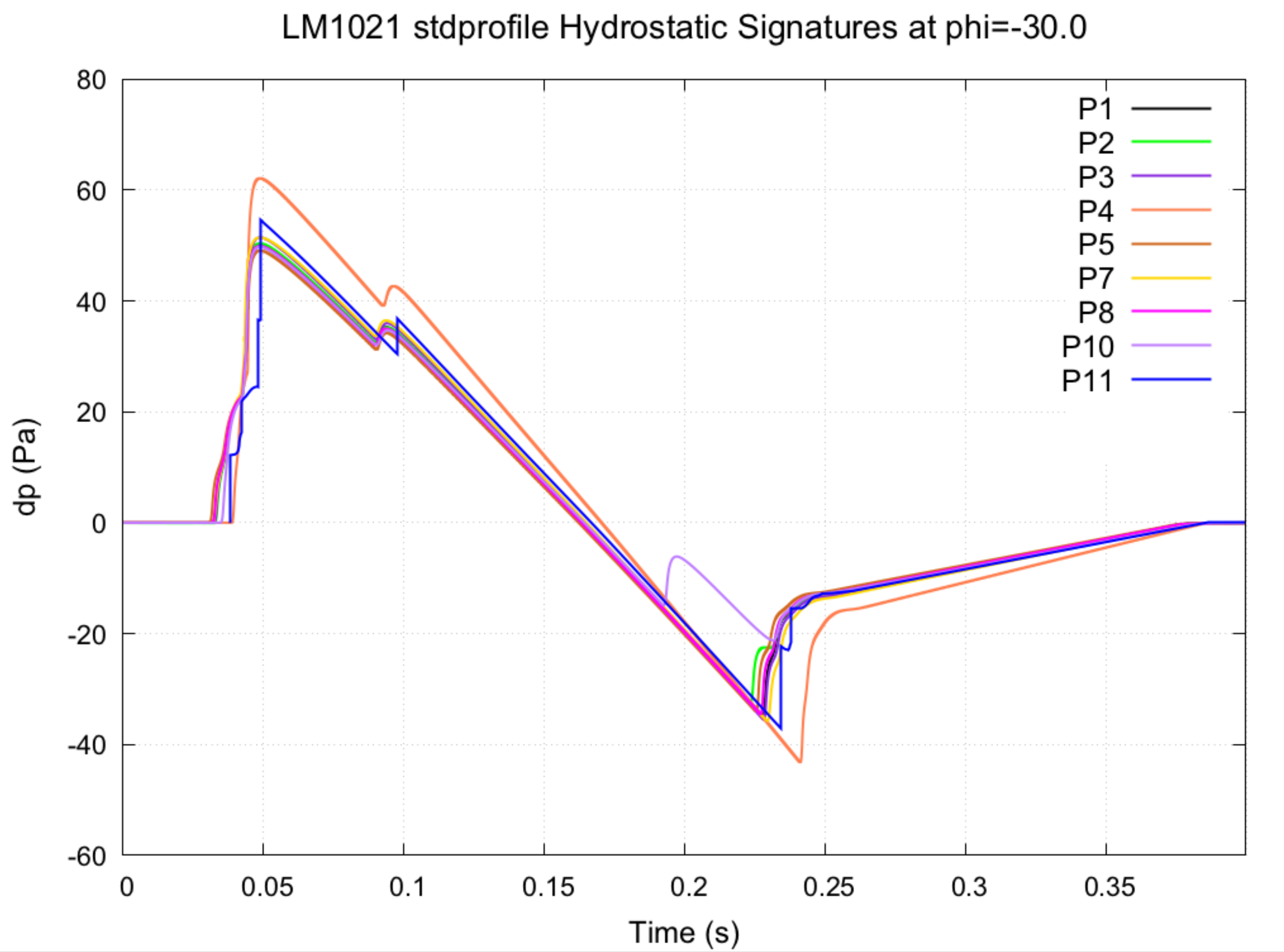
LM1021 – Std Profile, Hydrostatic, Phi = 0˚



LM1021 – Std Profile, Hydrostatic, Phi = 0˚

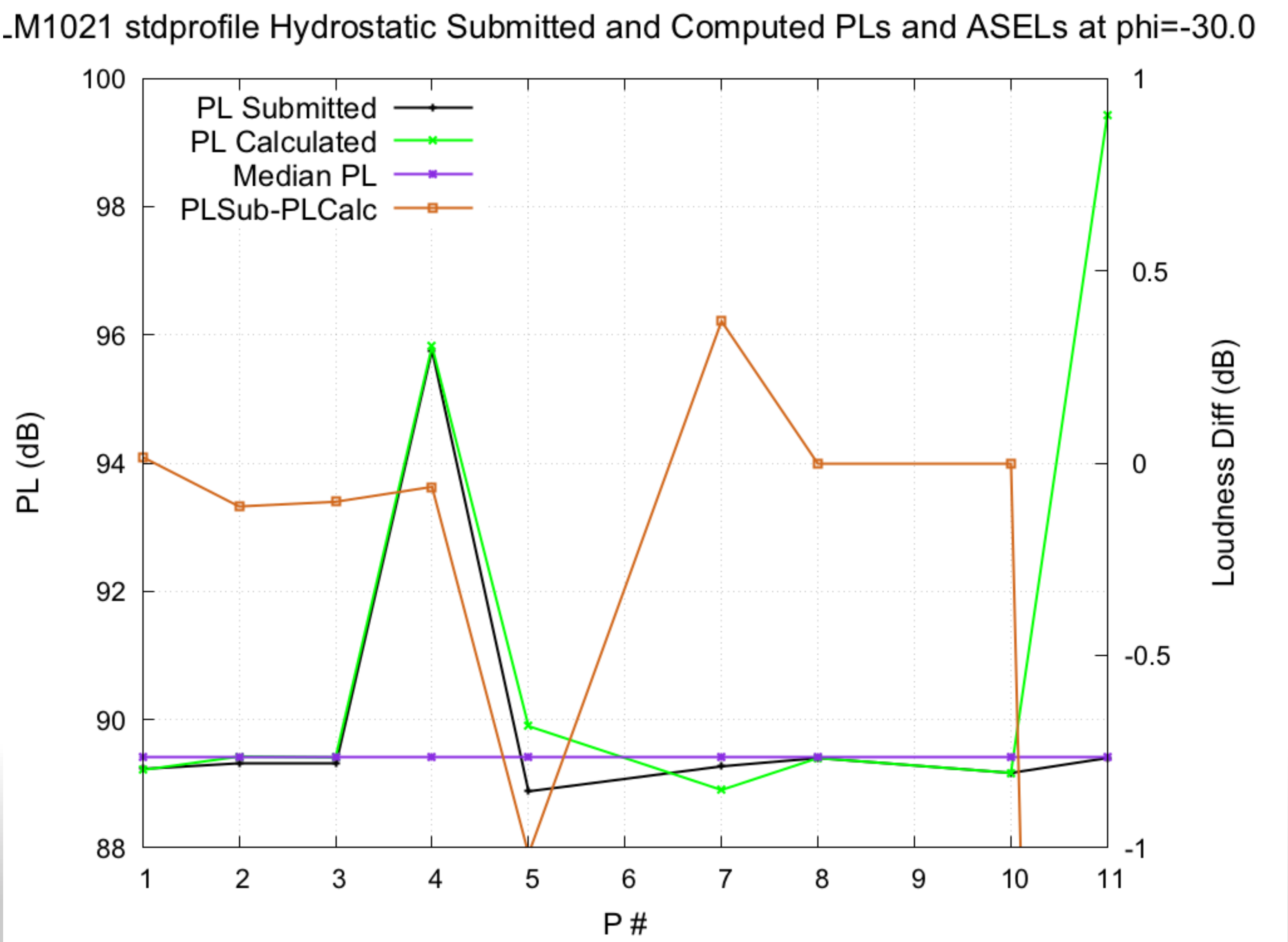


LM1021 – Std Profile, Hydrostatic, Phi = -30˚

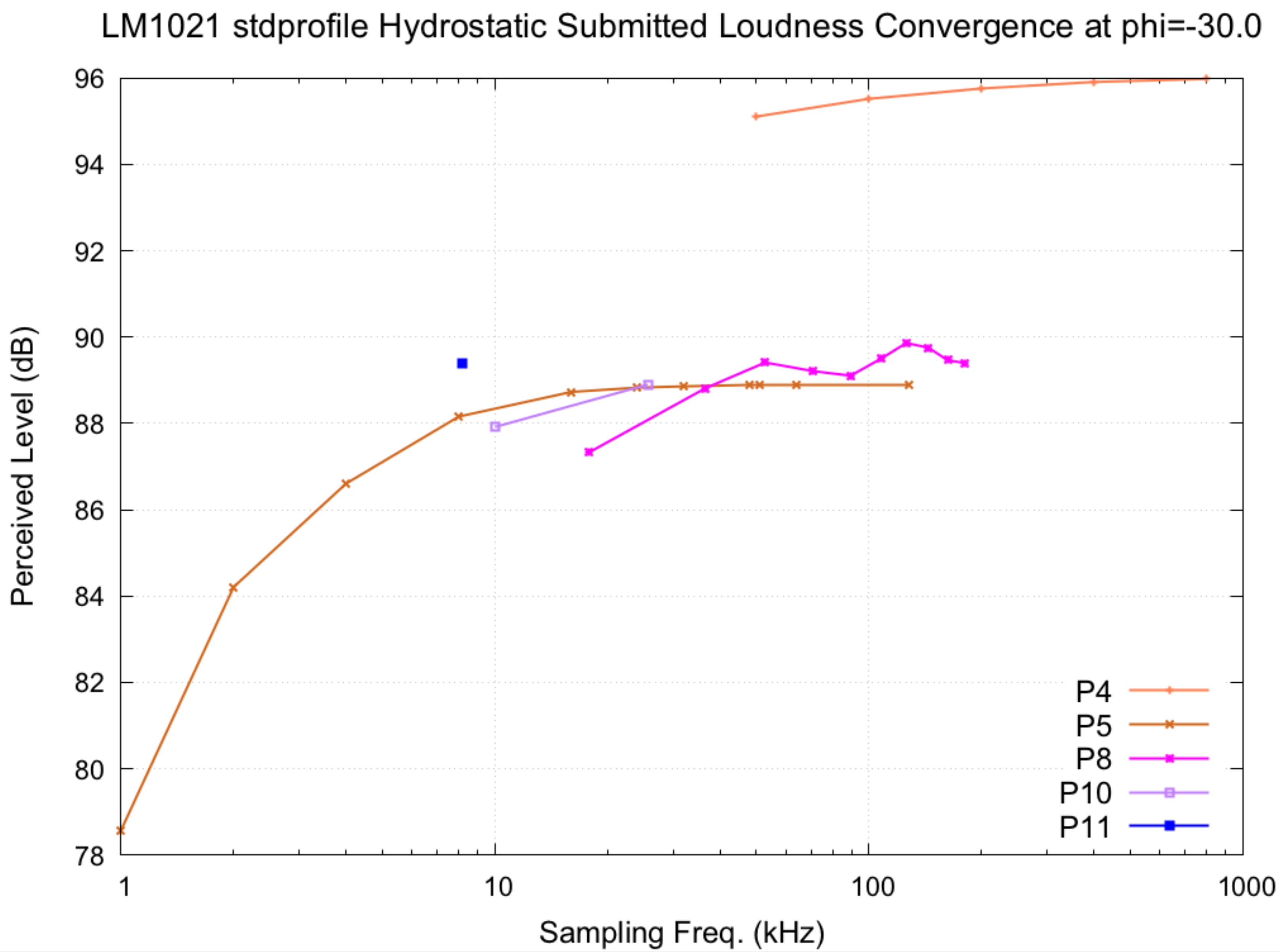


Sriram.Rallabhandi@nasa.gov

LM1021 – Std Profile, Hydrostatic, Phi = -30˚

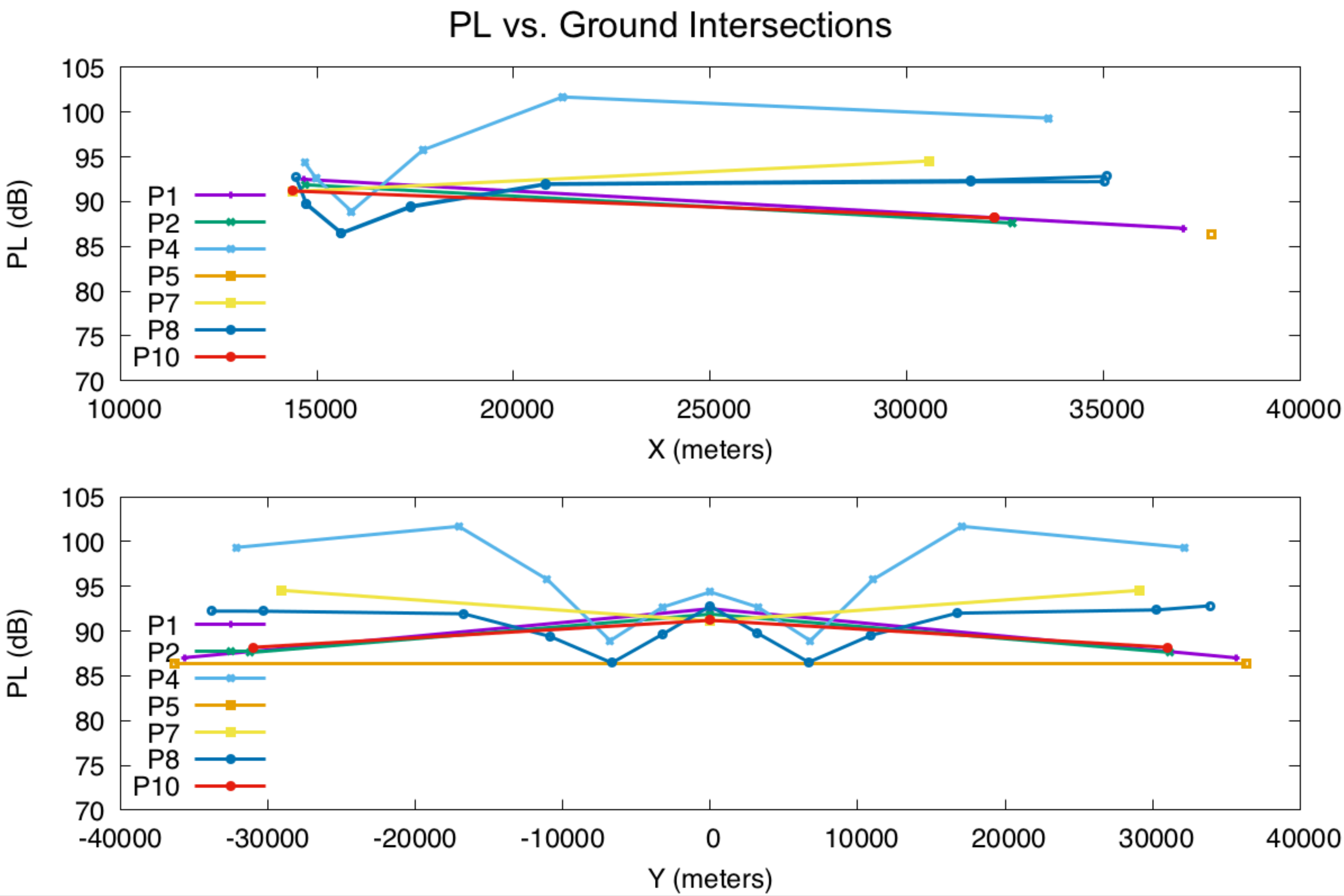


LM1021 – Std Profile, Hydrostatic, Phi = -30°

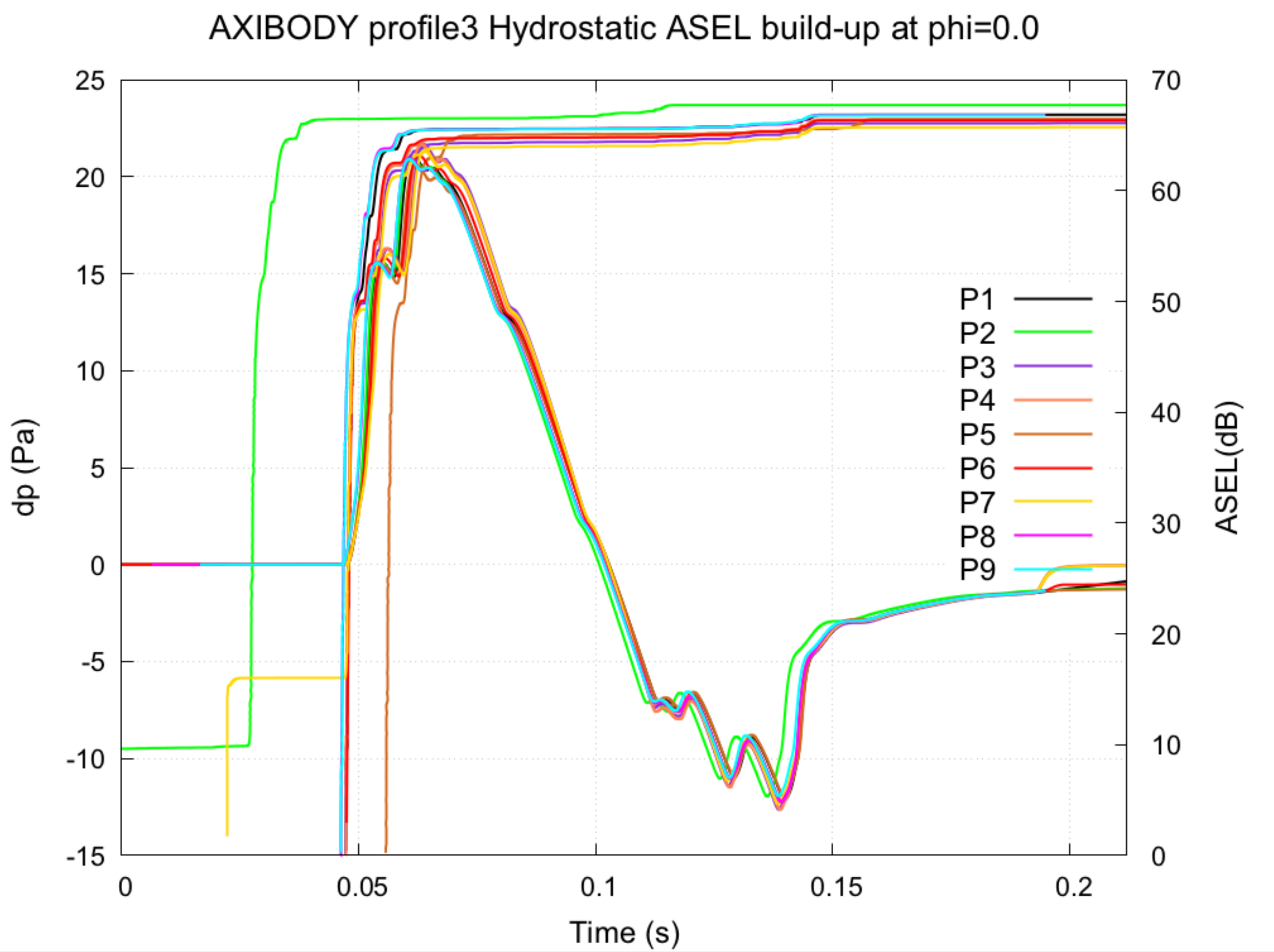


Sriram.Rallabhandi@nasa.gov

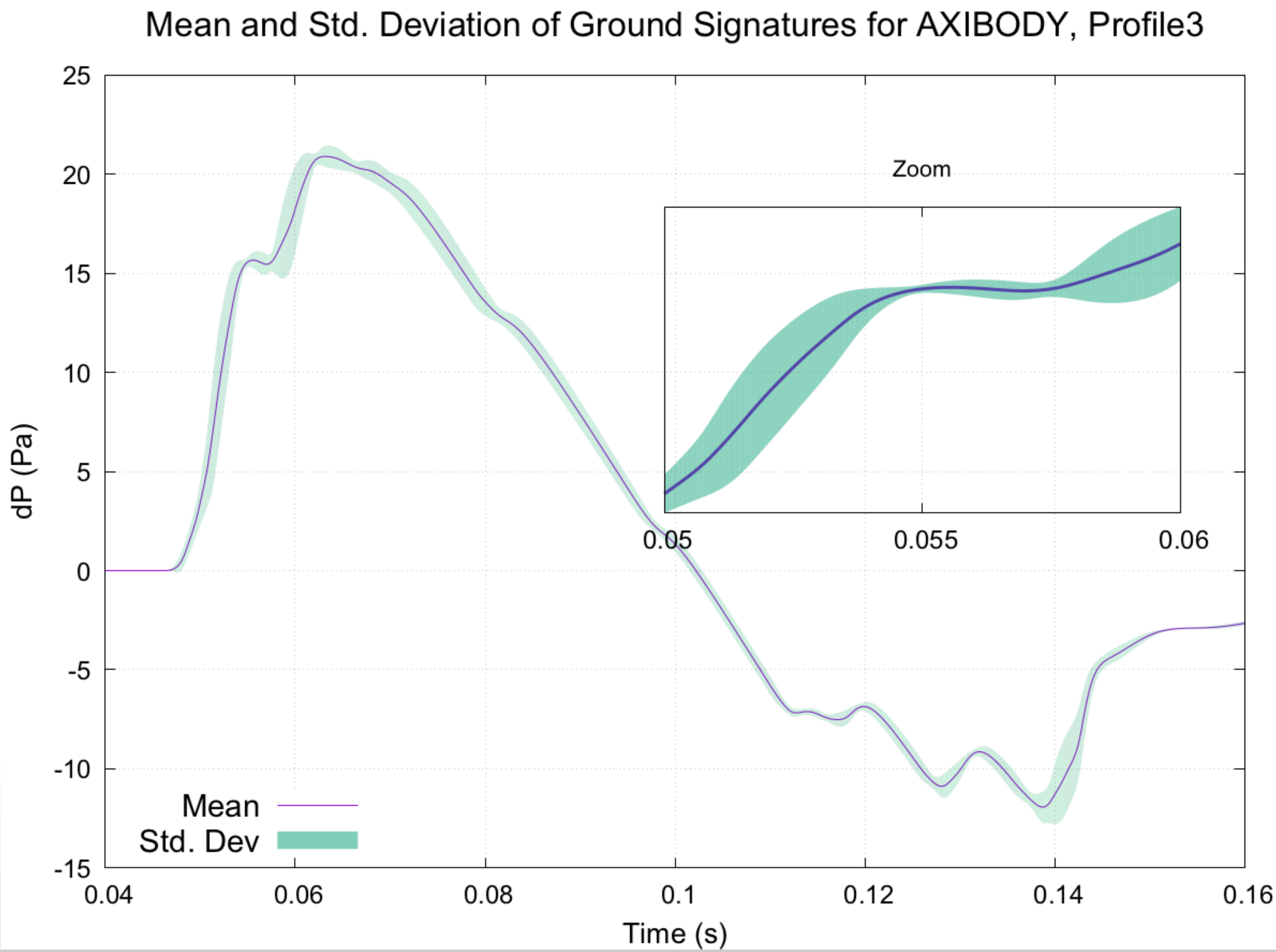
LM1021 – Std Profile, Ranges-PL



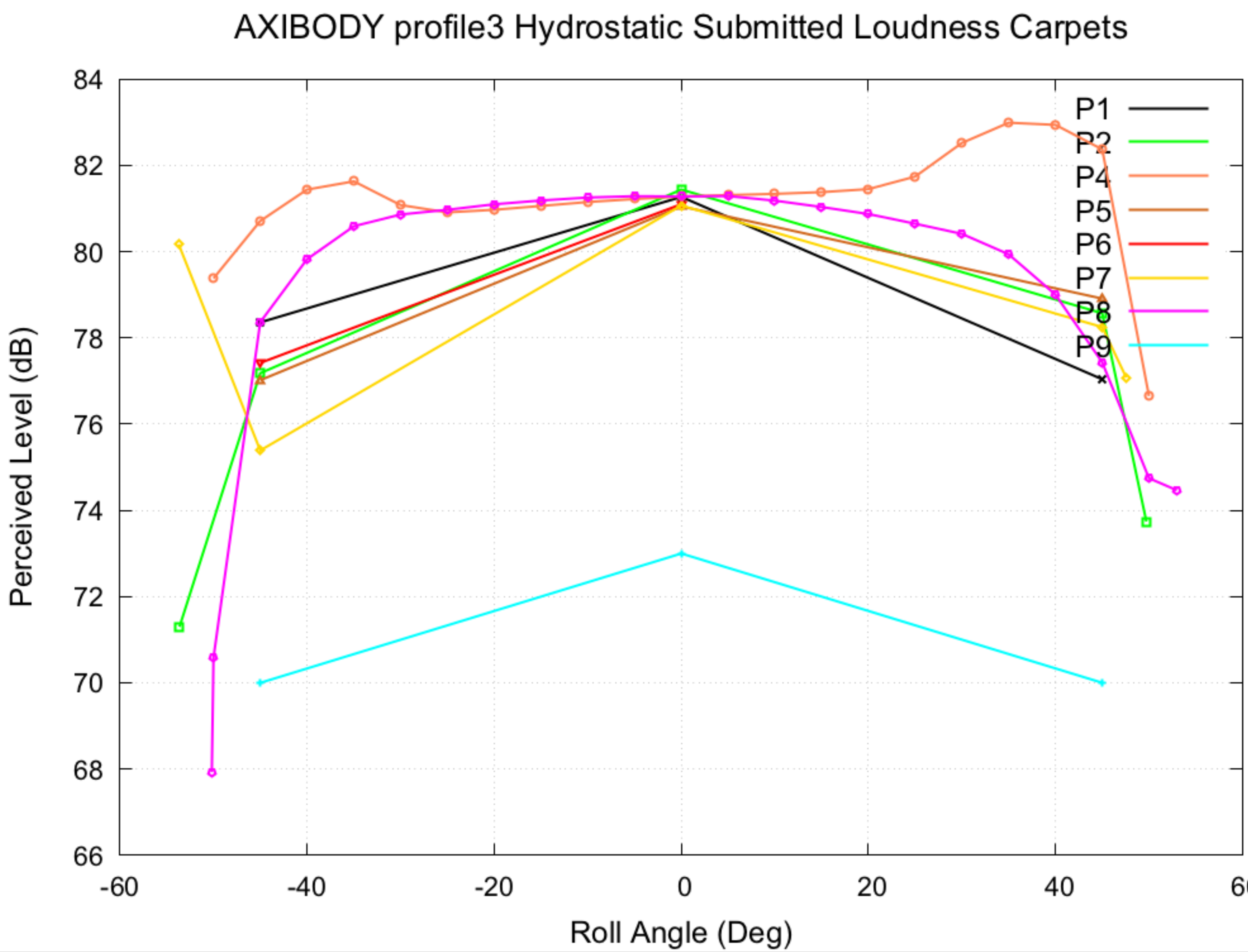
AXIBODY– Profile3, Hydrostatic, Phi = 0°



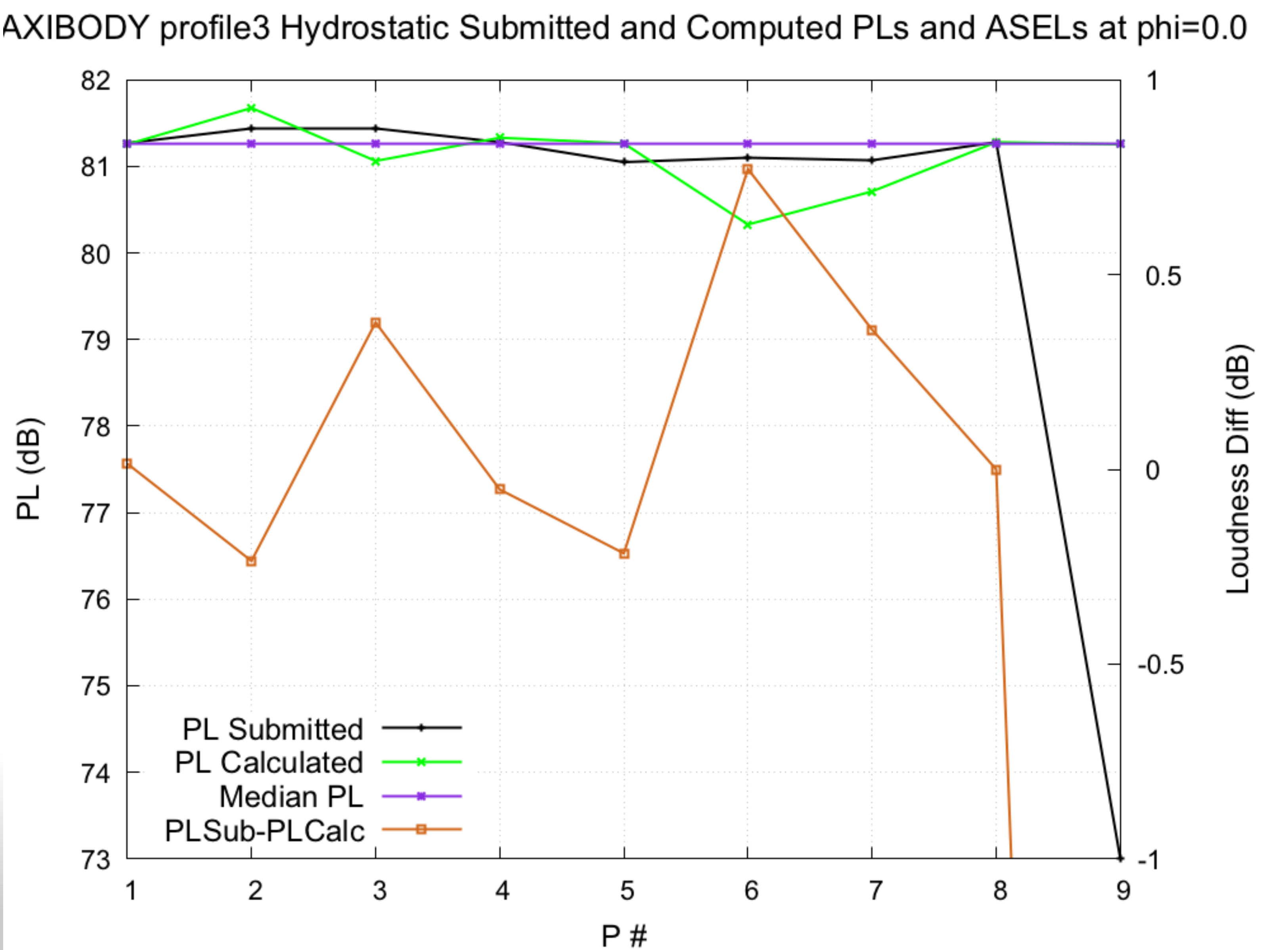
AXIBODY– Profile3, Mean and Std. Deviation



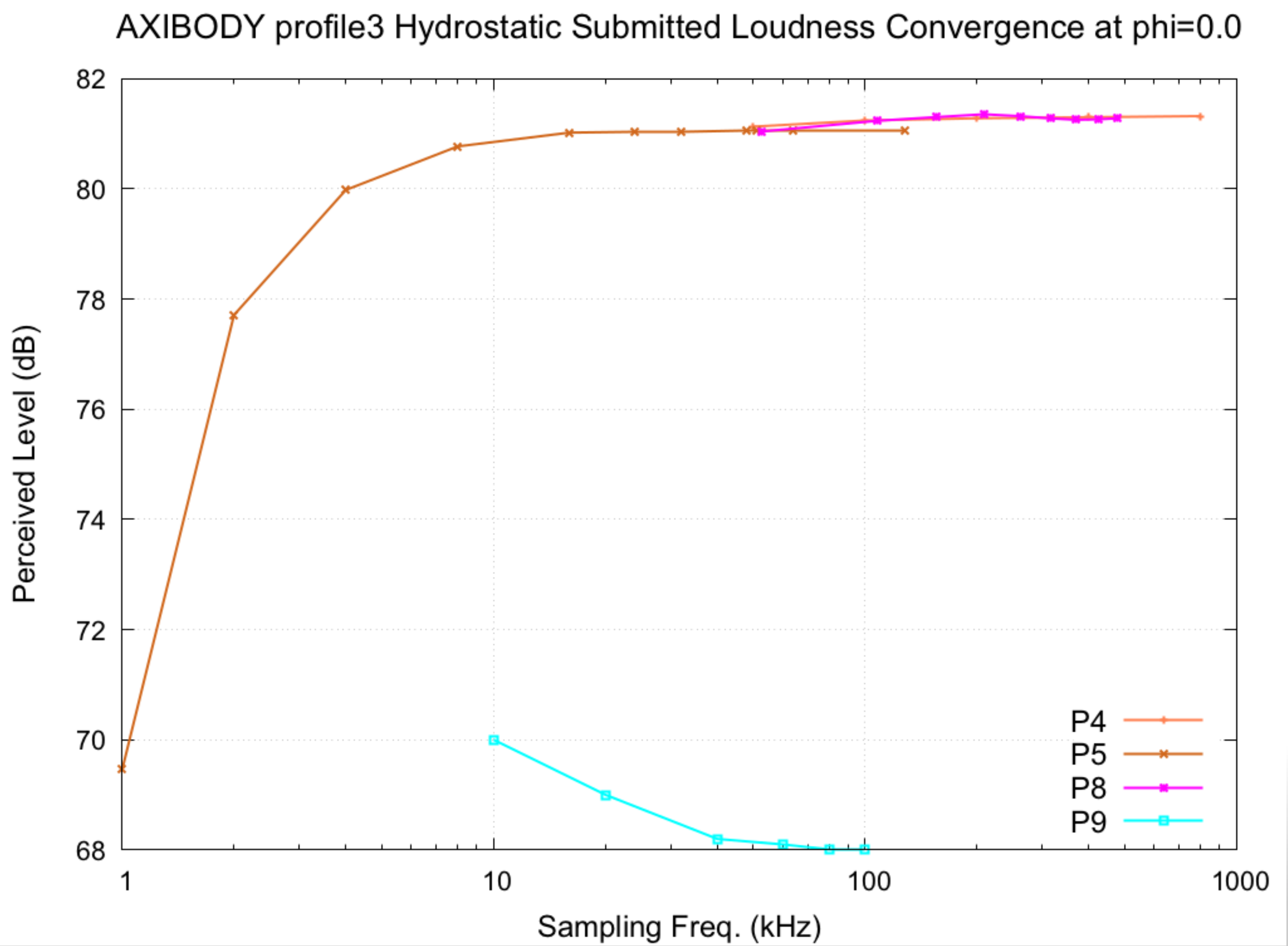
AXIBODY– Profile3, Hydrostatic, Carpet PL



AXIBODY– Profile3, Hydrostatic, Phi = 0°

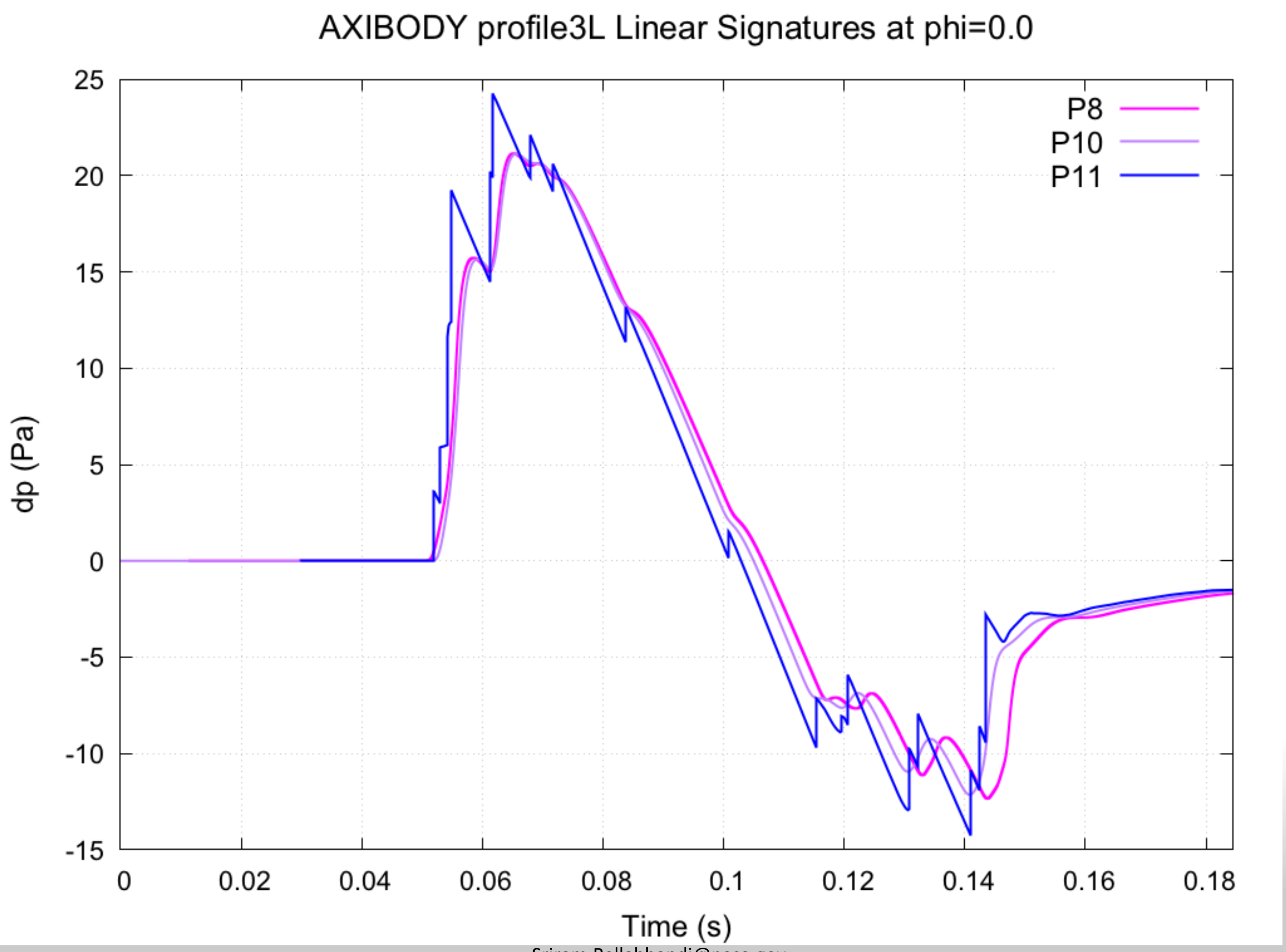


AXIBODY– Profile3, Hydrostatic, Phi = 0˚

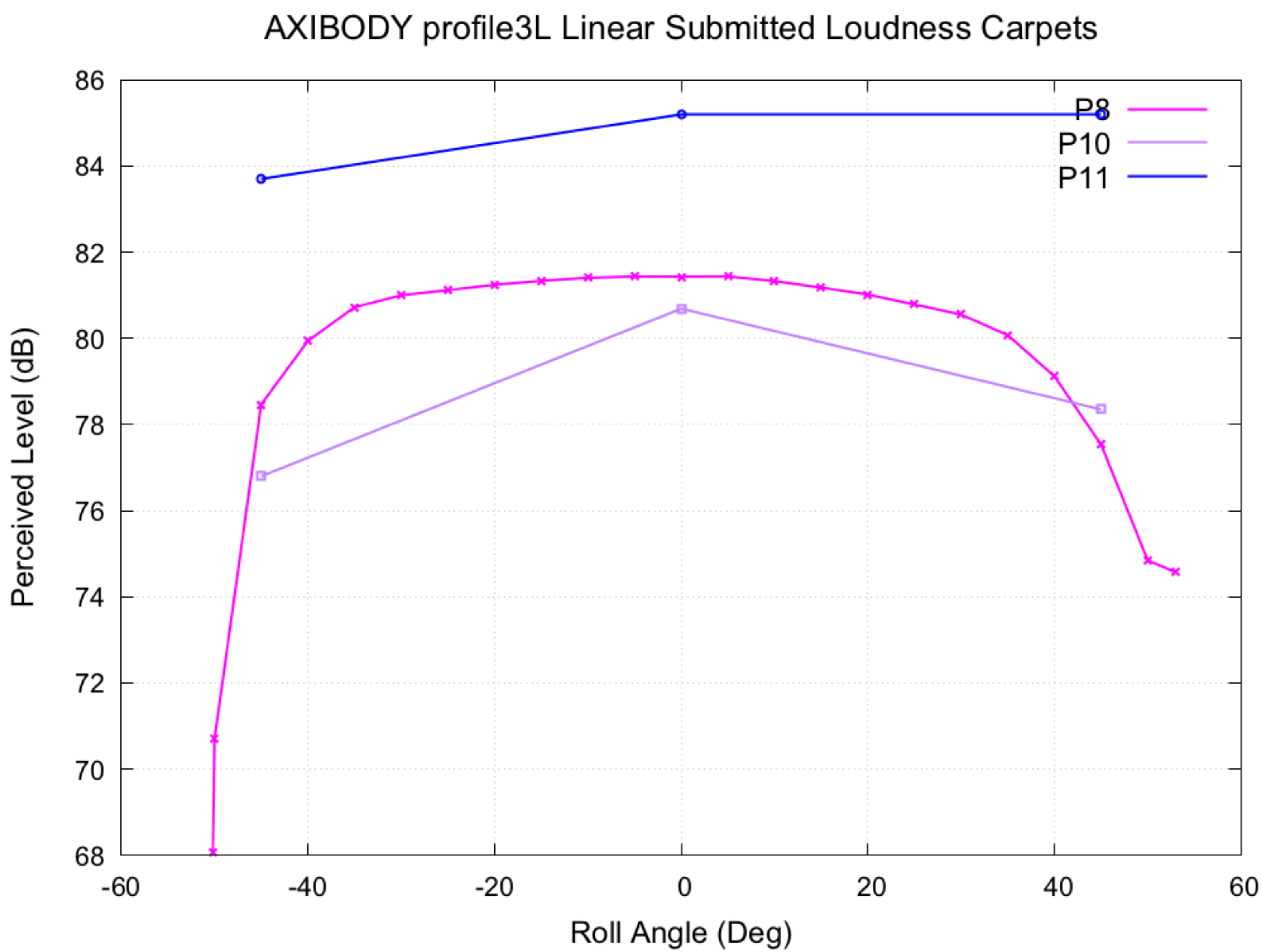


Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Linear, Phi = 0°

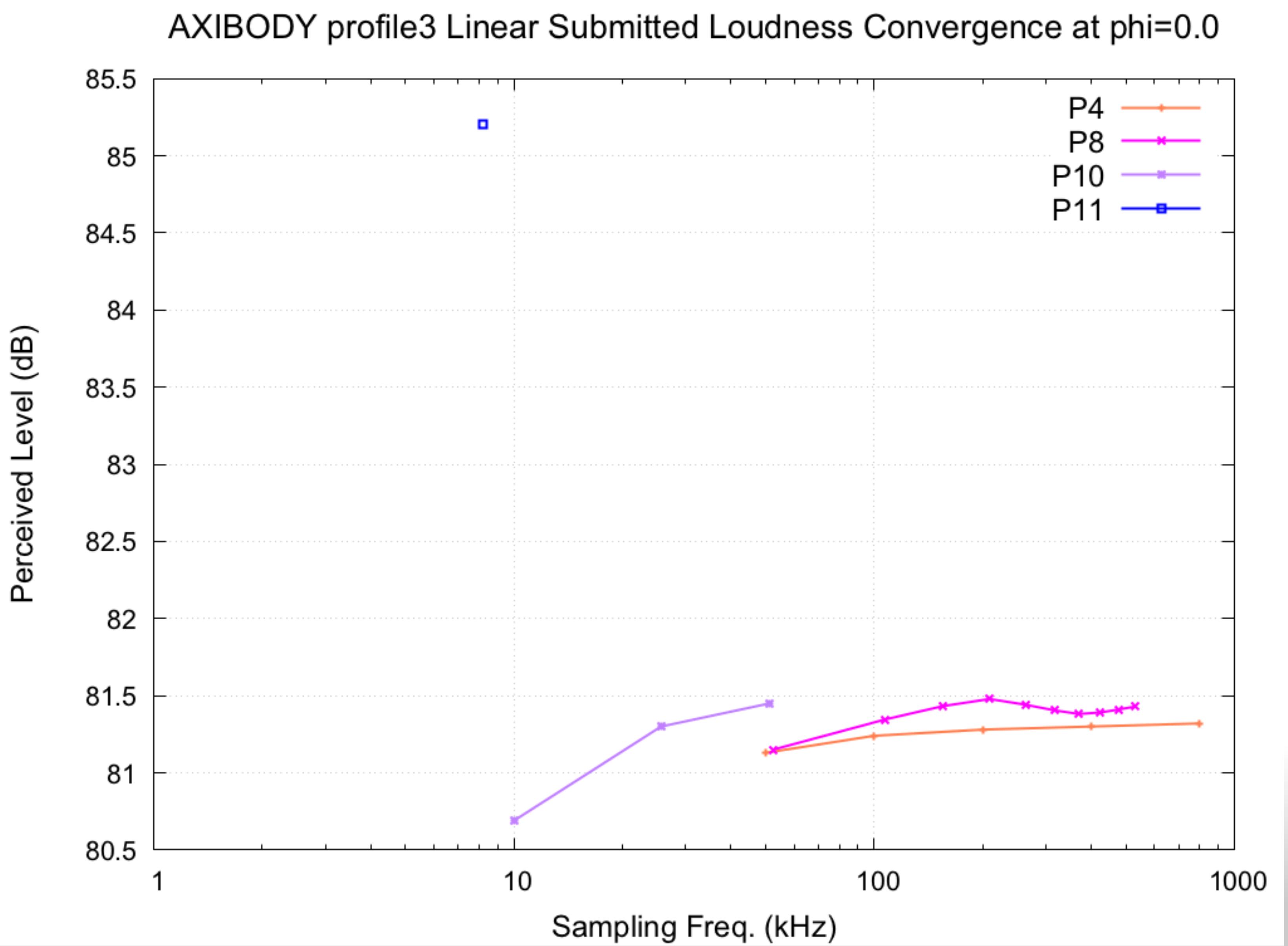


AXIBODY– Profile3, Linear, Carpet PL



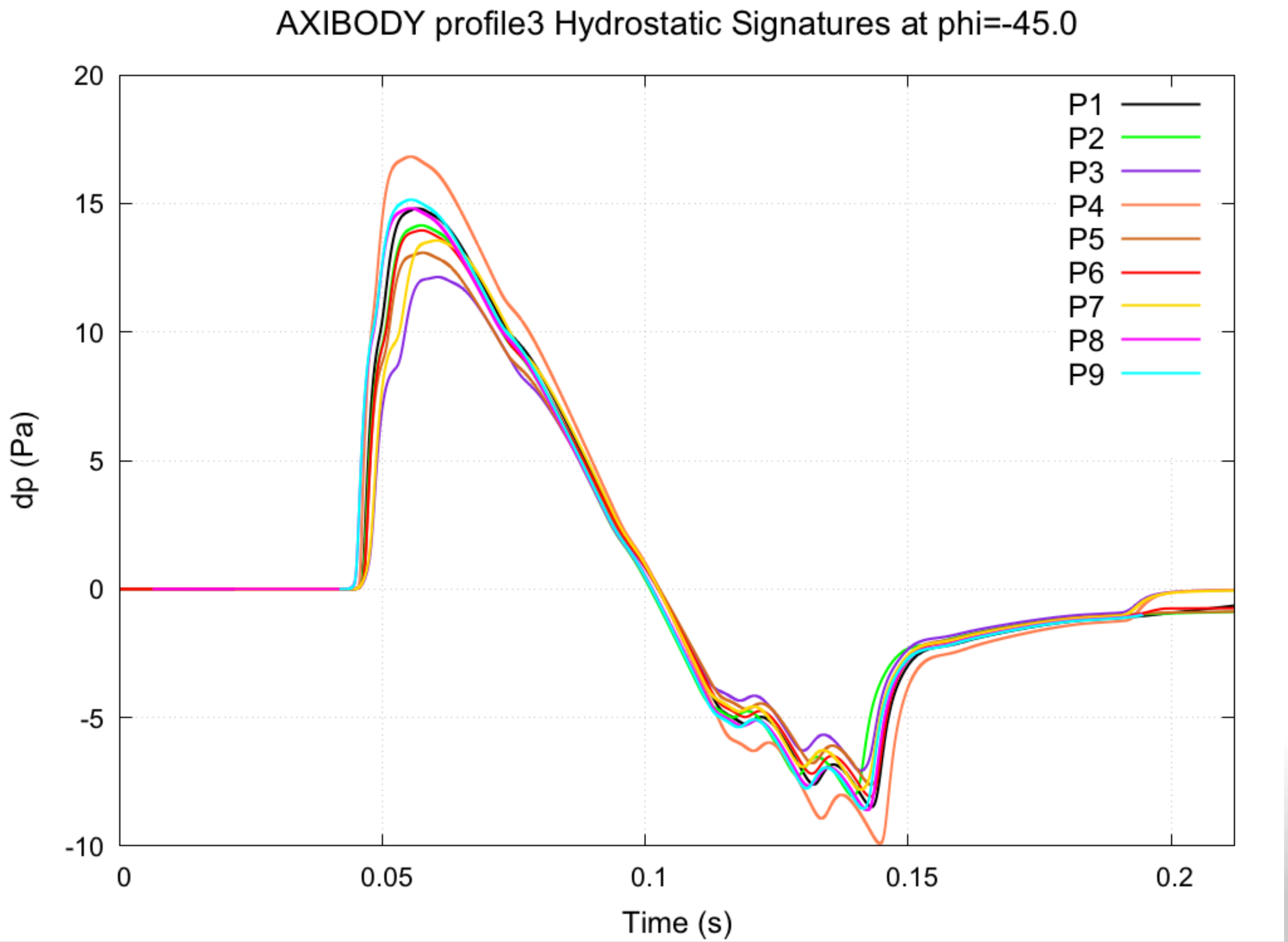
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Linear, Phi = 0°



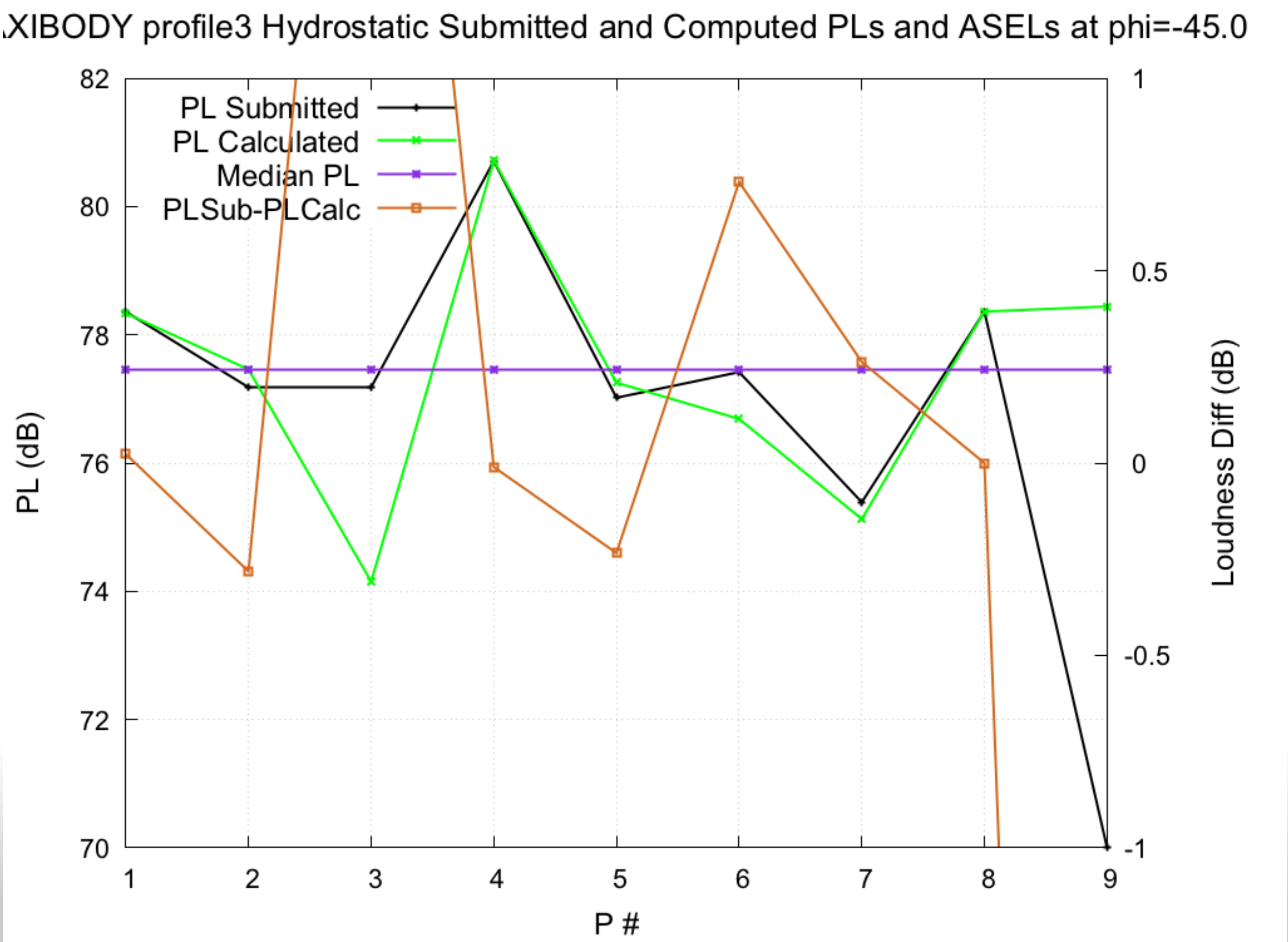
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Hydrostatic, Phi = -45˚

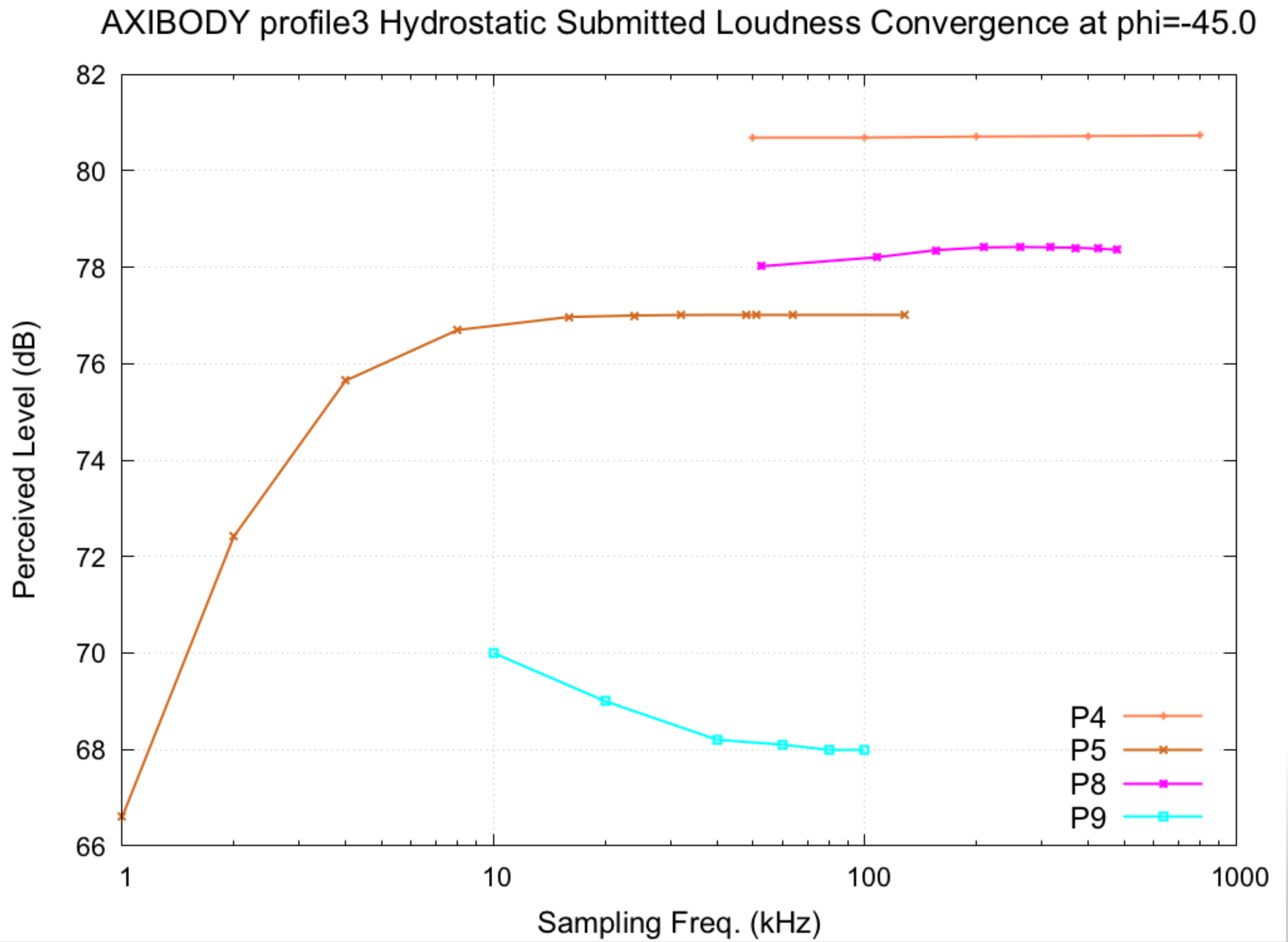


Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Hydrostatic, Phi = -45˚

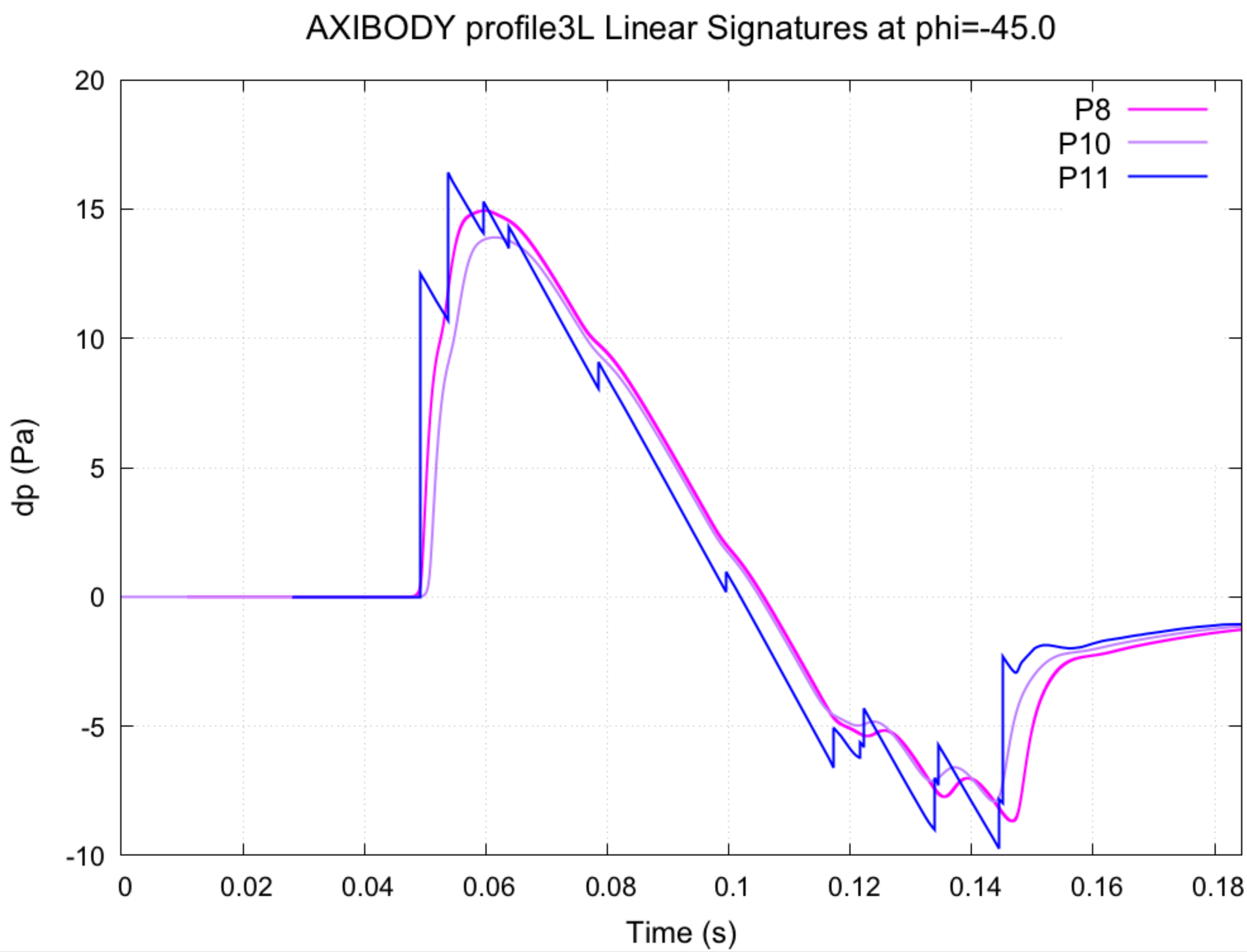


AXIBODY– Profile3, Hydrostatic, Phi = -45°



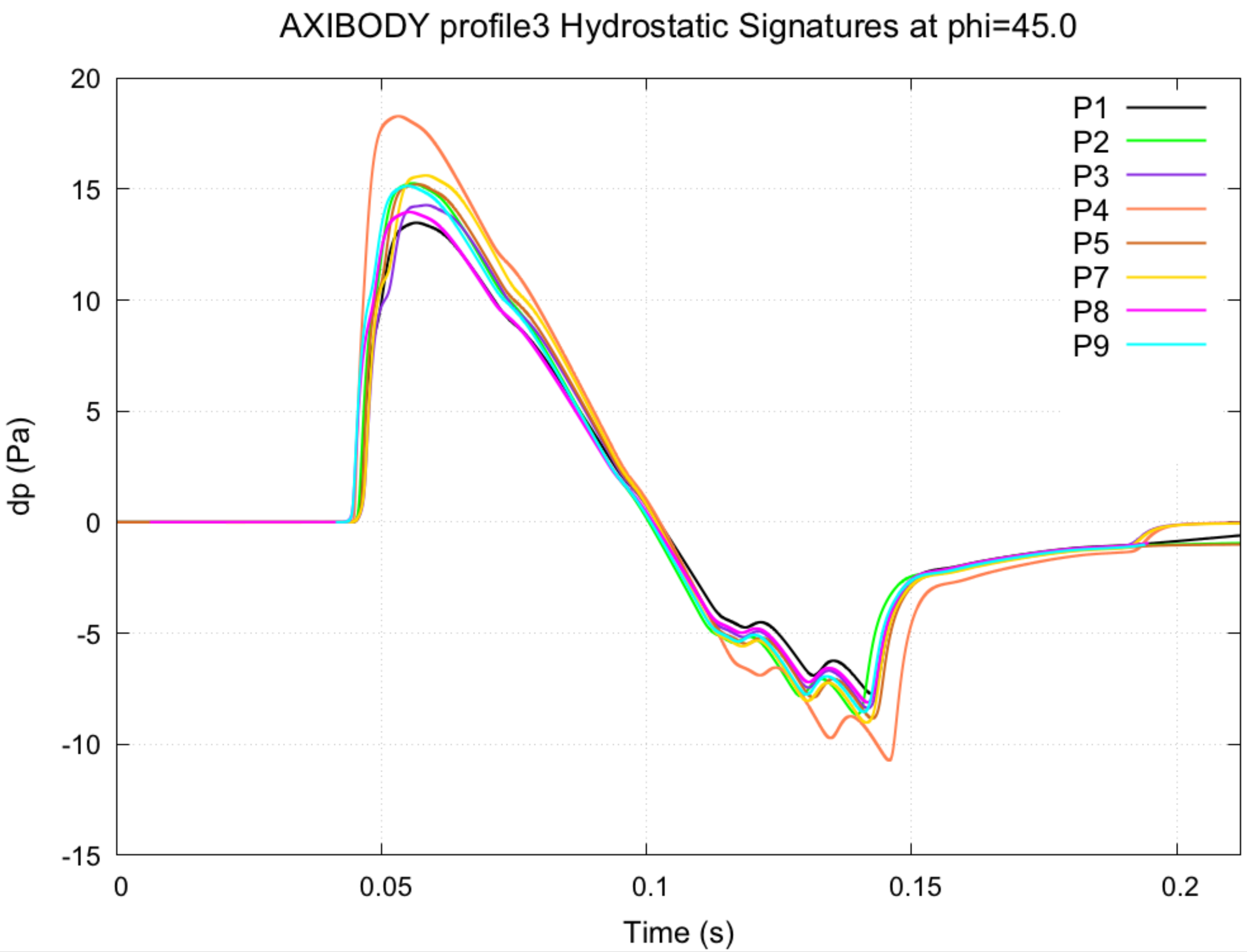
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Linear, Phi = -45°



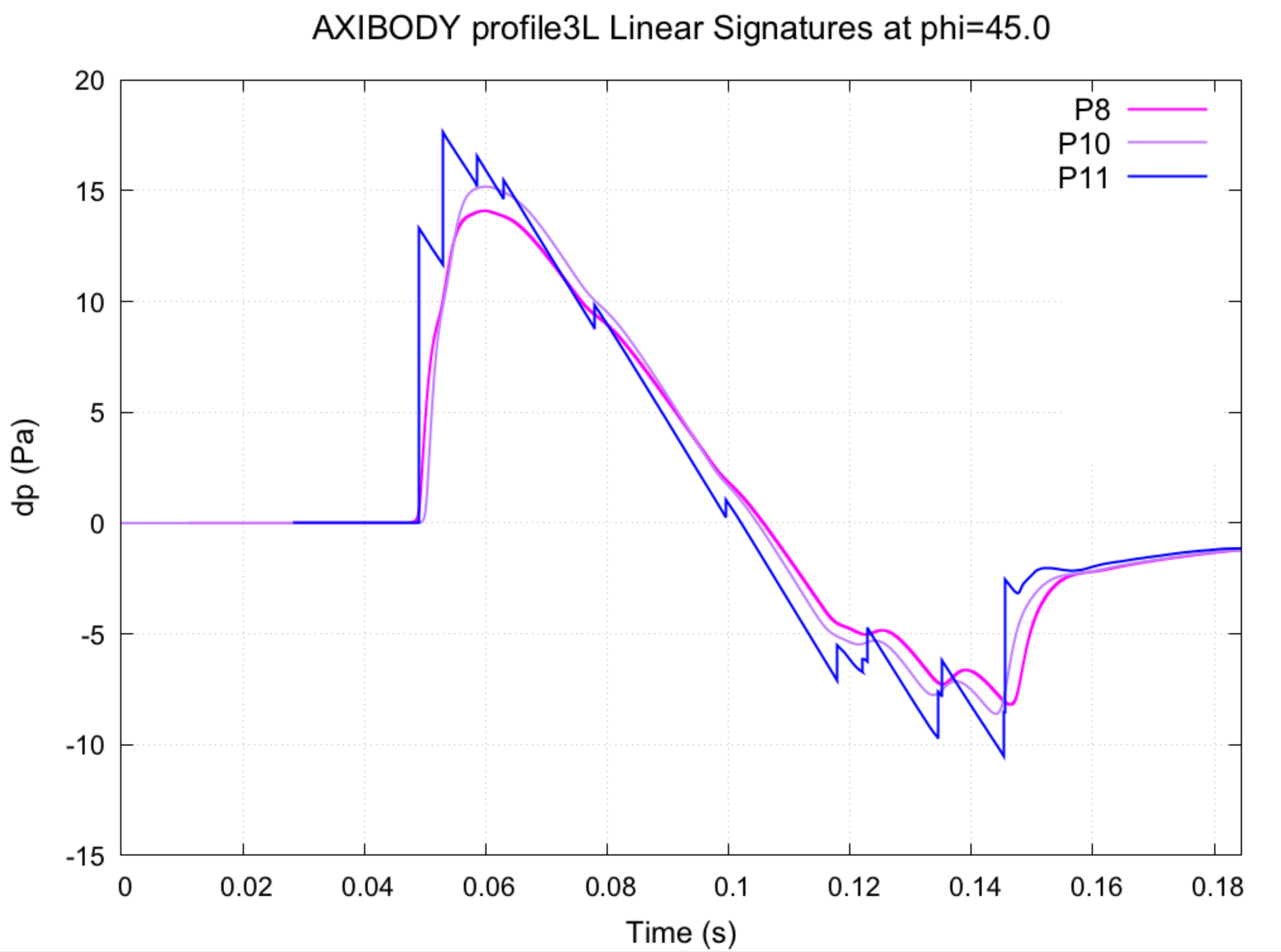
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile3, Hydrostatic, Phi = 45˚

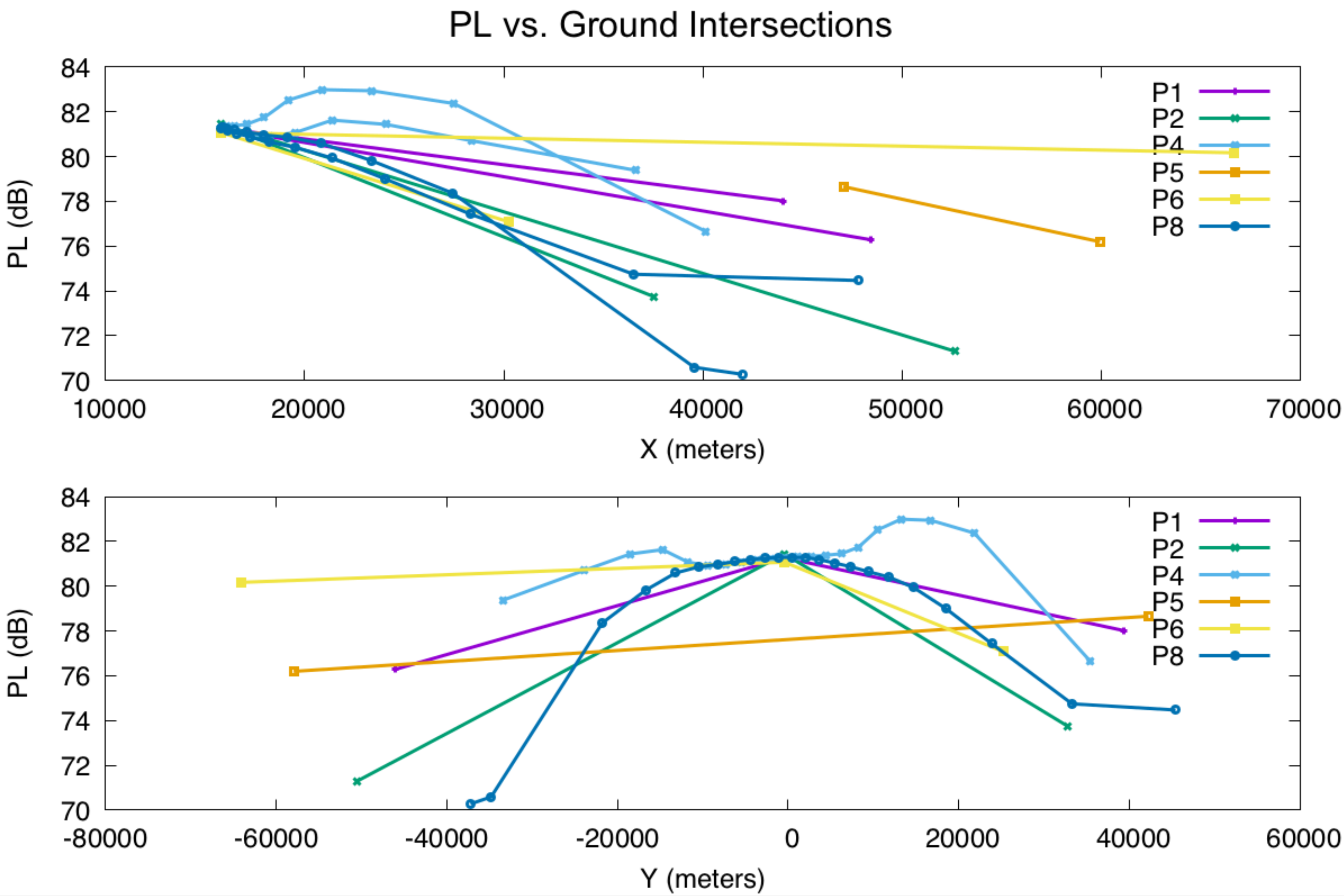


Sriram.Rallabhandi@nasa.gov

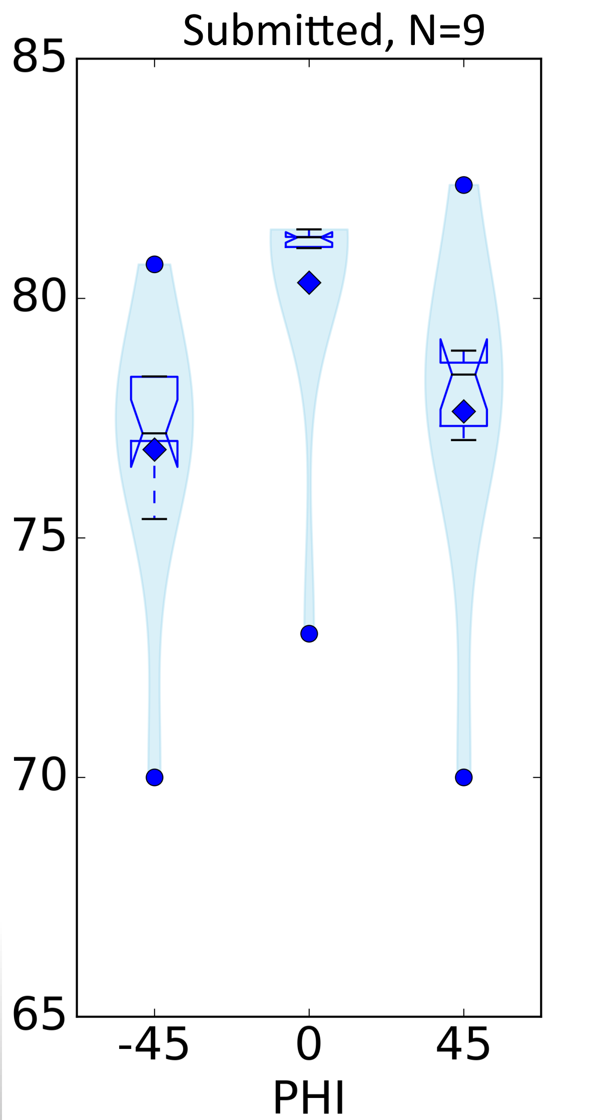
AXIBODY– Profile3, Linear, Phi = 45°

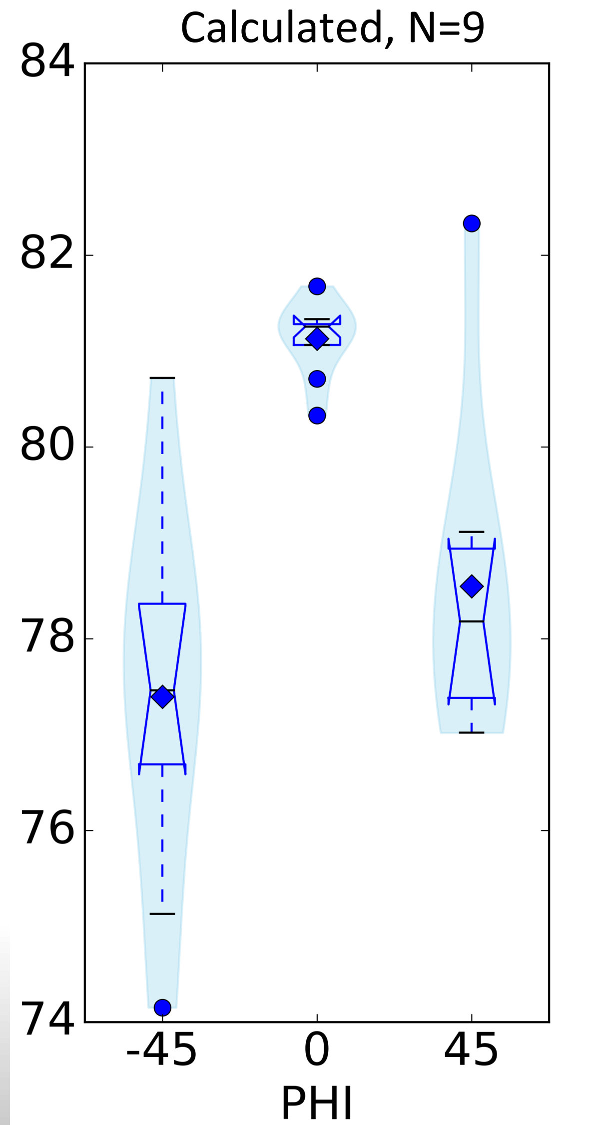


AXIBODY– Profile3, Hydrostatic, Ranges - PL



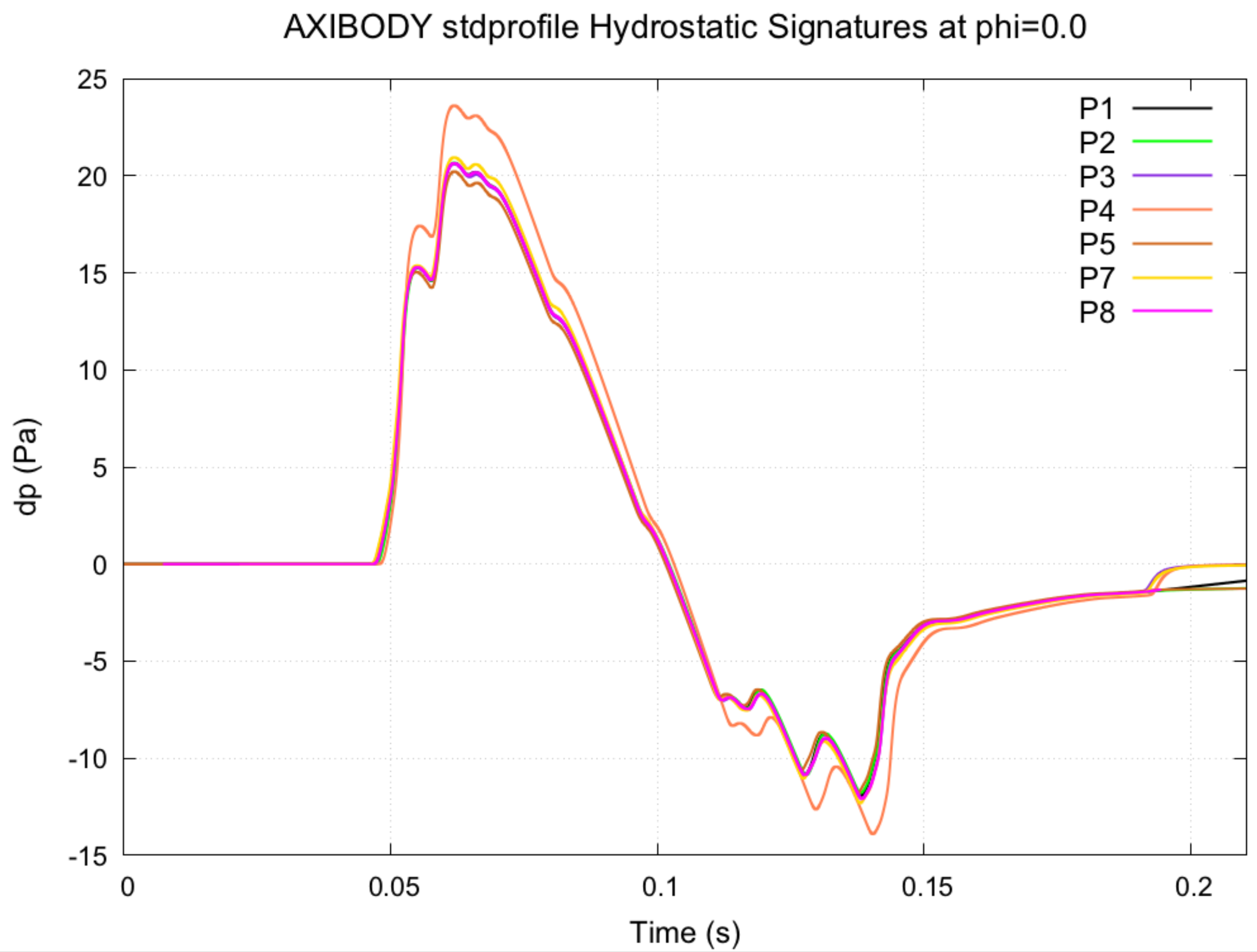
AXIBODY– Profile3, PL Statistics



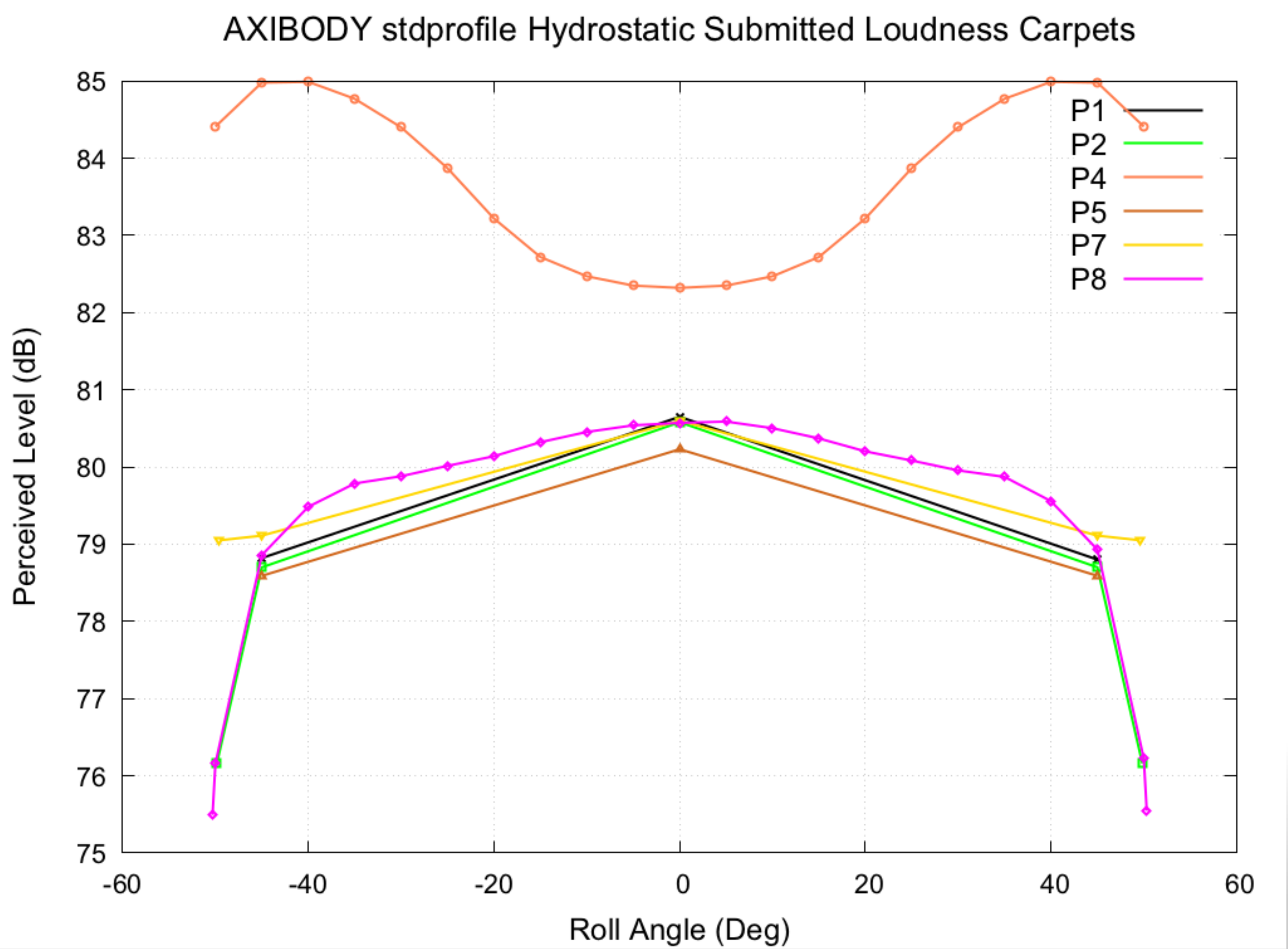


Sriram.Rallabhandi@nasa.gov

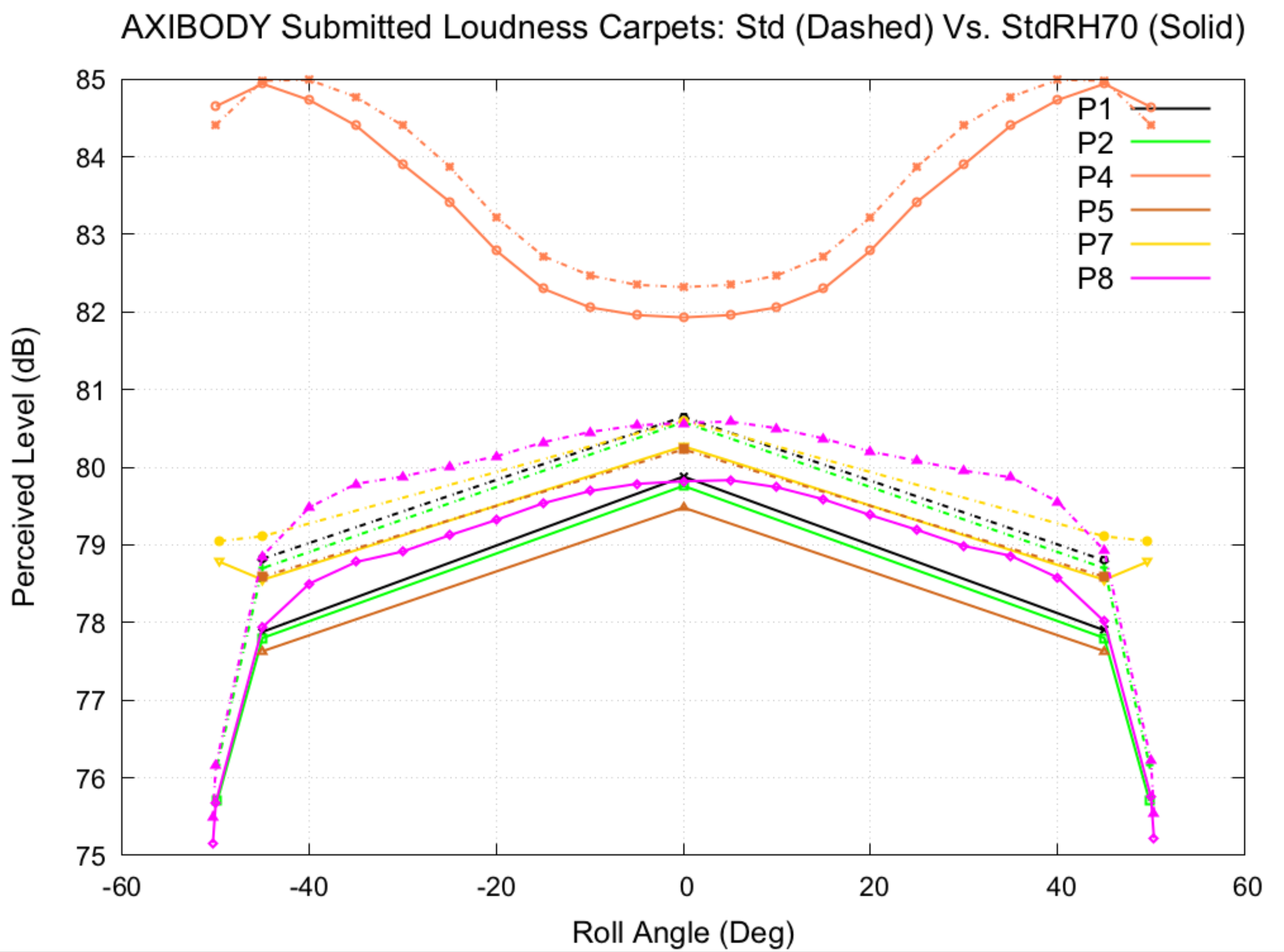
AXIBODY– StdProfile, Hydrostatic, Phi = 0˚



AXIBODY– StdProfile, Hydrostatic, Carpet PL

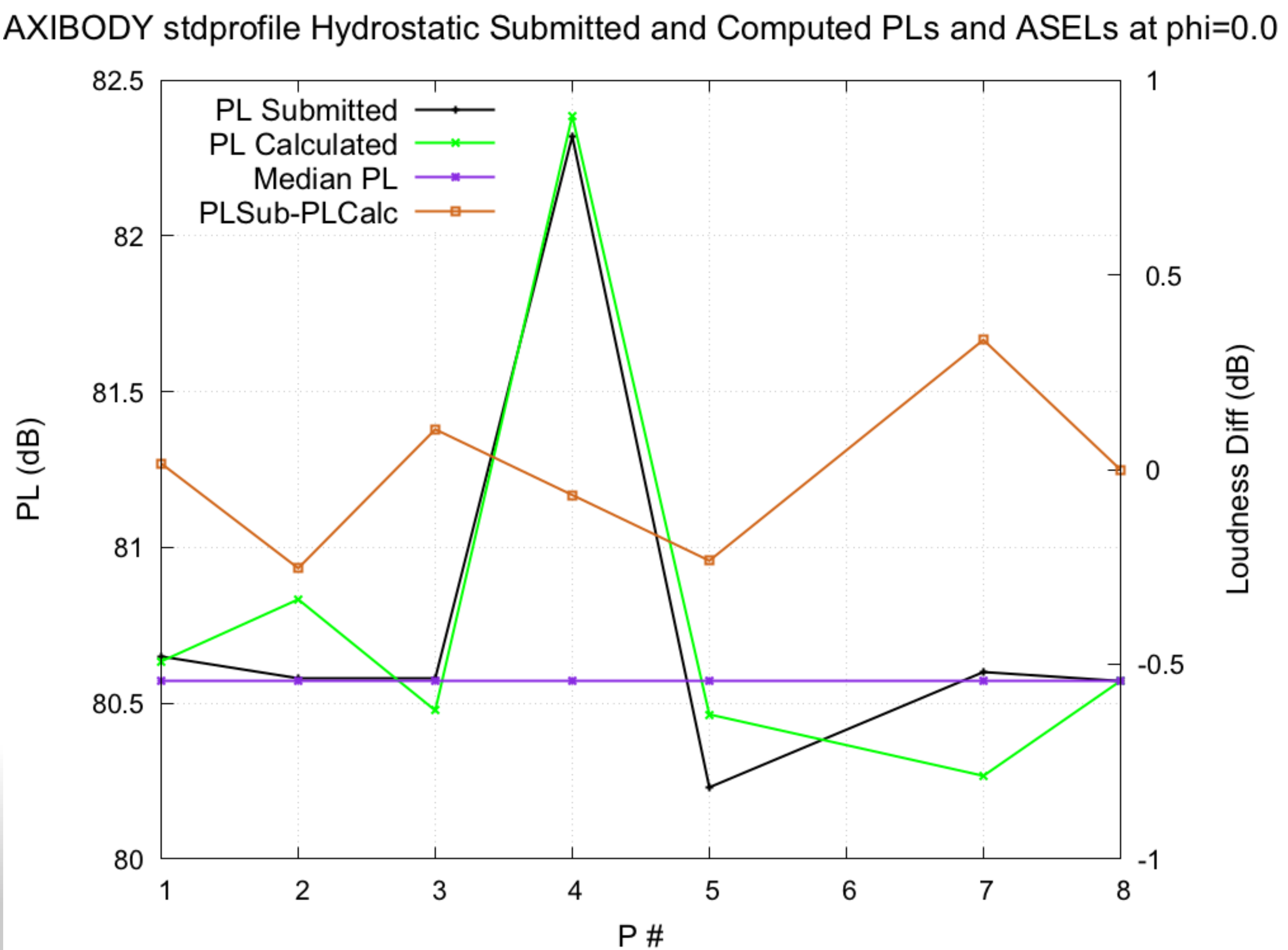


AXIBODY– Carpet PLs, Std Vs. StdRH70

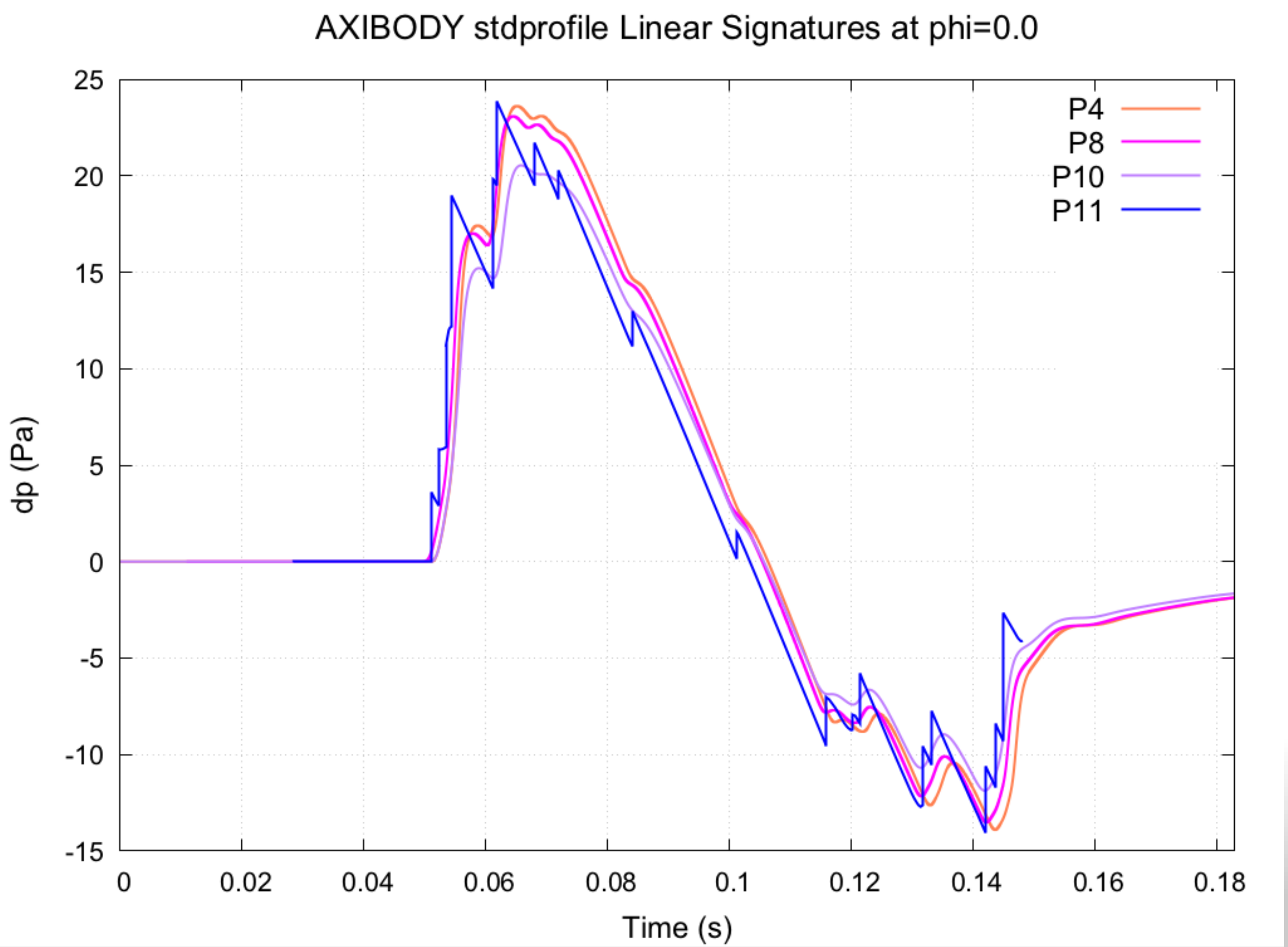


Sriram.Rallabhandi@nasa.gov

AXIBODY– StdProfile, Hydrostatic, Phi = 0˚

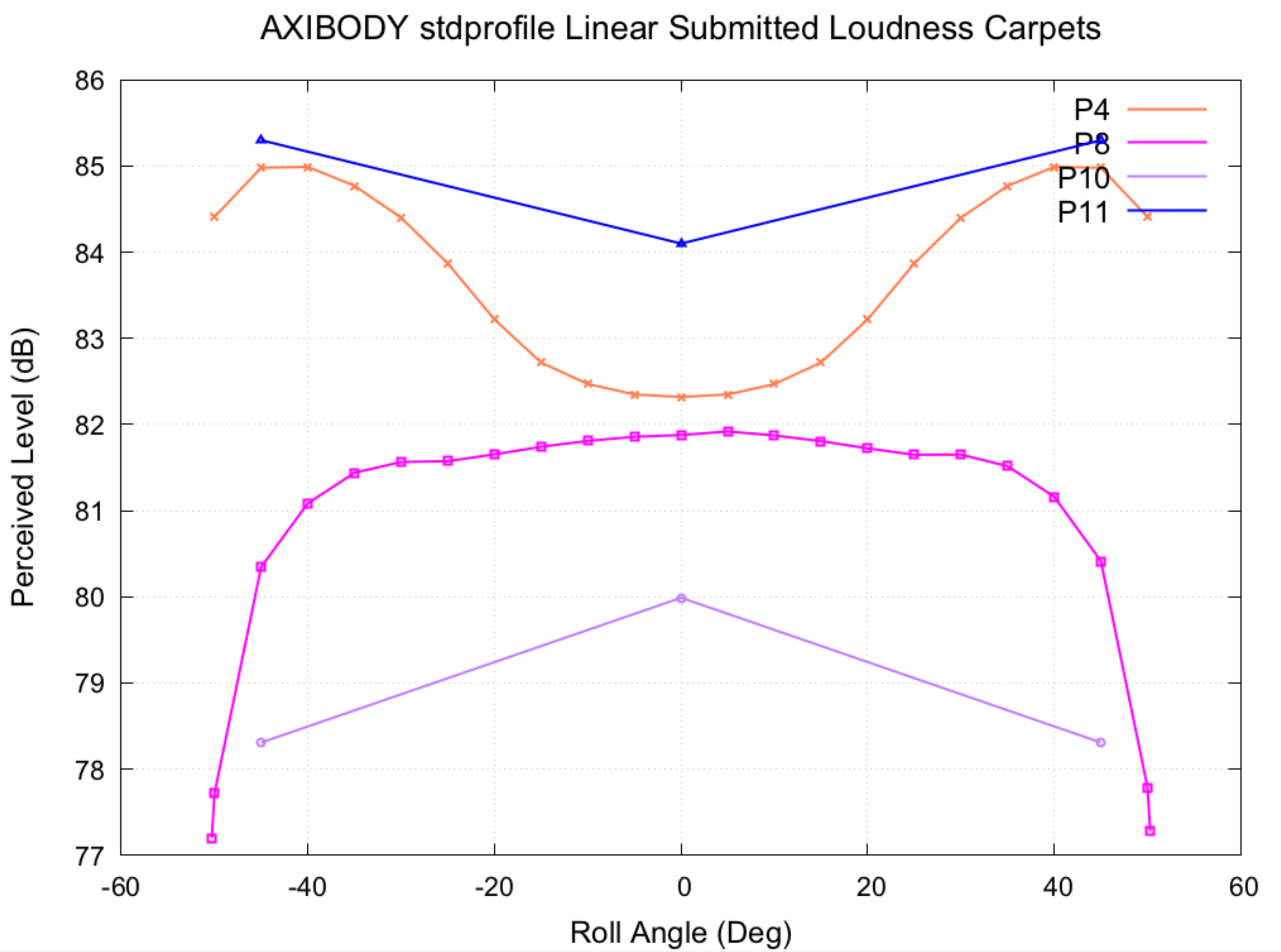


AXIBODY– StdProfile, Linear, Phi = 0°



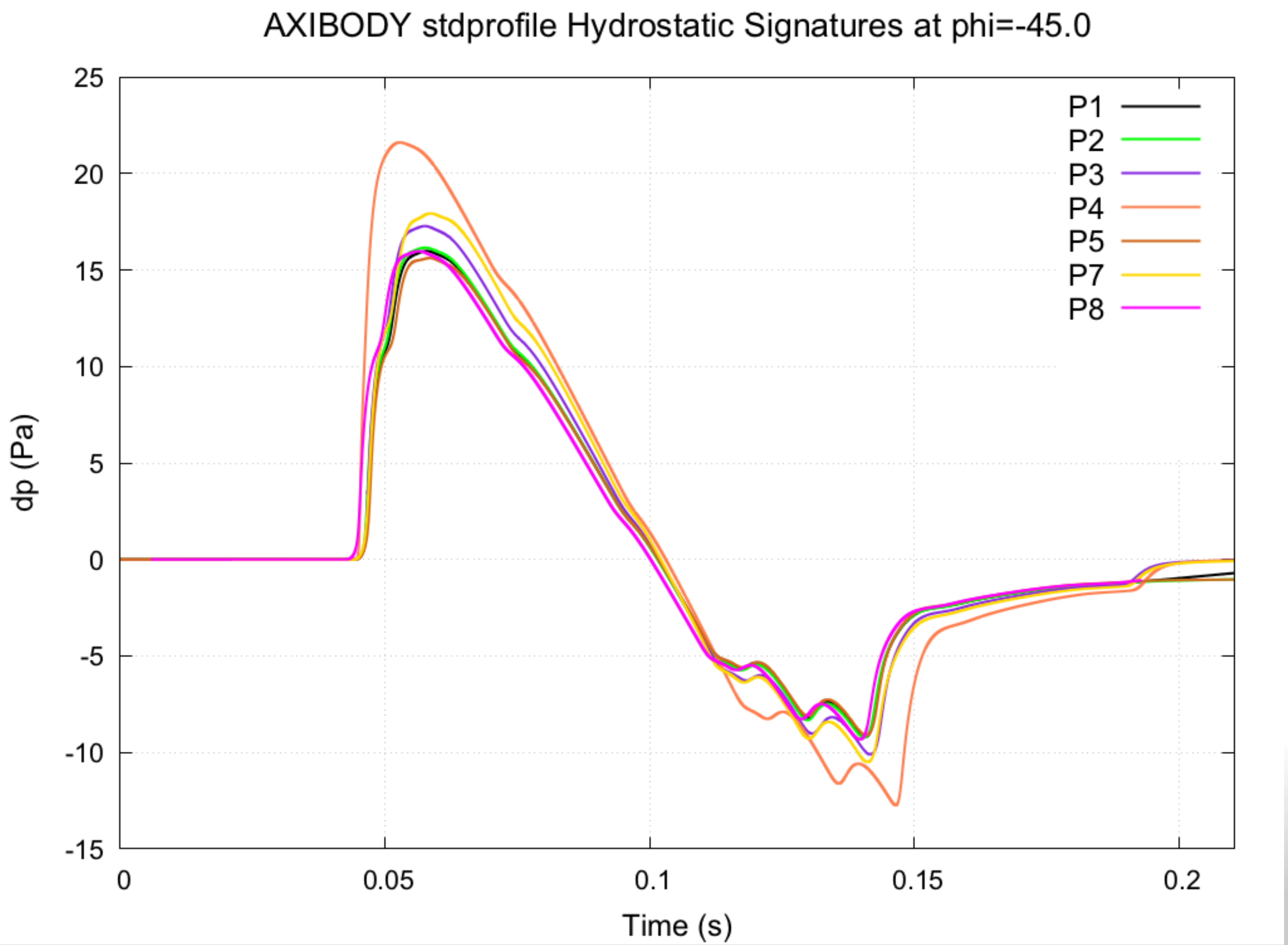
Sriram.Rallabhandi@nasa.gov

AXIBODY– StdProfile, Linear, Carpet PL

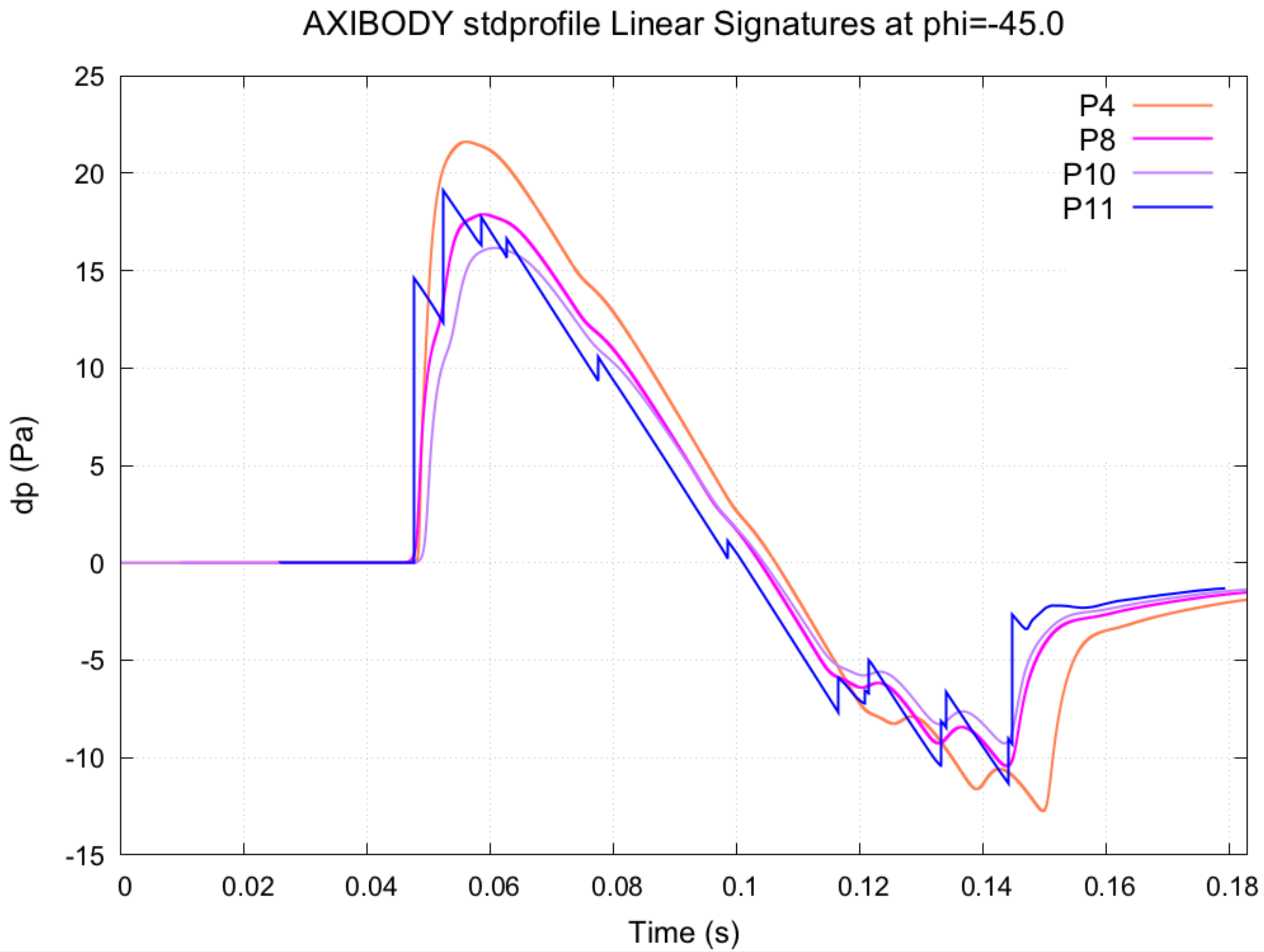


Sriram.Rallabhandi@nasa.gov

AXIBODY– StdProfile, Hydrostatic, Phi = -45°

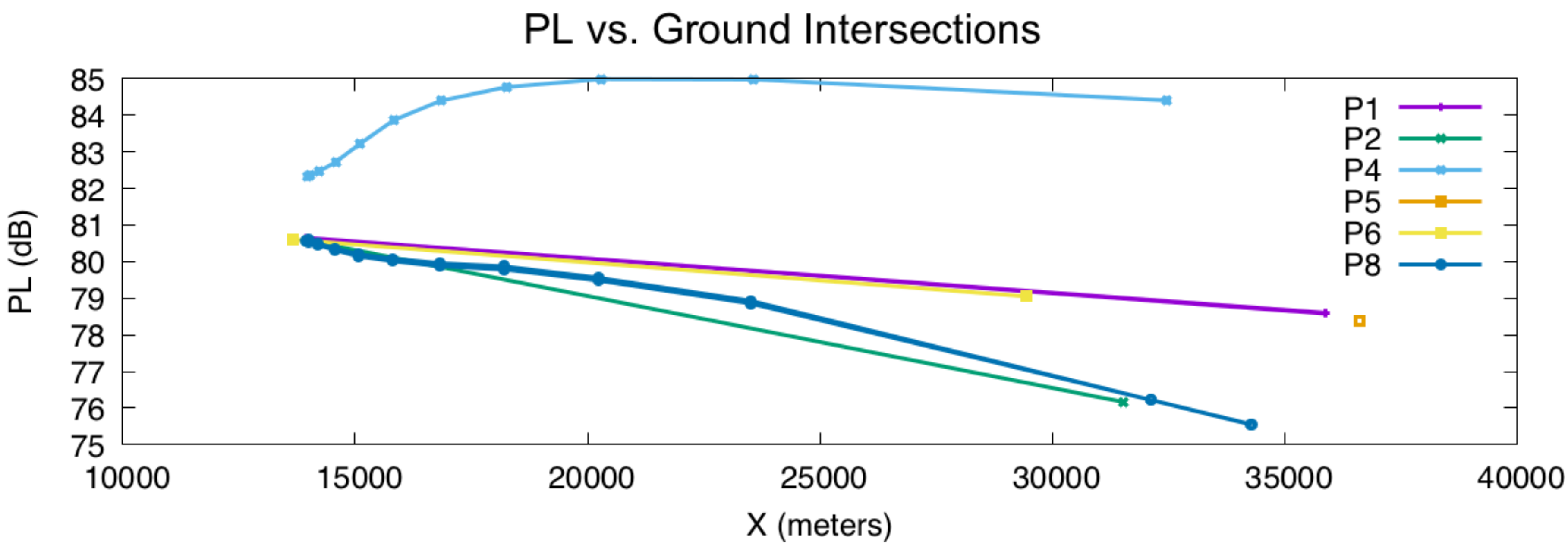


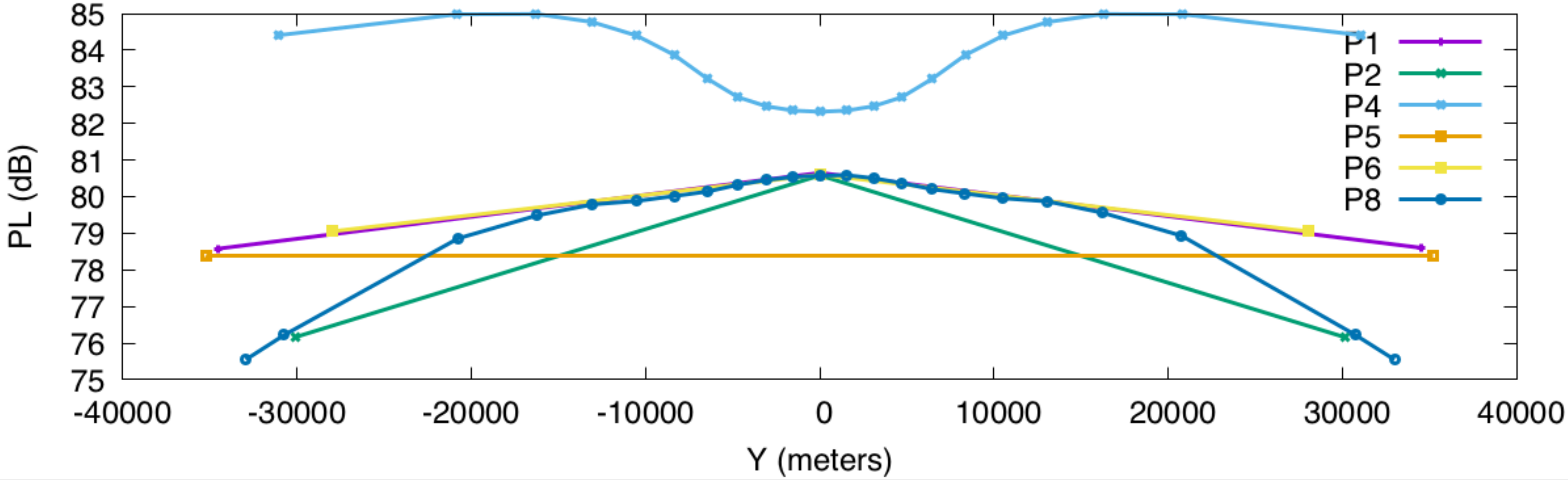
AXIBODY– StdProfile, Linear, Phi = -45°



Sriram.Rallabhandi@nasa.gov

AXIBODY– StdProfile, Hydrostatic, Ranges - PL

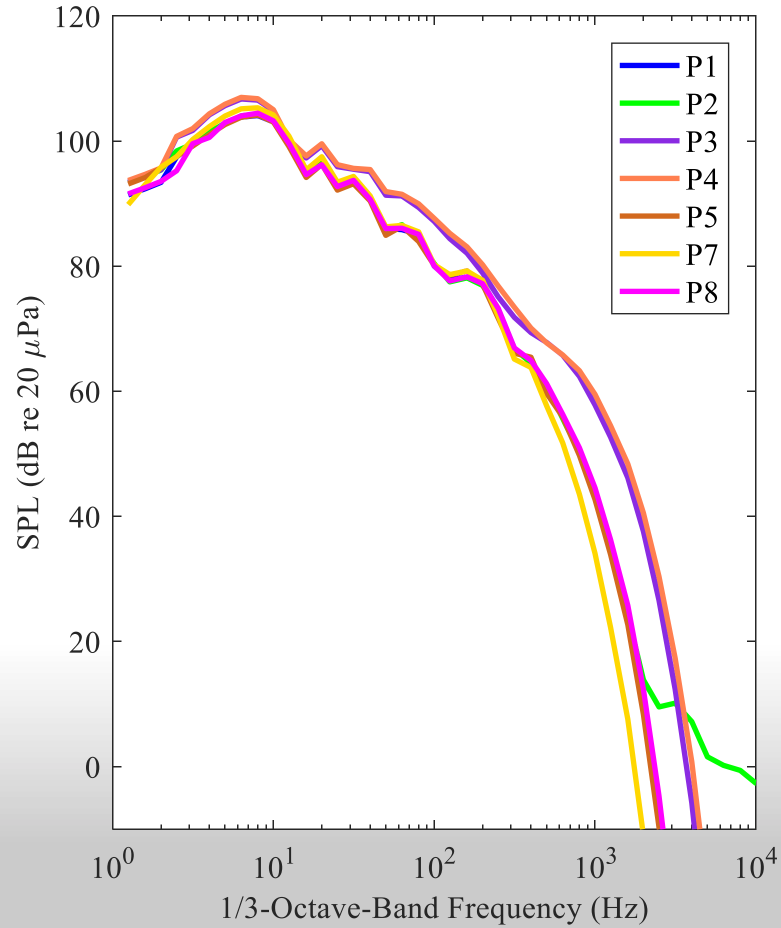




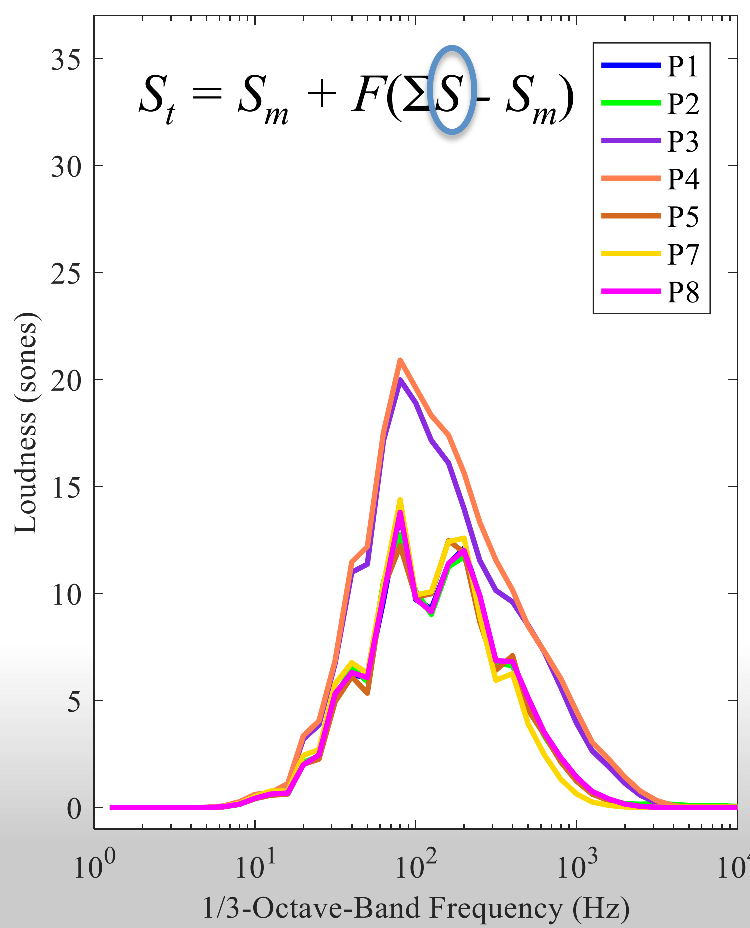
Sriram.Rallabhandi@nasa.gov

1/3-Octave-Band and Loudness Spectra

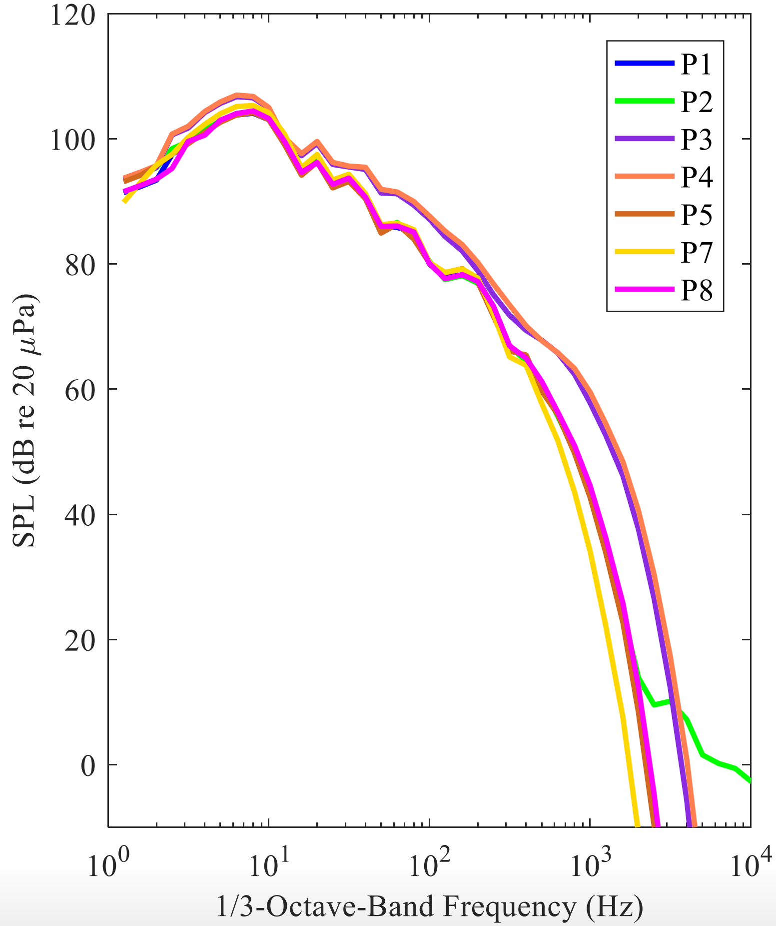
Spectra indicate the energy in different 1/3-octave frequency bands

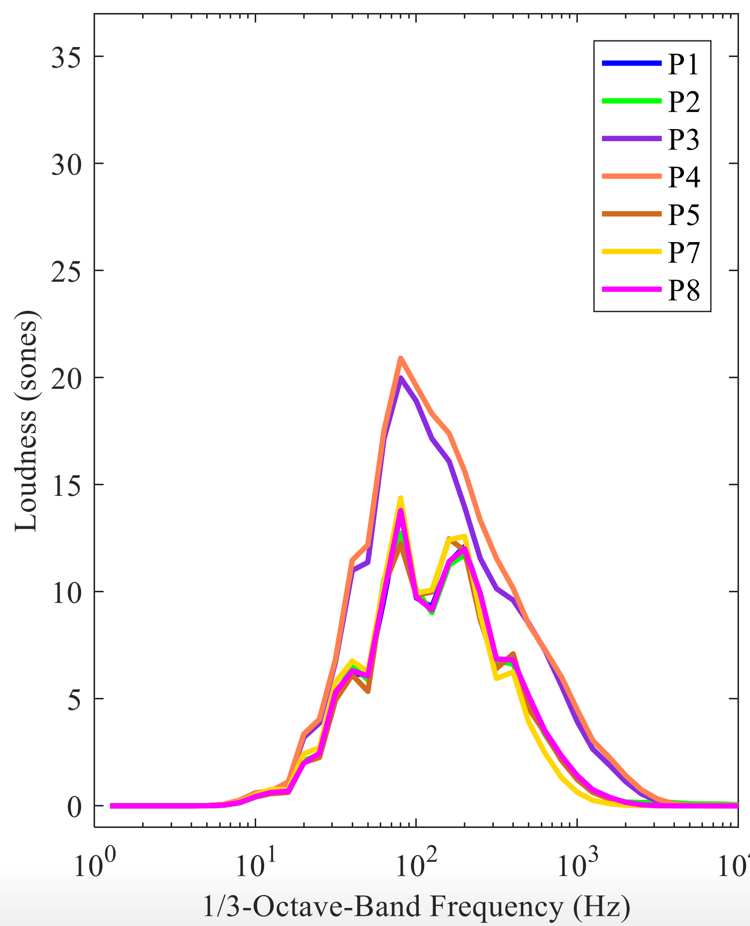


Loudness spectra indicate the frequency bands which are most important to the calculation of PL (which approximates the sensitivity of human hearing)

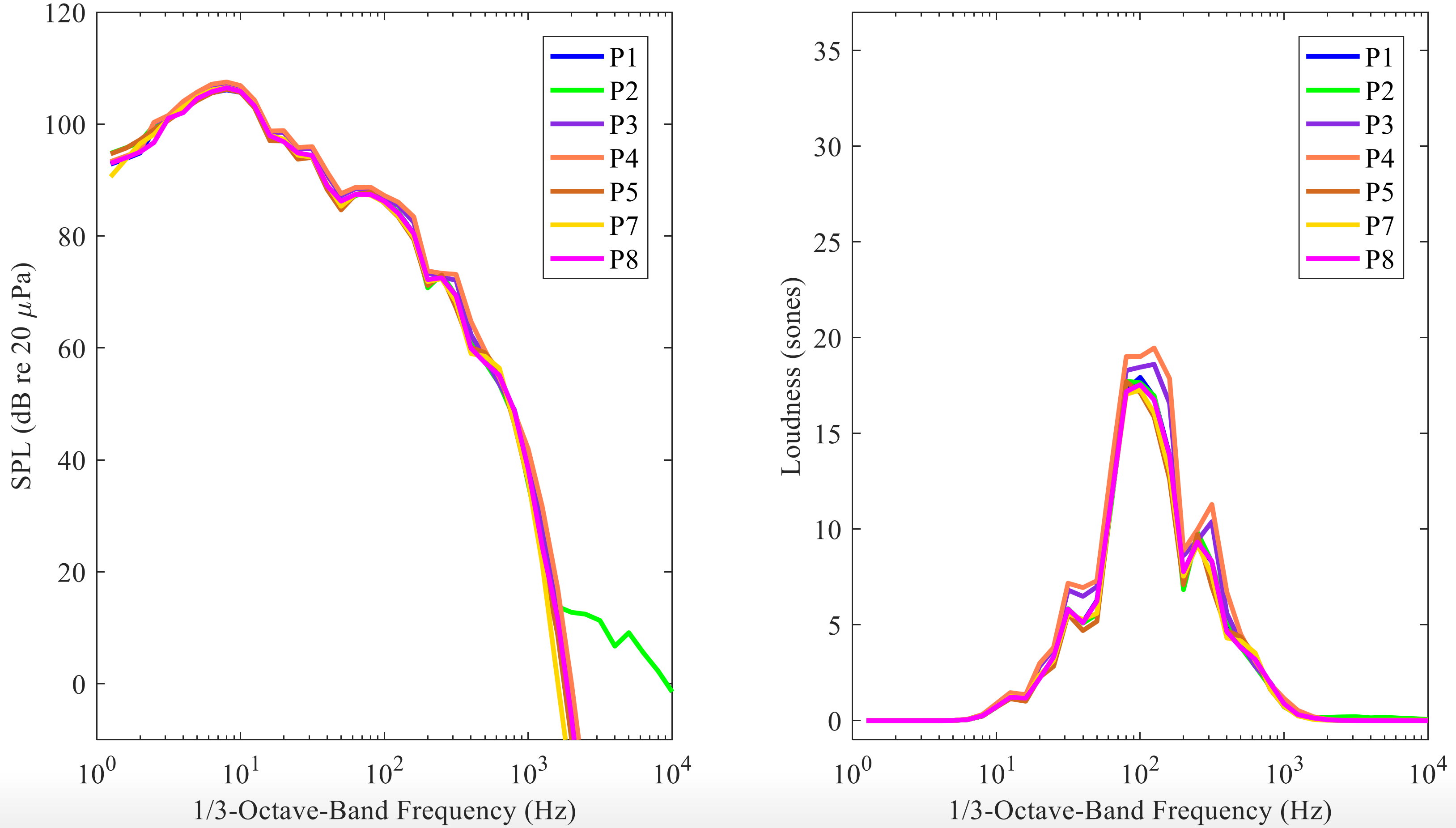


Axi-symmetric, Standard Atm, Phi = -45°

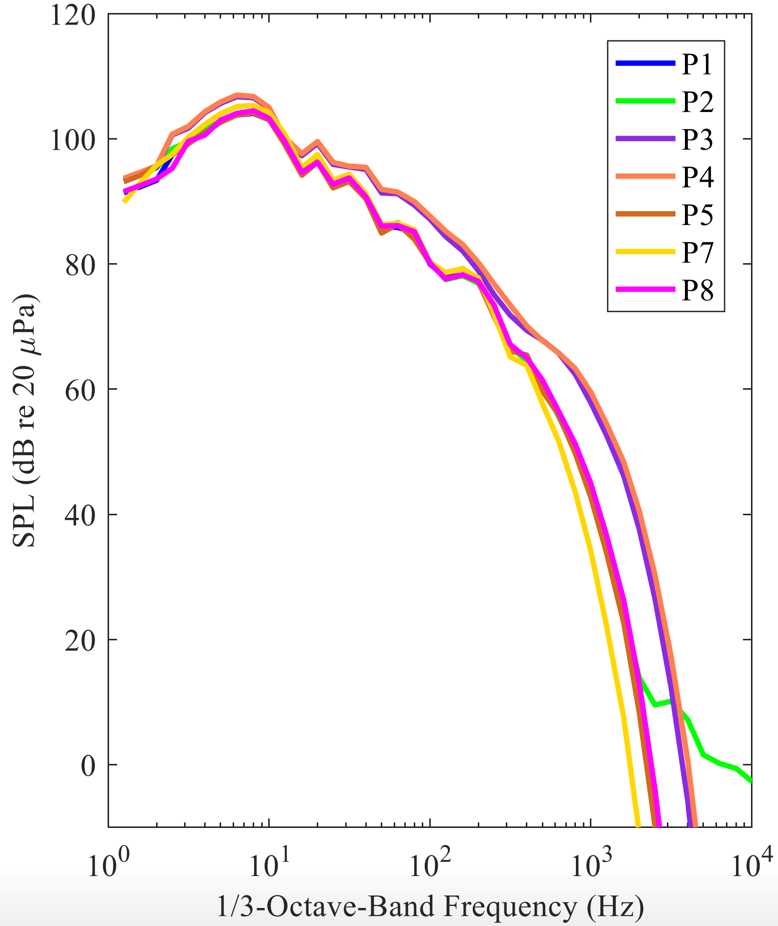


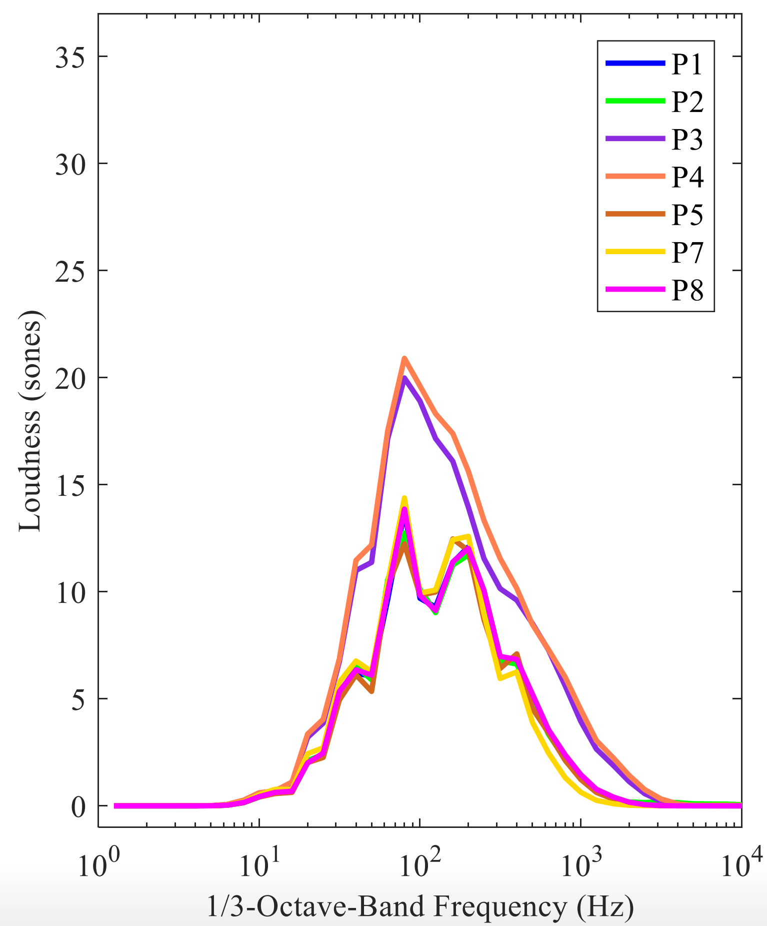


Axi-symmetric, Standard Atm, Phi = 0°

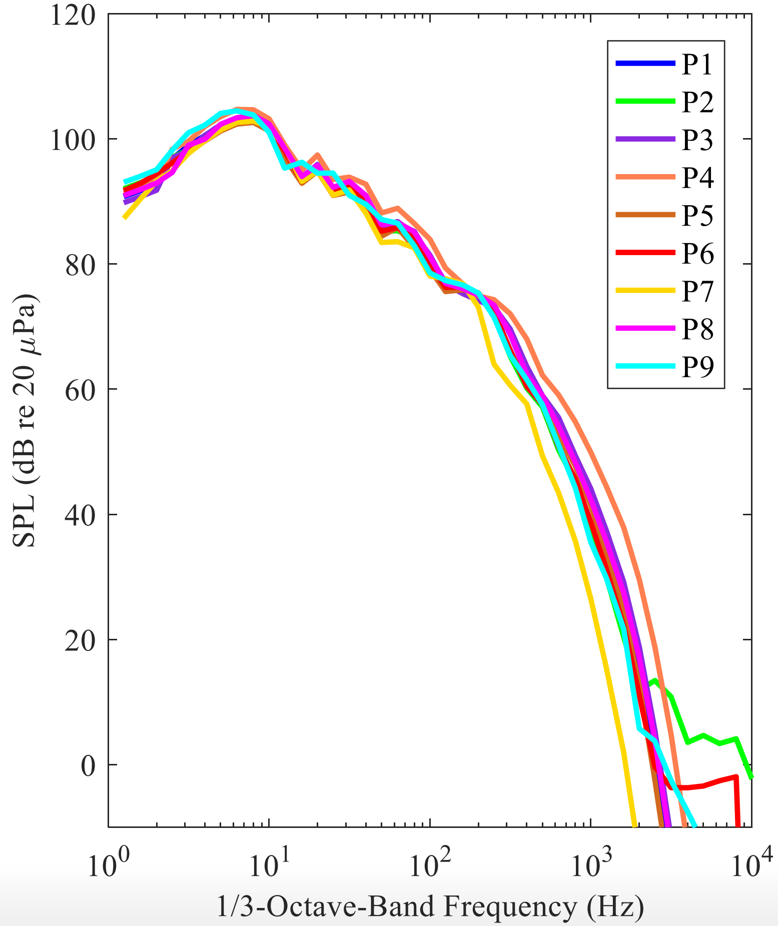


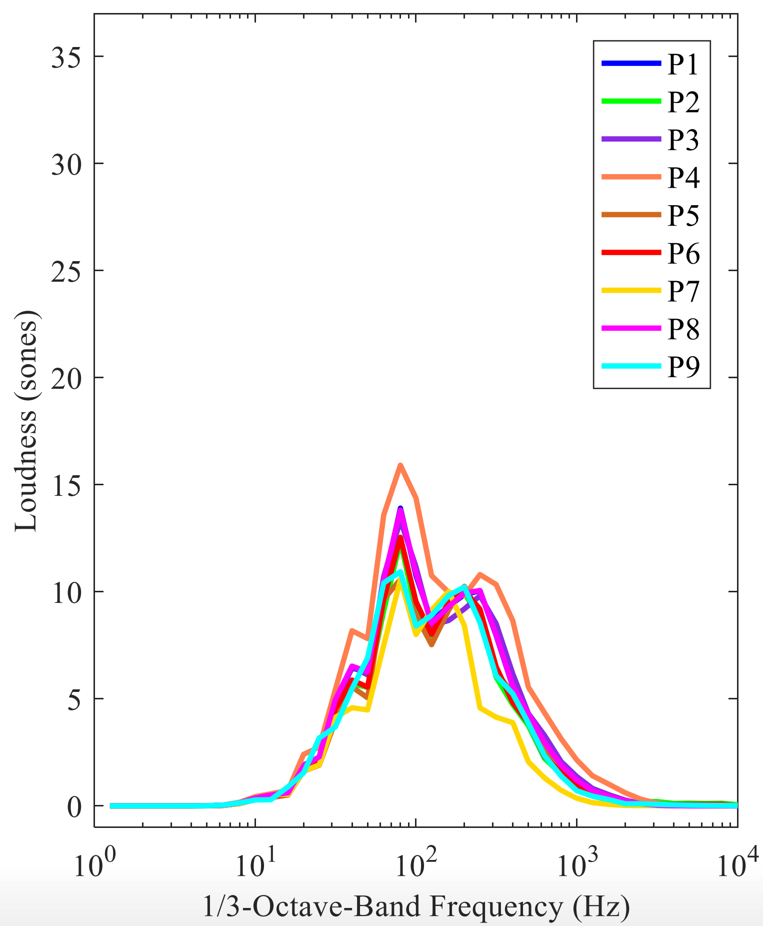
Axi-symmetric, Standard Atm, Phi = +45°



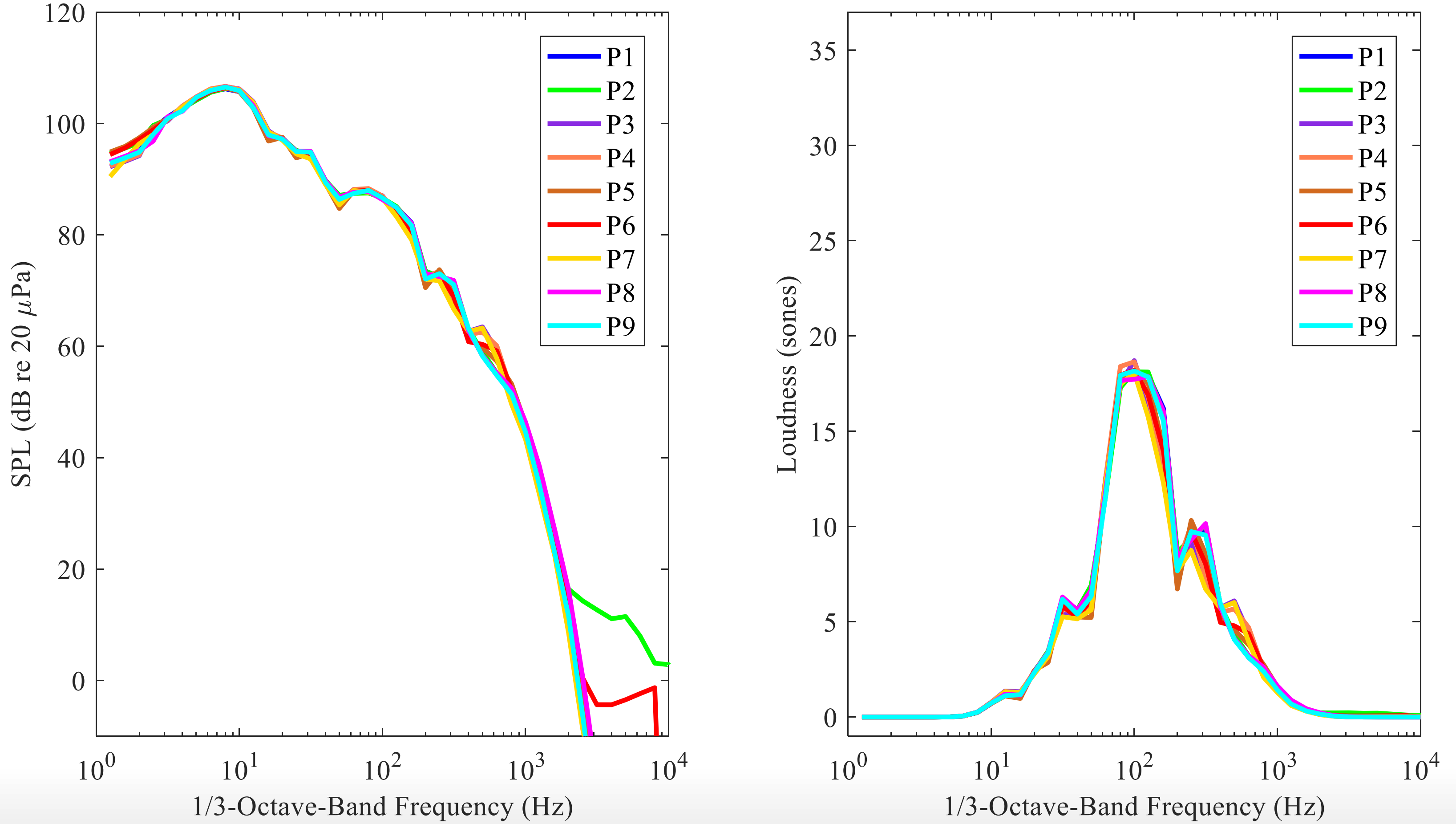


Axi-symmetric, Atm Profile 3, Phi = -45°

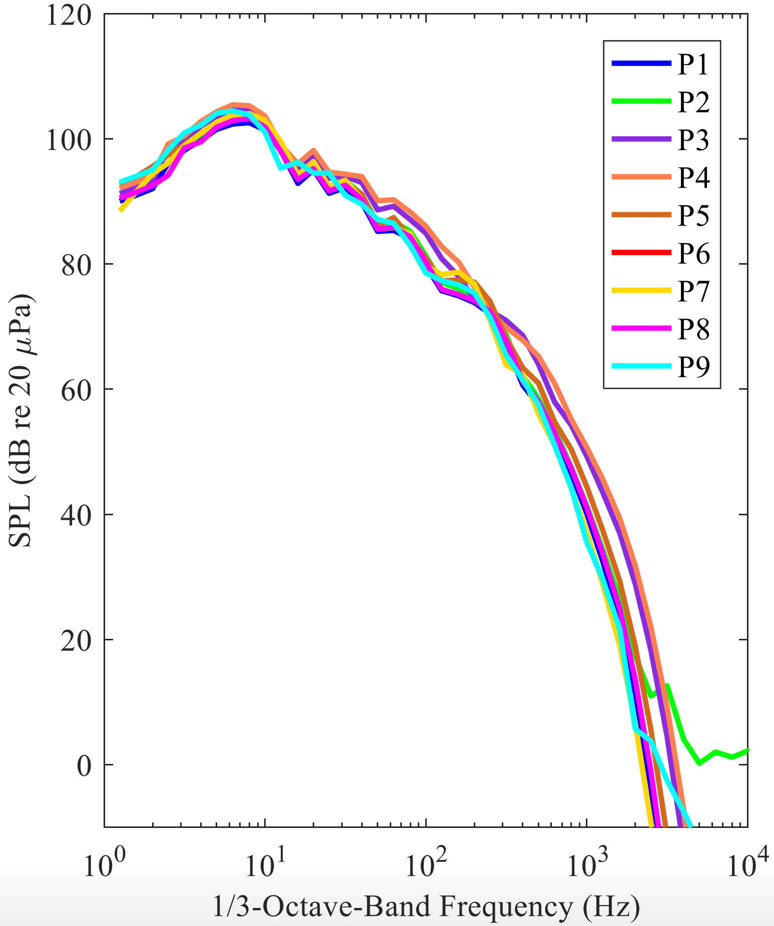


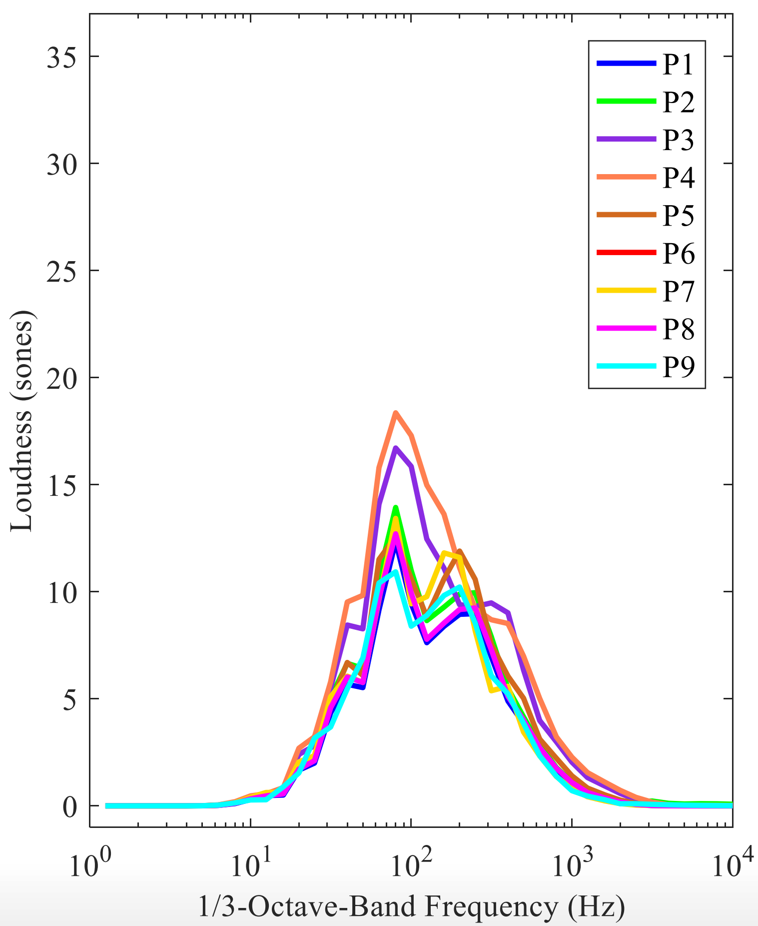


Axi-symmetric, Atm Profile 3, Phi = 0˚

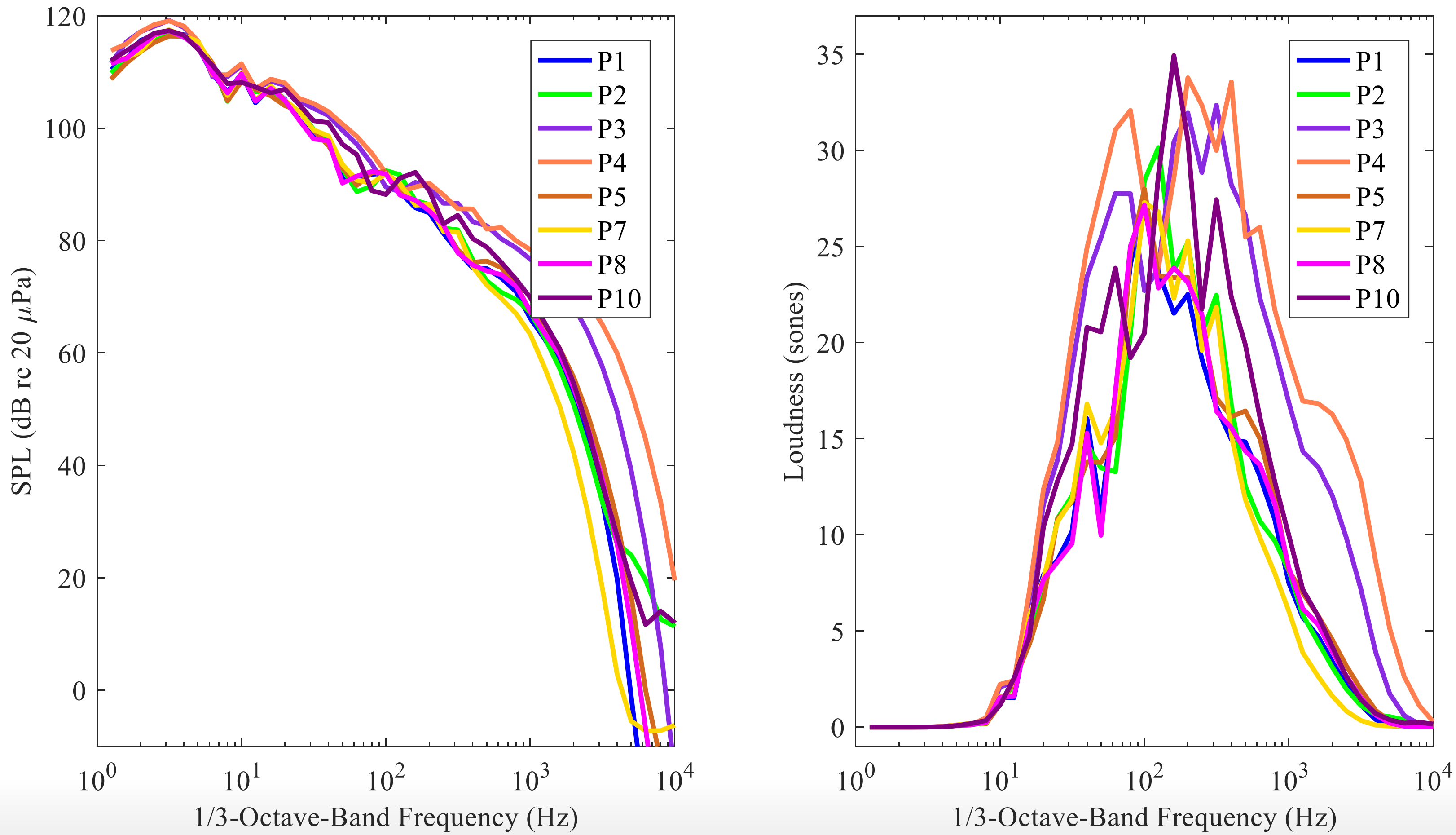


Axi-symmetric, Atm Profile 3, Phi = +45°

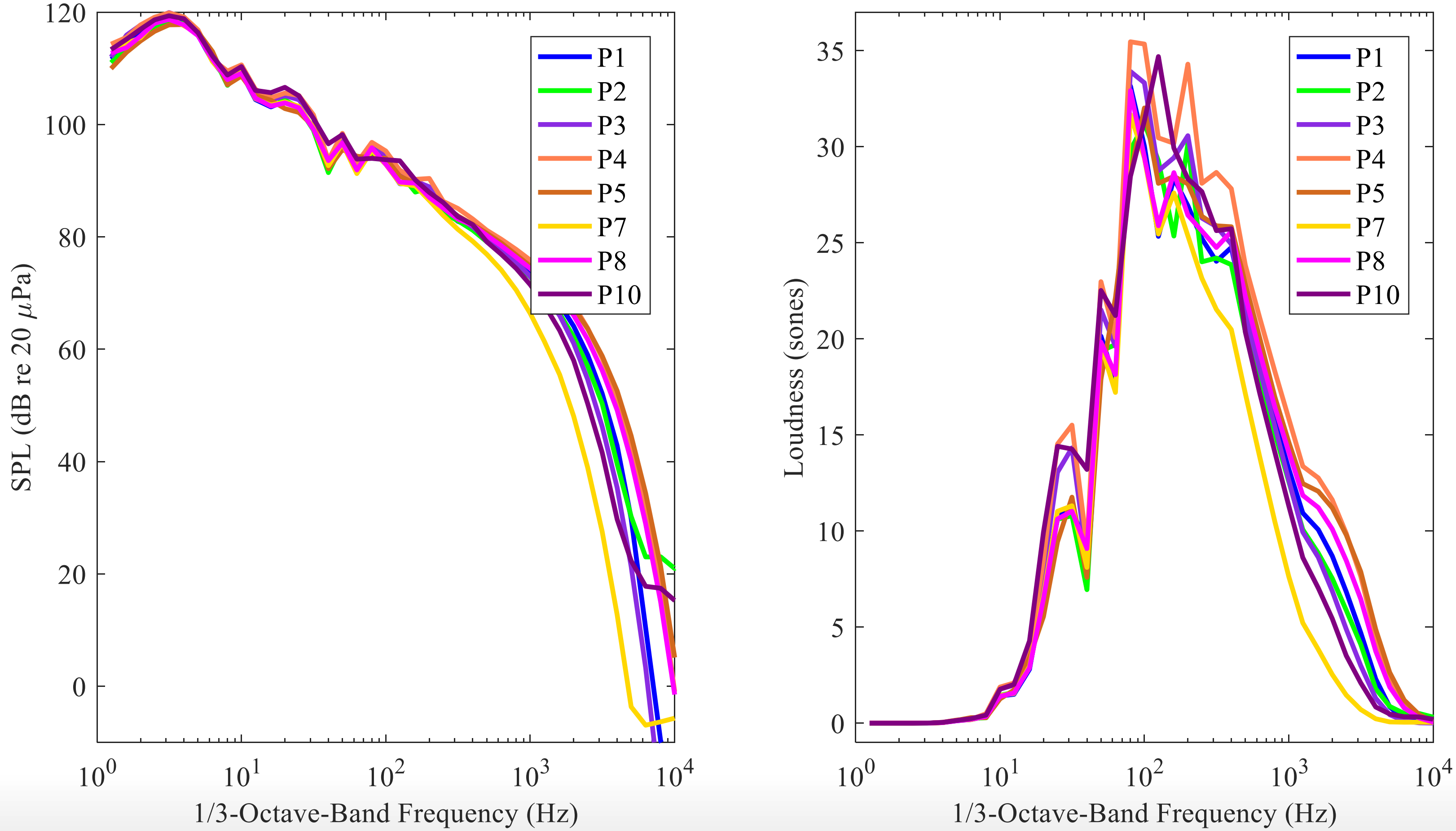




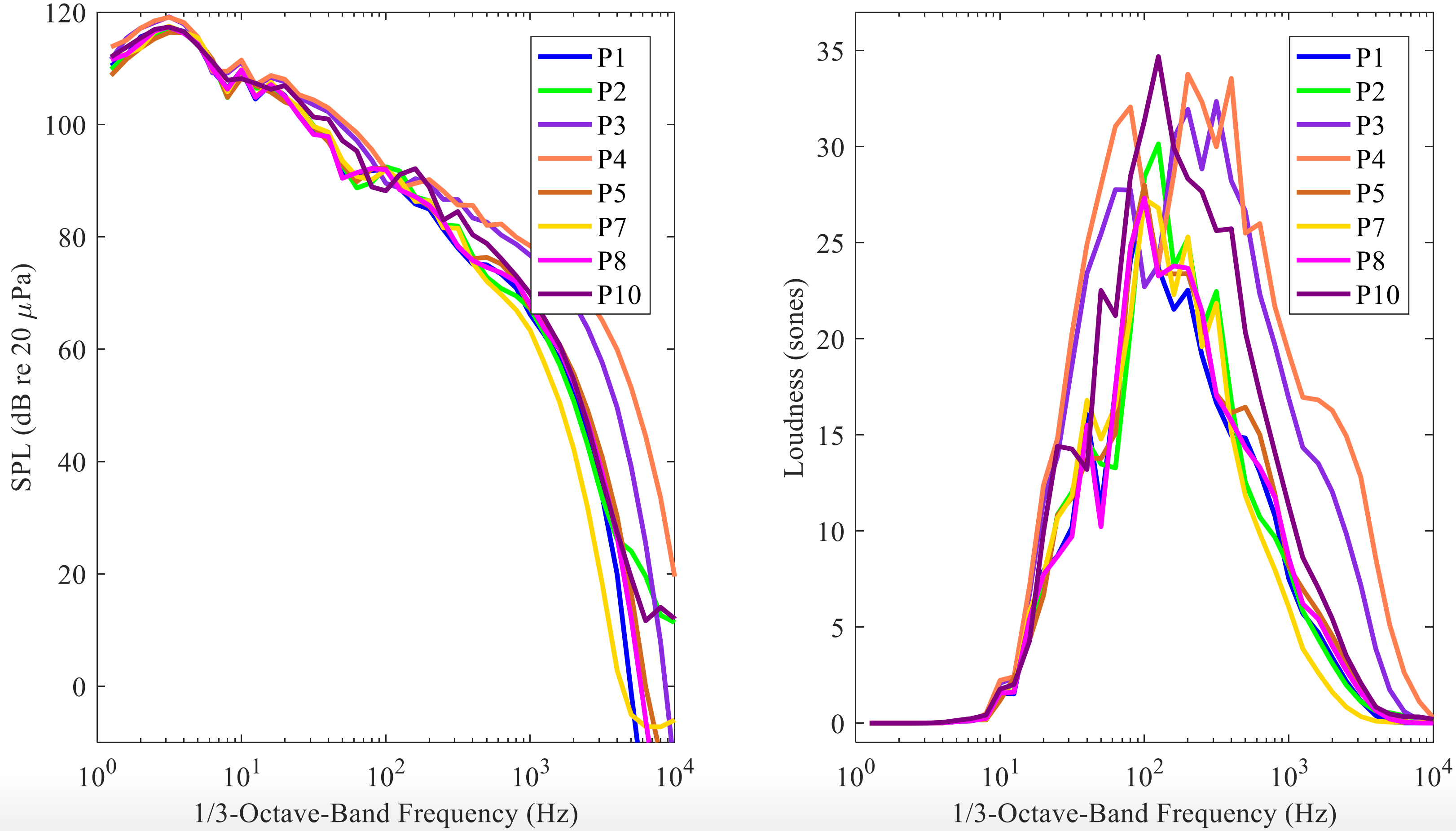
LM1021, Standard Atm, Phi = -30˚



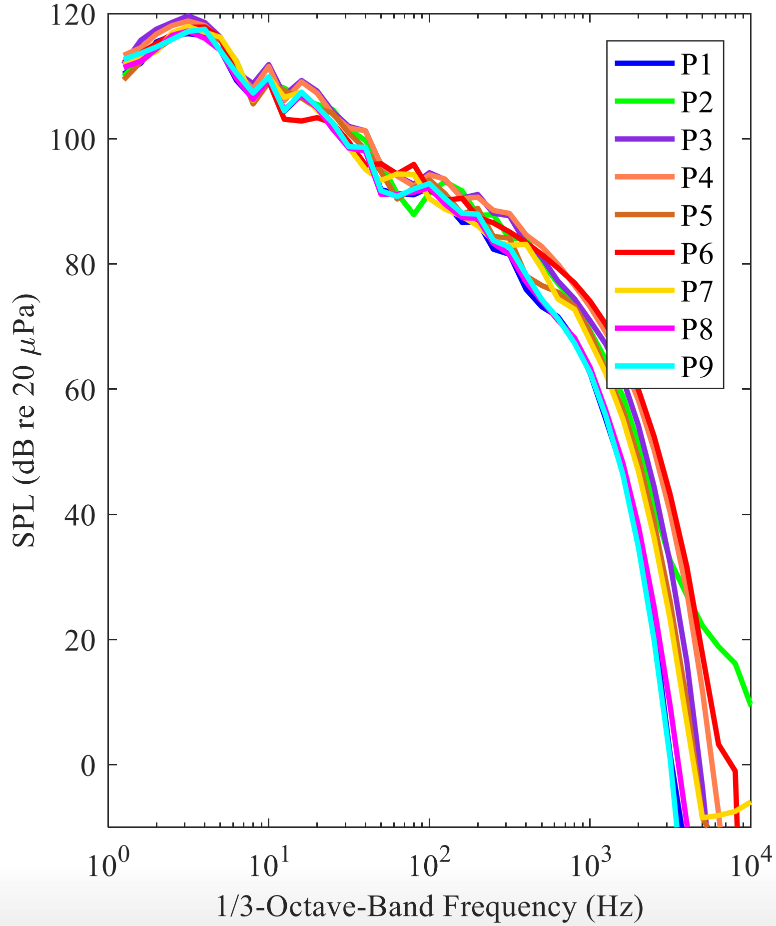
LM1021, Standard Atm, Phi = 0°

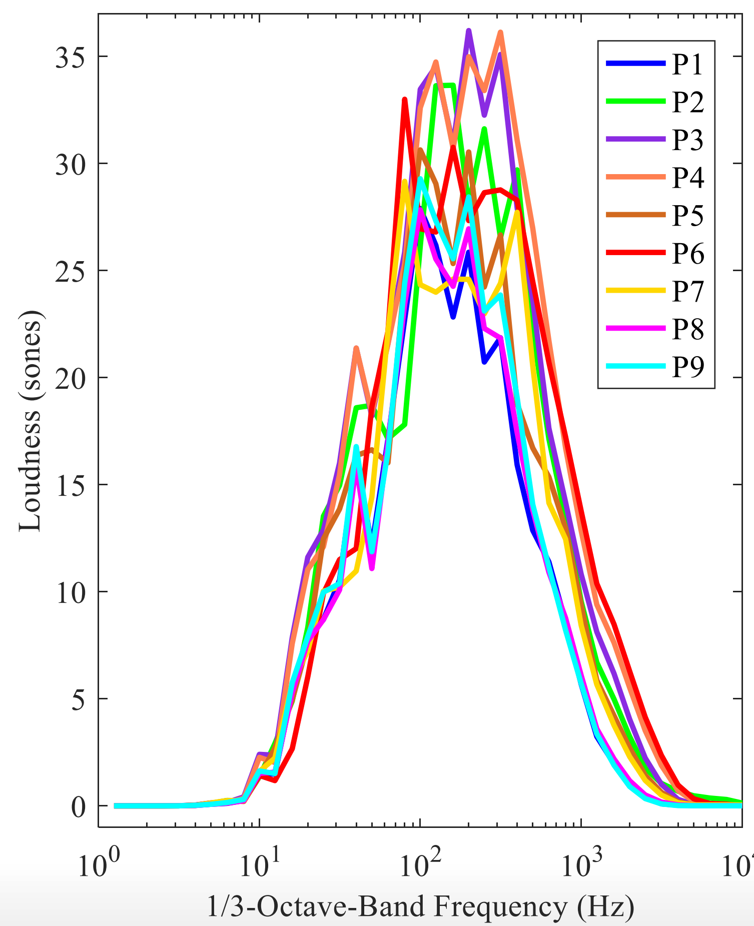


LM1021, Standard Atm, Phi = +30°

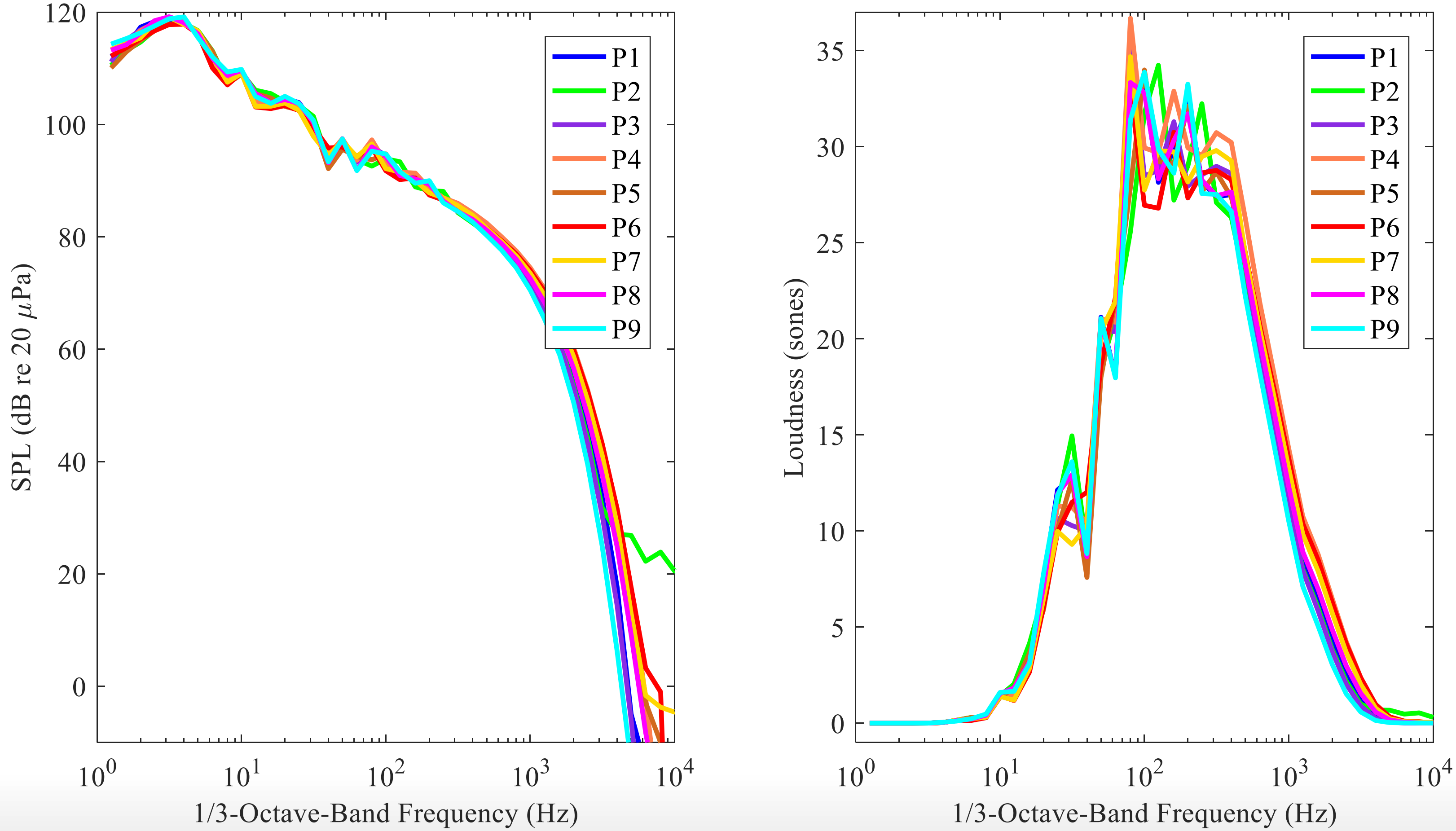


LM1021, Atm Profile 1, Phi = -30°

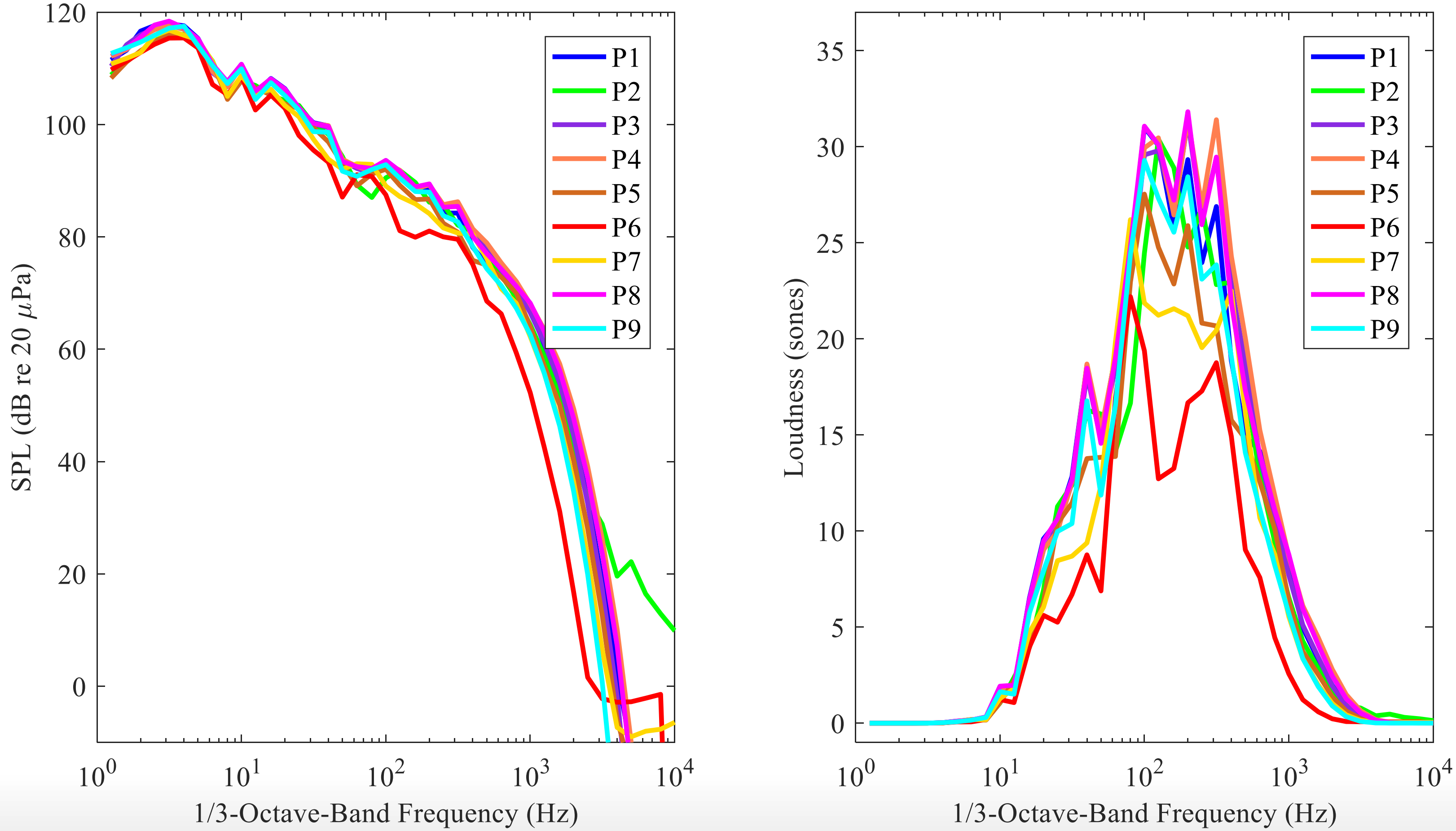




LM1021, Atm Profile 1, Phi = 0°

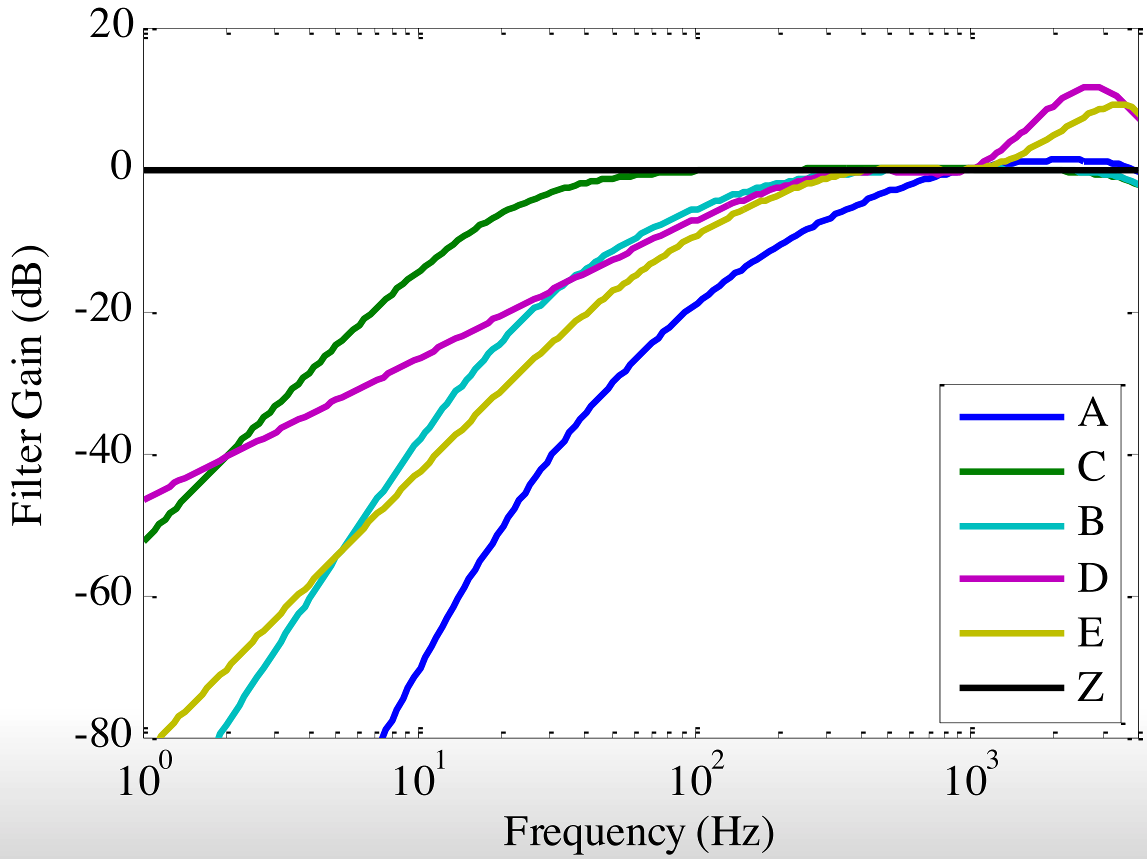


LM1021, Atm Profile 1, Phi = +30°



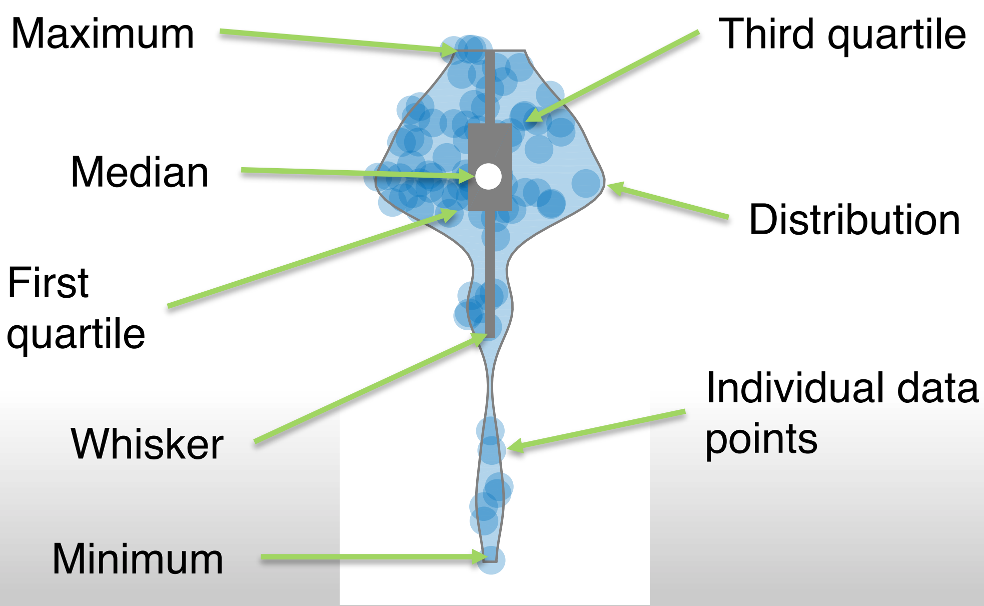
Noise Metrics Analysis

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



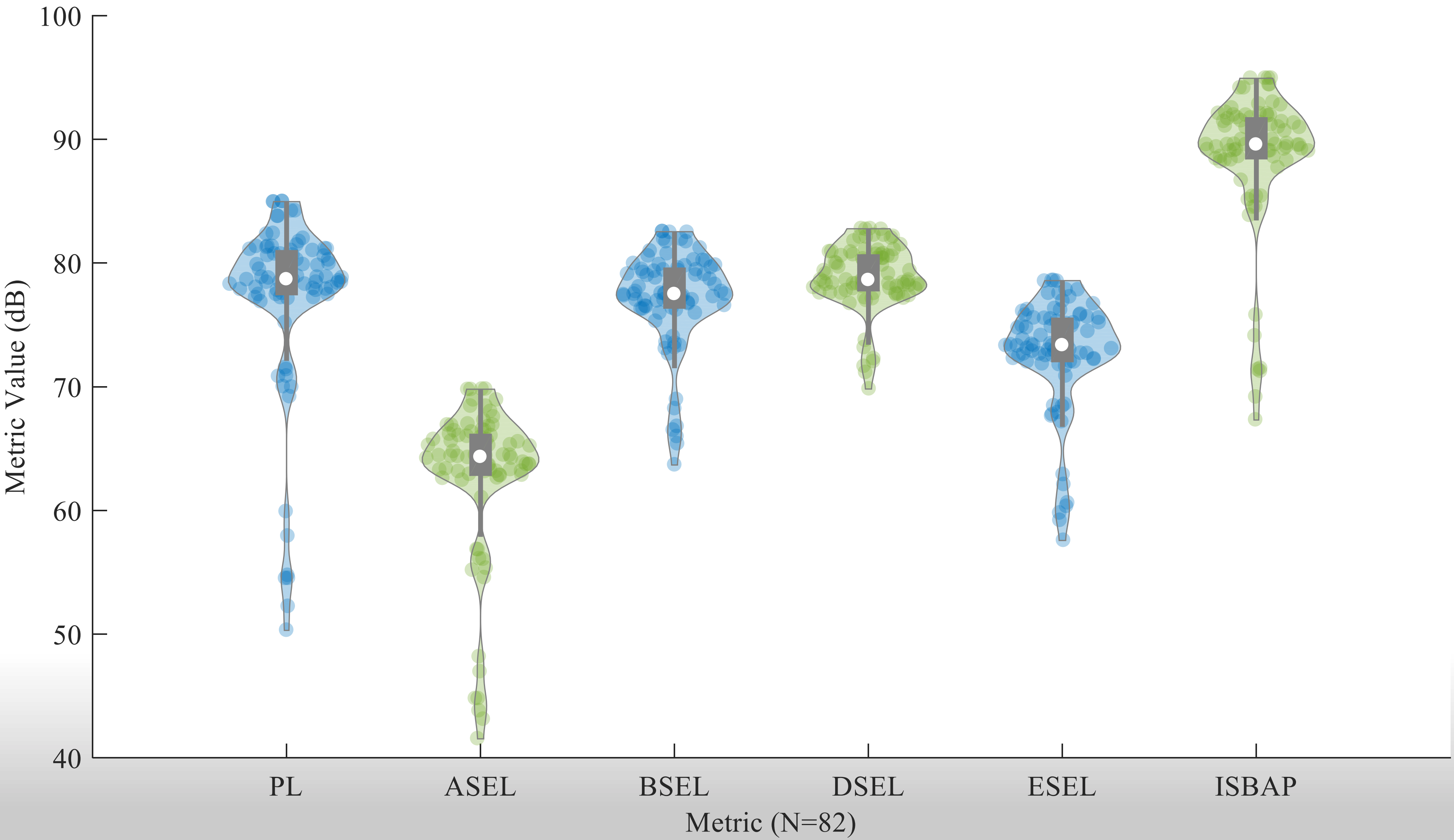
Noise Metrics Analysis

- 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

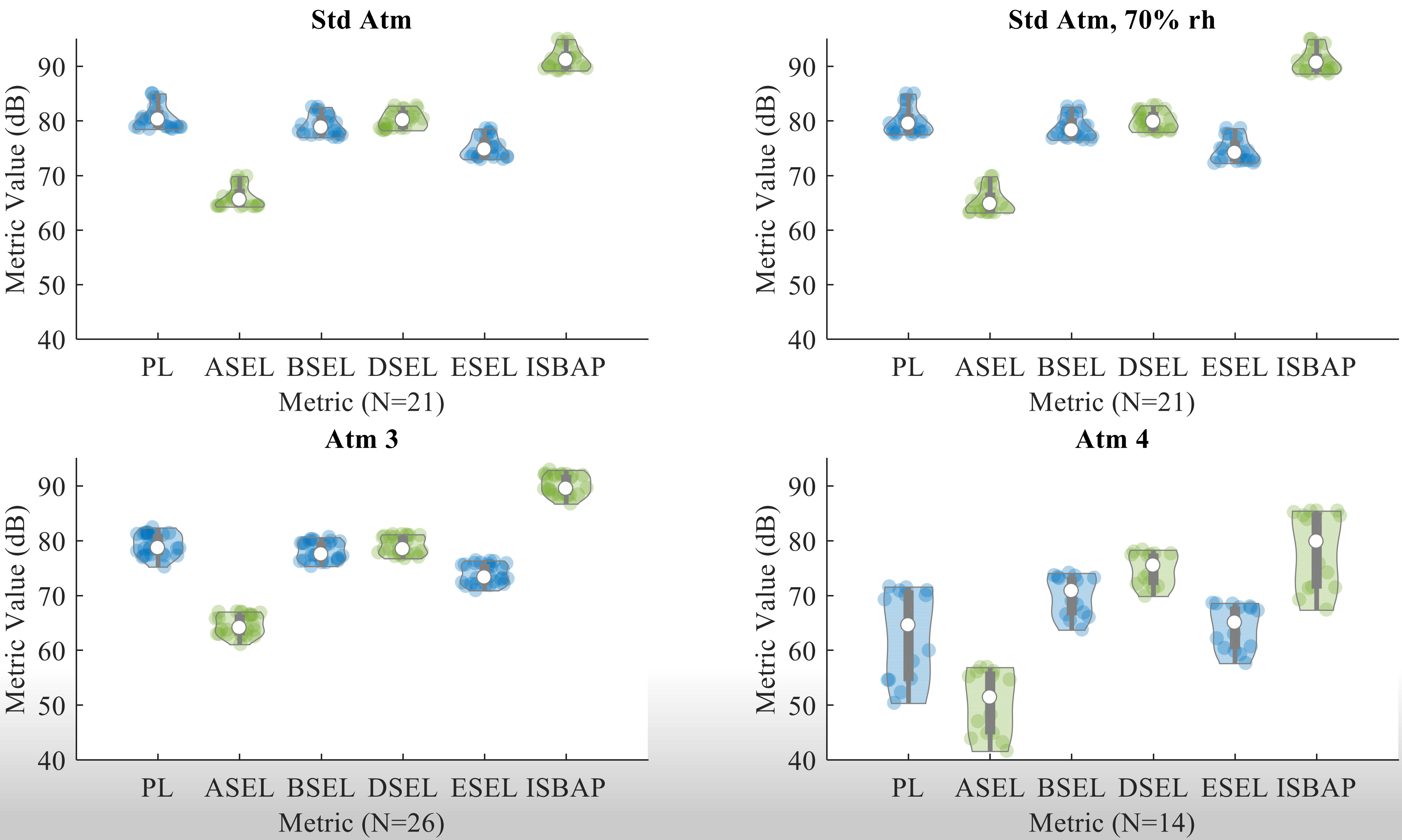


*A. Loubeau, Y. Naka, B. G. Cook, V. W. Sparrow, and J. M. Morgenstern. A new evaluation of noise metrics for sonic booms using existing data. 20th International Symposium on Nonlinear Acoustics, 2015.

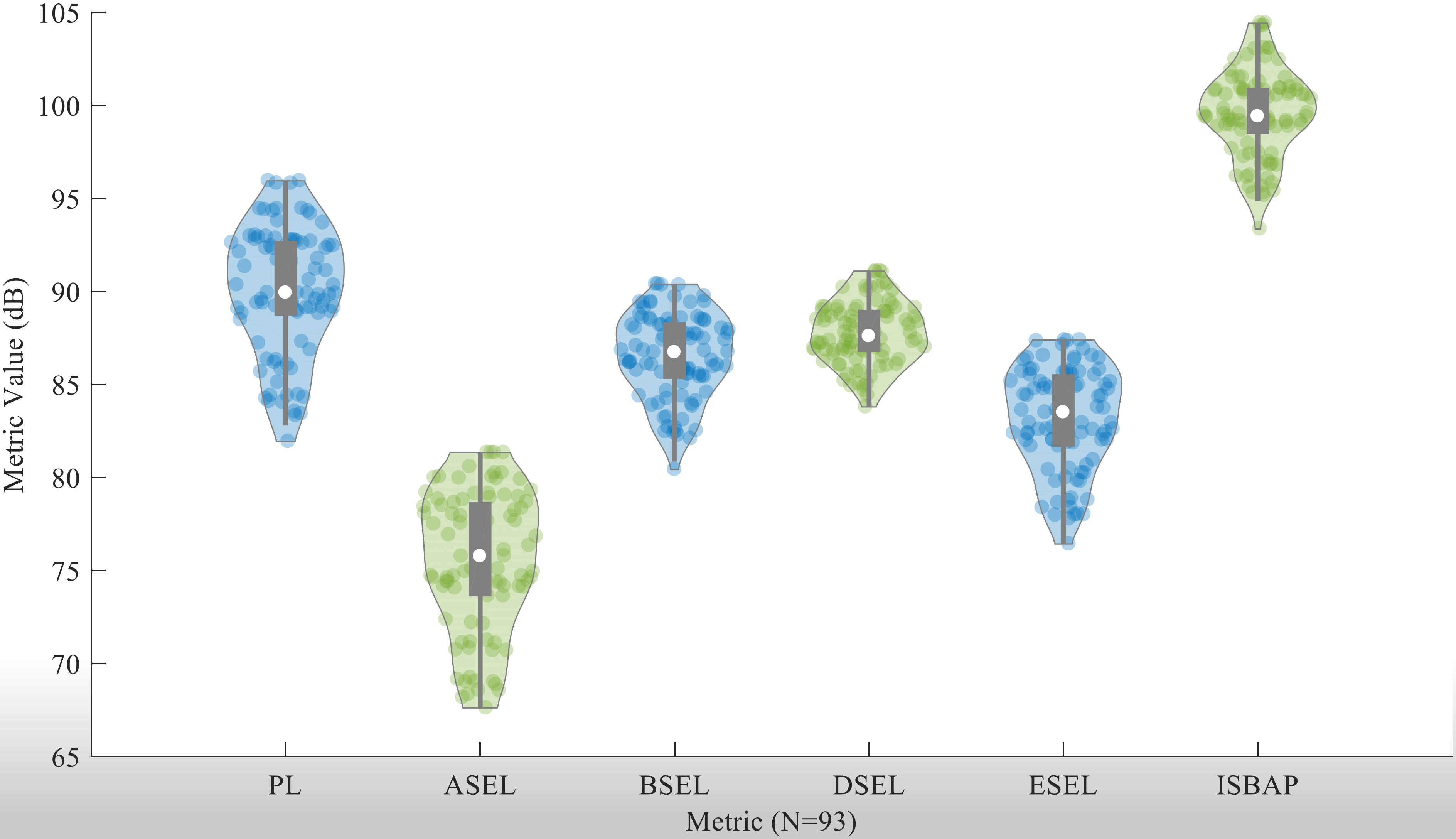
Axi-symmetric Case, All Atmospheres



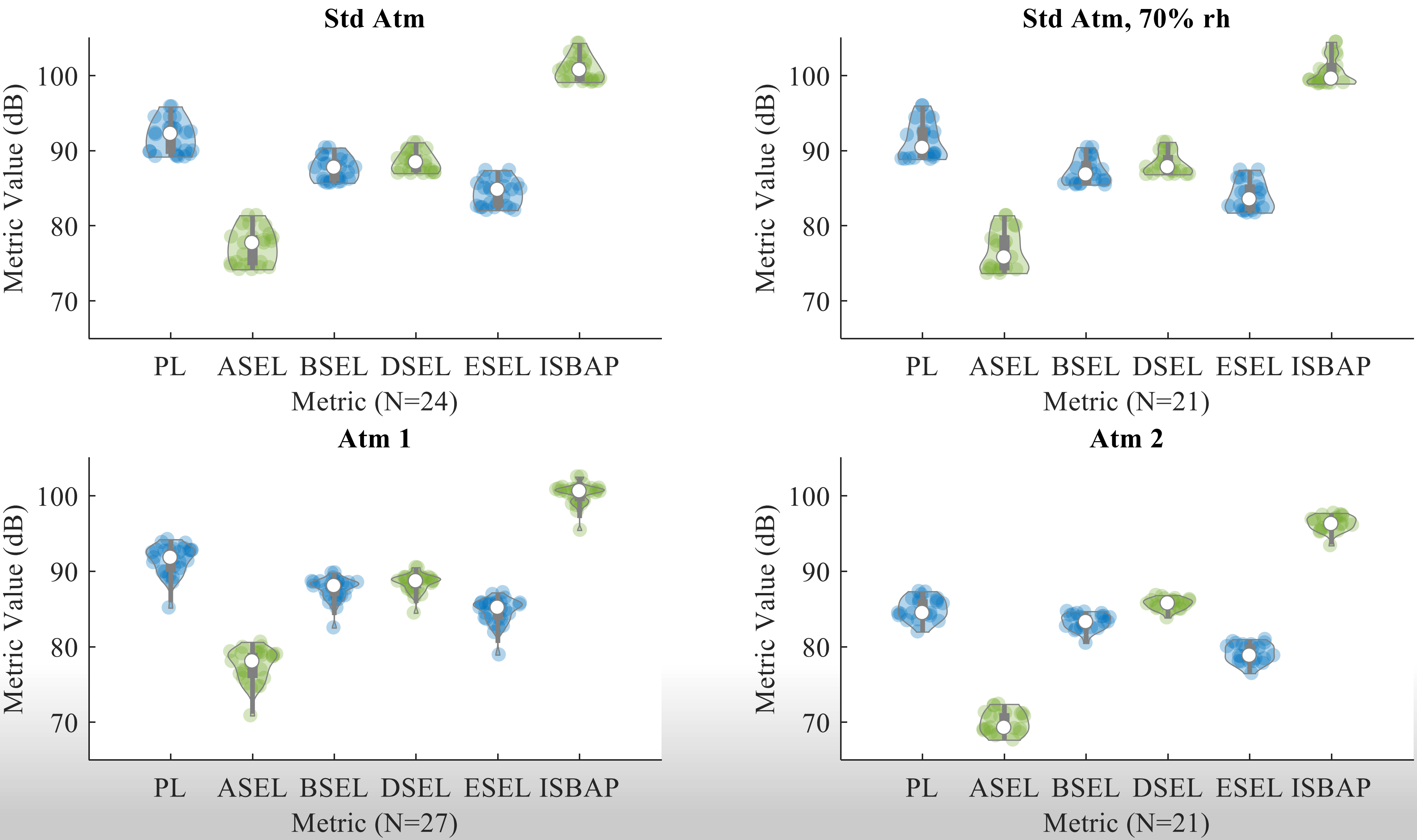
Axi-symmetric Case



LM1021 Case, All Atmospheres

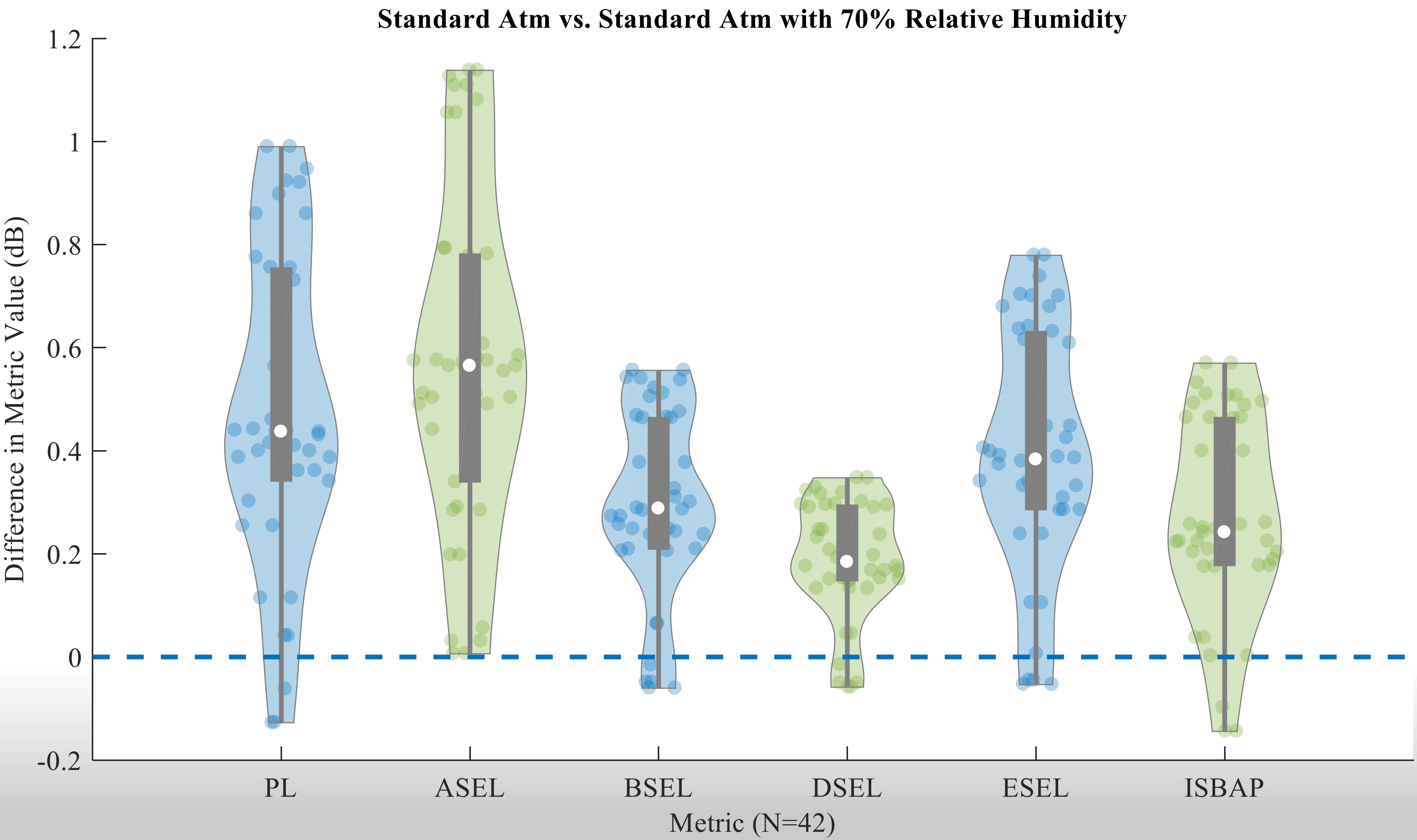


LM1021 Case



Std Atm
Std Atm, 70% rh
Atm 1
Atm 2
Metric Value (dB)
100
90
80
70
PL
ASEL
BSEL
DSEL
ESEL
ISBAP
Metric (N=24)
Metric (N=21)
Metric (N=27)
Metric (N=21)

Effect of Constant 70% Relative Humidity



Summary

- Most results match under-track in terms of ground signatures
- The discrepancy seems to increase for off-track roll angles, particularly near lateral cut-offs
- The PL calculation from some participants seems off
- 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
- Higher sampling frequencies (>100 kHz) seem warranted for loudness convergence < 0.1 dB

Sriram.Rallabhandi@nasa.gov

Future Work

- Dig deeper into the statistics of different submissions
- Narrow band and 1/3 octave band spectral comparisons of all submissions
- Ranges
- Loudness build-ups and additional diagnostics

- AVIATION 2017: Paper/presentation on extensive discussions of the submissions and additional comparisons, Sriram K. Rallabhandi, Alexandra Loubeau
- ASA, Boston 2017: Paper presentation on lessons learned, and progress made between the workshops and an informal propagation comparisons done in 2013

Acknowledgments

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

Discussion

- Were the cases used in SBPW2 appropriate?
- What’s the best dissemination methods for all participants

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

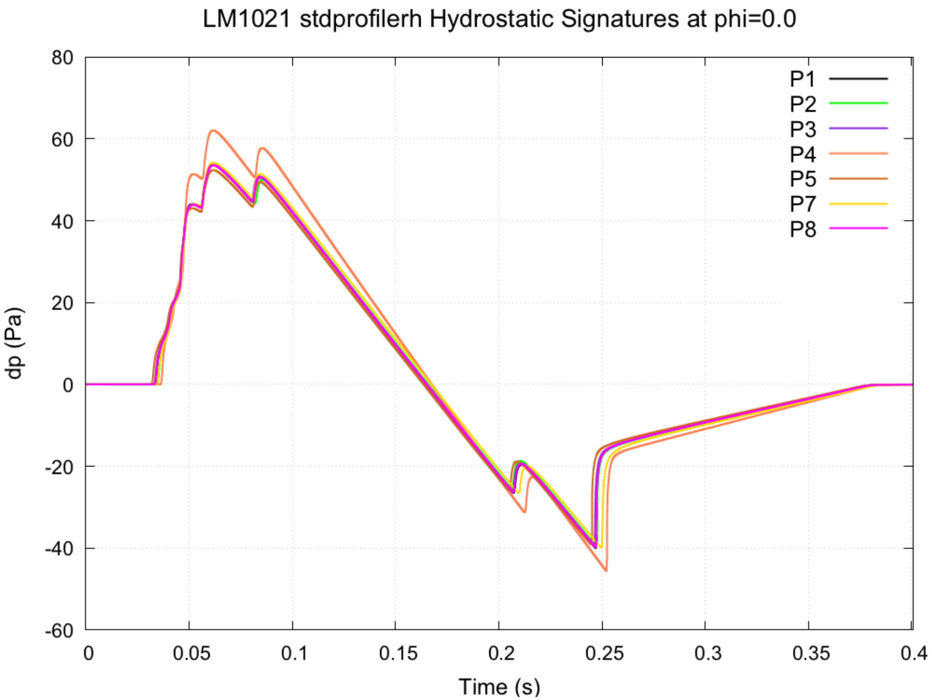
SBPW3

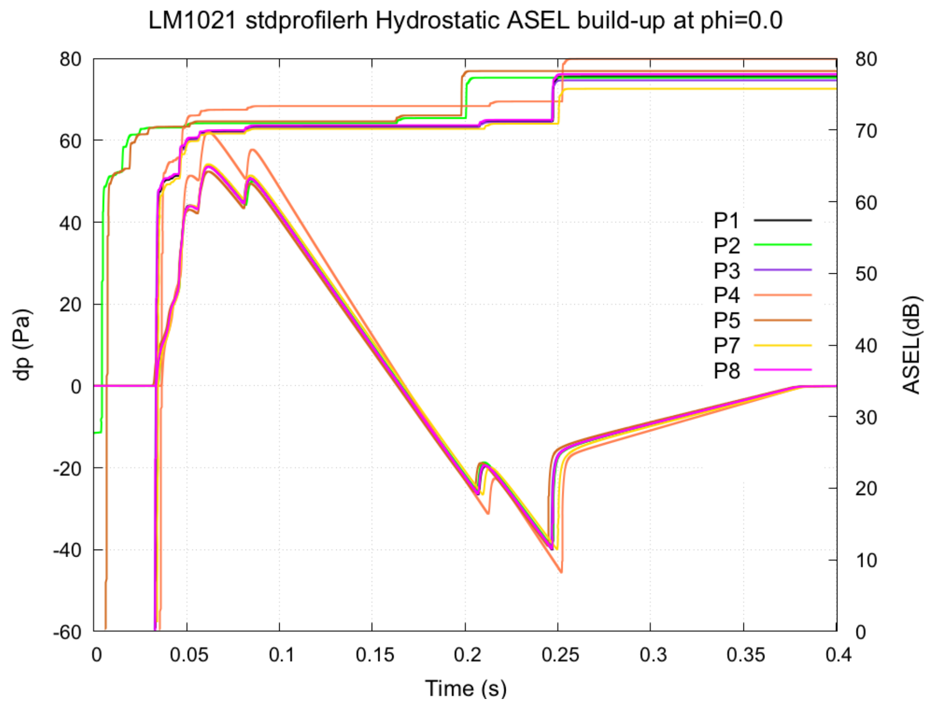
- Potential additional jnformation to gather
  - Frequency spectra
  - Execution time (wall clock?)
  - Propagation time to ground
  - Ray tube area
- Will specify wind convention and atmospheric condition interpolation method (or provide fine resolution)

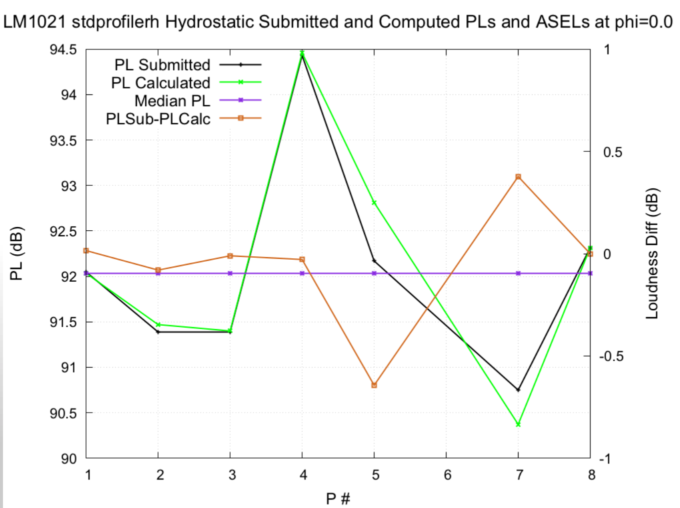
Sriram.Rallabhandi@nasa.gov

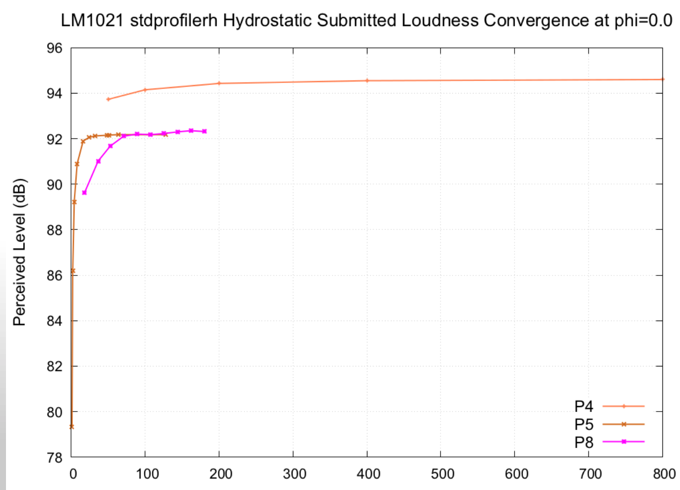
EXTRAS

LM1021 – Std Profile 70, Hydrostatic, Phi = 0.0

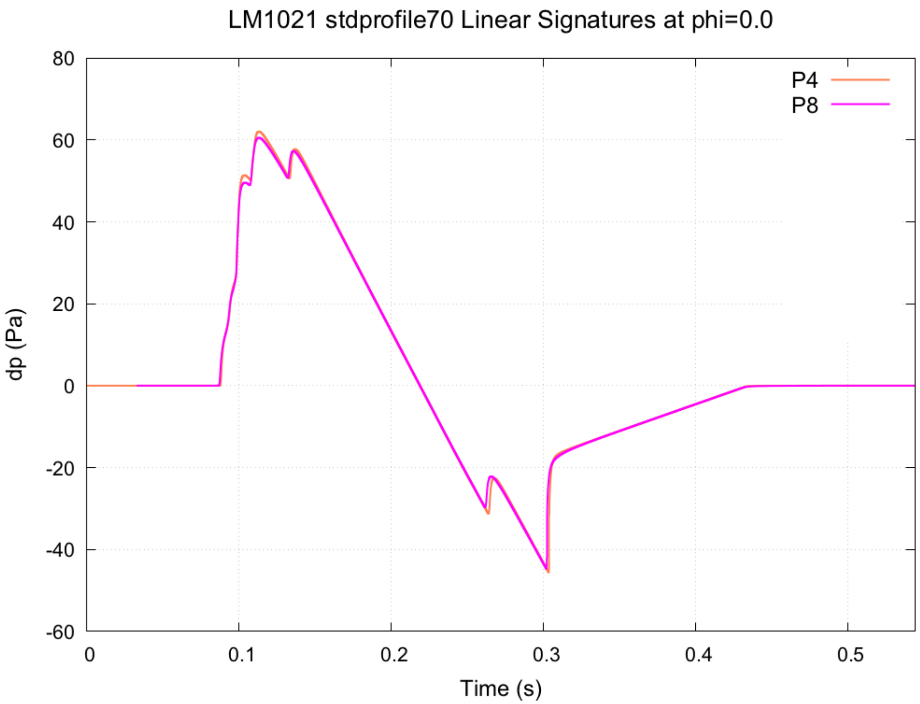


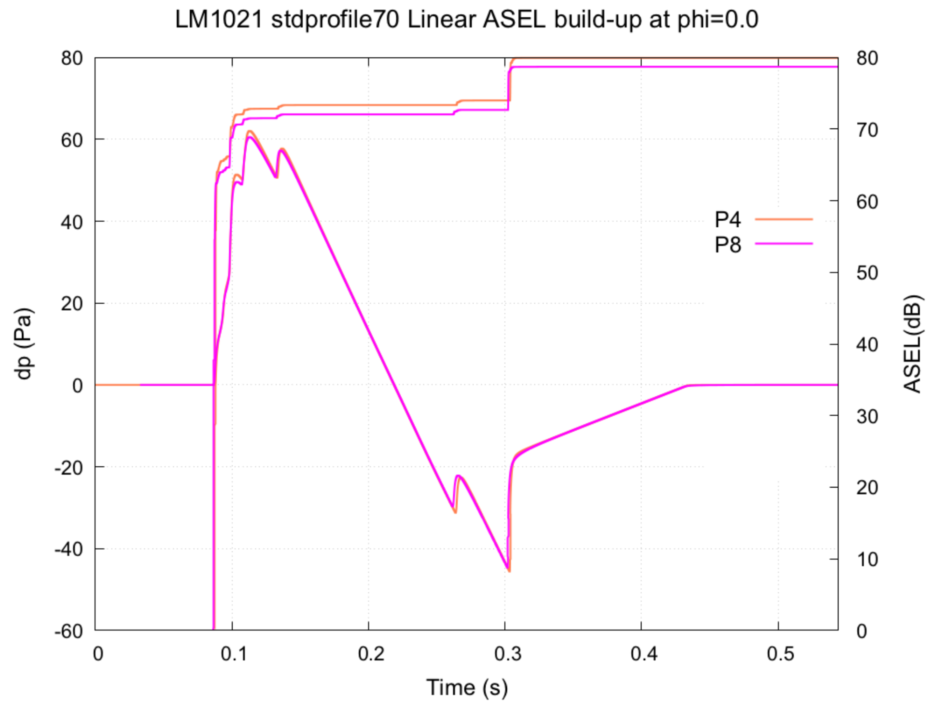


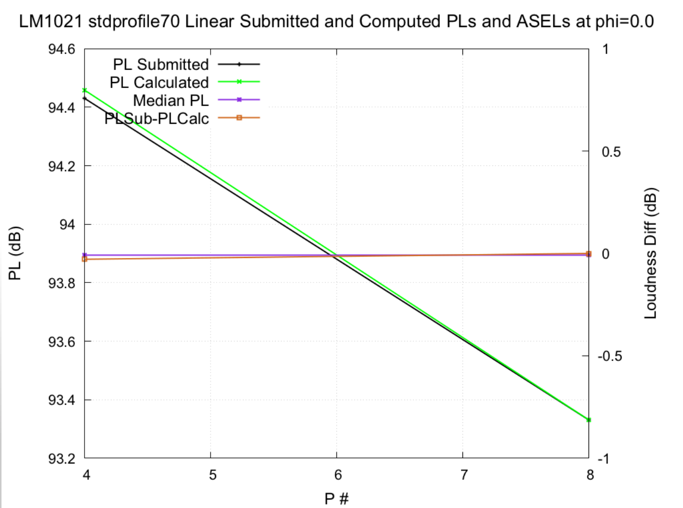


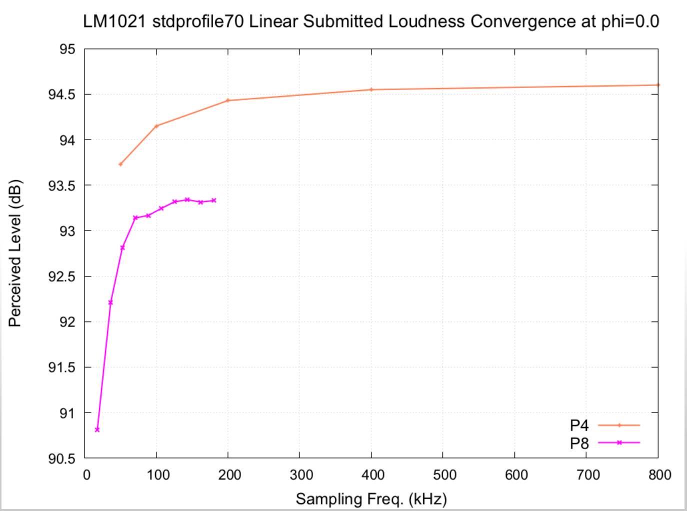


LM1021 – Std Profile 70, Linear, Phi = 0.0



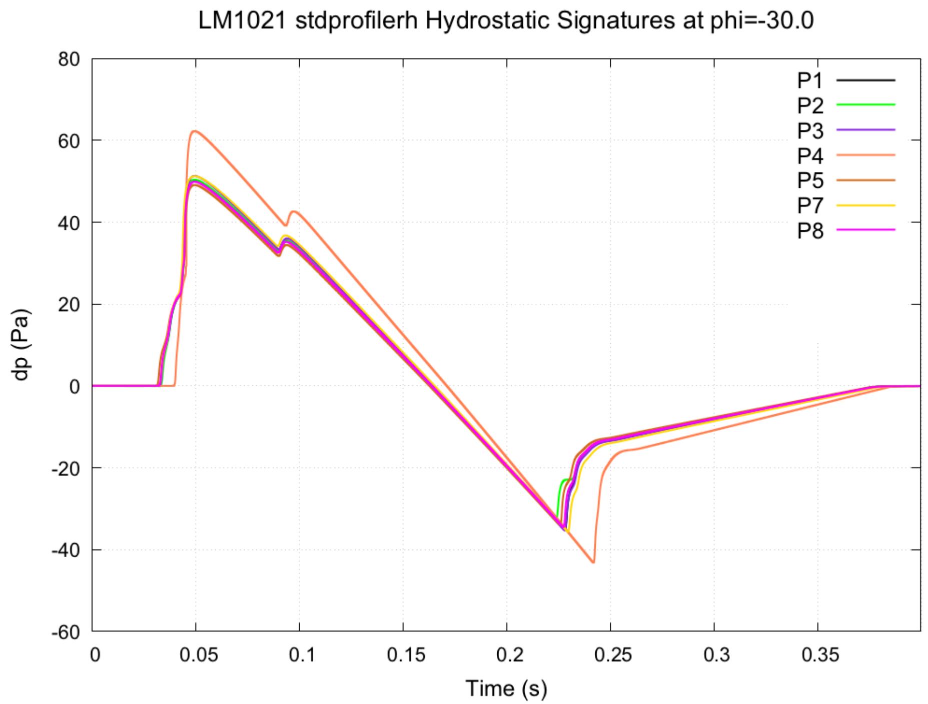


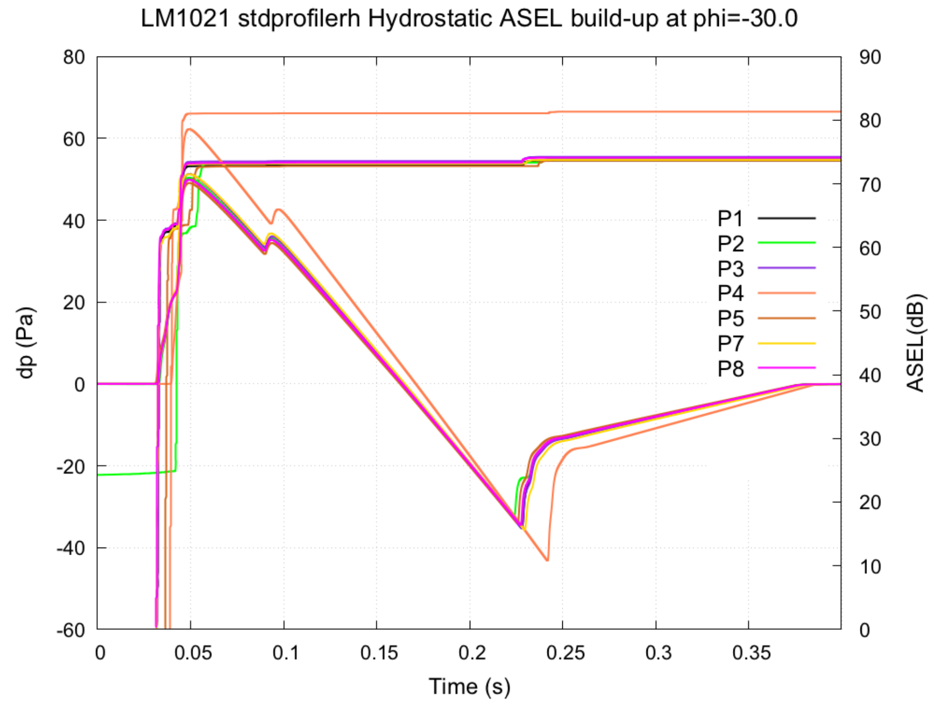


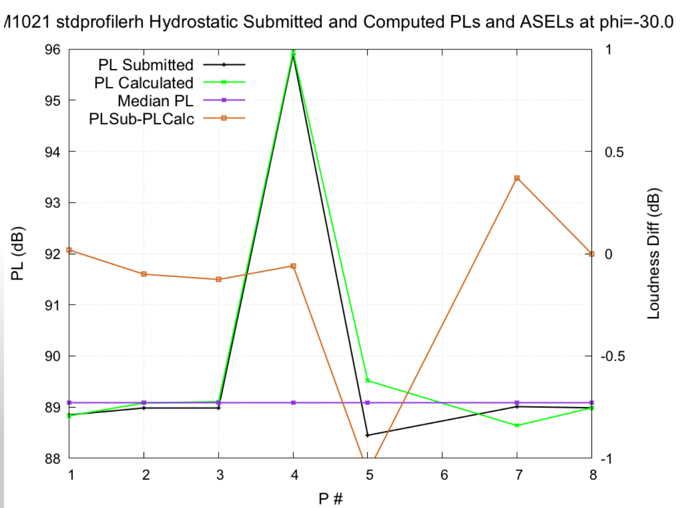


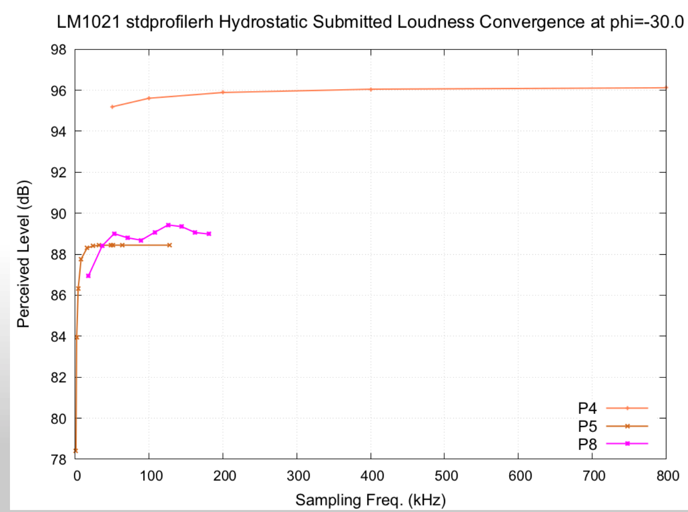
Sriram.Rallabhandi@nasa.gov

LM1021 – Std Profile 70, Hydrostatic, Phi = -30.0

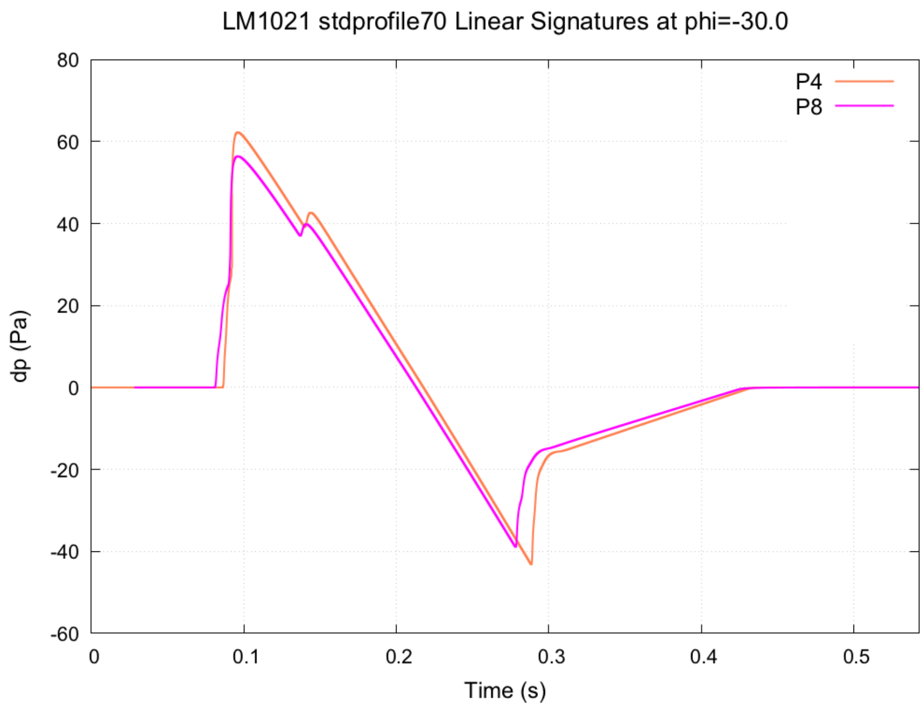


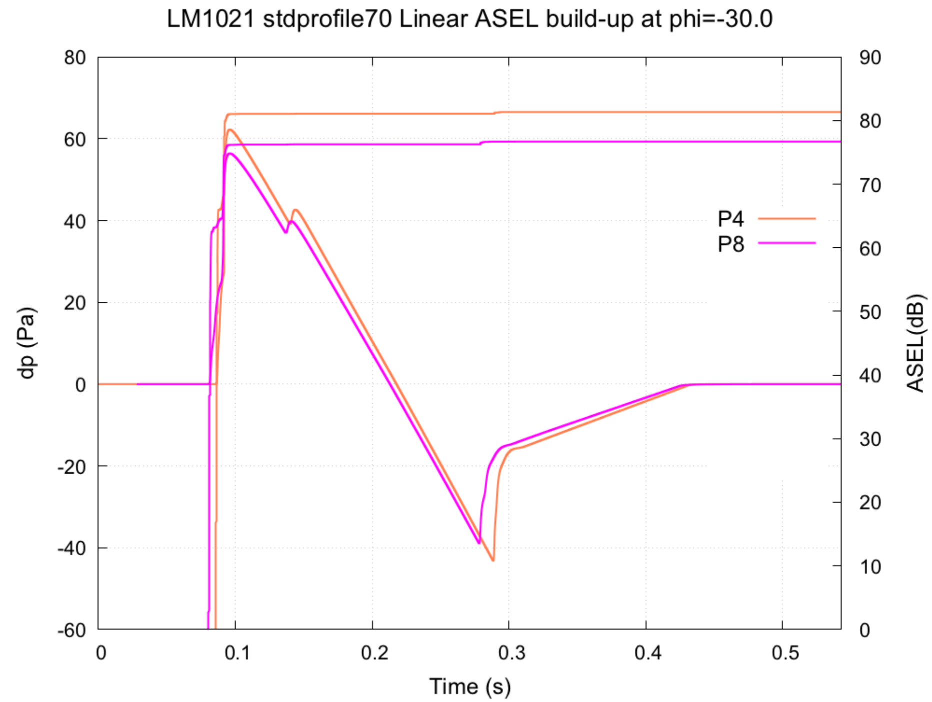


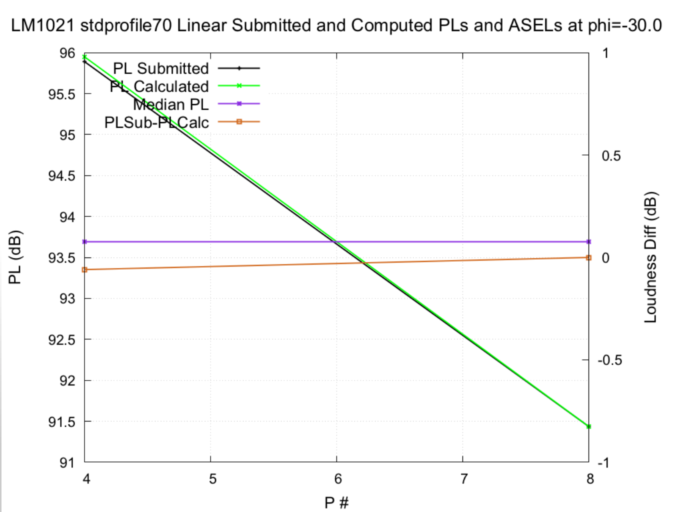


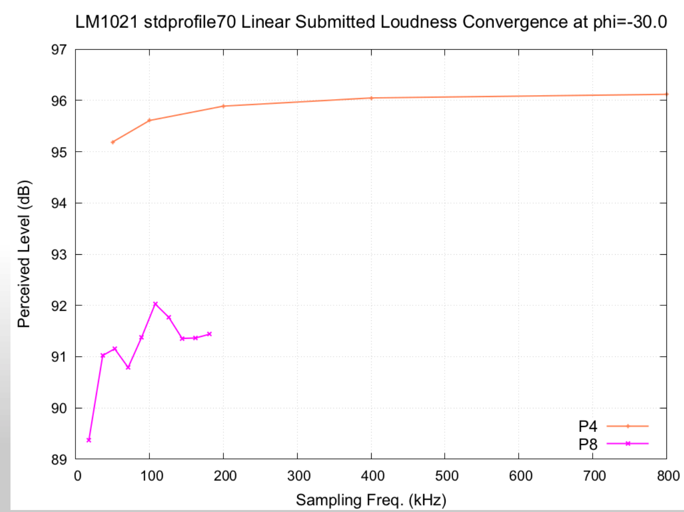


LM1021 – Std Profile 70, Linear, Phi = -30.0



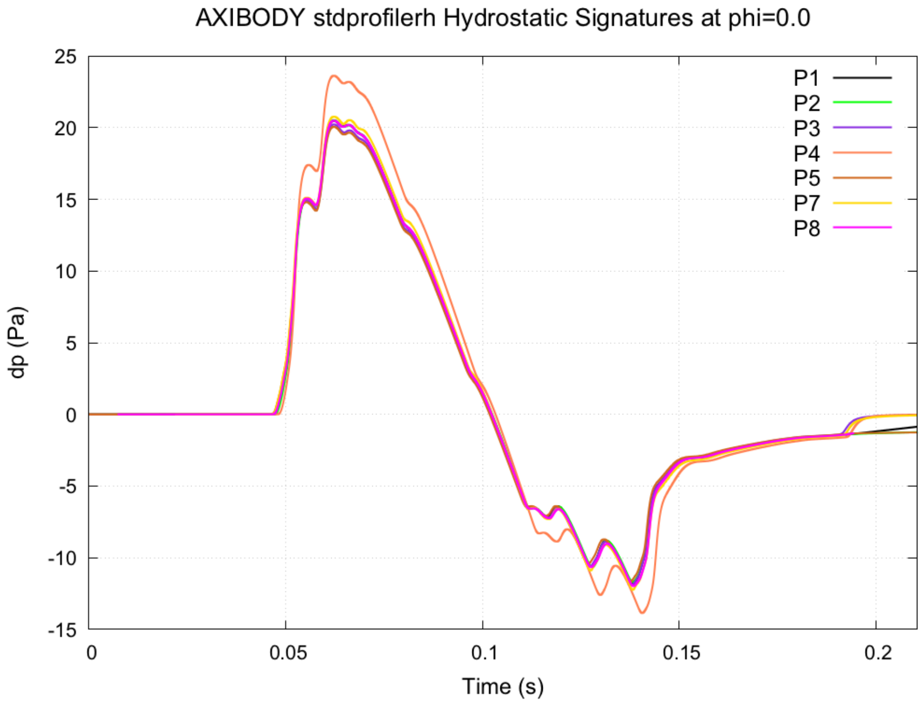


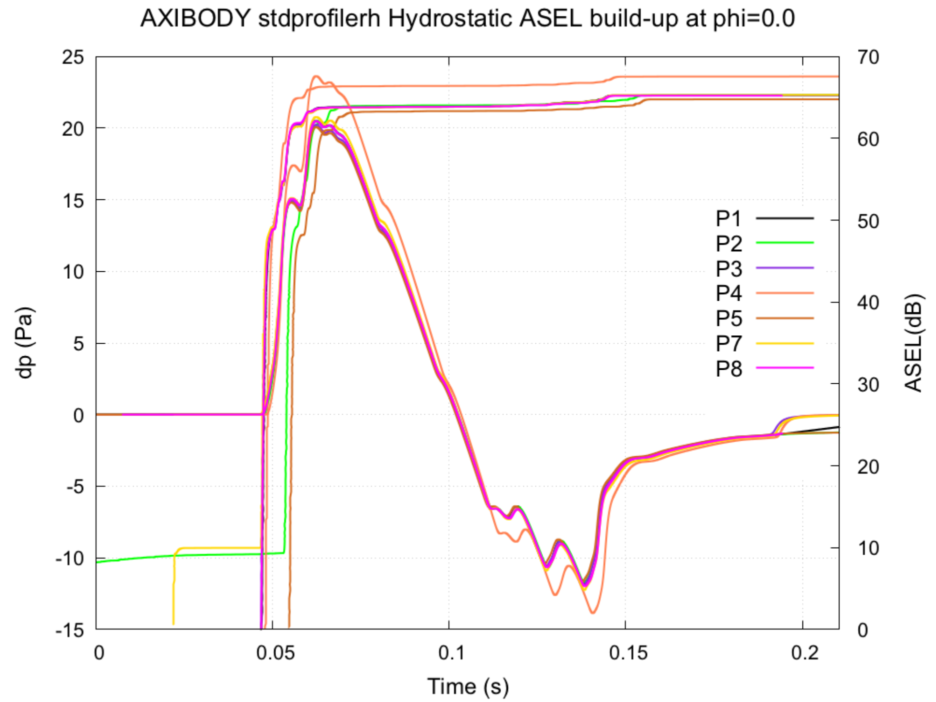


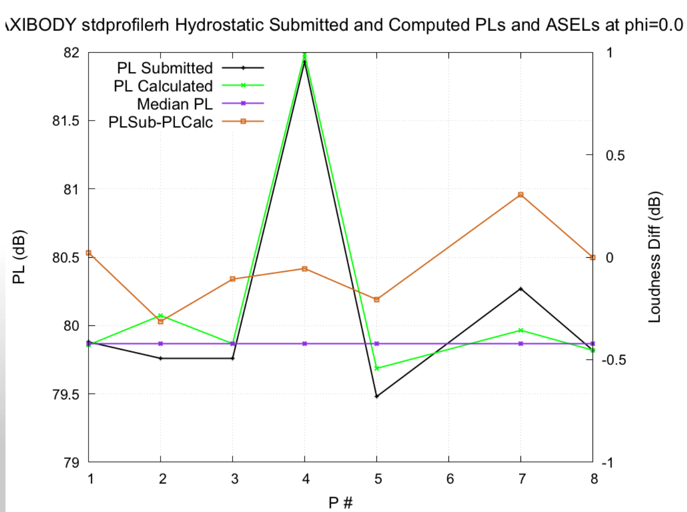


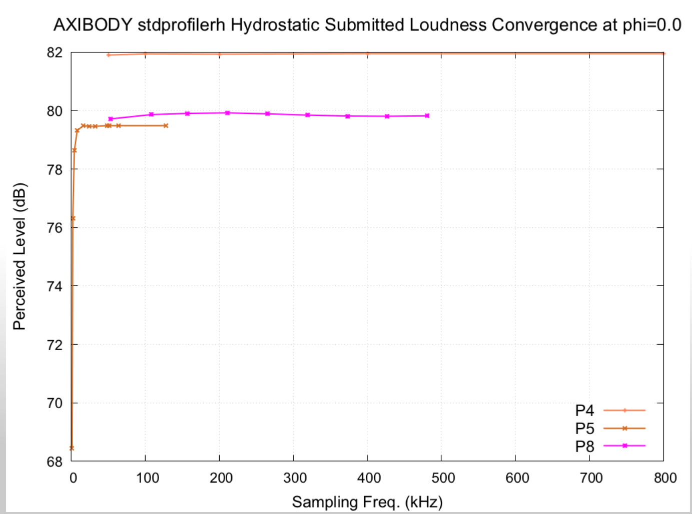
Sriram.Rallabhandi@nasa.gov

AXIBODY– Std70, Hydrostatic, Phi = 0.0



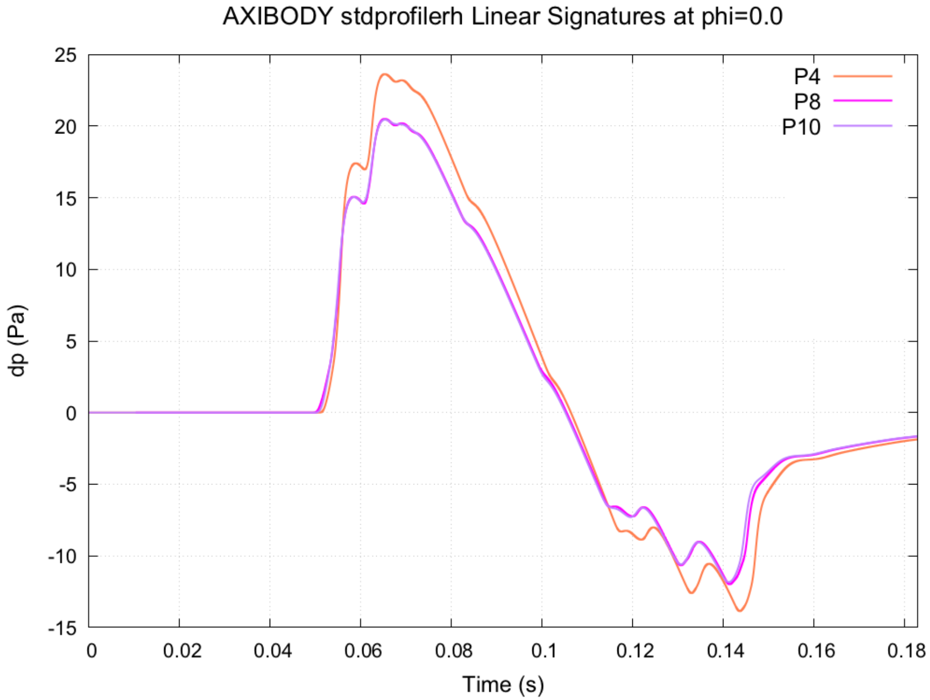


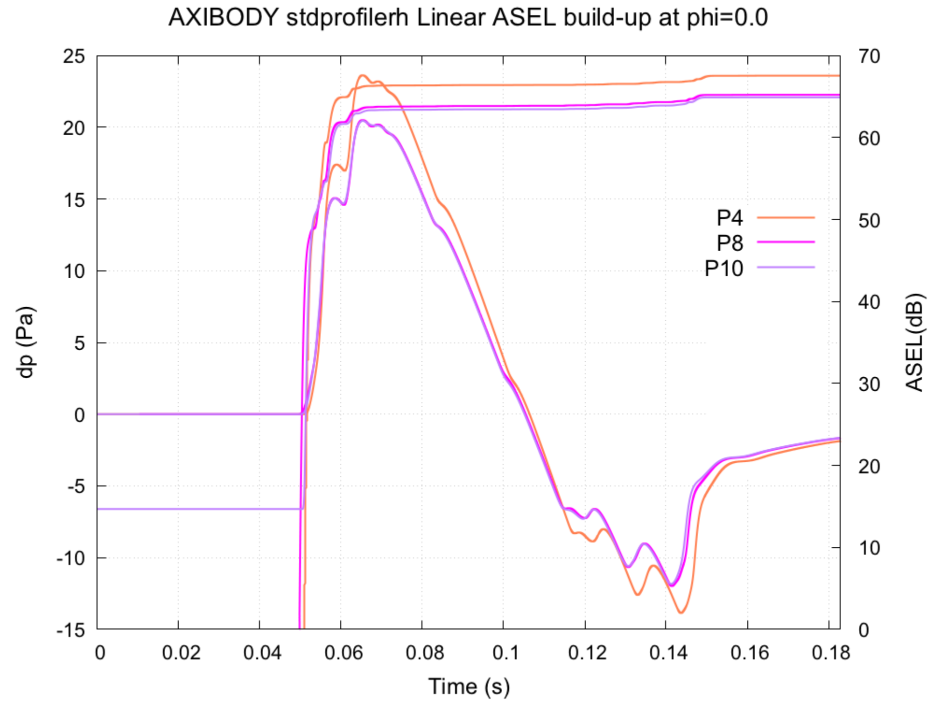


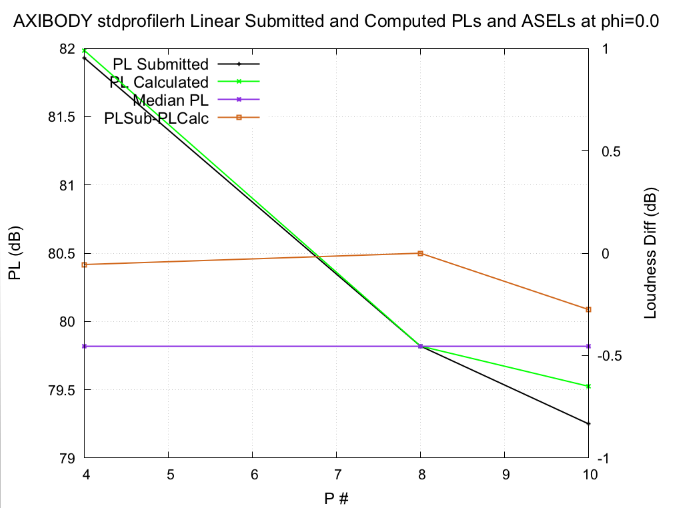


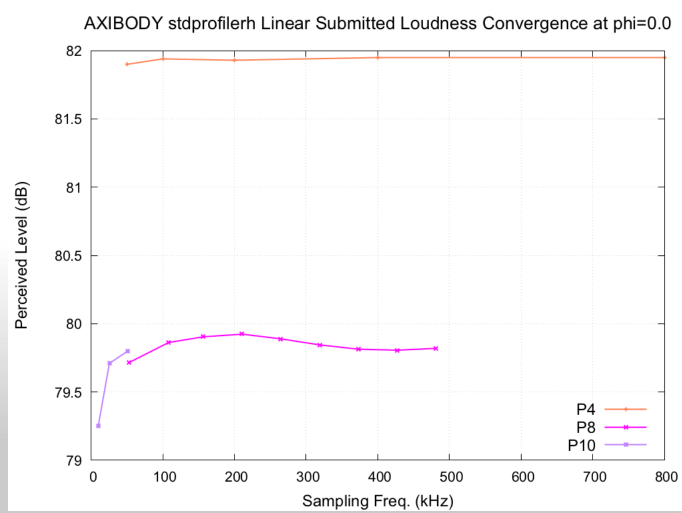
Sriram.Rallabhandi@nasa.gov

AXIBODY– Std70, Linear, Phi = 0.0



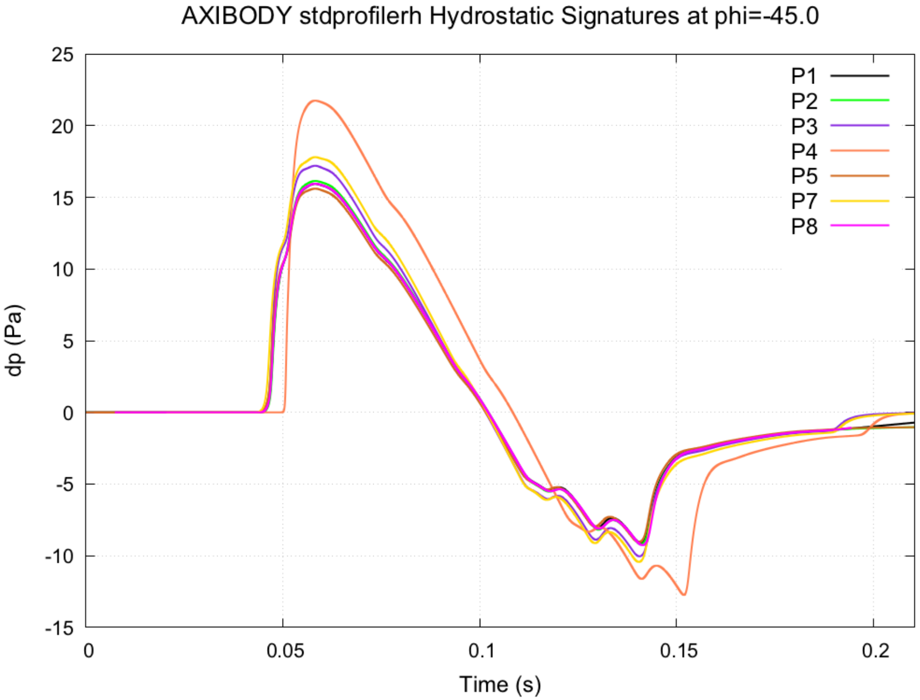


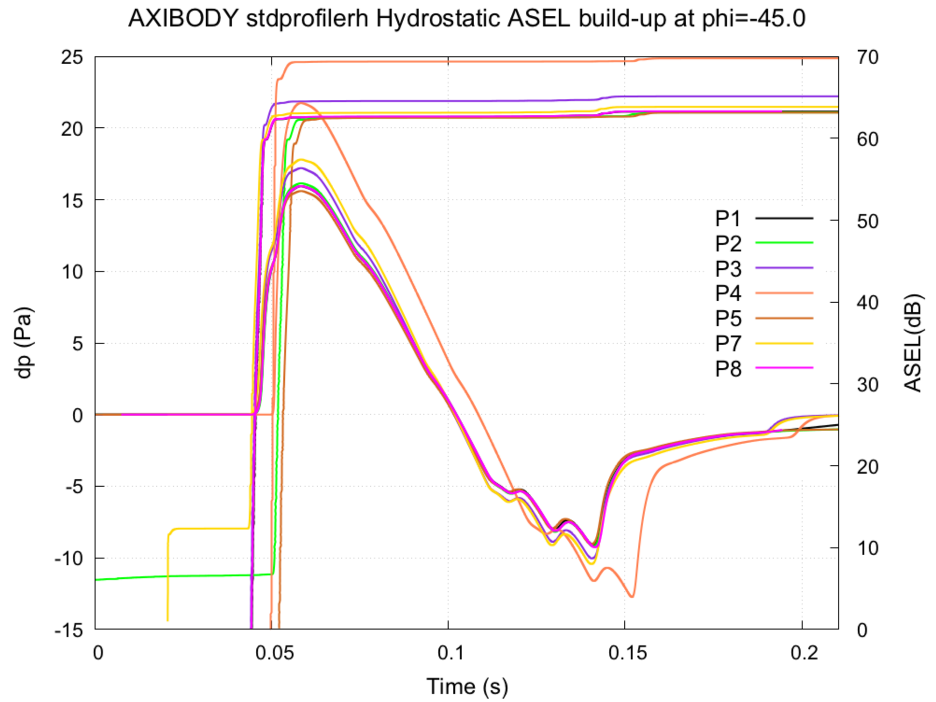


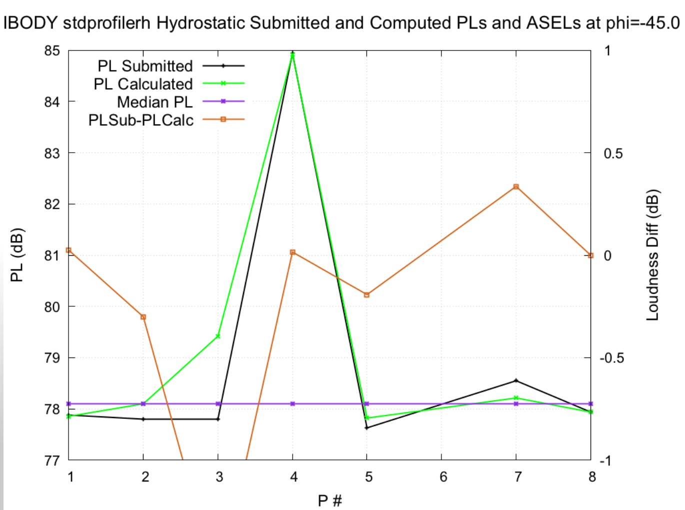


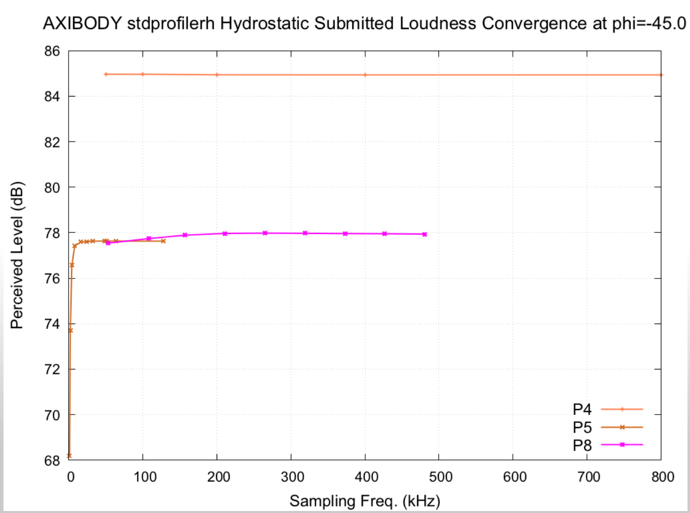
Sriram.Rallabhandi@nasa.gov

AXIBODY– Std70, Hydrostatic, Phi = -45.0

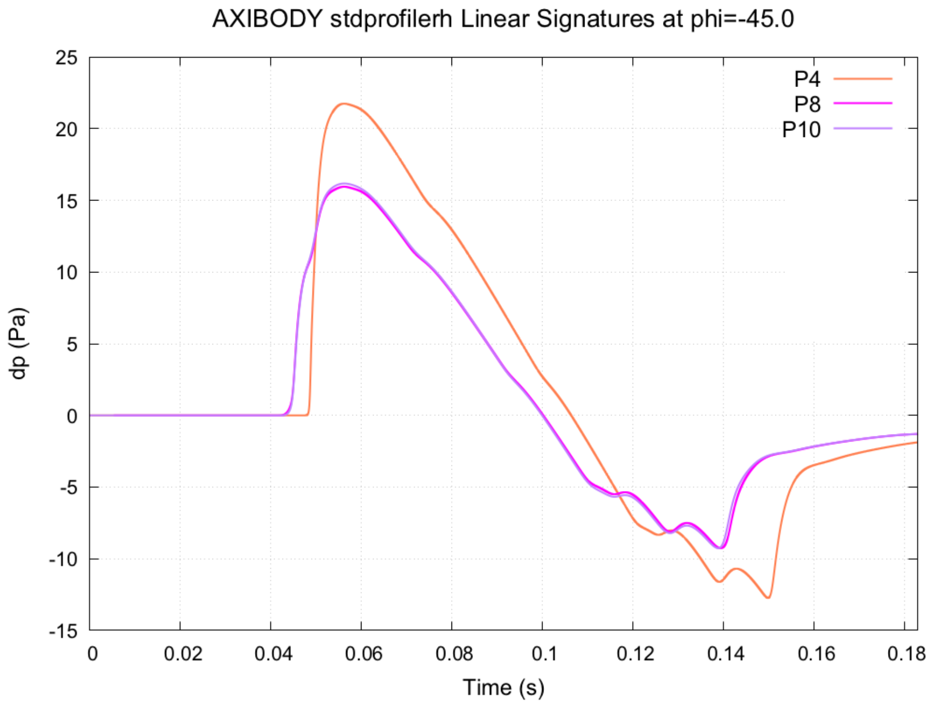


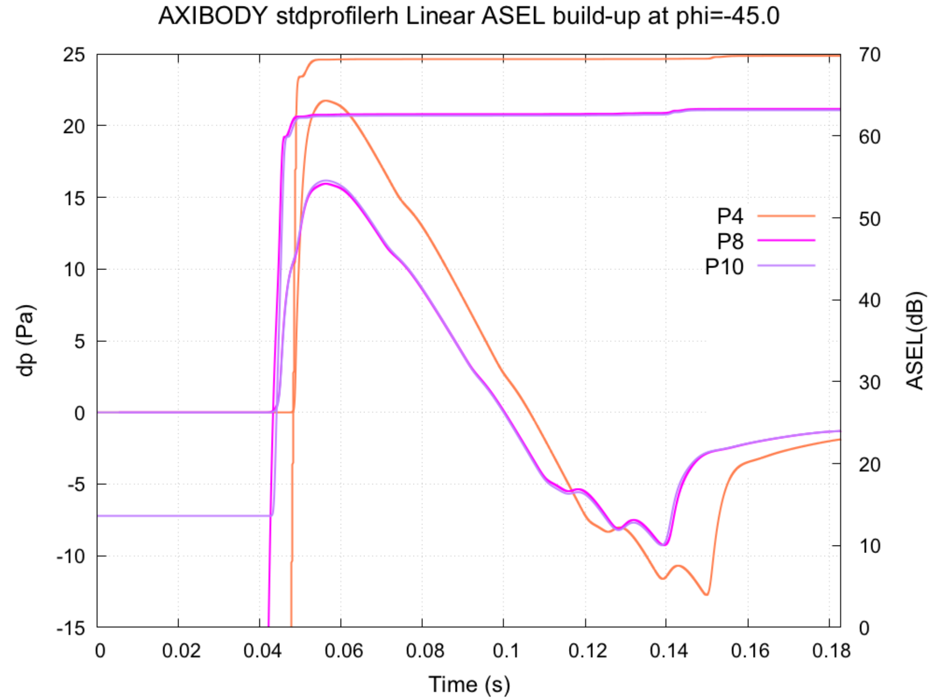


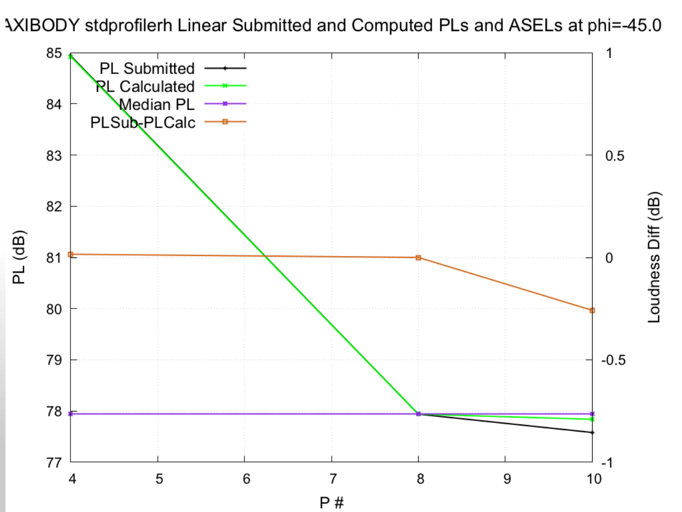


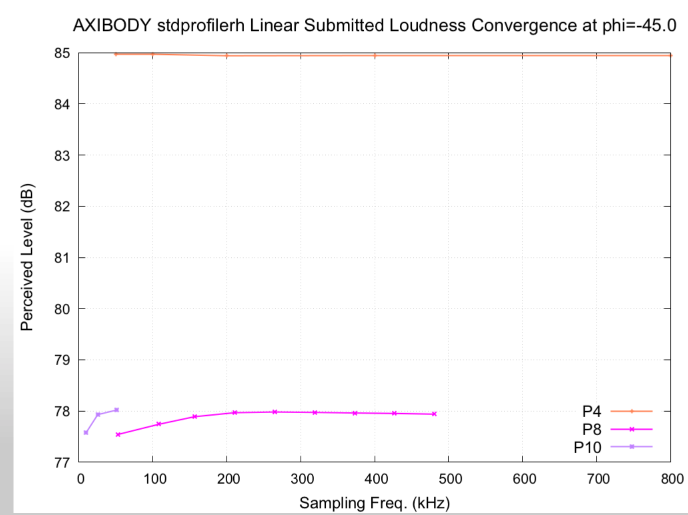


AXIBODY– Std70, Linear, Phi = -45.0



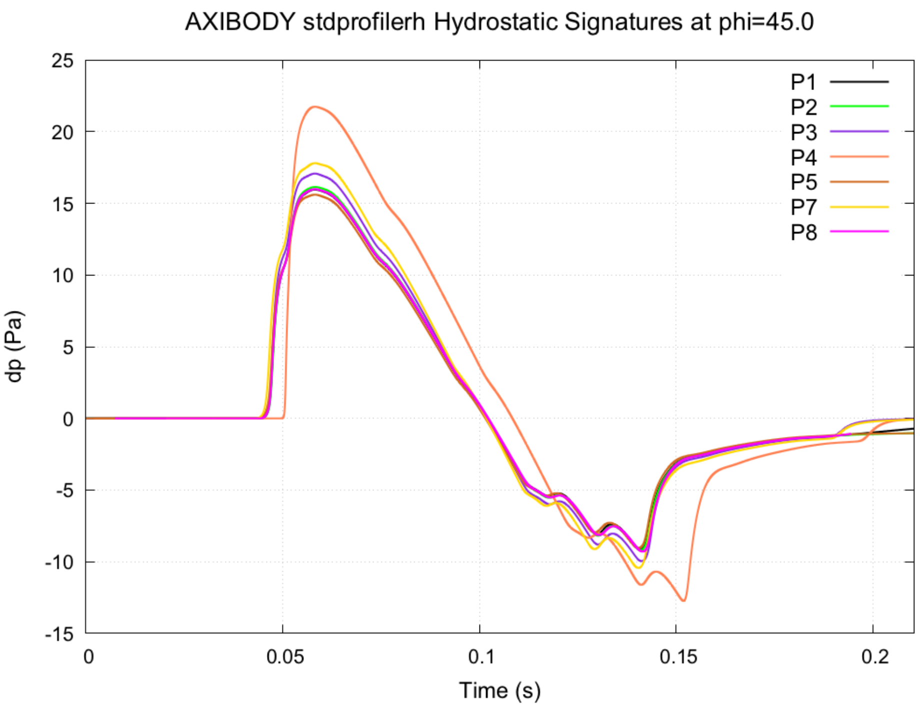


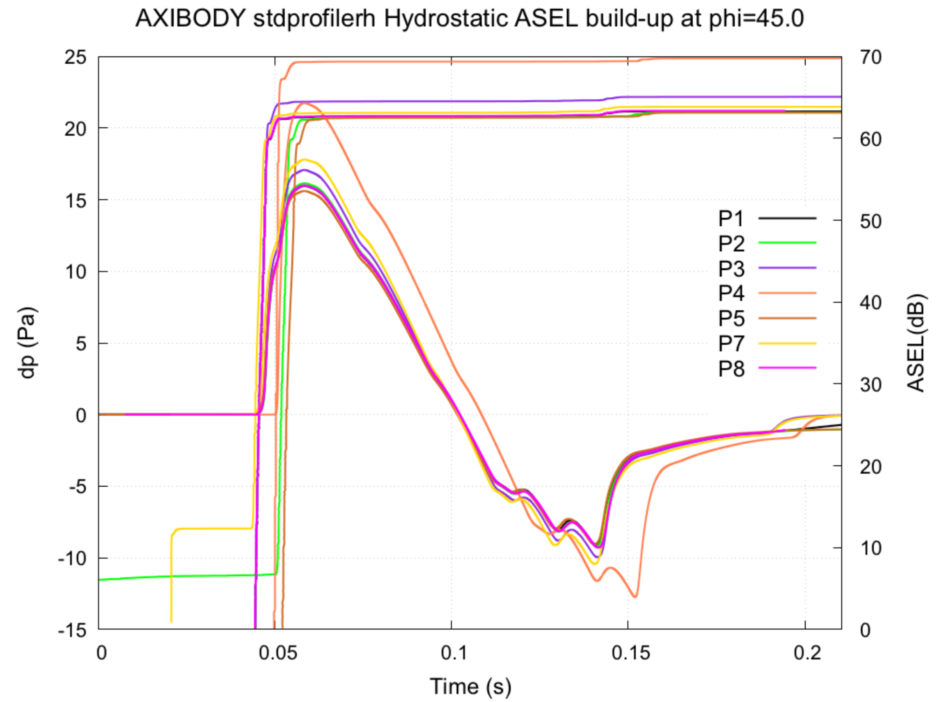


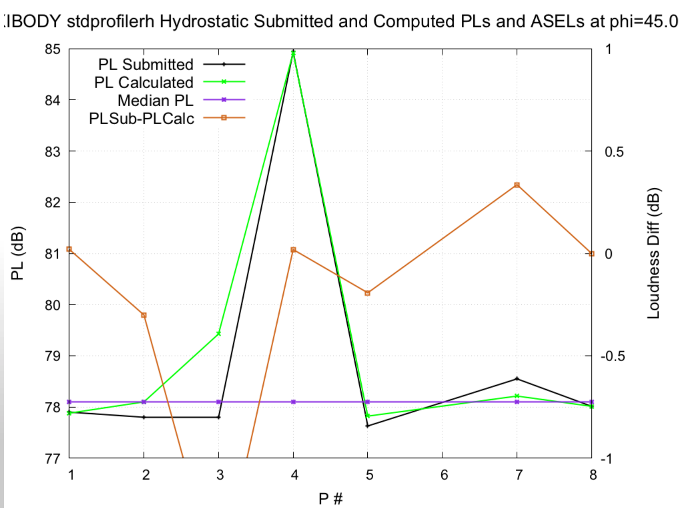


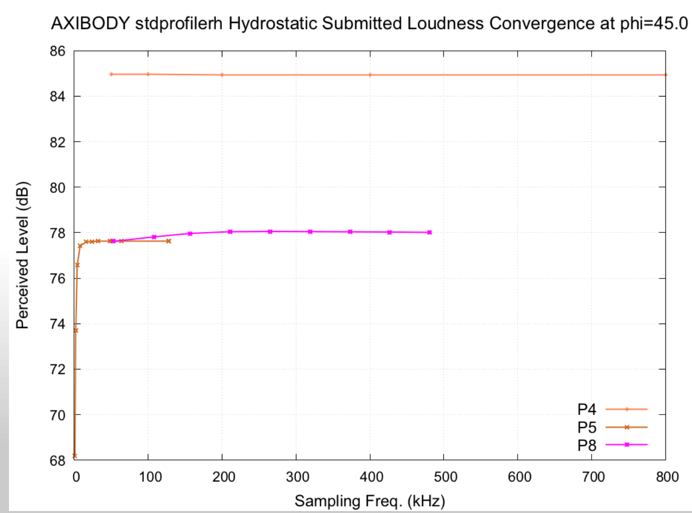
Sriram.Rallabhandi@nasa.gov

AXIBODY– Std70, Hydrostatic, Phi = 45.0



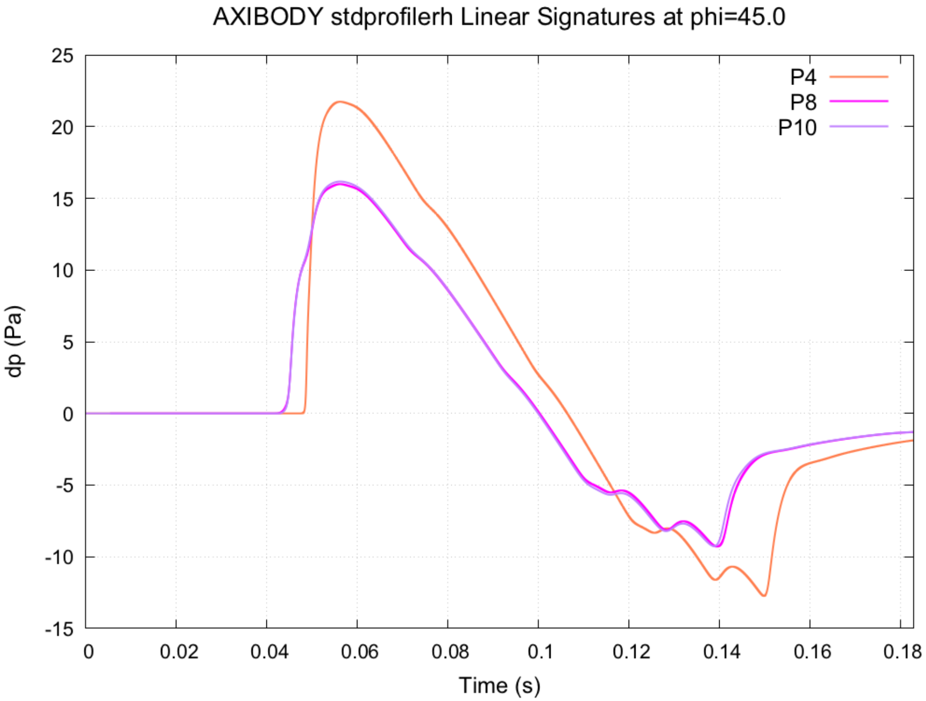


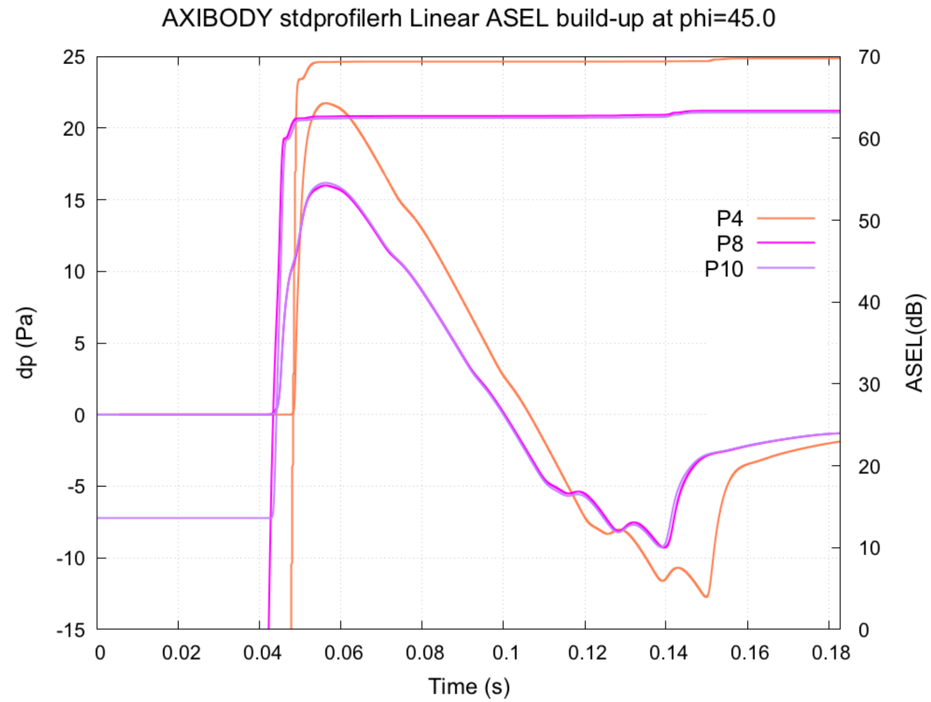


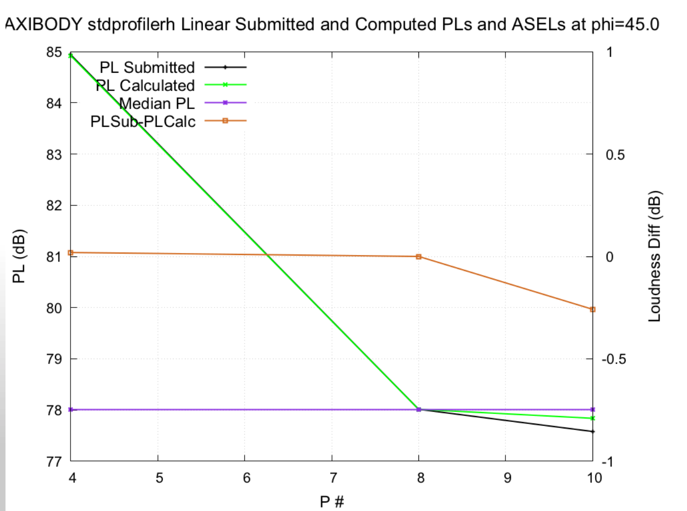


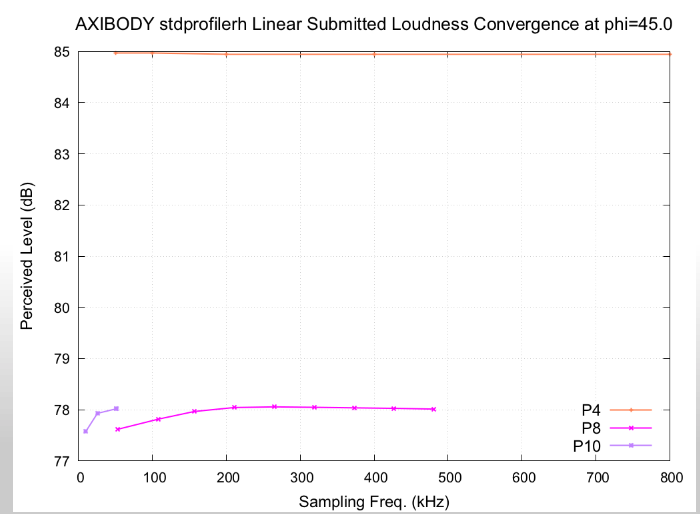
Sriram.Rallabhandi@nasa.gov

AXIBODY– Std70, Linear, Phi = 45.0



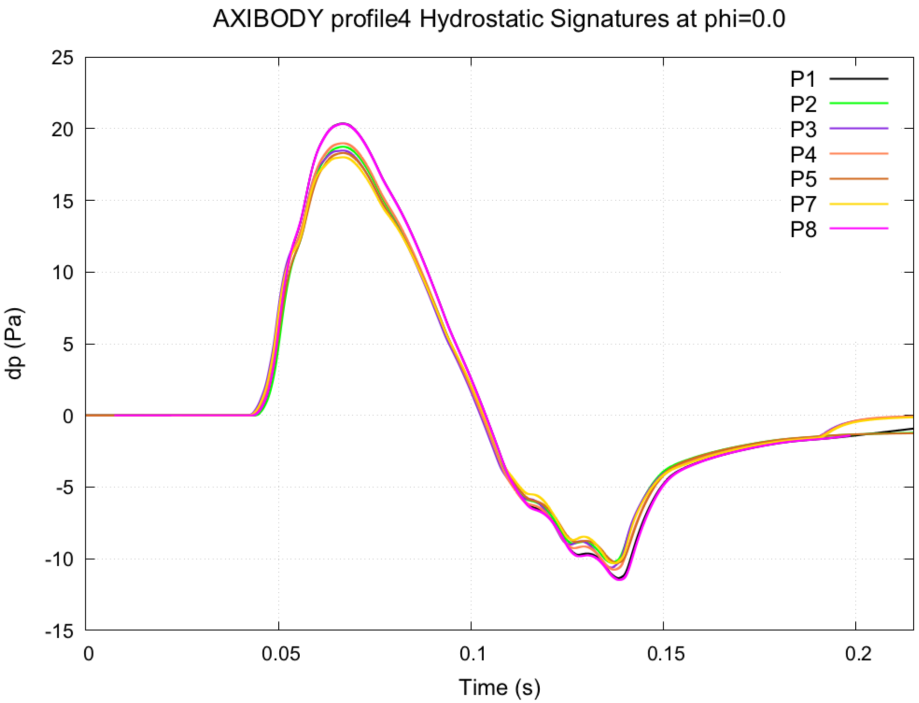


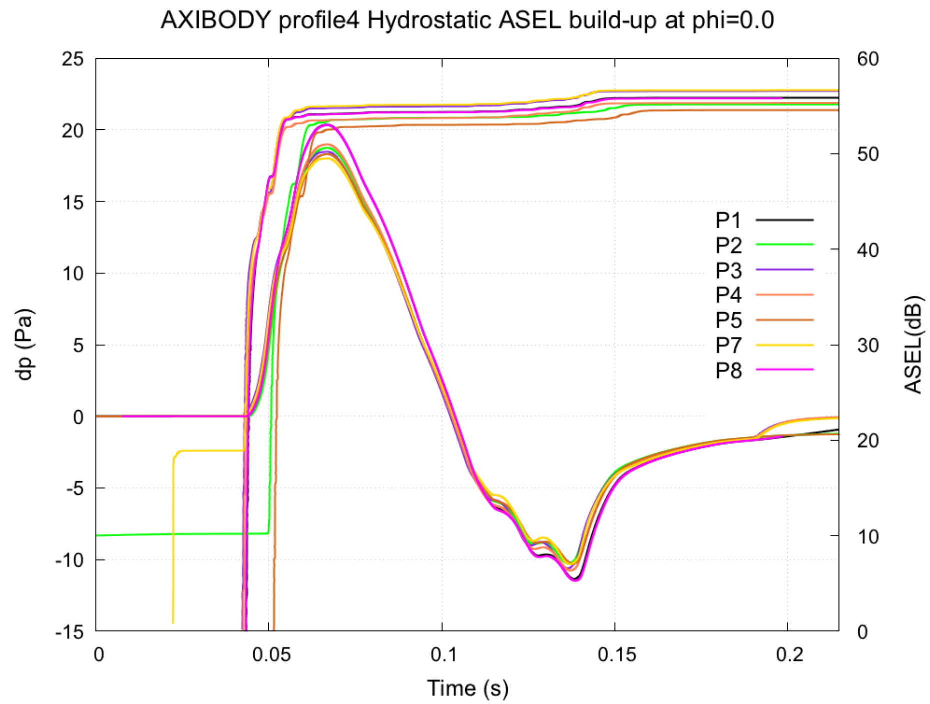


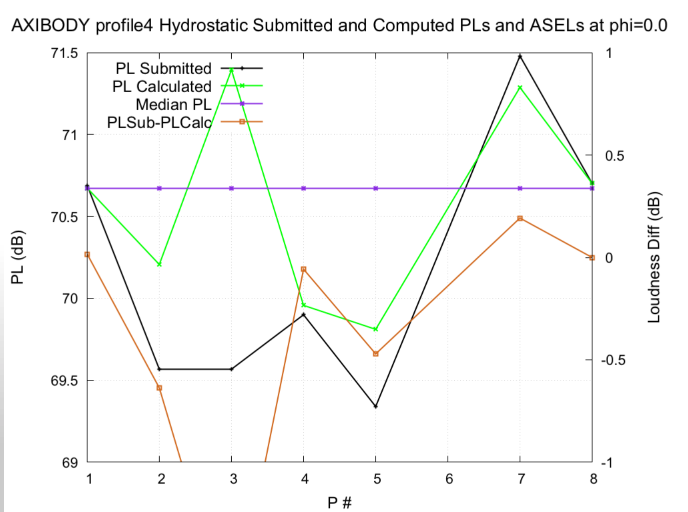


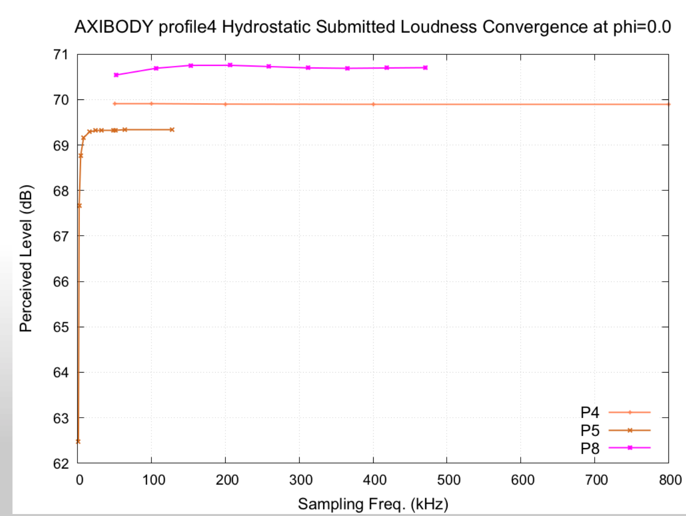
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Hydrostatic, Phi = 0.0



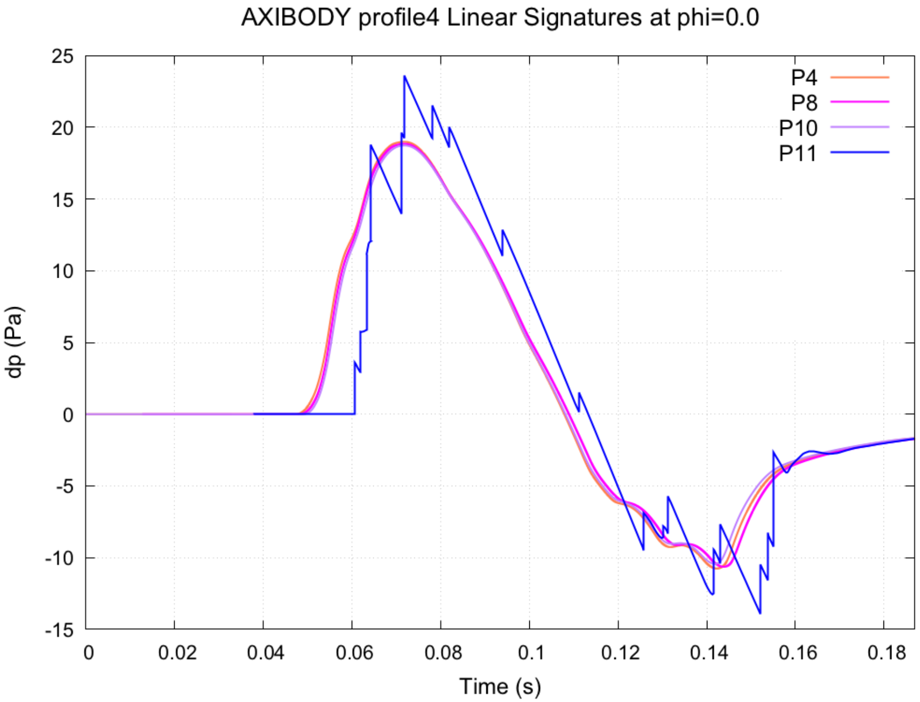


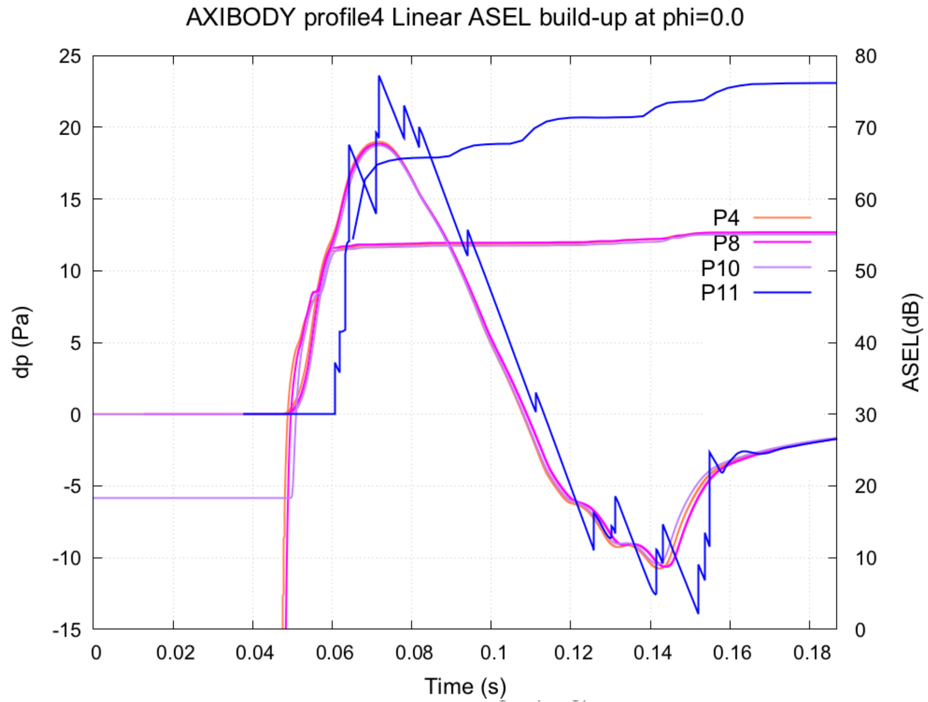


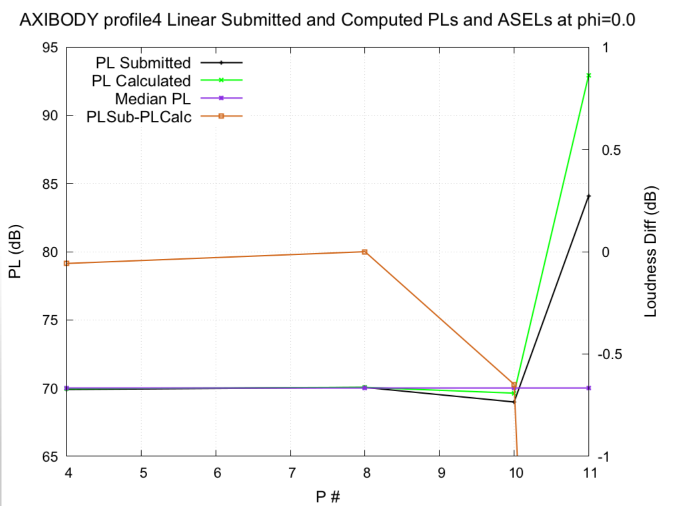


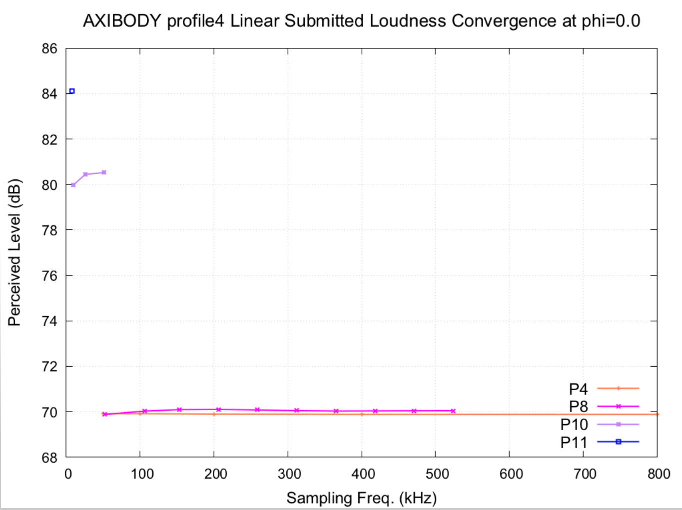
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Linear, Phi = 0.0



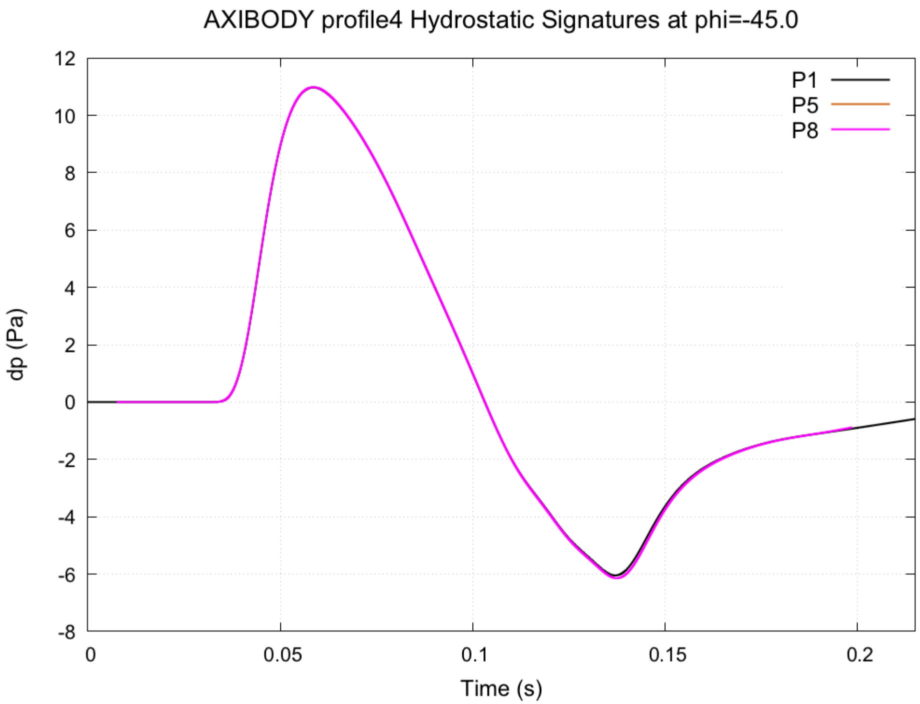


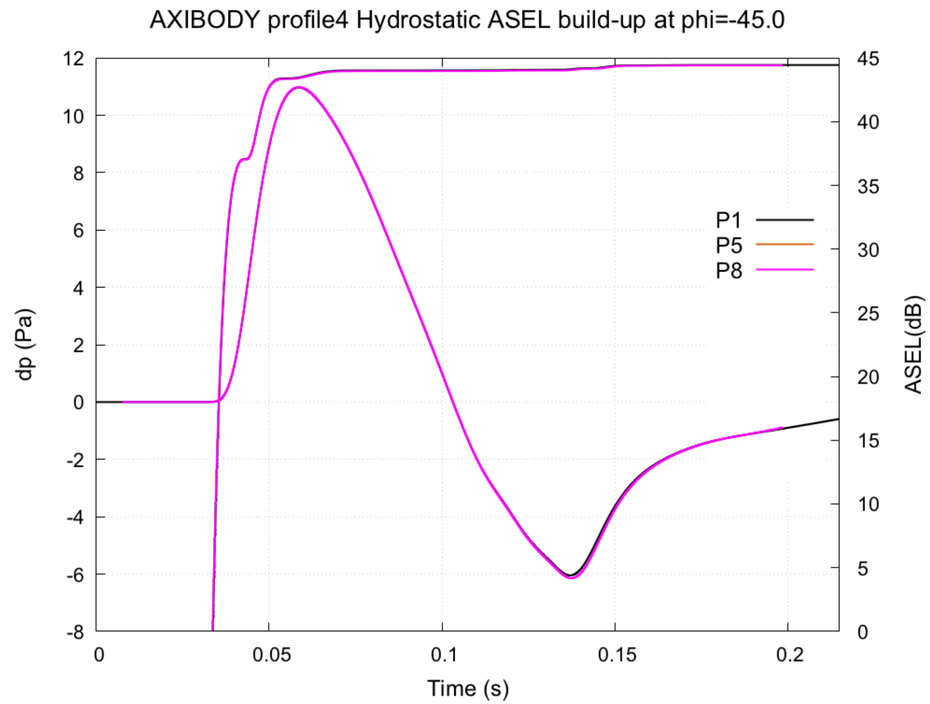


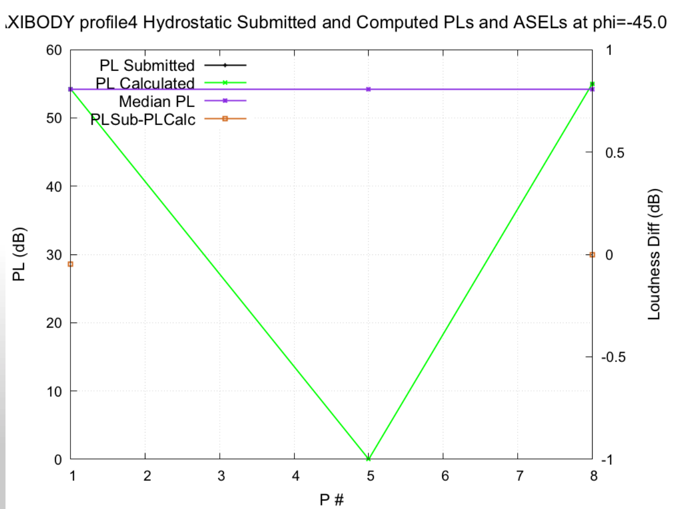


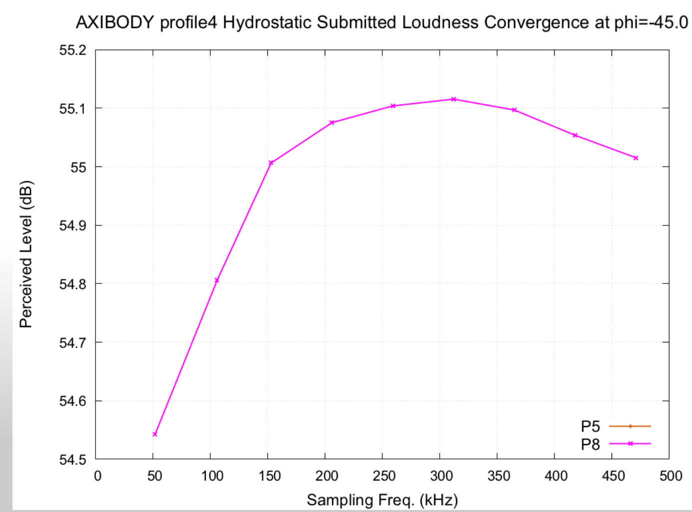
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Hydrostatic, Phi = -45.0



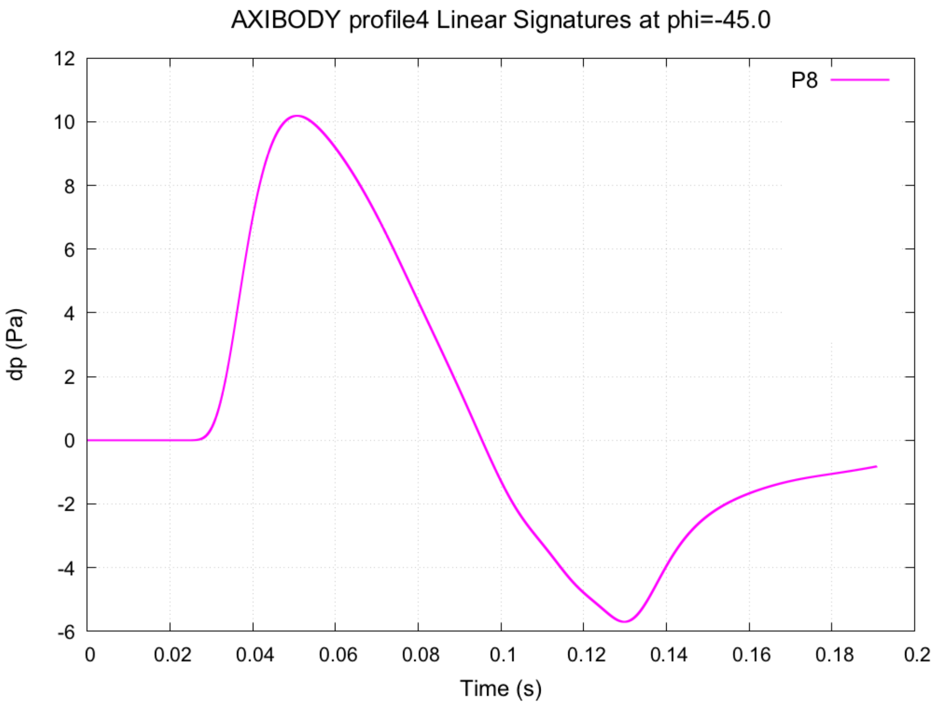


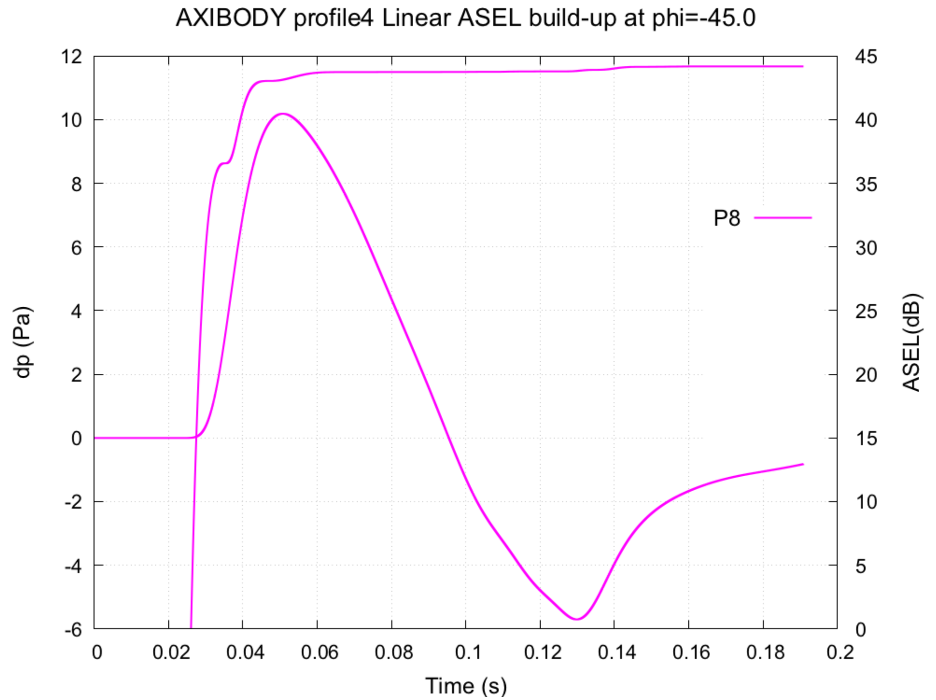


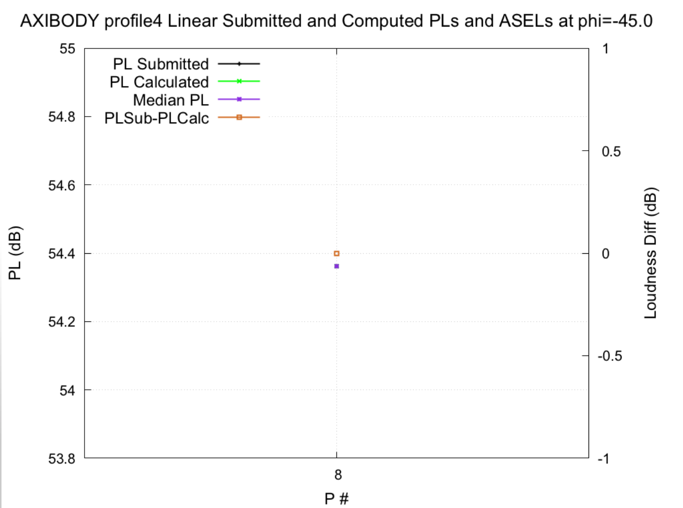


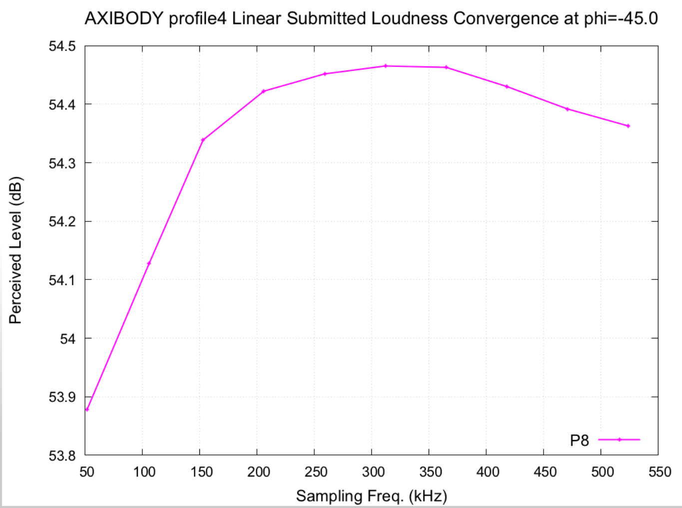
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Linear, Phi = -45.0



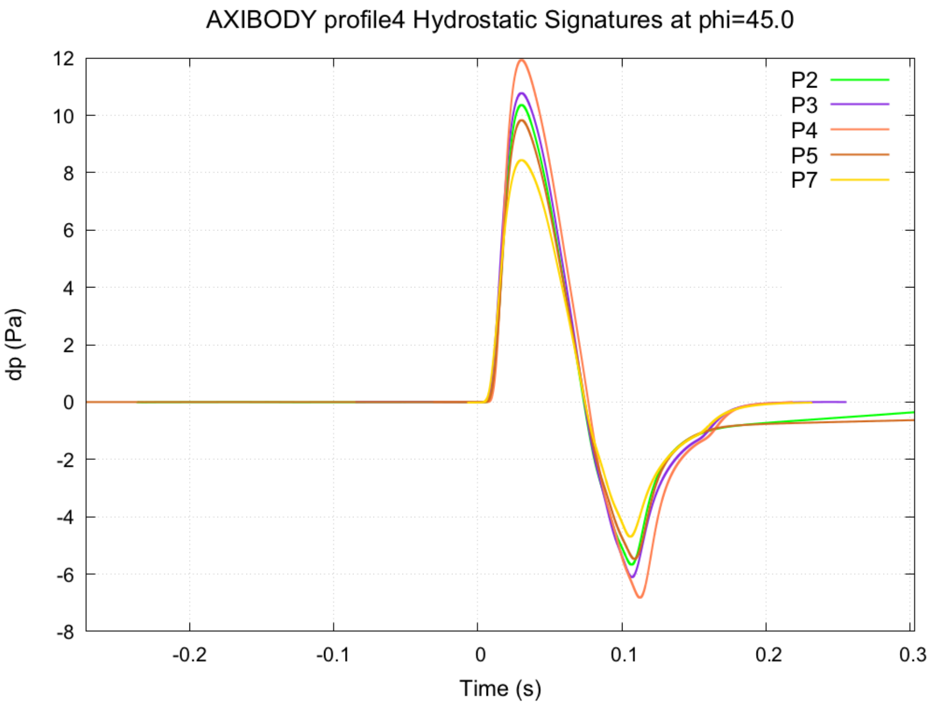


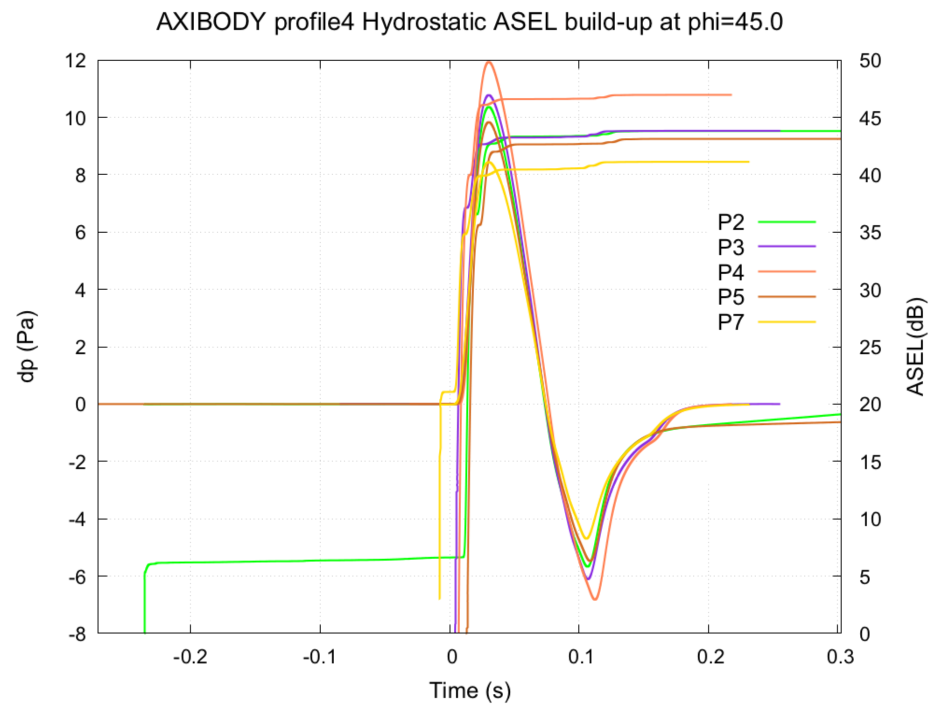


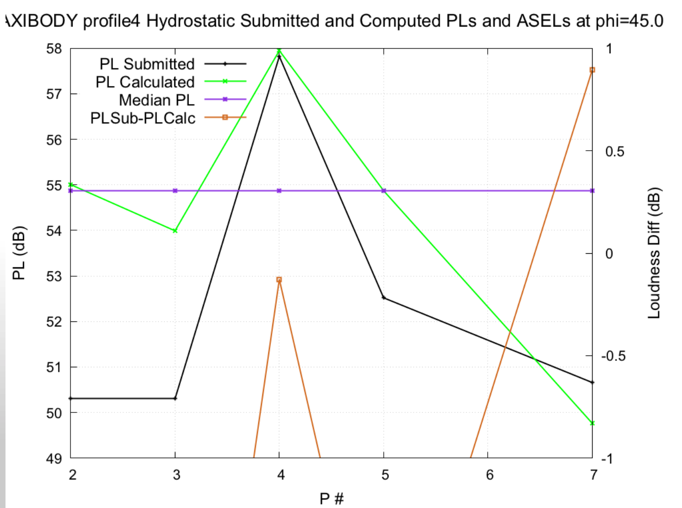


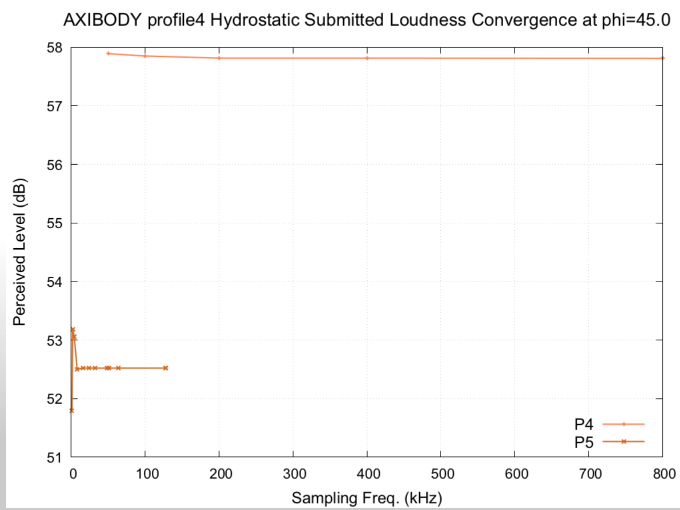
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Hydrostatic, Phi = 45.0



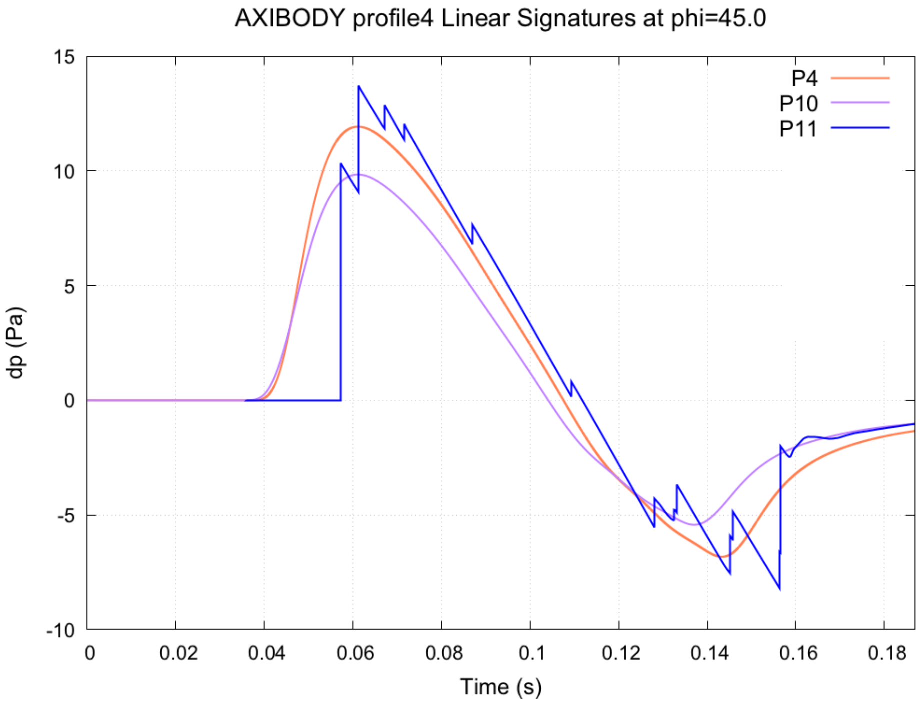


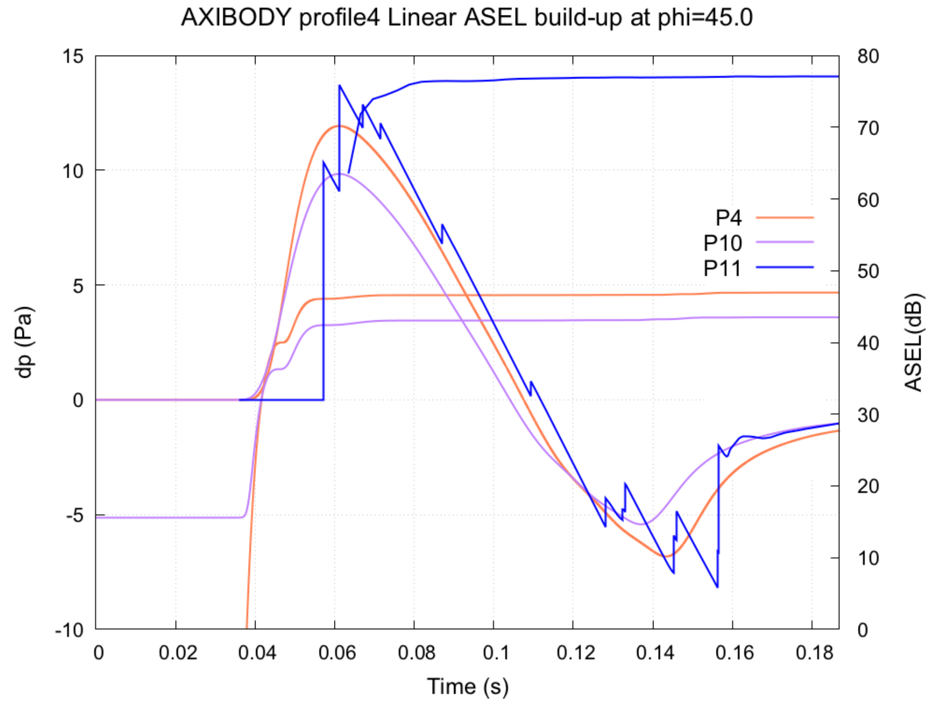


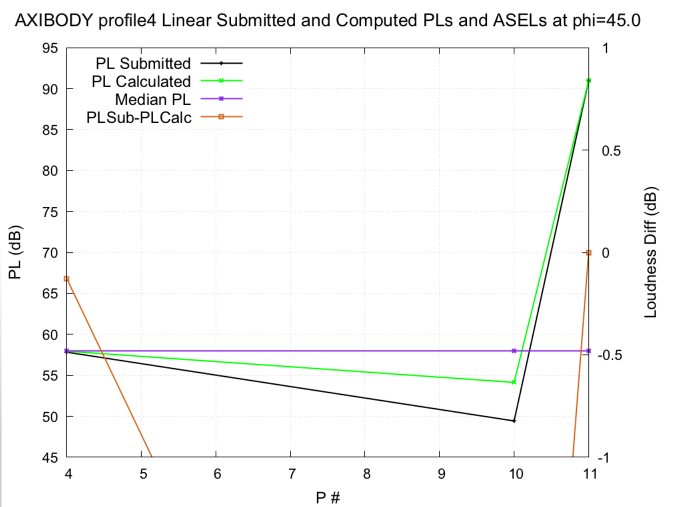


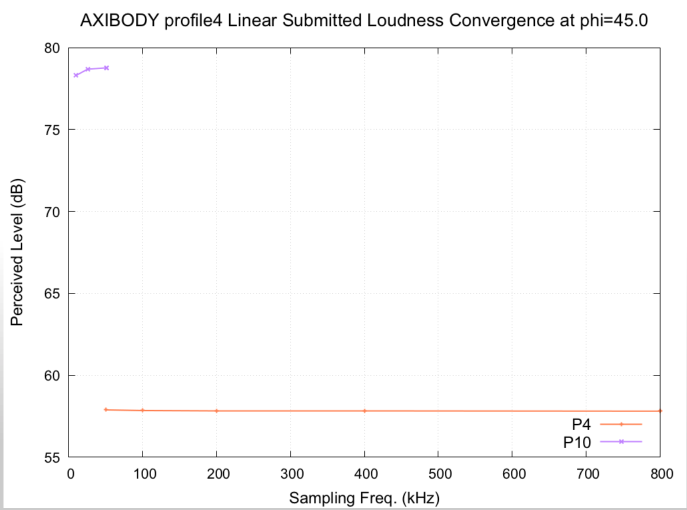
Sriram.Rallabhandi@nasa.gov

AXIBODY– Profile4, Linear, Phi = 45.0



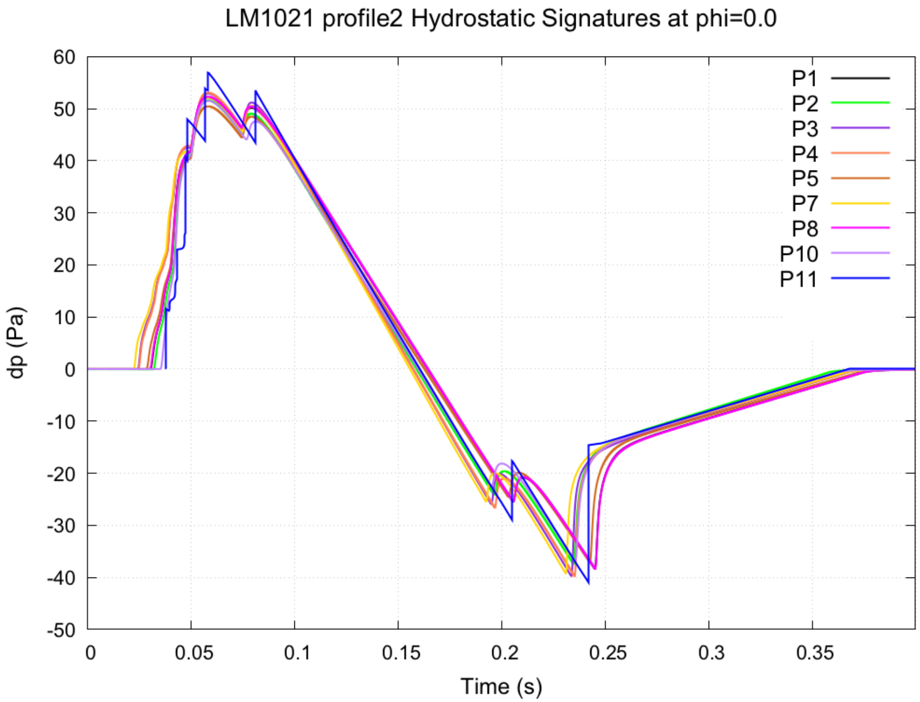


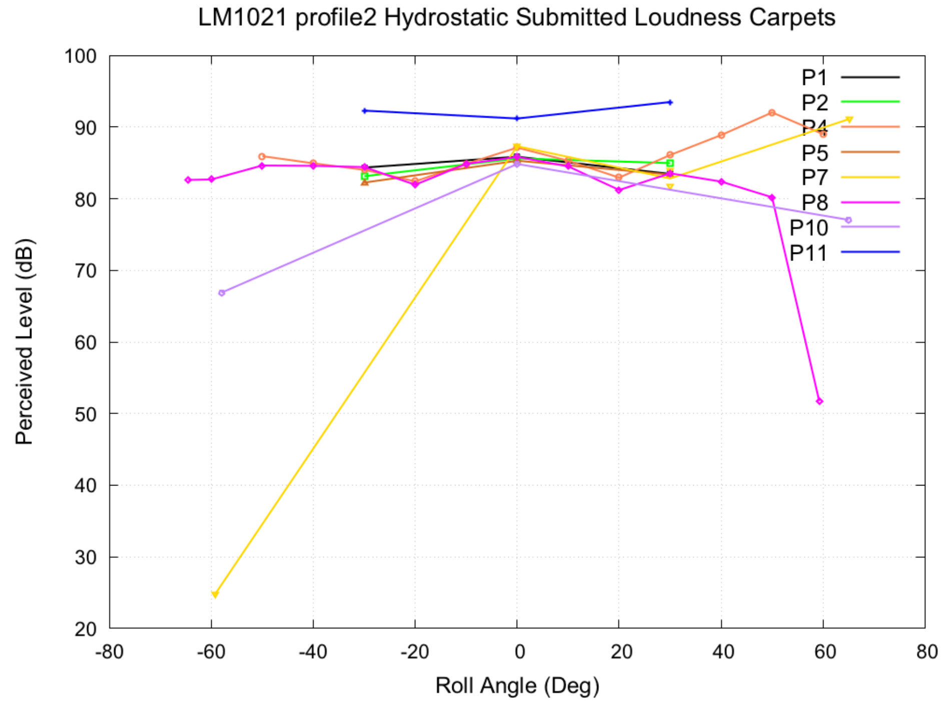


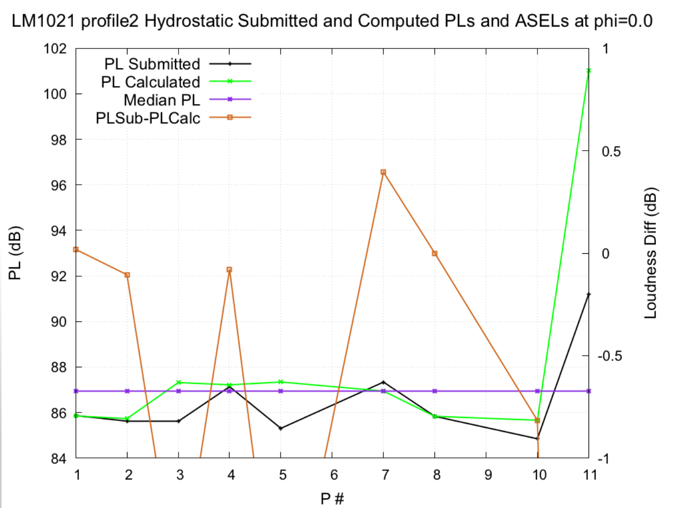


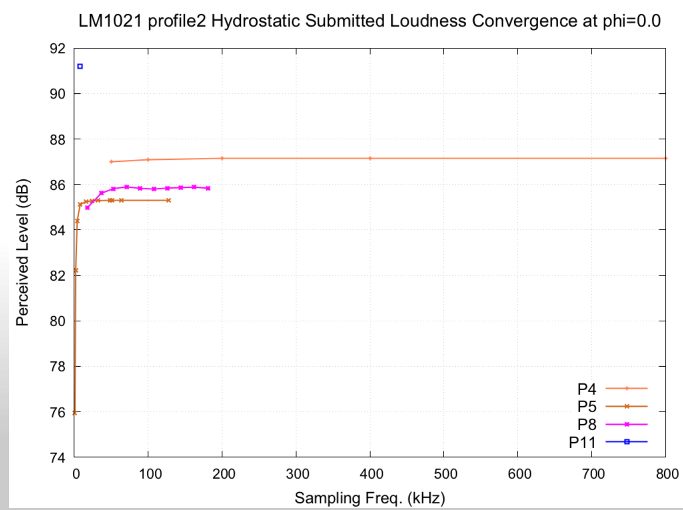
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile2, Hydrostatic, Phi = 0.0



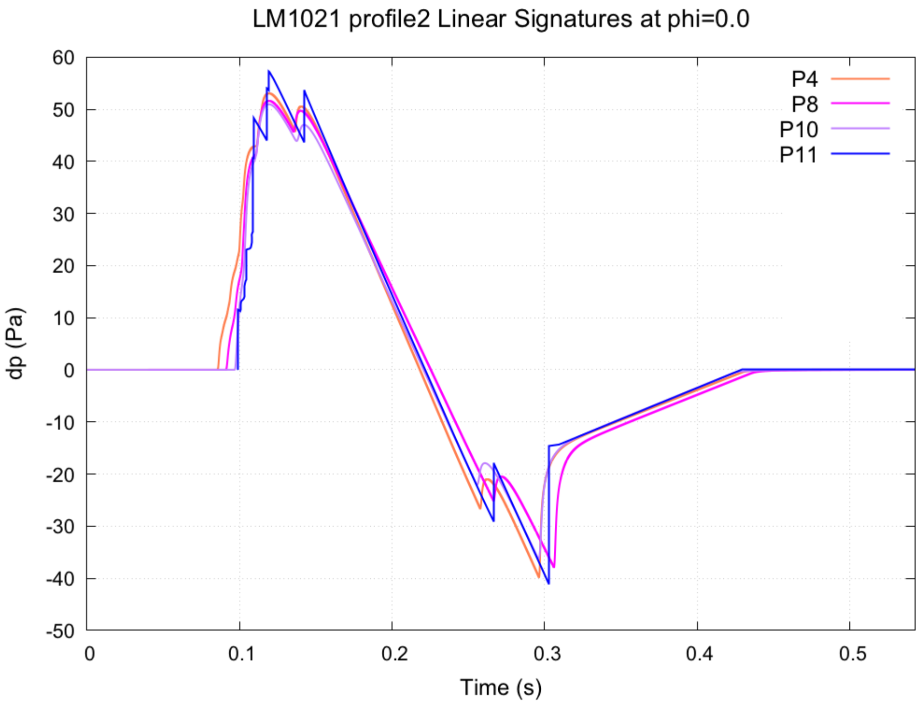


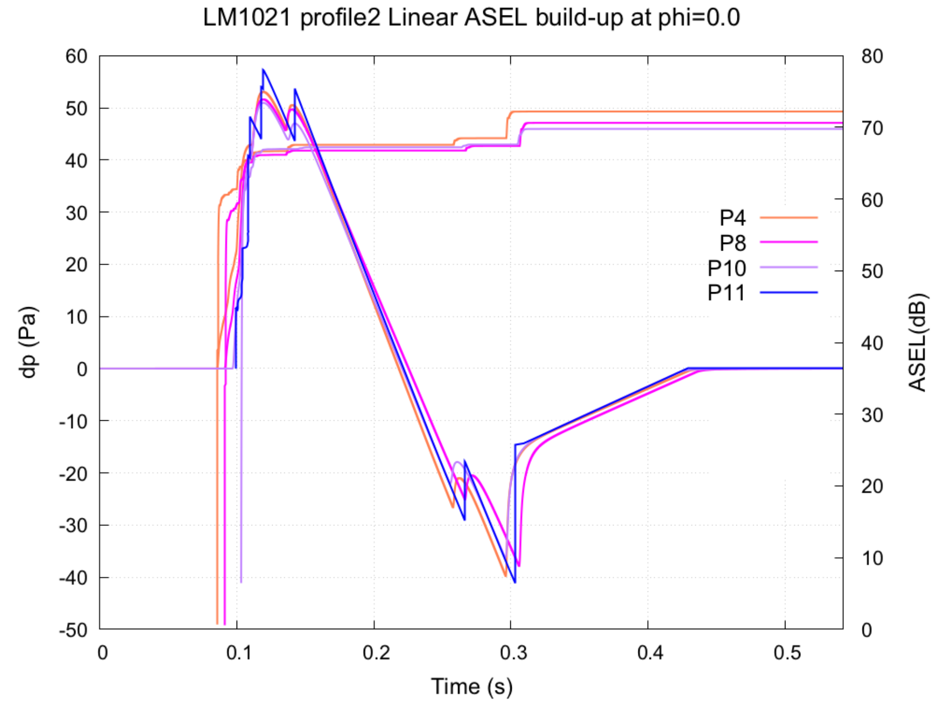


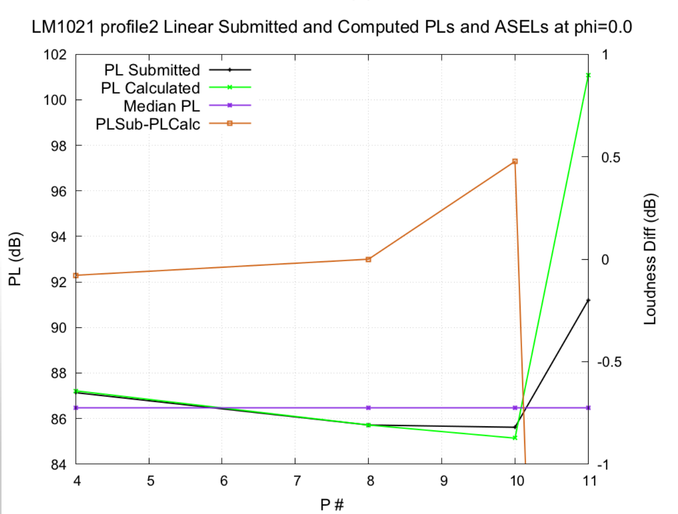


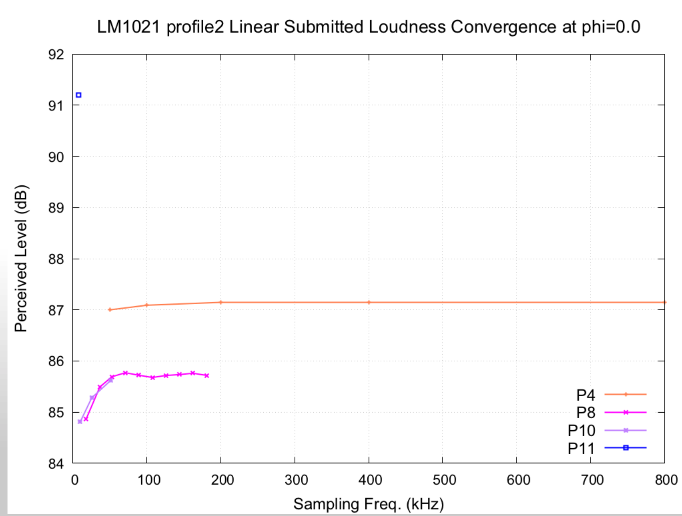
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile2, Linear, Phi = 0.0



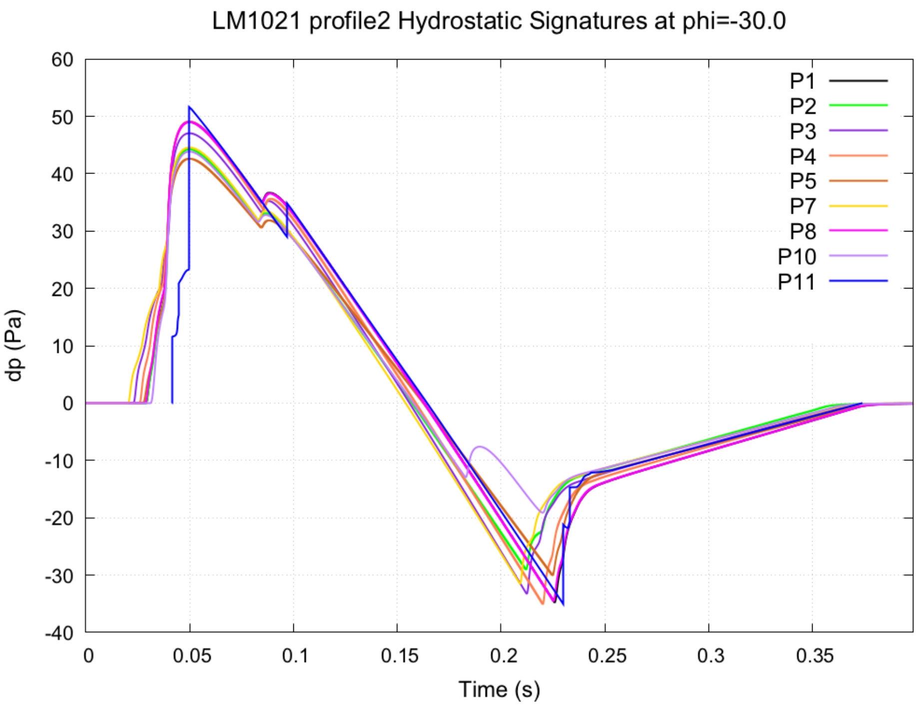


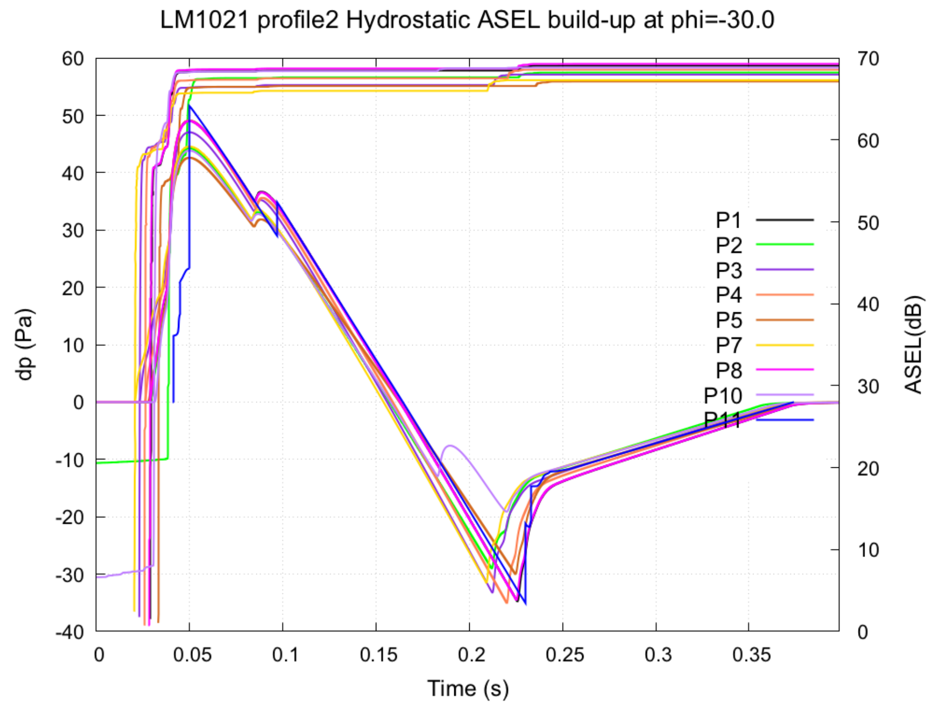


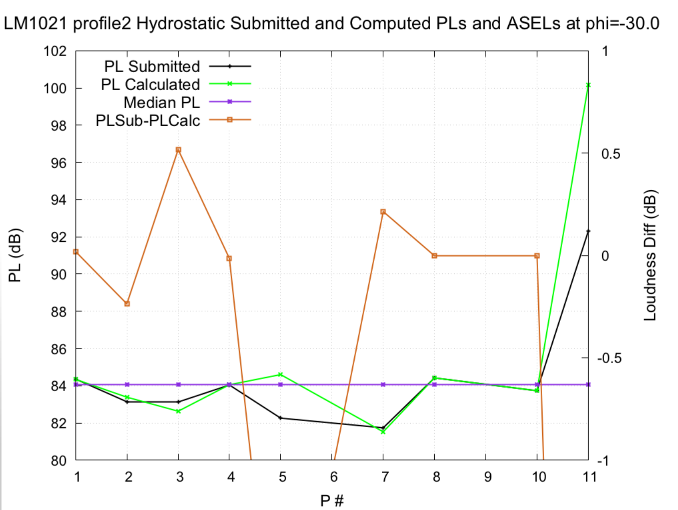


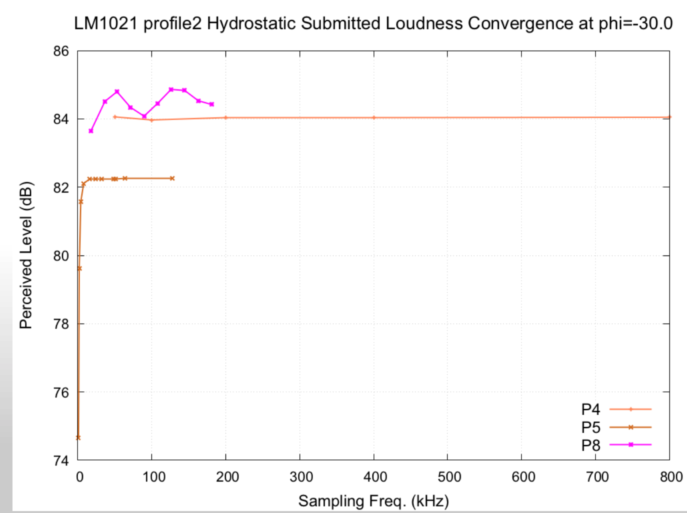
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile2, Hydrostatic, Phi = -30.0

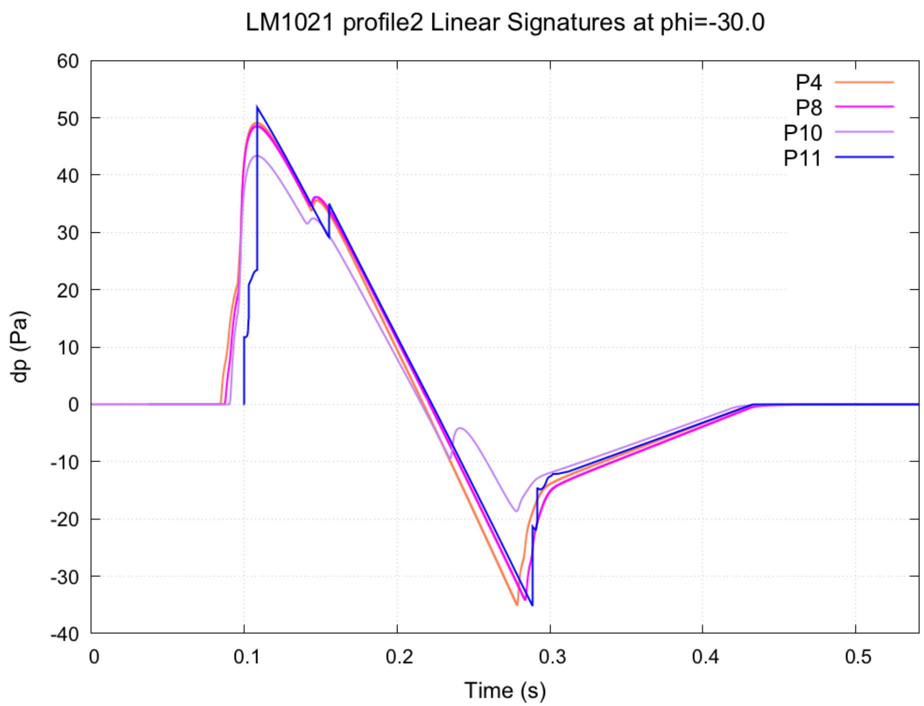


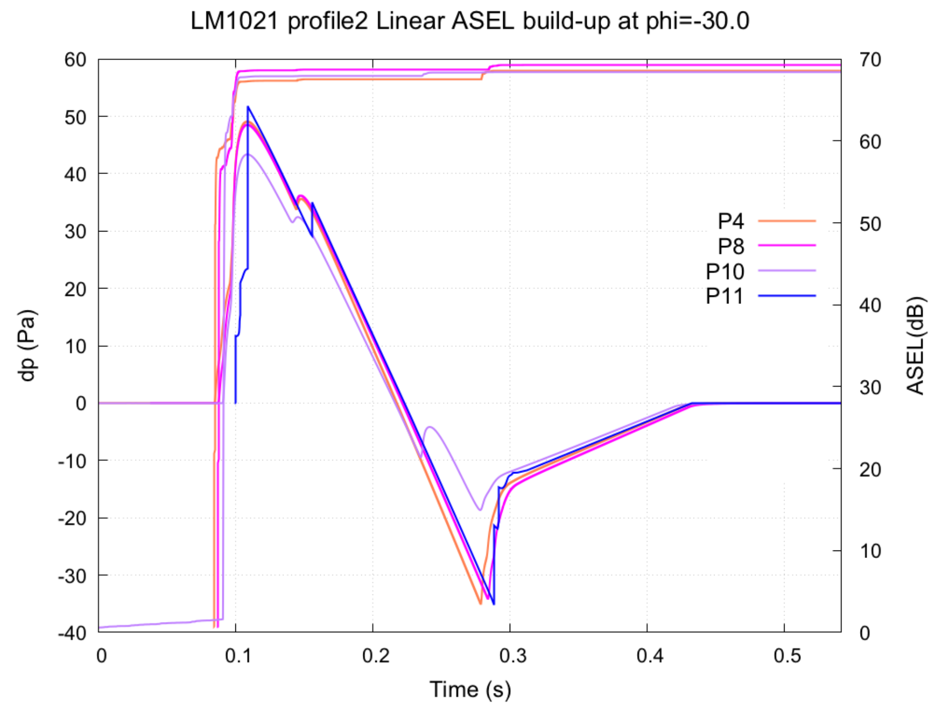


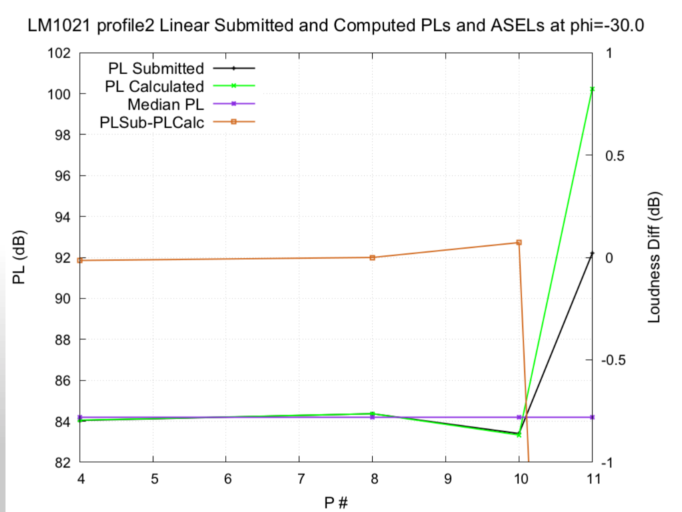


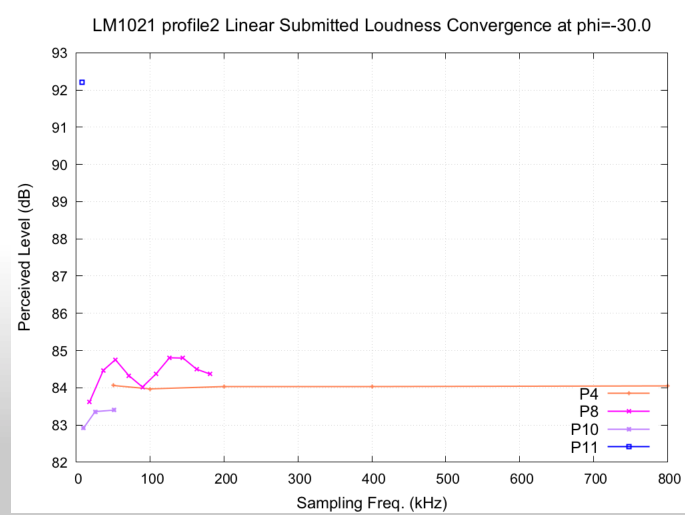


LM1021 – Profile2, Linear, Phi = -30.0

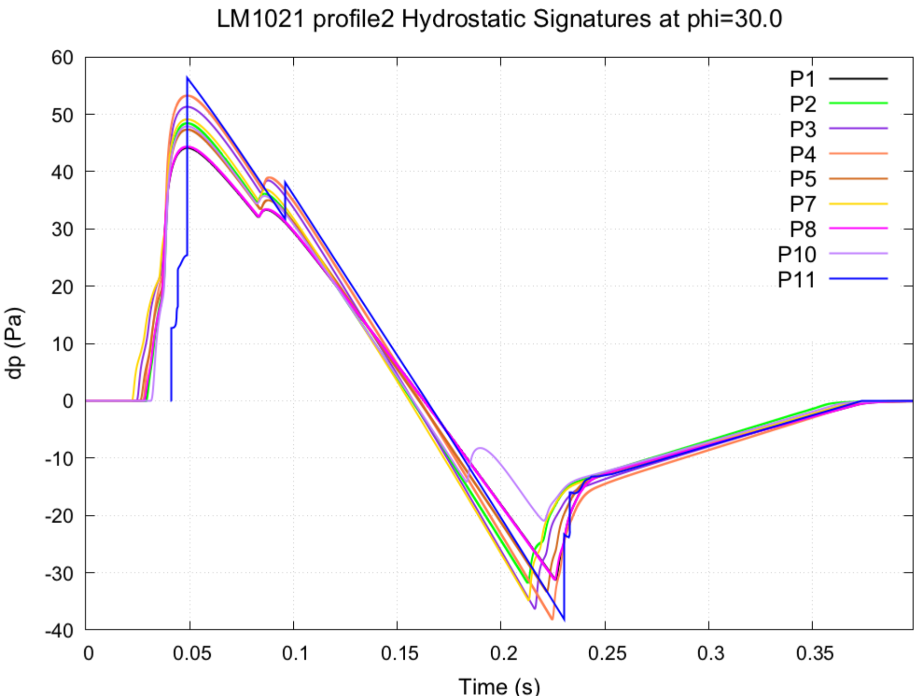


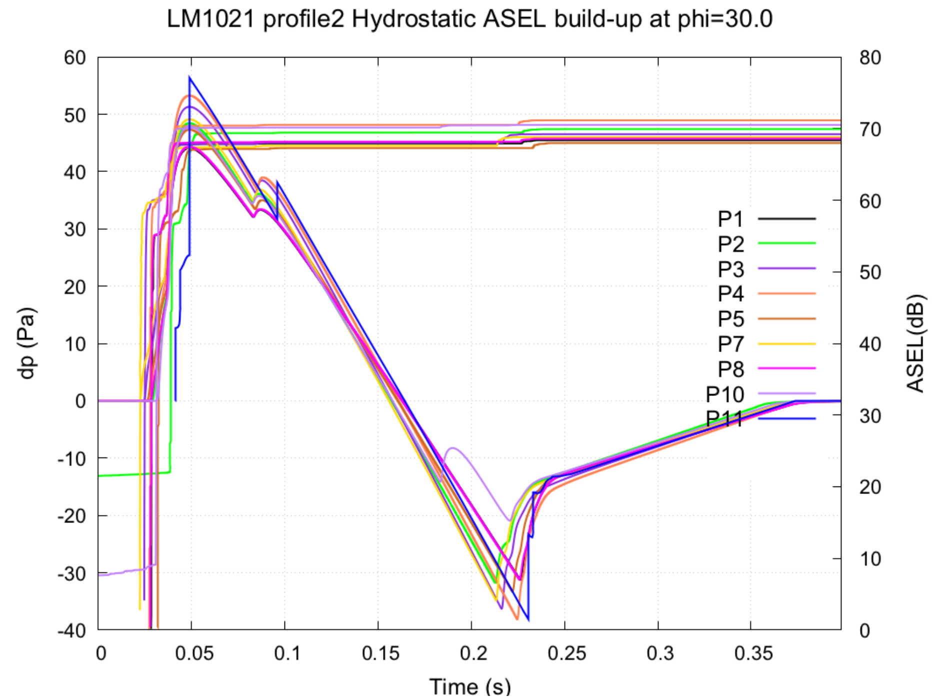


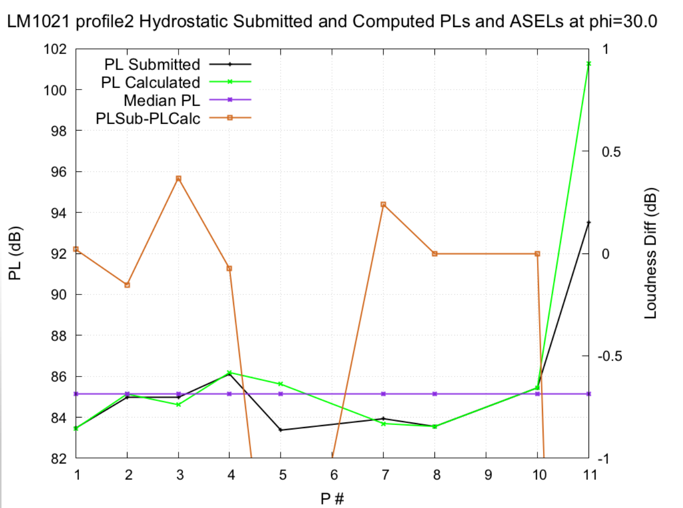


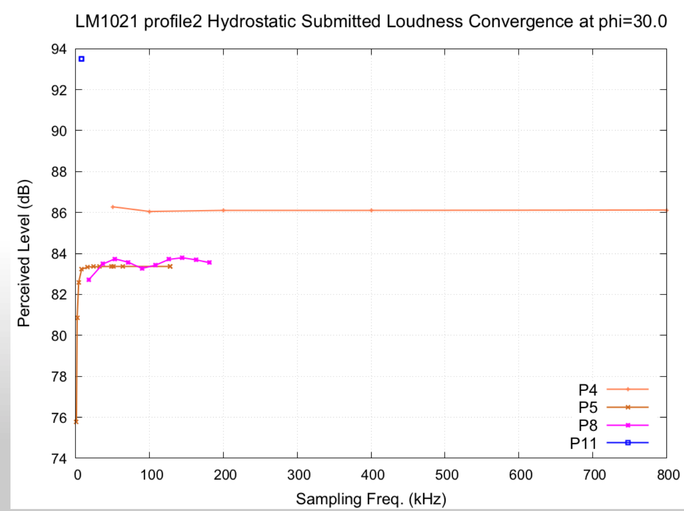


LM1021 – Profile2, Hydrostatic, Phi = 30.0



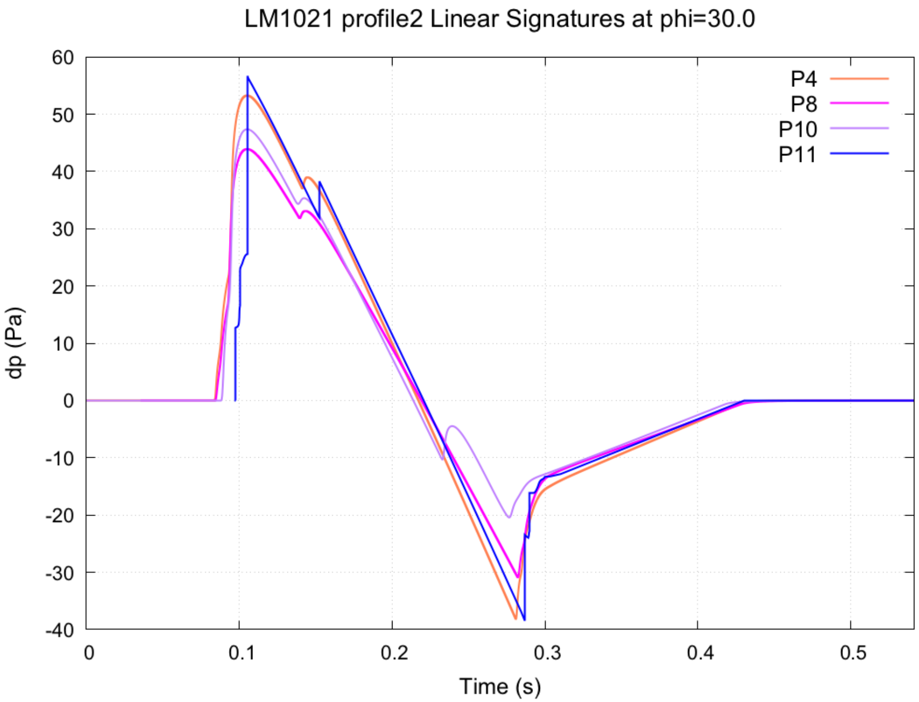


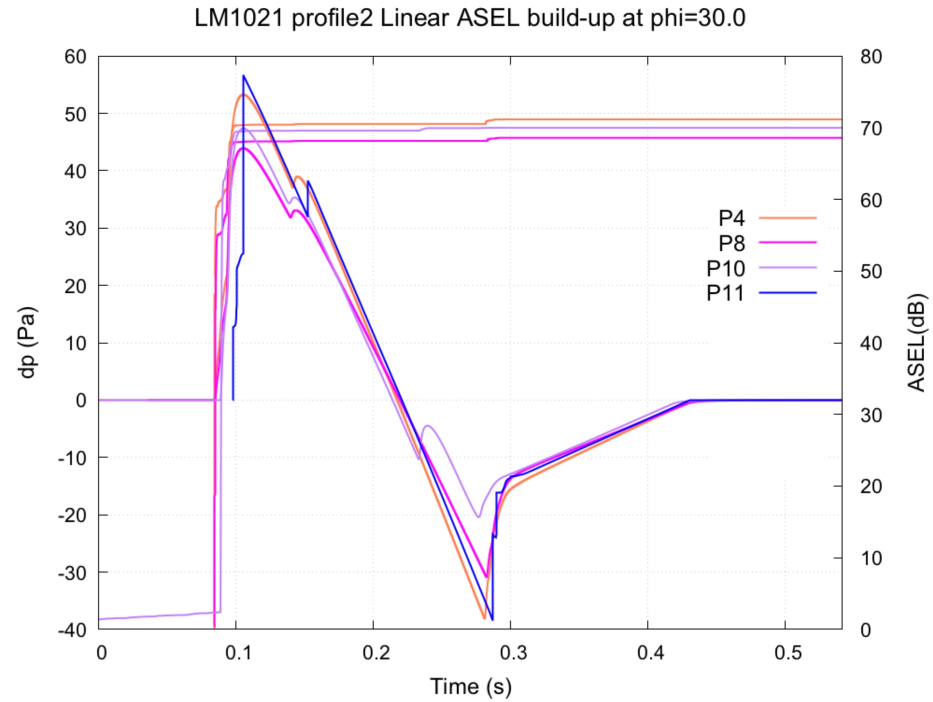


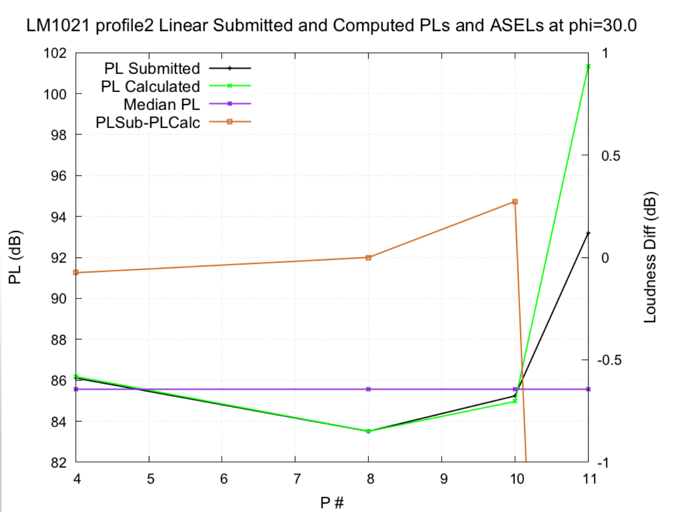


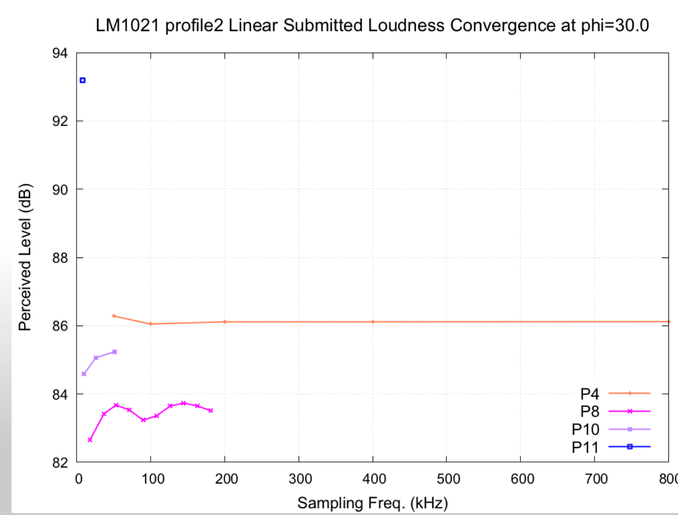
Sriram.Rallabhandi@nasa.gov

LM1021 – Profile2, Linear, Phi = 30.0



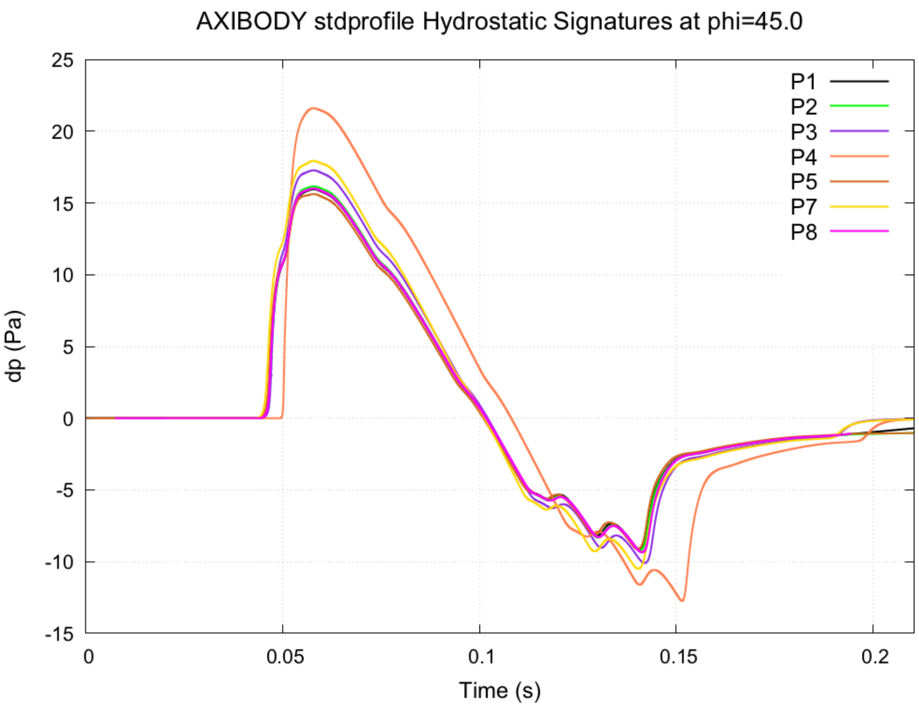


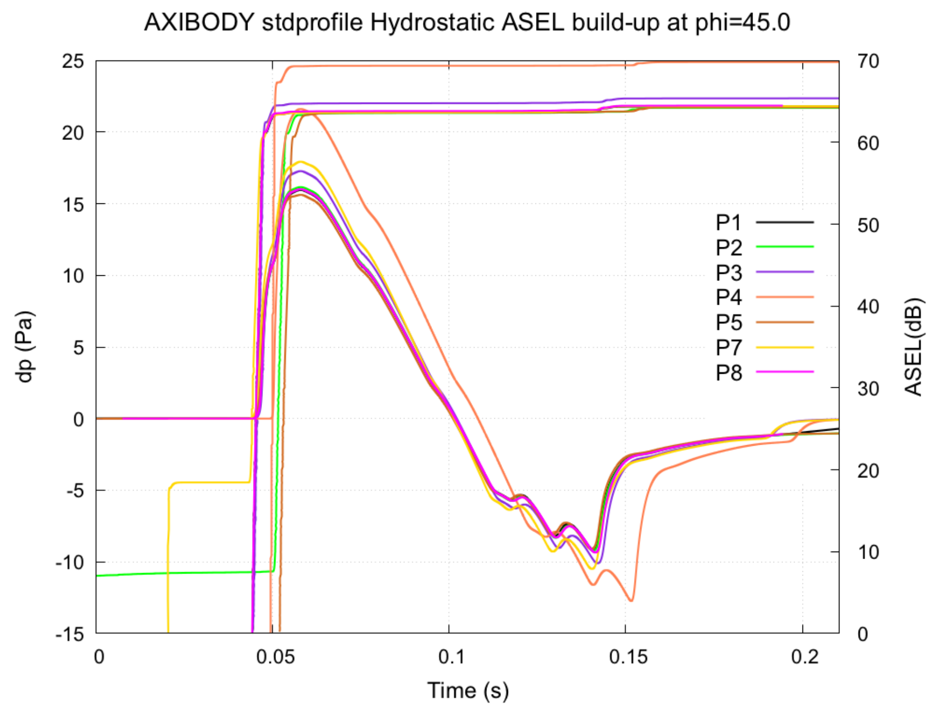


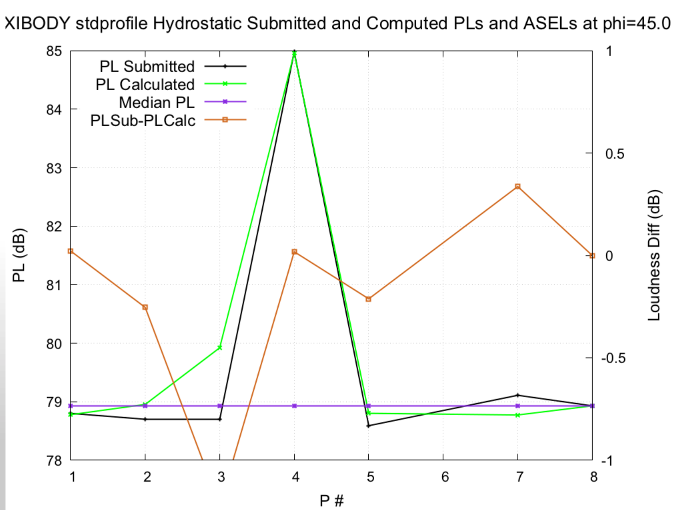


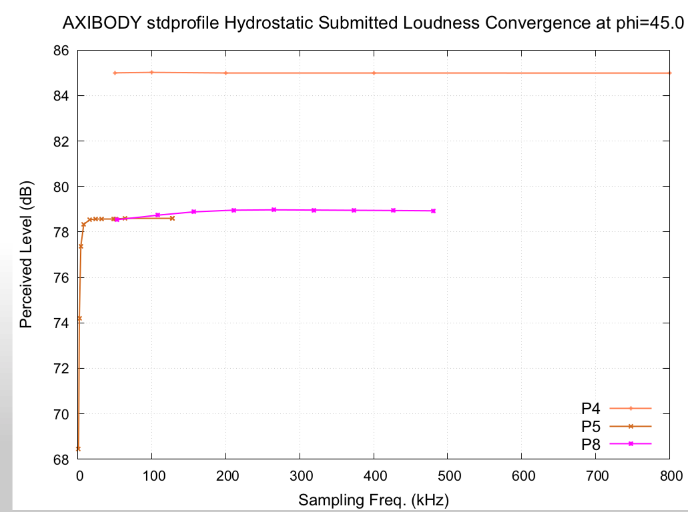
Sriram.Rallabhandi@nasa.gov

AXIBODY– StdProfile, Hydrostatic, Phi = 45.0

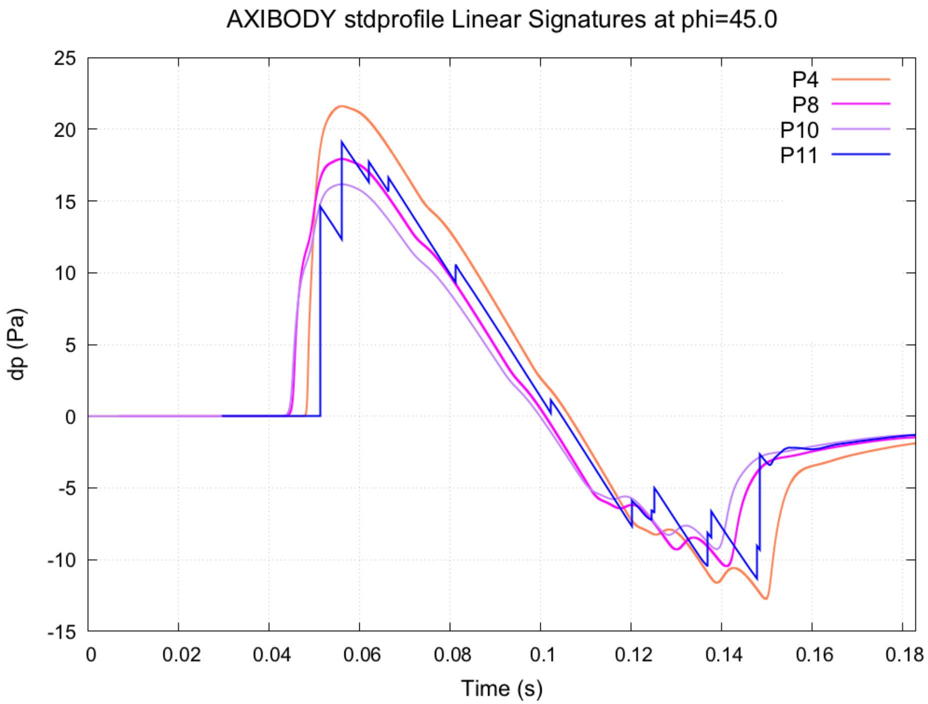


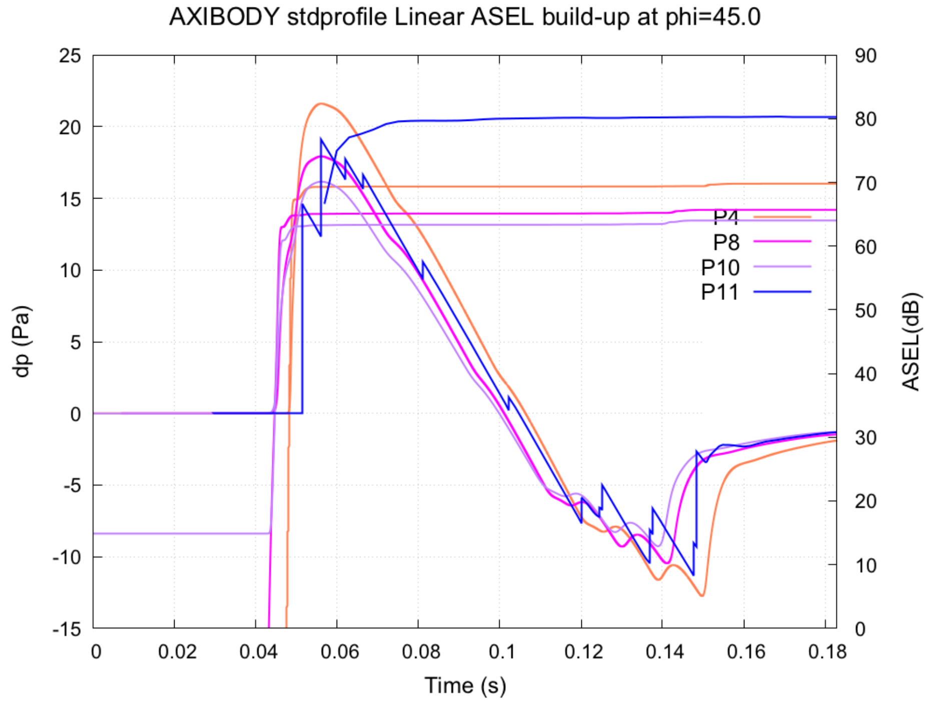


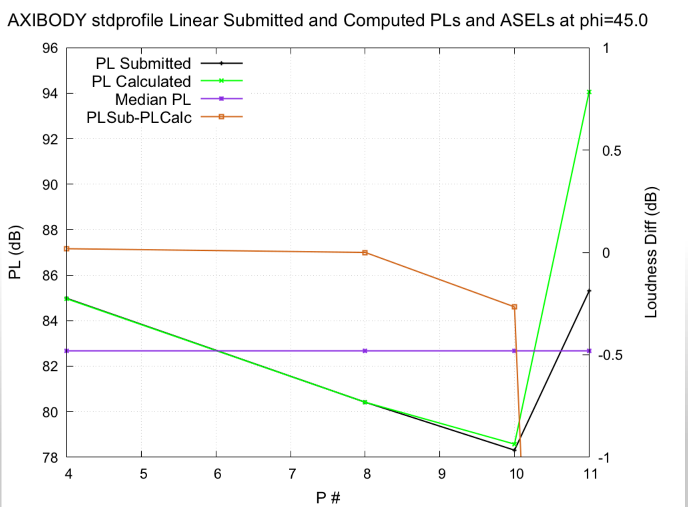


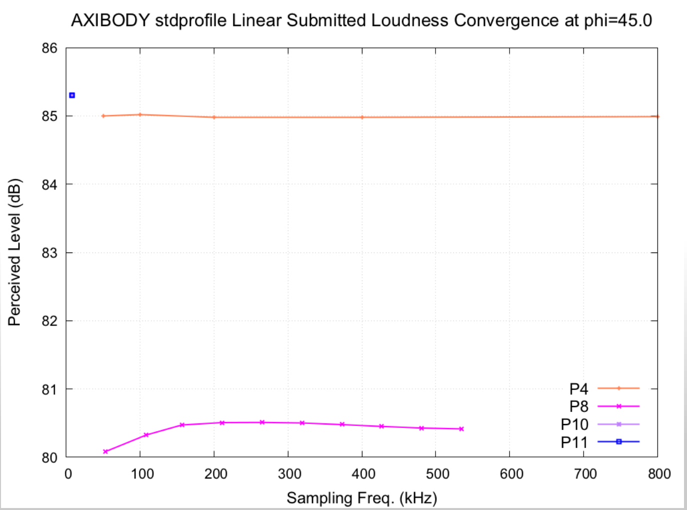


AXIBODY– StdProfile, Linear, Phi = 45.0



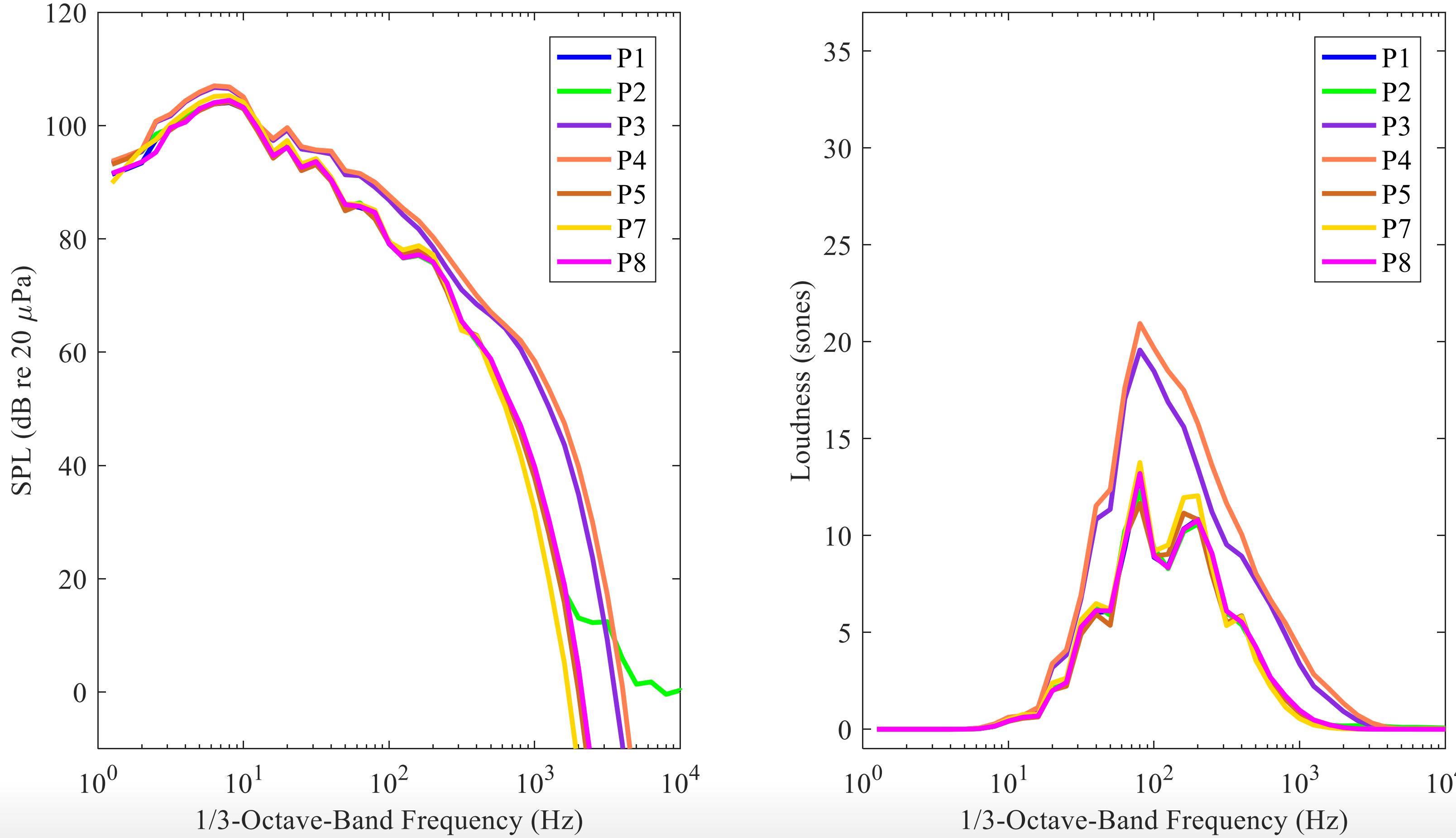




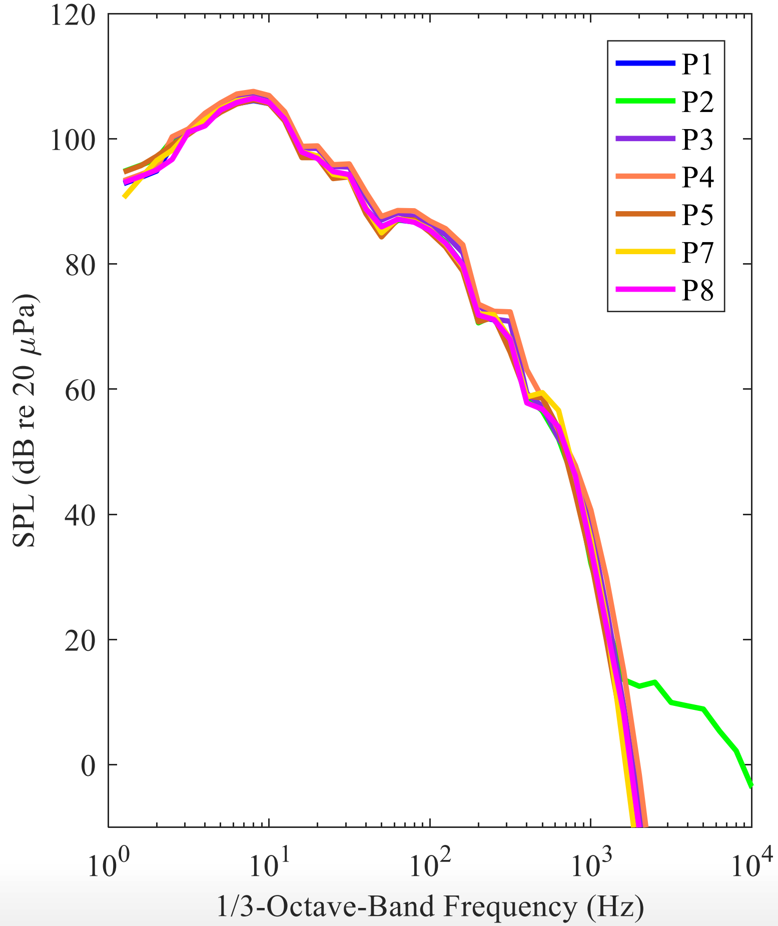


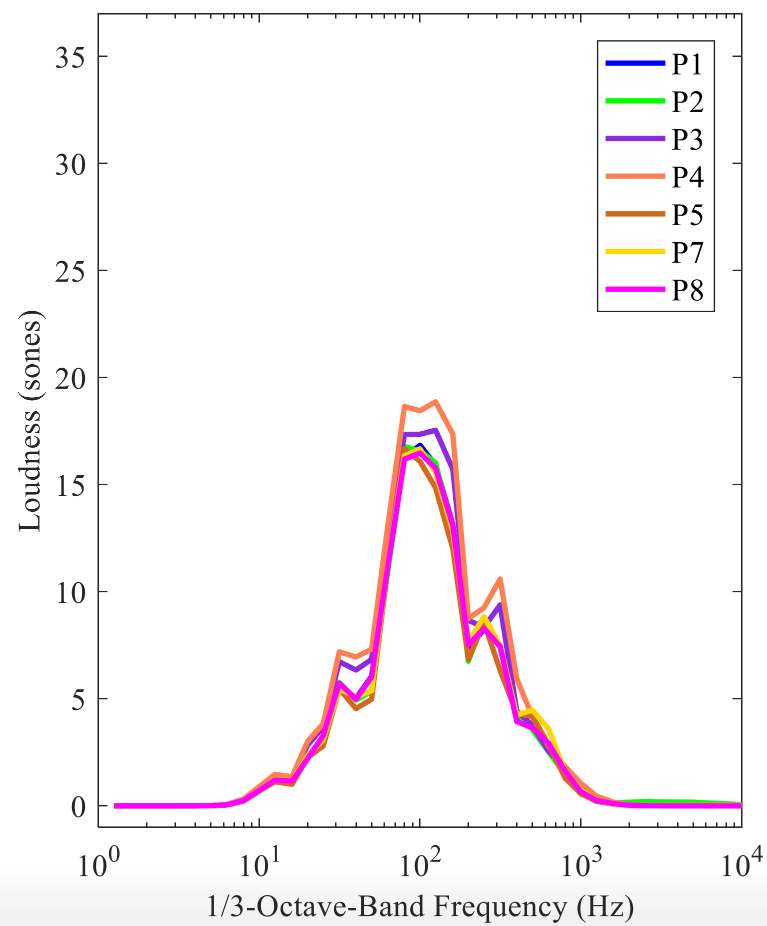
Sriram.Rallabhandi@nasa.gov

Axi-symmetric, Std Atm, 70% rh, Phi = -45°

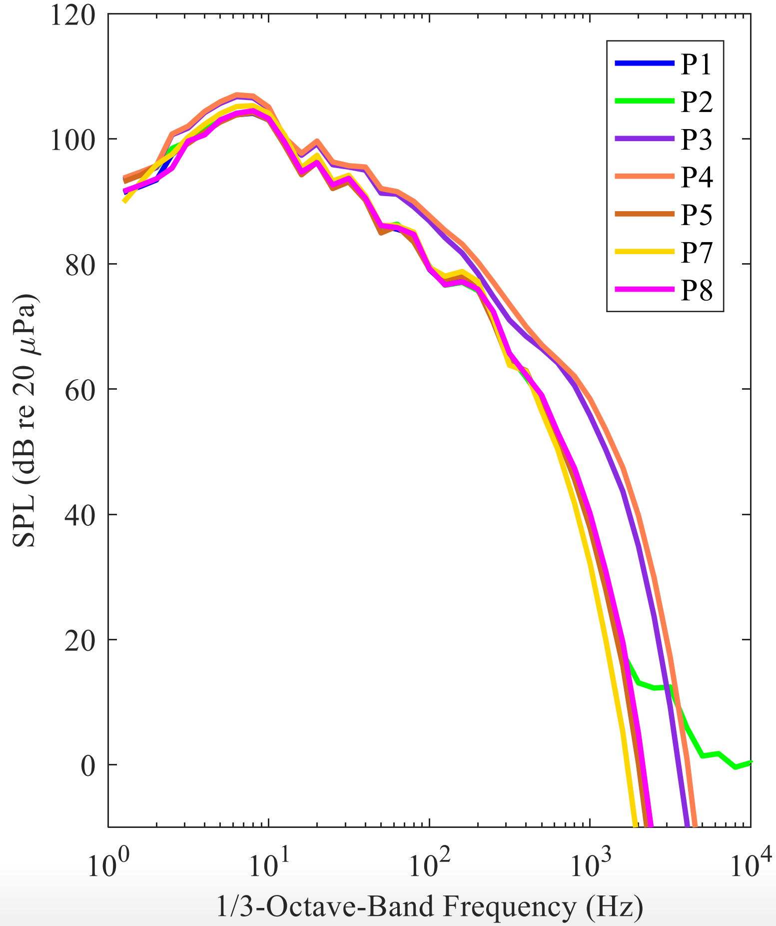


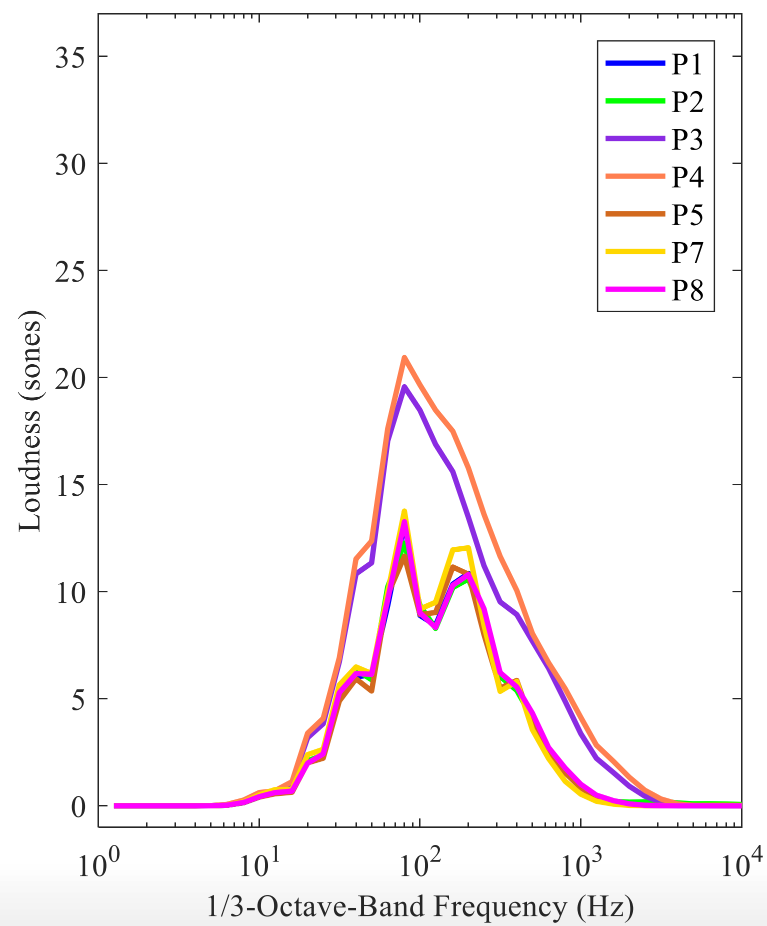
Axi-symmetric, Std Atm, 70% rh, Phi = 0˚



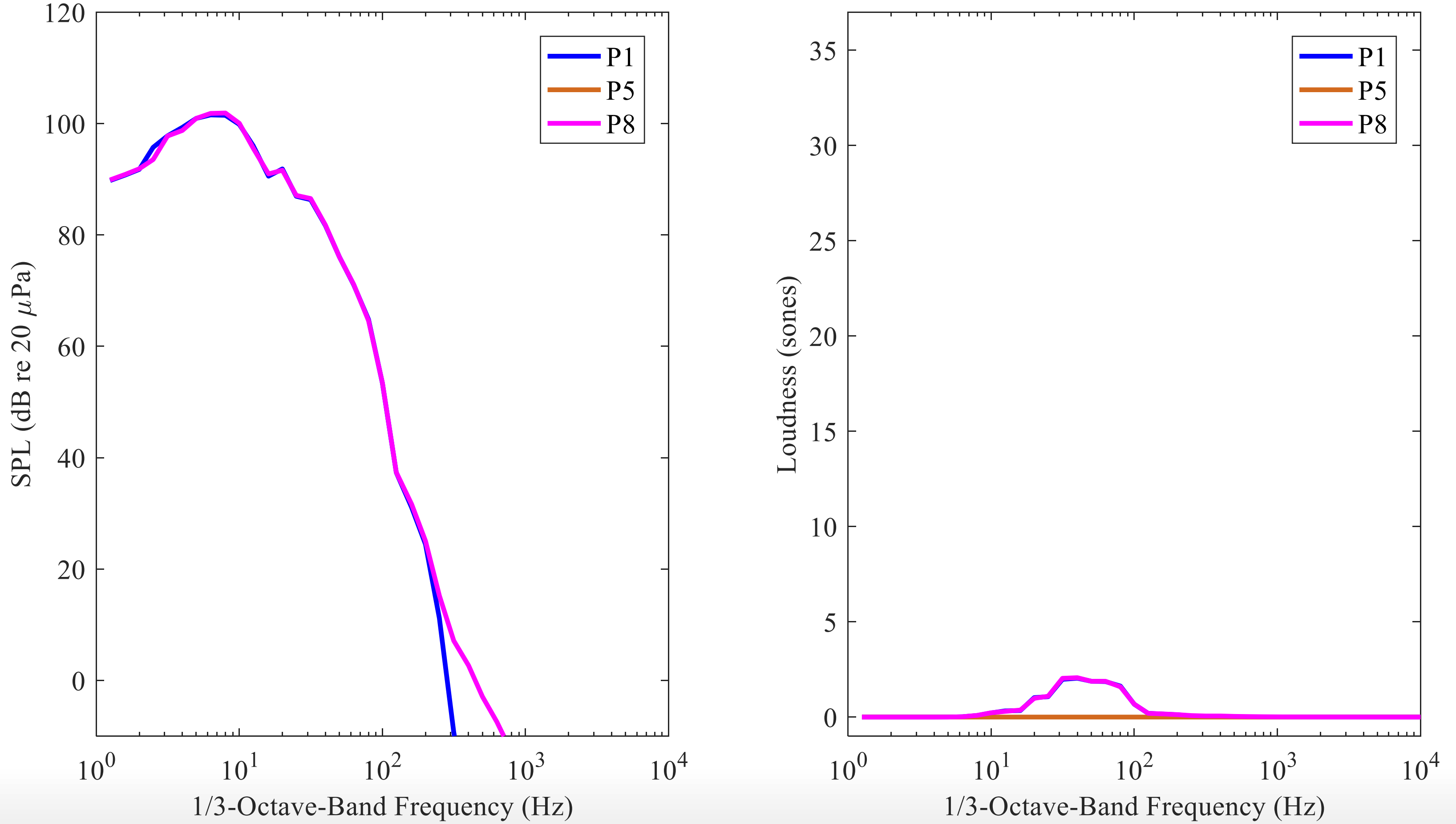


Axi-symmetric, Std Atm, 70% rh, Phi = +45°

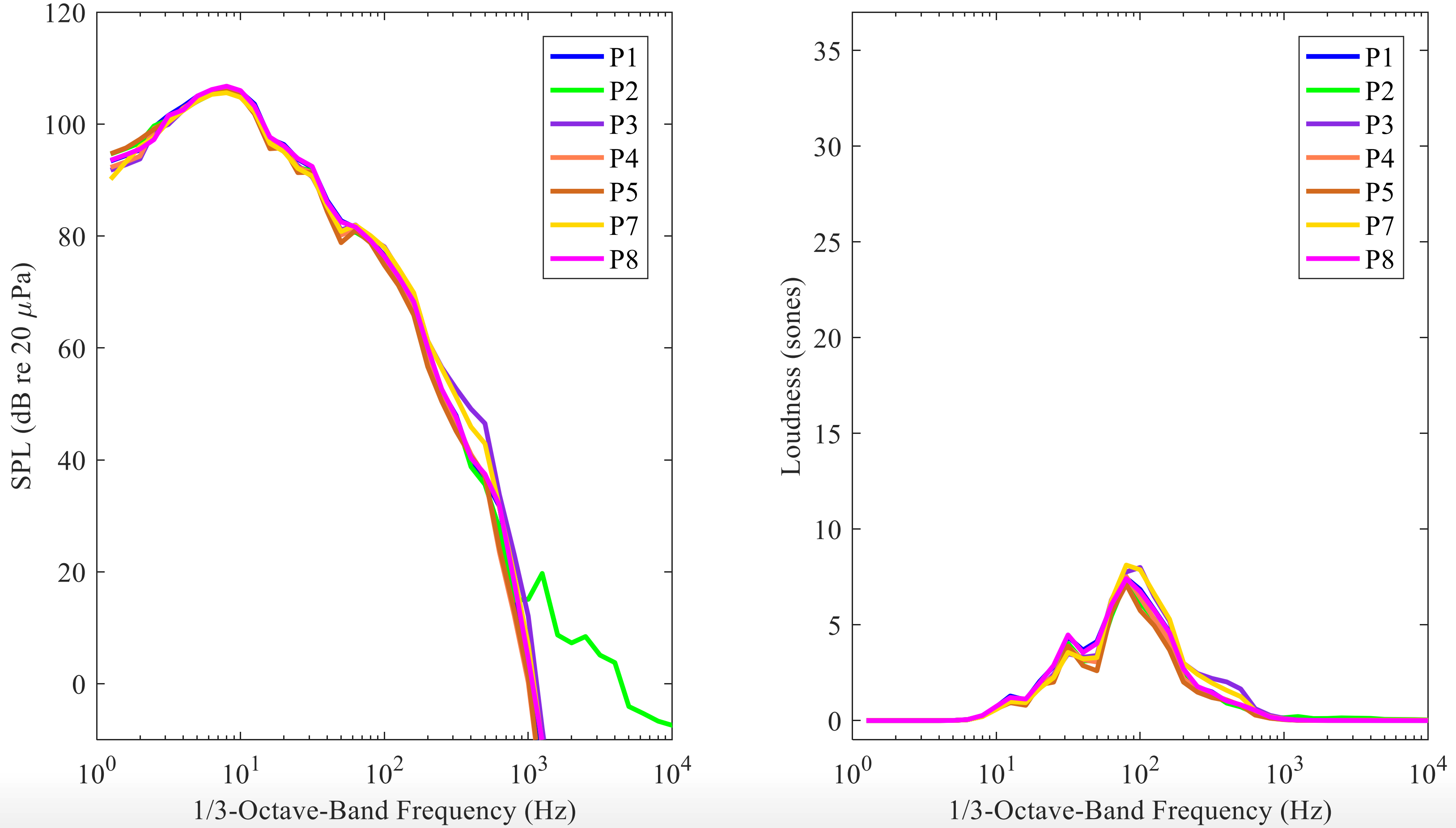




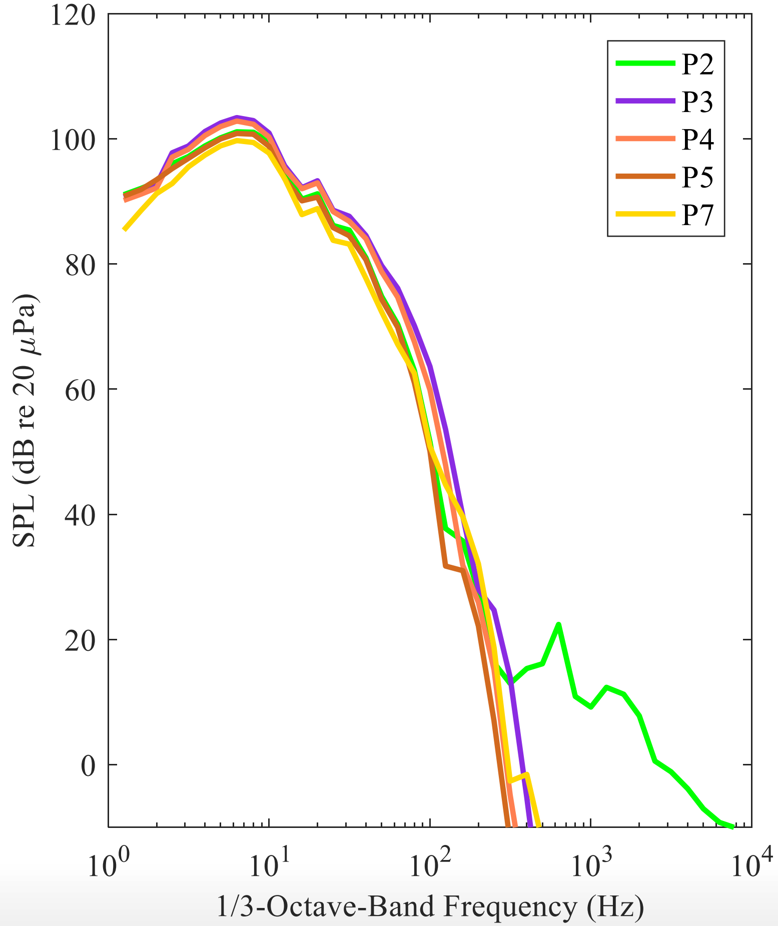
Axi-symmetric, Atm Profile 4, Phi = -45˚

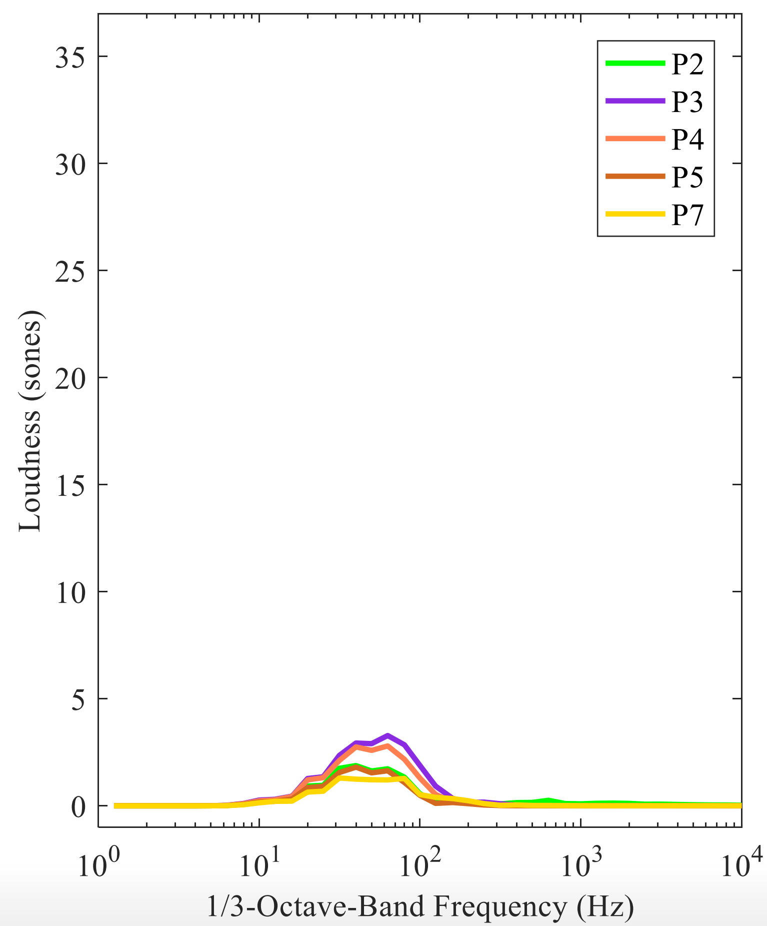


Axi-symmetric, Atm Profile 4, Phi = 0°

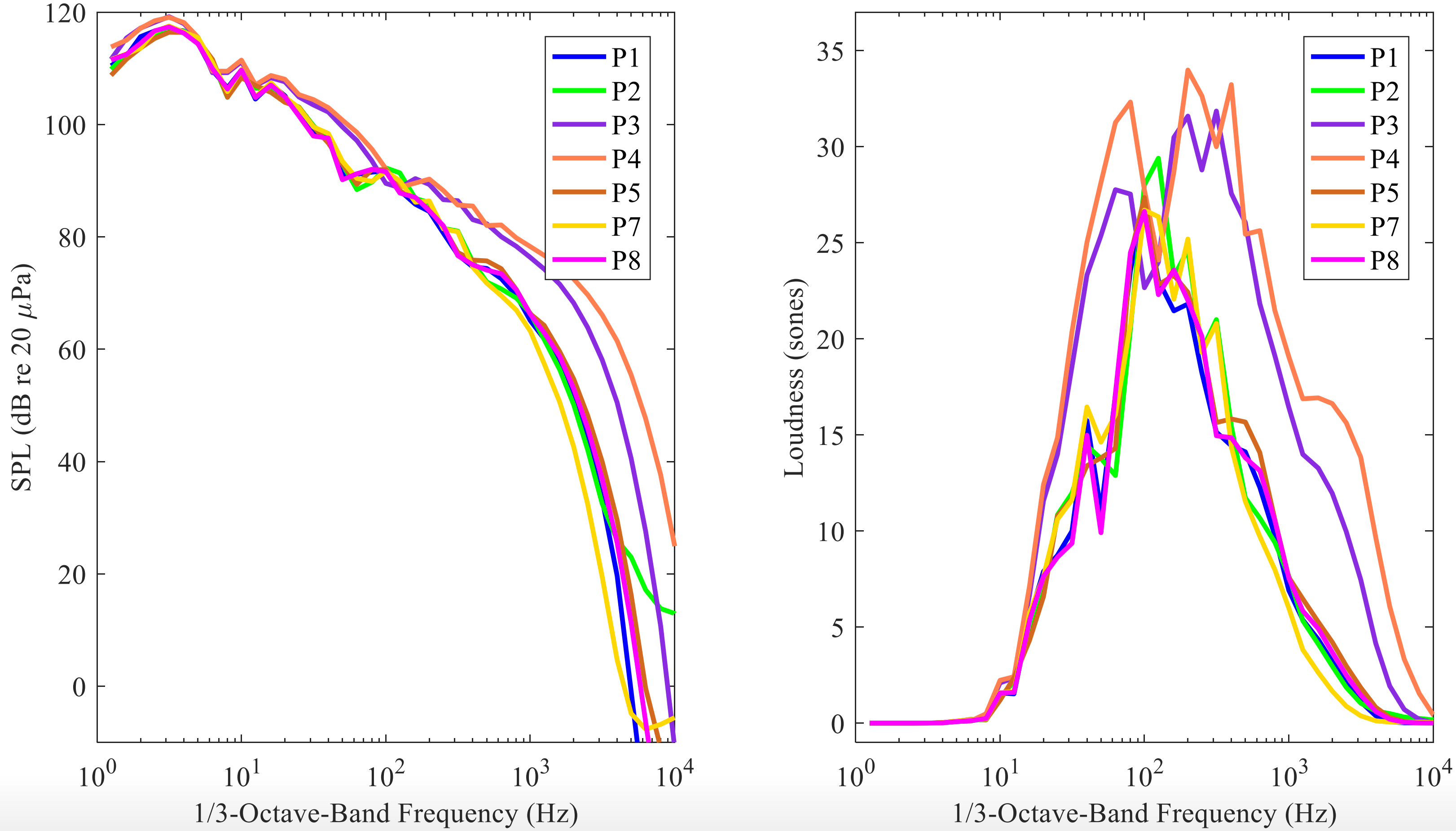


Axi-symmetric, Atm Profile 4, Phi = +45°

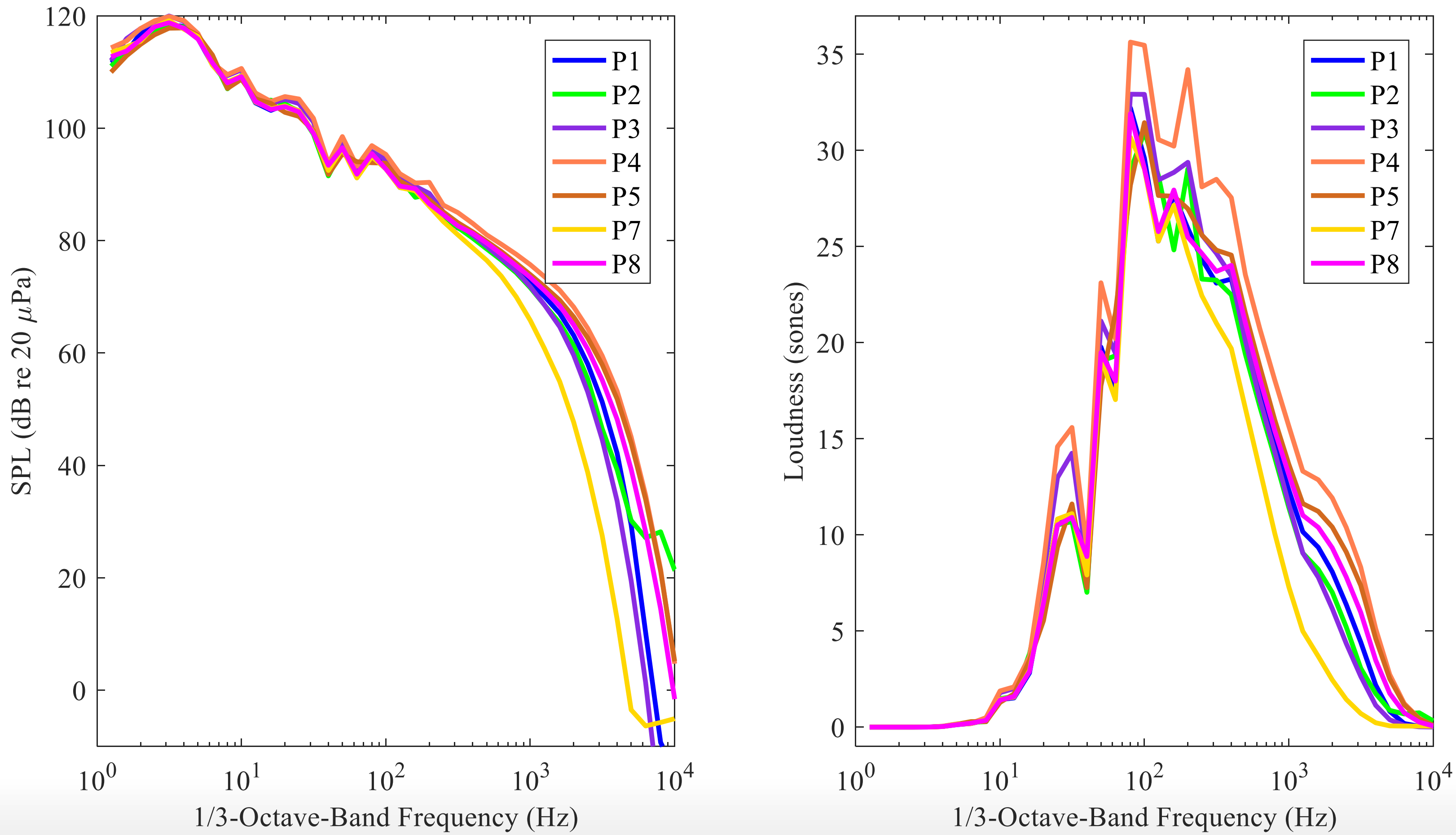




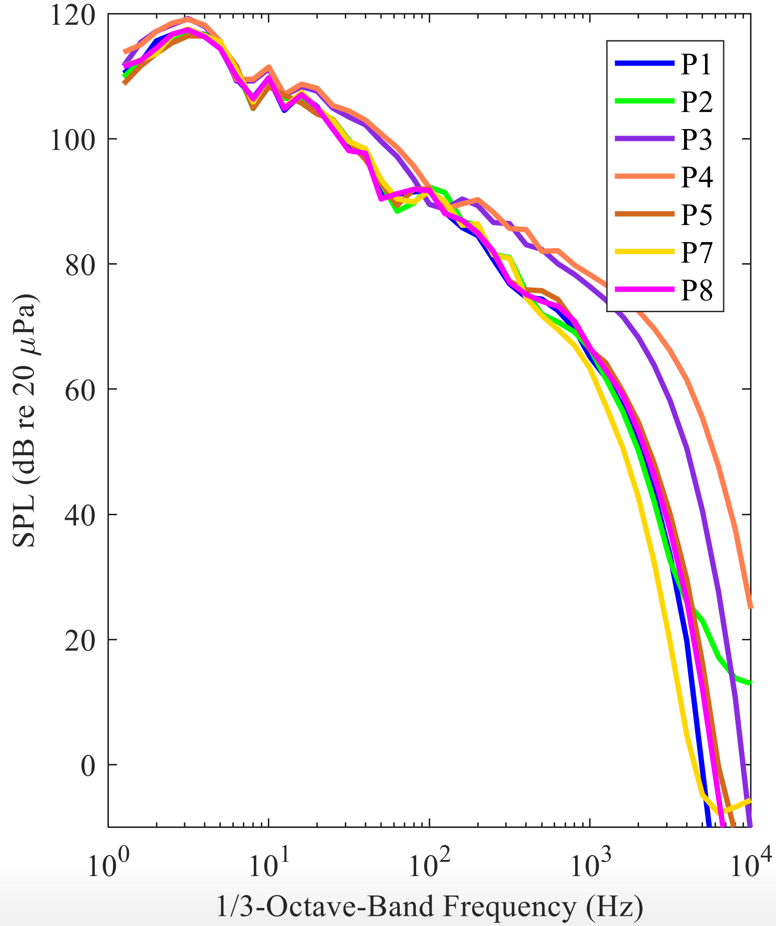
LM1021, Std Atm, 70% rh, Phi = -30˚

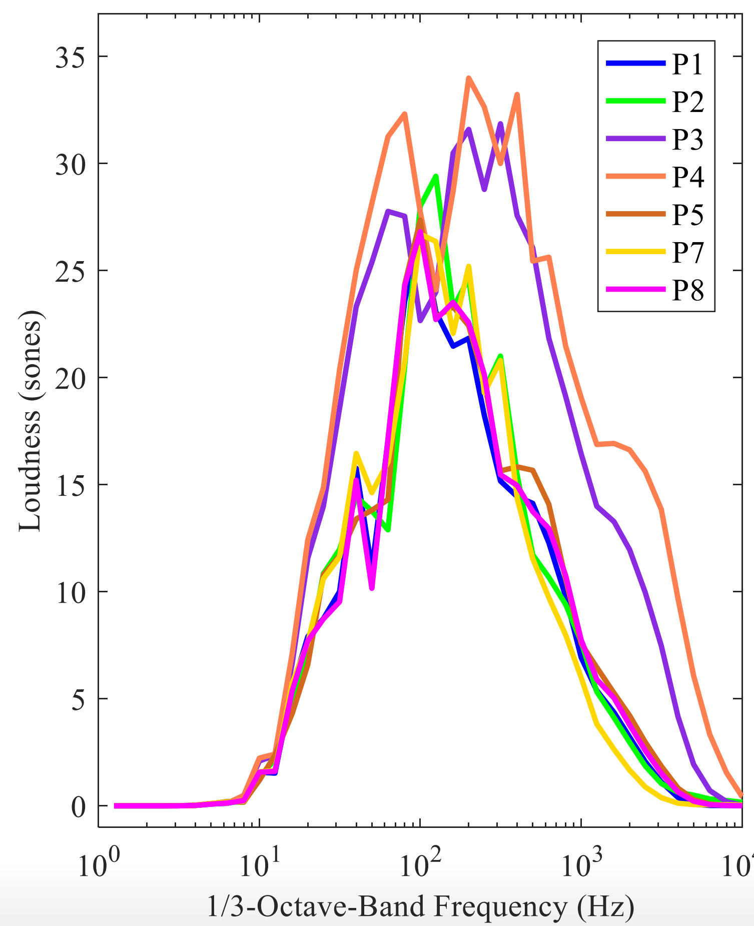


LM1021, Std Atm, 70% rh, Phi = 0˚

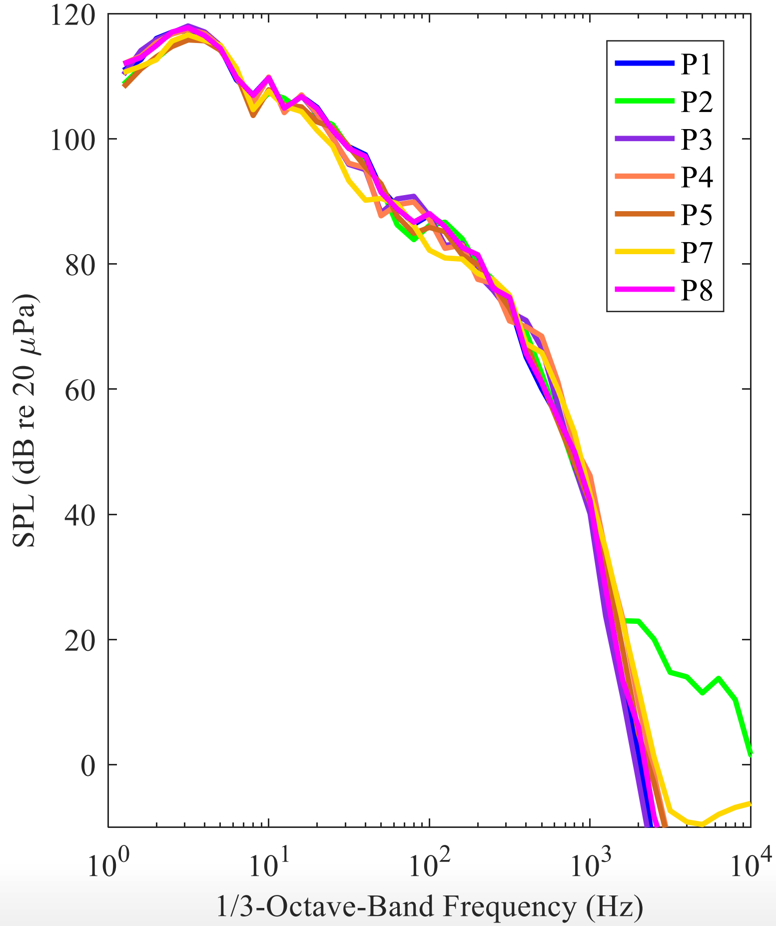


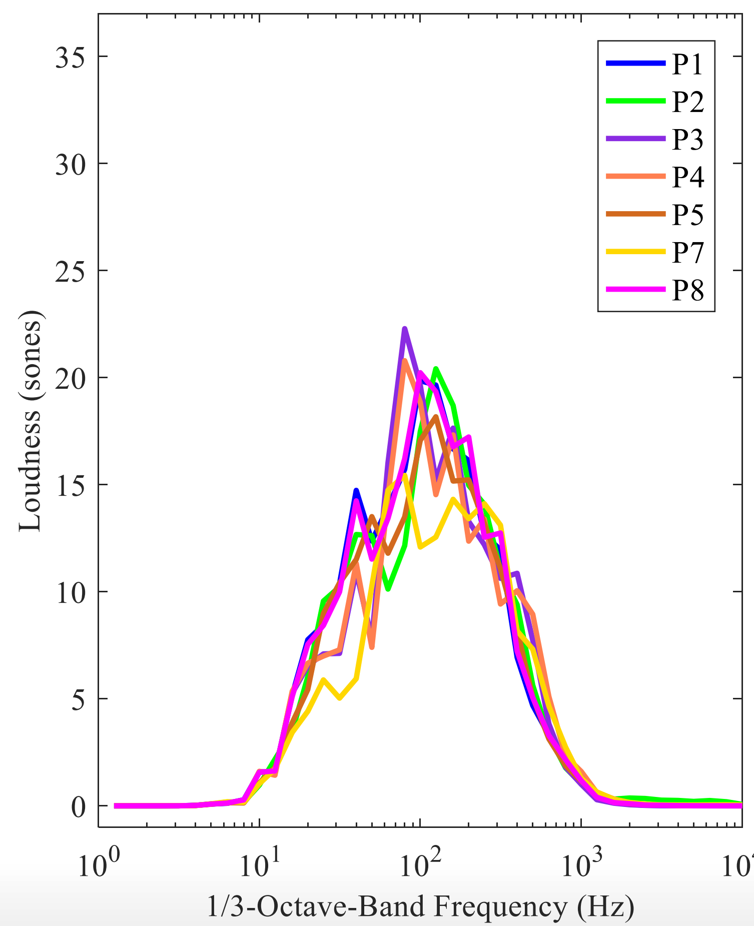
LM1021, Std Atm, 70% rh, Phi = +30°



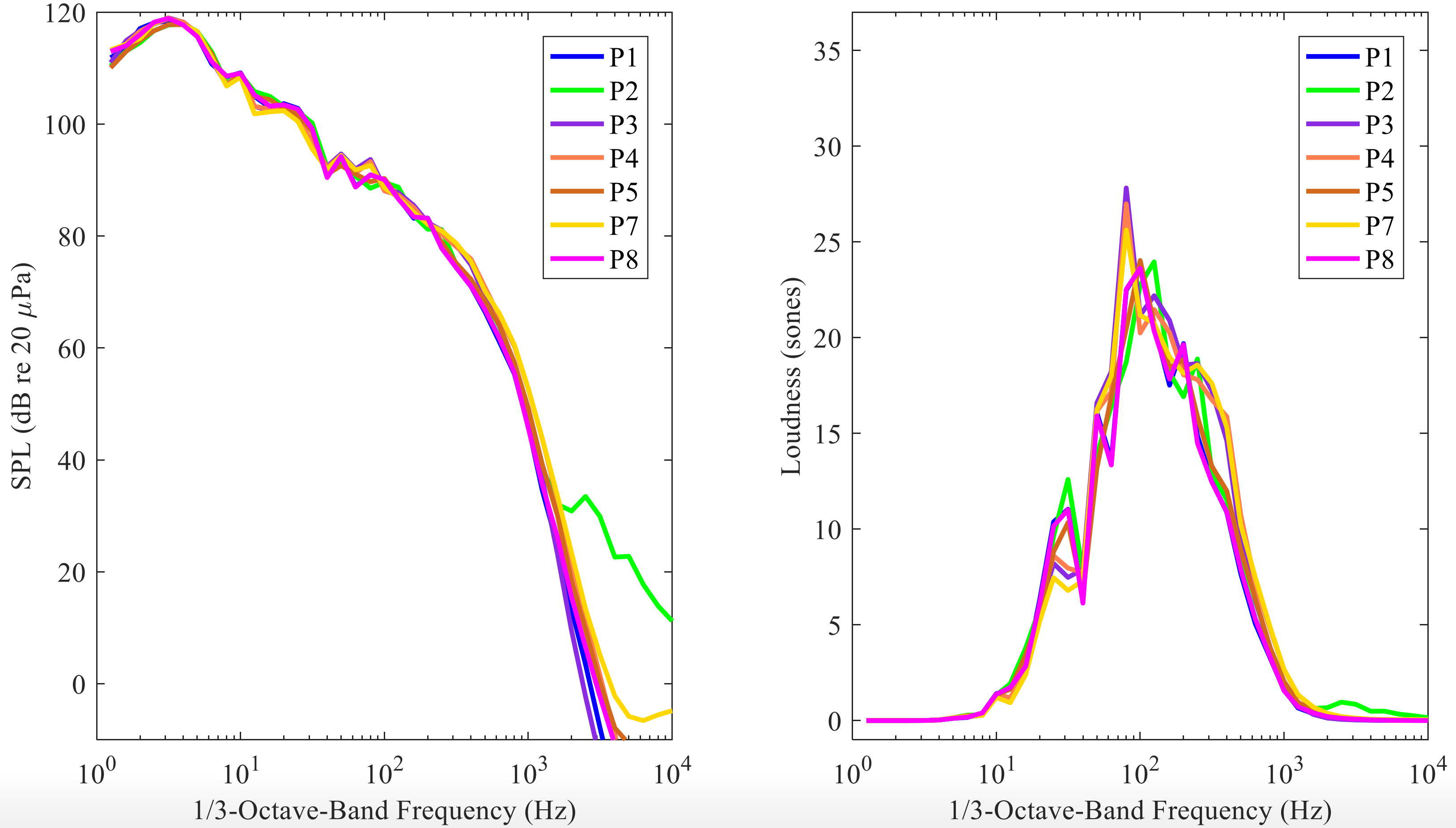


LM1021, Atm Profile 2, Phi = -30°





LM1021, Atm Profile 2, Phi = 0°



123

LM1021, Atm Profile 2, Phi = +30°