First AIAA Sonic Boom Prediction Workshop Overview

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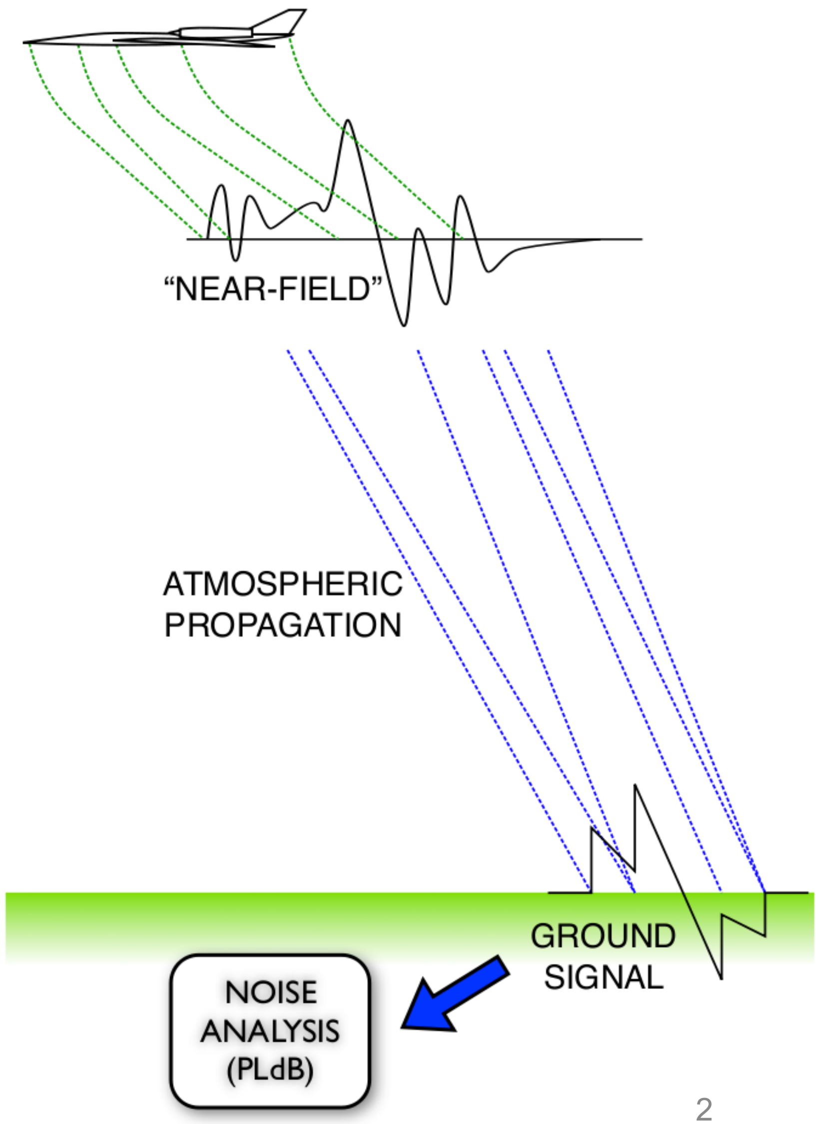
Motivation

- Near-field CFD is part of sonic boom prediction
- Explore the issues
- Impartially compare signatures by uniform application of
  - Loudness measures
  - Validation metrics



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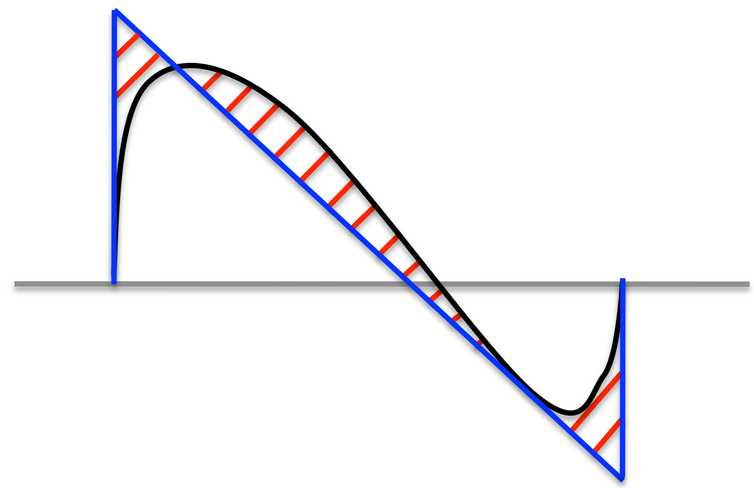
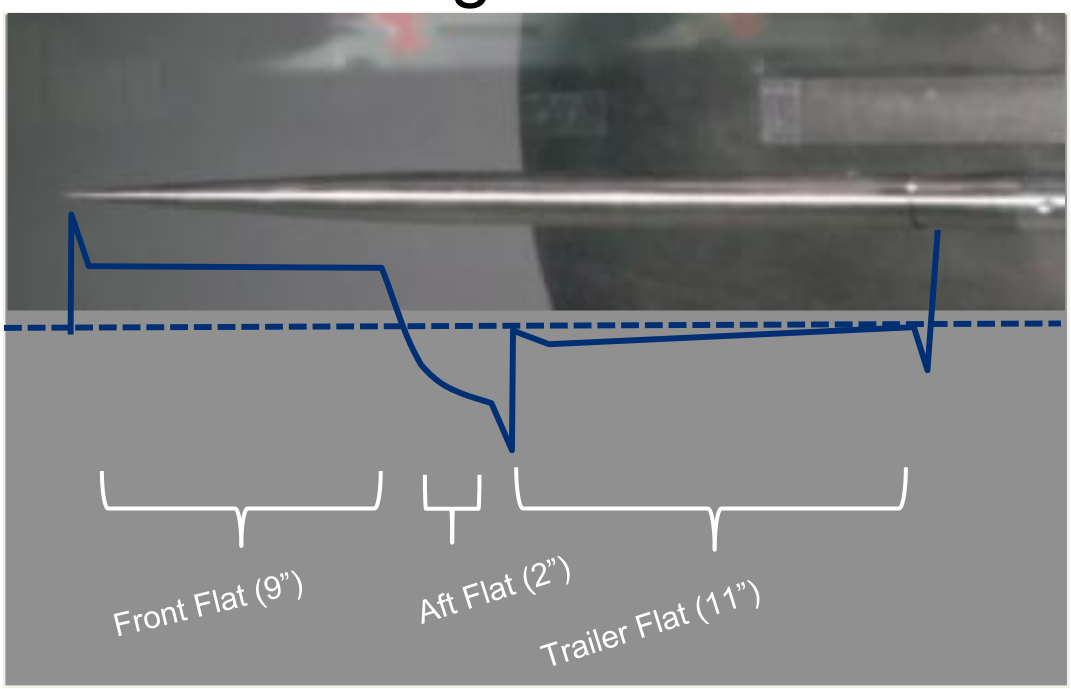


Models and Cases

- Axisymmetric body
- Simple Delta Wing Body
- Full Wing Body Nacelle Configurations

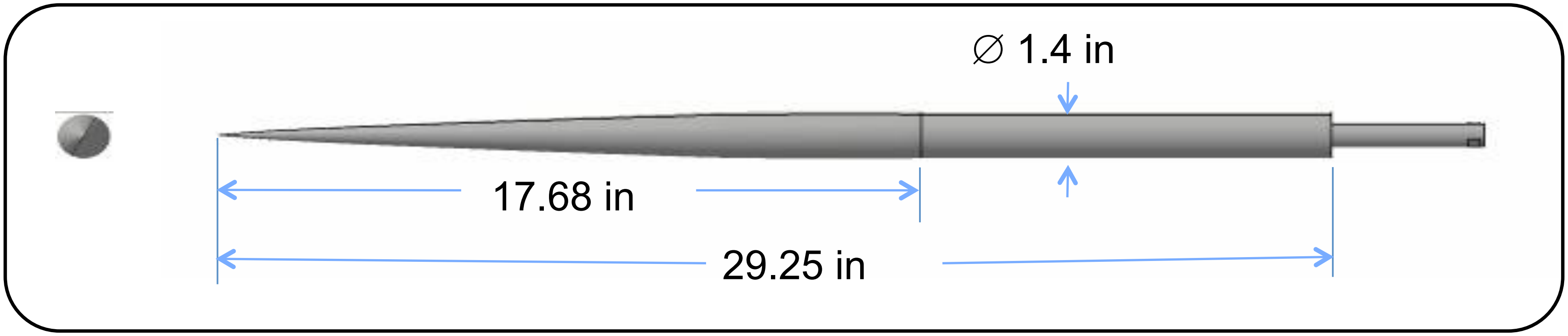
SEEB-ALR

- Axisymmetric body designed by Lockheed Martin for the validation of a flat-top signature design method
  - Seebass and George with aft lift relaxation



SEEB-ALR

- 17.68in long
- Examining at H=**21.2in** and 42.0in
- Mach 1.6



SEEB-ALR Geometry

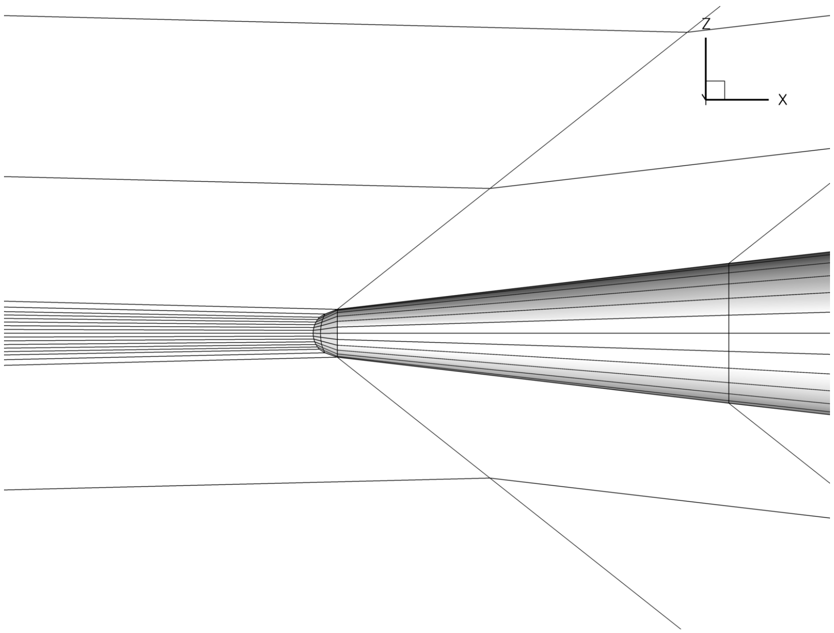
- STEP and IGES geometry provided by John Morgenstern (Lockheed Martin)
  - Parasolid part created by NASA Langley Geometry Laboratory

SEEB-ALR Structured Grid

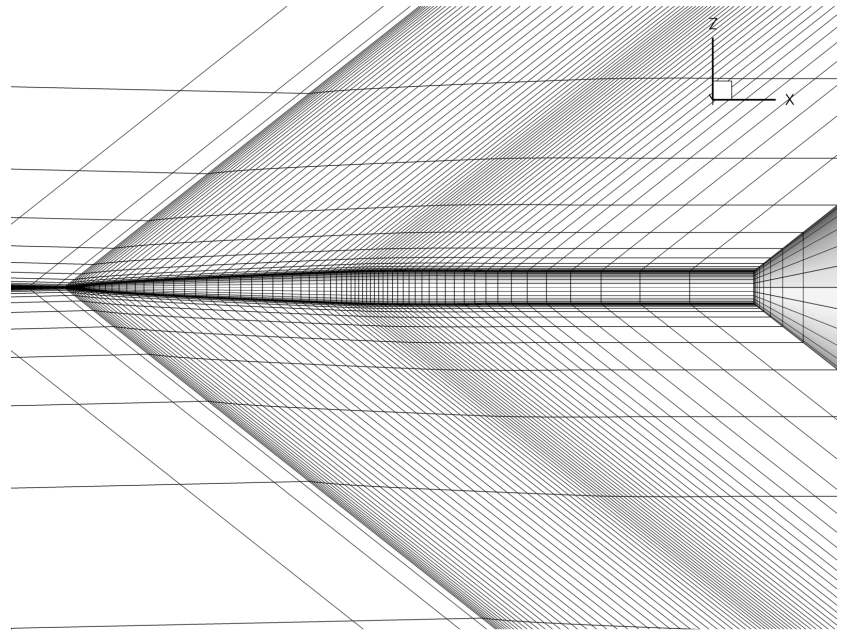
- Point-matched structured Plot3D grids provided by Jiaye Gan (U. Miami)
  - Neutral map file and CGNS conversion by Park

SEEB-ALR S4 Grid

Recursively coarsened 4 times
(removing every other grid line)



Nose detail

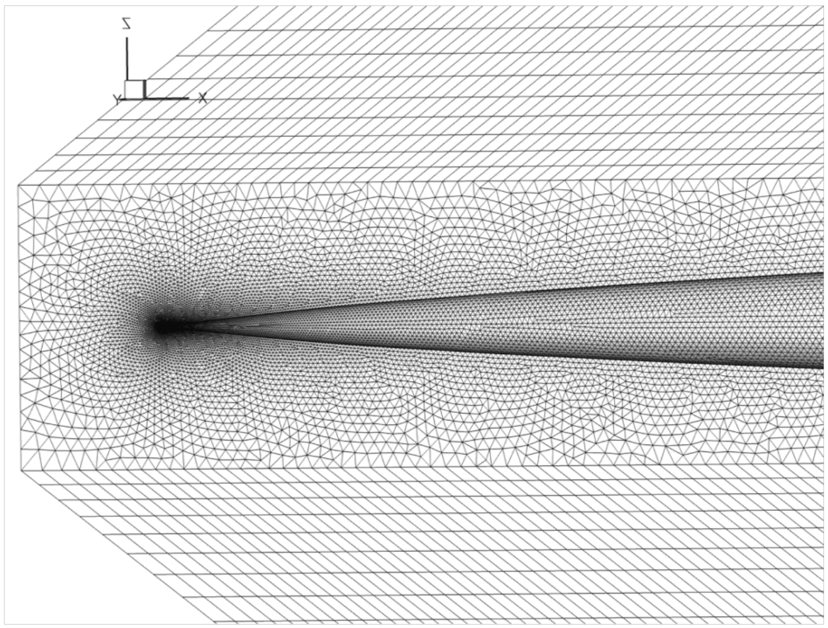


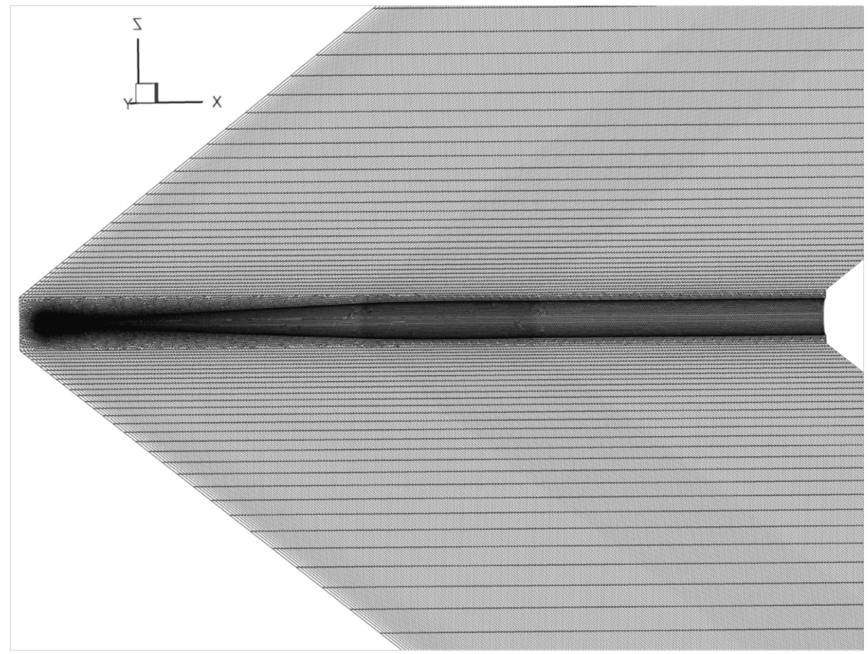
Symmetry plane and model

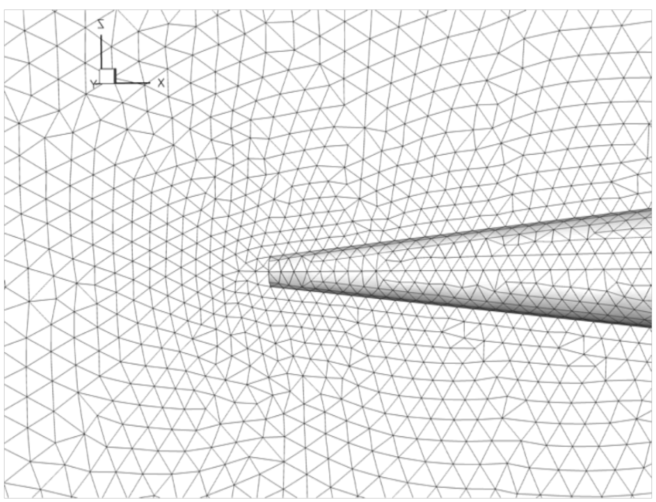
SEEB-ALR Unstructured Grid

- FELISA tetrahedral core grid and Inflate prismatic collar grid (Park et al. AIAA-2014-115)
  - Five uniformly refined grids with a characteristic length scaled 0.80, 1.00, 1.25, 1.56, 2.00
    - Yields a doubling of grid nodes and elements
  - Mixed-element grid converted to purely-tetrahedral

SEEB-ALR h=2.00 Mixed-Element

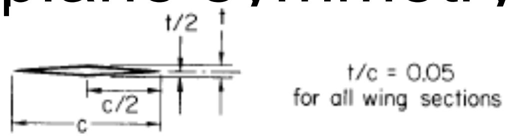




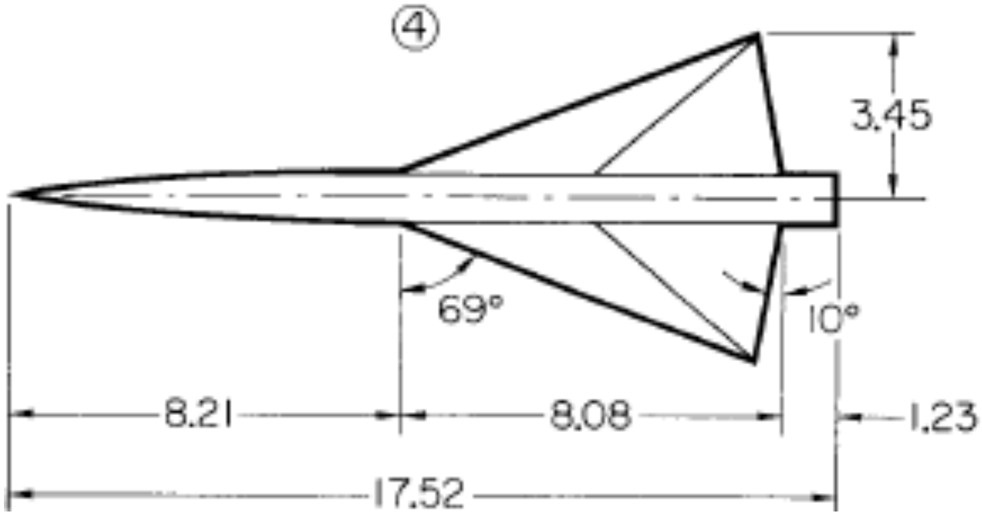


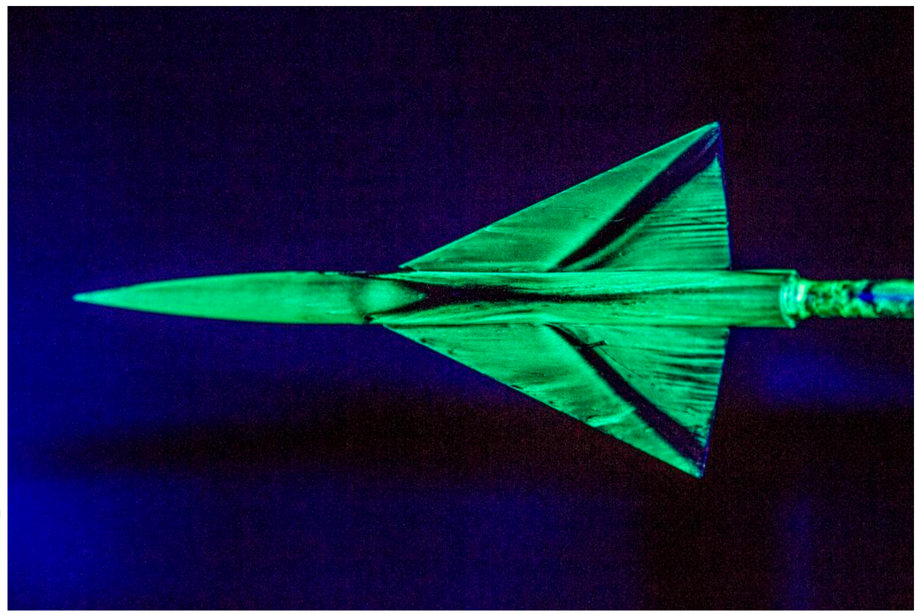
Delta Wing Body

- Originally defined in 1973 by Hunton, Hicks, and Mendoza (NASA TN D-7160)
  - Un-cambered x-y plane symmetry, 5% thick diamond airfoil



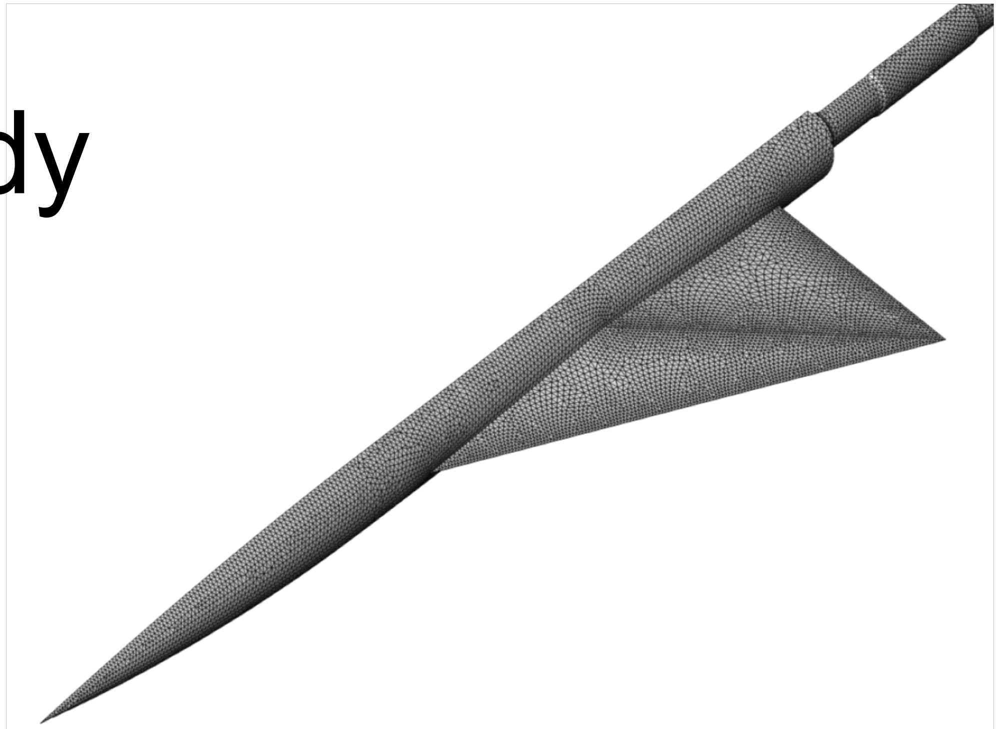
  - Parabolic nose definition $r = 0.540-0.011(x-7.01)^2$

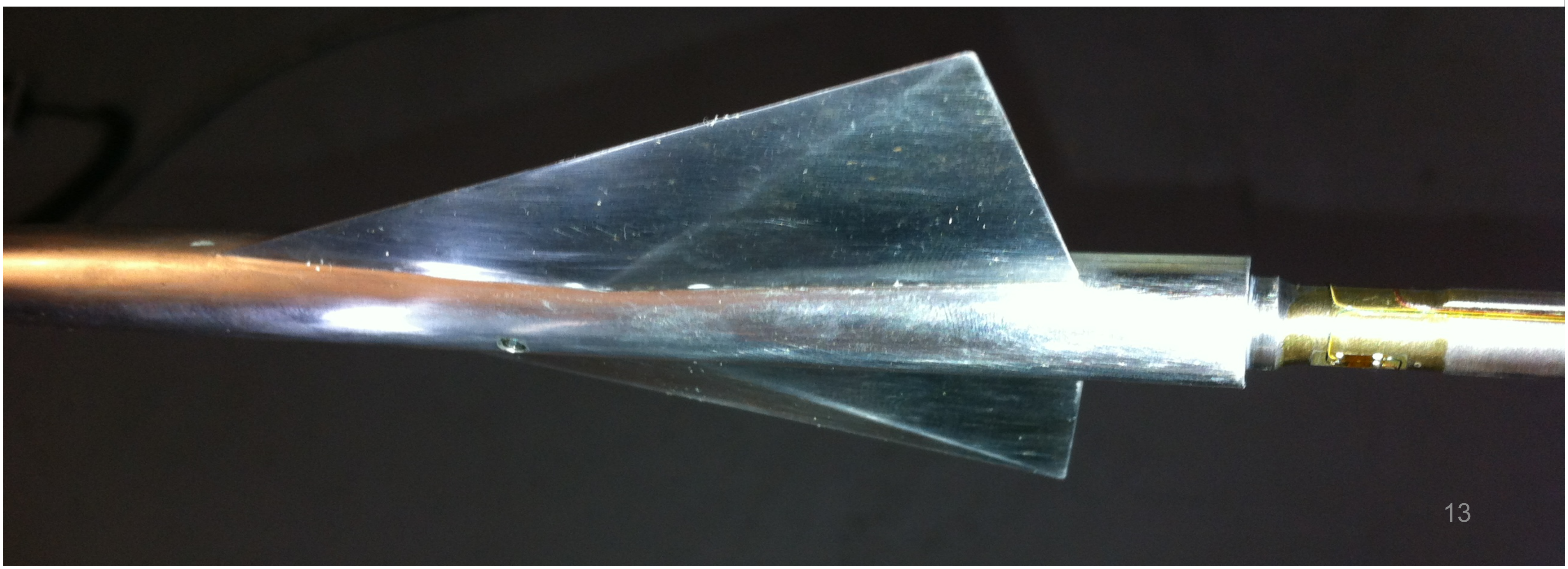




Delta Wing Body

- 6.9 inches long
- Mach 1.7, zero degrees angle of attack





Delta Wing Body Geometry

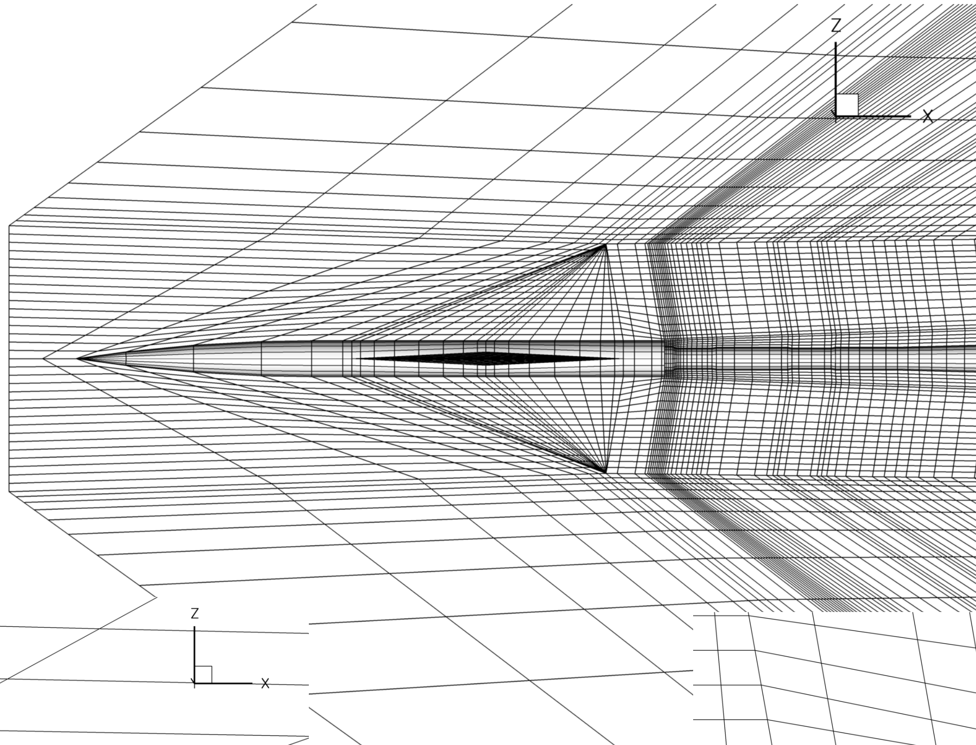
- Model created from limited analytical description in the report by Yoshikazu Makino (JAXA)
- Sting created by Bil Kleb (NASA) from 2D drawings

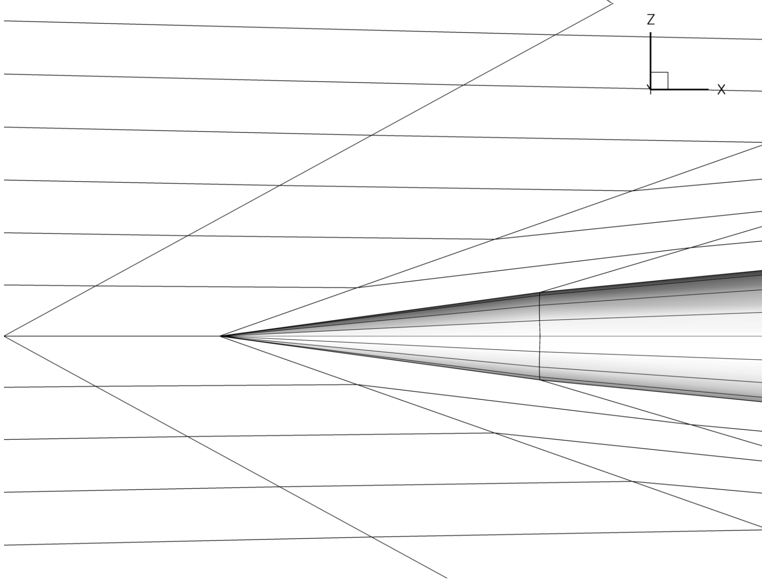
Delta Wing Body Structured Grid

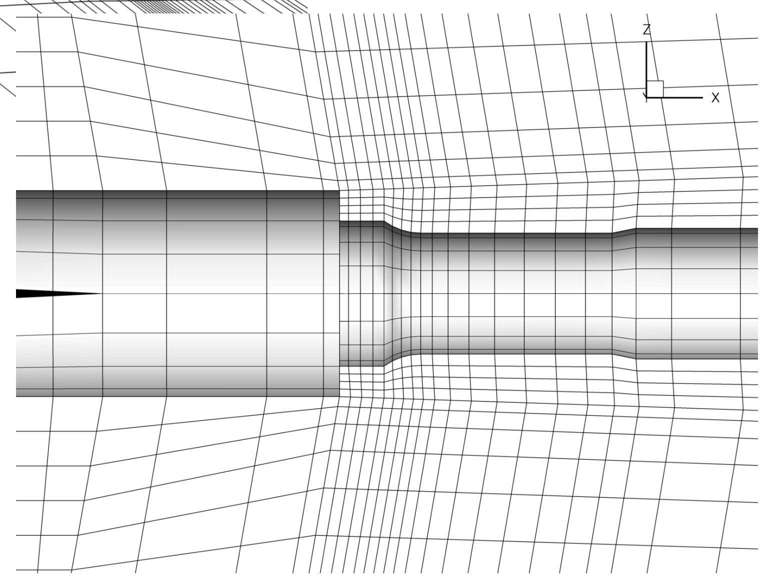
- Point-match structured Plot3D grid and neutral map file generated by the NASA Langley Geometry Laboratory
  – CGNS conversion by Park

Delta Wing Body S4 Grid

Recursively coarsened 4 times (removing every other grid line)



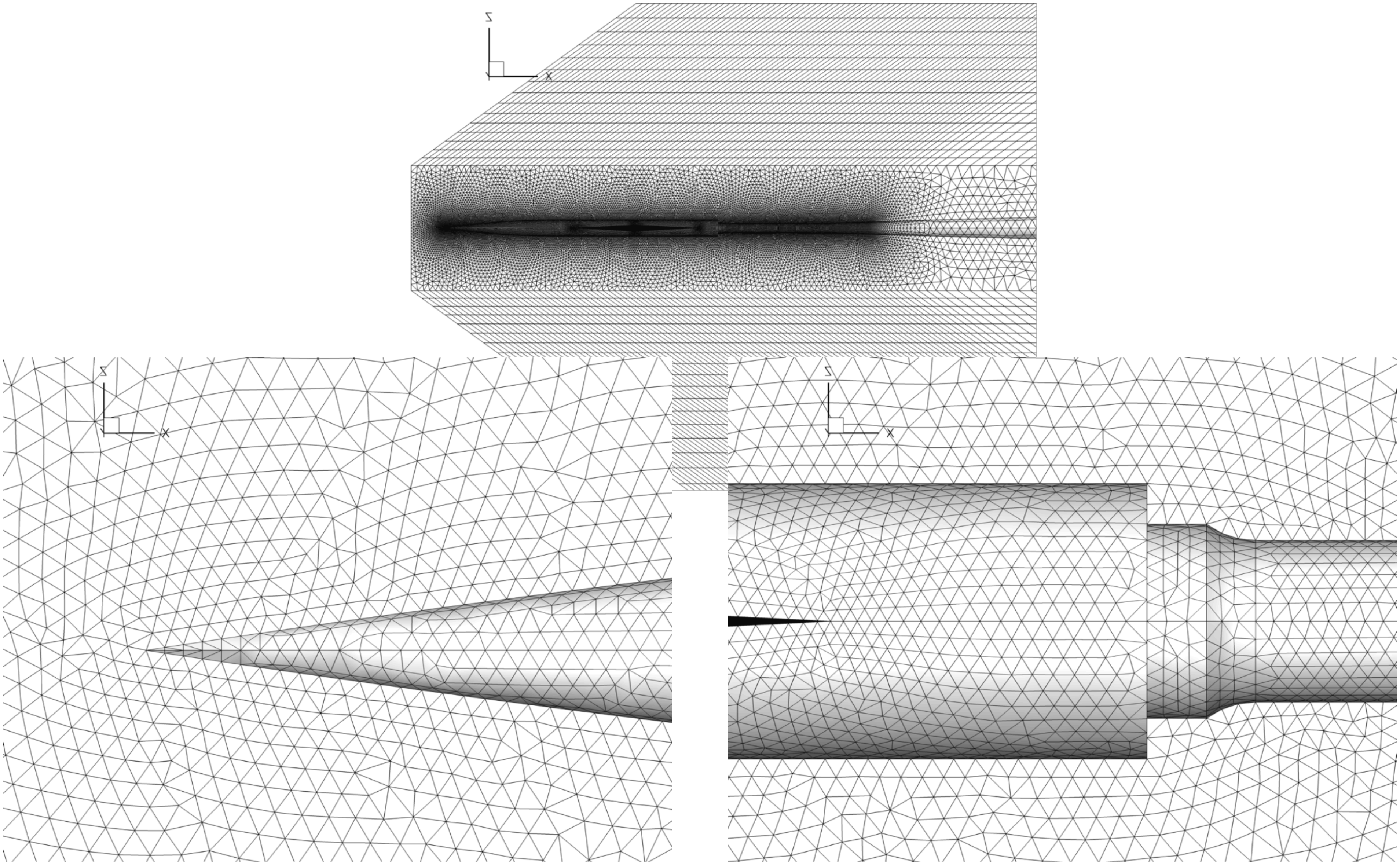




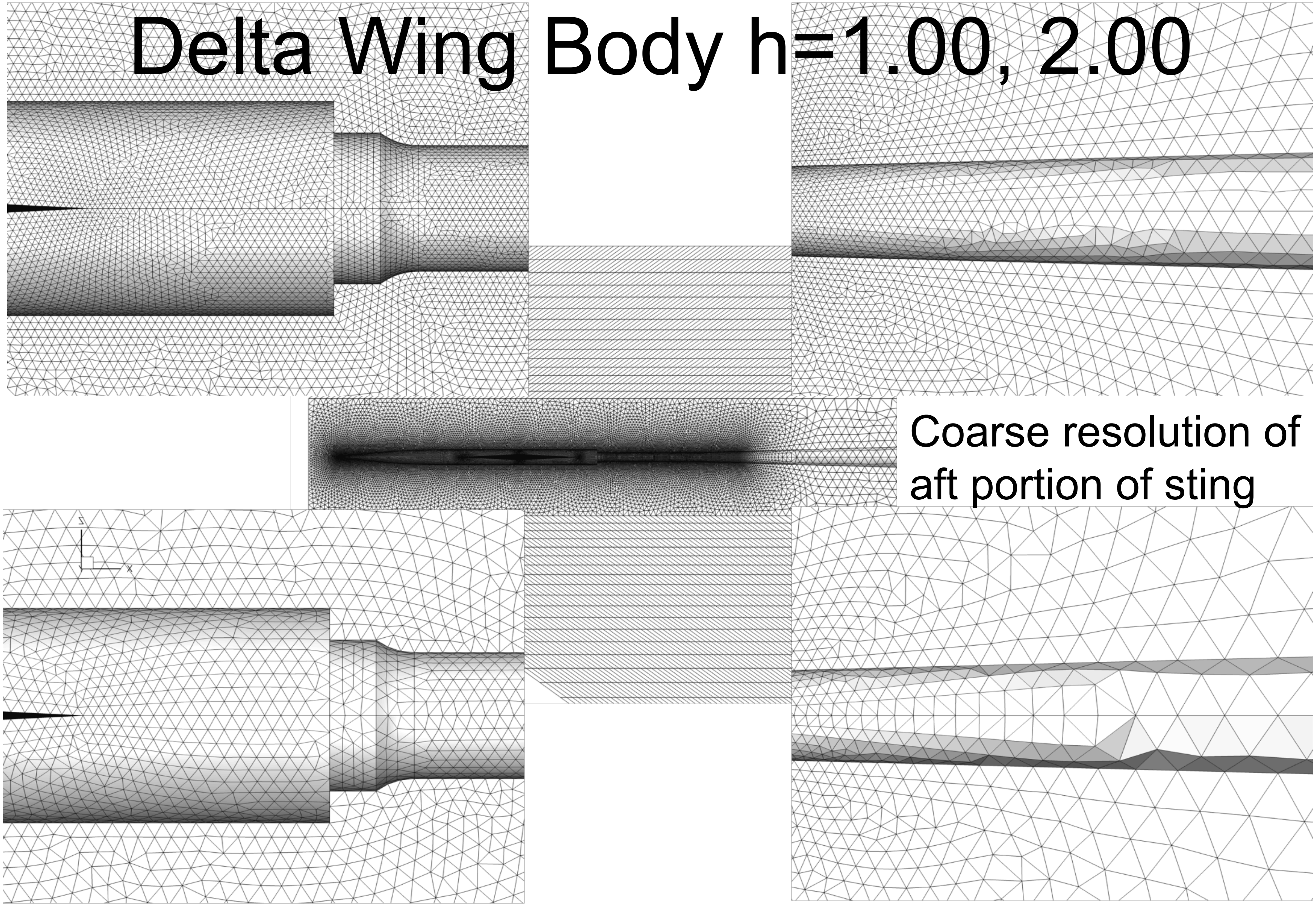
Delta Wing Body Unstructured Grid

- FELISA tetrahedral core grid and Inflate prismatic collar grid (Park et al. AIAA-2014-115)
  - Four uniformly refined grids with a characteristic length 1.00, 1.25, 1.56, 2.00
    - Yields a doubling of grid nodes and elements
  - Mixed-element grid converted to purely-tetrahedral

Delta Wing Body h=2.00 Mixed



Delta Wing Body h=1.00, 2.00



Coarse resolution of aft portion of sting

Tecplot Extraction Macro

- Consistent method to extract signatures from a volume solution (**available measurements are bold**)
  - SEEB-ALR (18in length)
    - Centerline H=**21.2in** and 42.0in
  - Delta Wing Body (6.9in length)
    - Centerline H=0.5in and 21.2in
    - **0**, **30**, **60**, and **90** degree off-track H=**24.8in**
    - **0**, **30**, **60**, and **90** degree off-track H=**31.8in**

Data Processing and Quality

- Received signatures via FTP or email
- Some were converted to plain text, scaled, or reformatted
- Plotted
- Contacted participants for clarification when
  - Incorrect location or incomplete signature
  - Significant differences between submissions of same participant

Return to the Intension

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- Explore the issues
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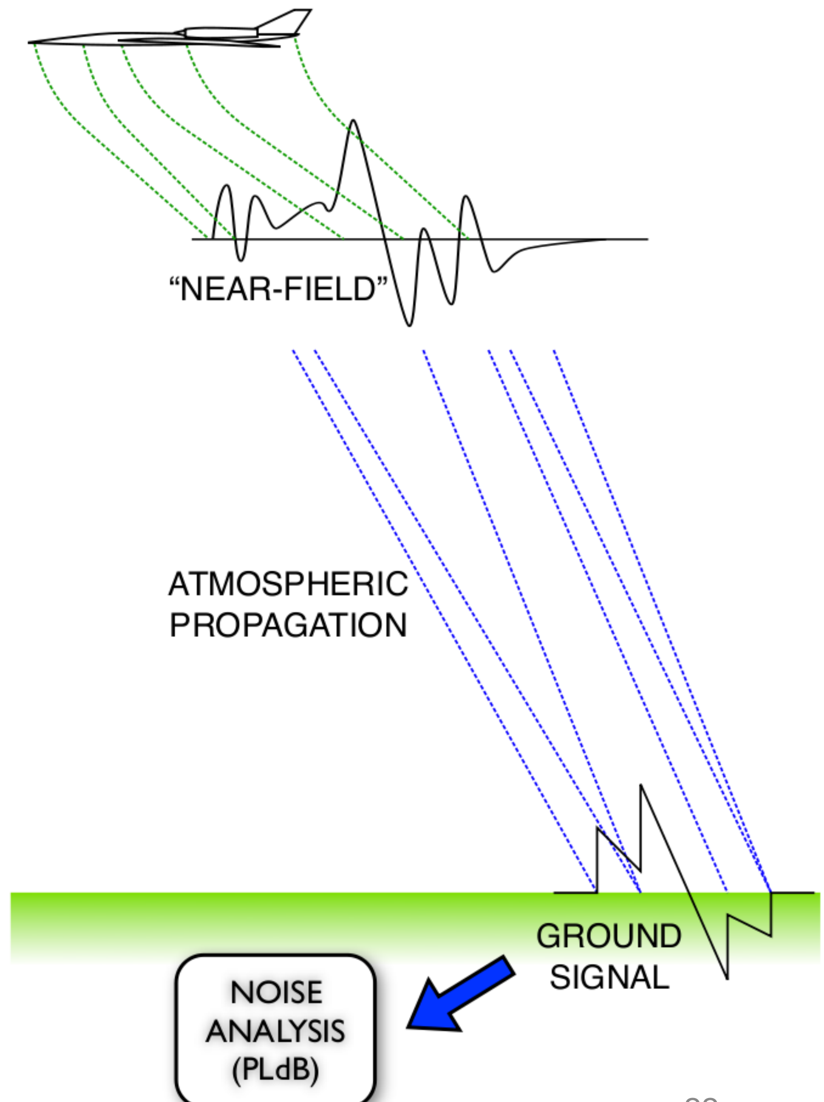


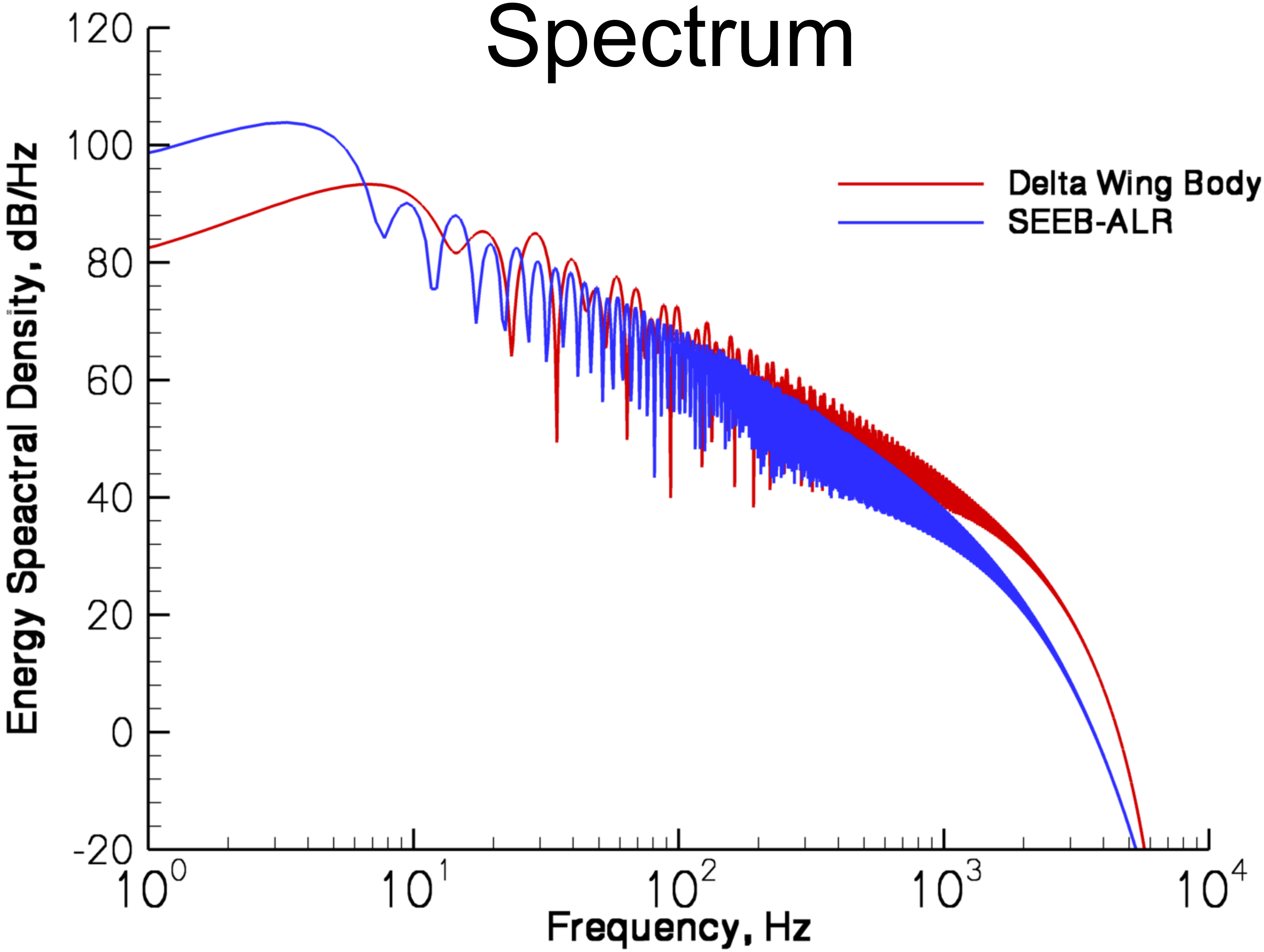
Ground Propagation

- Assume flight conditions of “full-scale”
  - Scale x-dimension of the signature
    - 0.006 scale SEEB-ALR
    - 0.0065 scale Delta Wing Body
  - 55 thousand foot altitude
  - Standard atmosphere
- sBOOM (Rallabhandi)
  - Burgers equation with molecular relaxation

Loudness and Annoyance

- Subjective metrics
- These human experiences are correlated to noise descriptors through experiments (Leatherwood et al. JASA 2002)
  - Stevens Mark VII Perceived Level (PL)

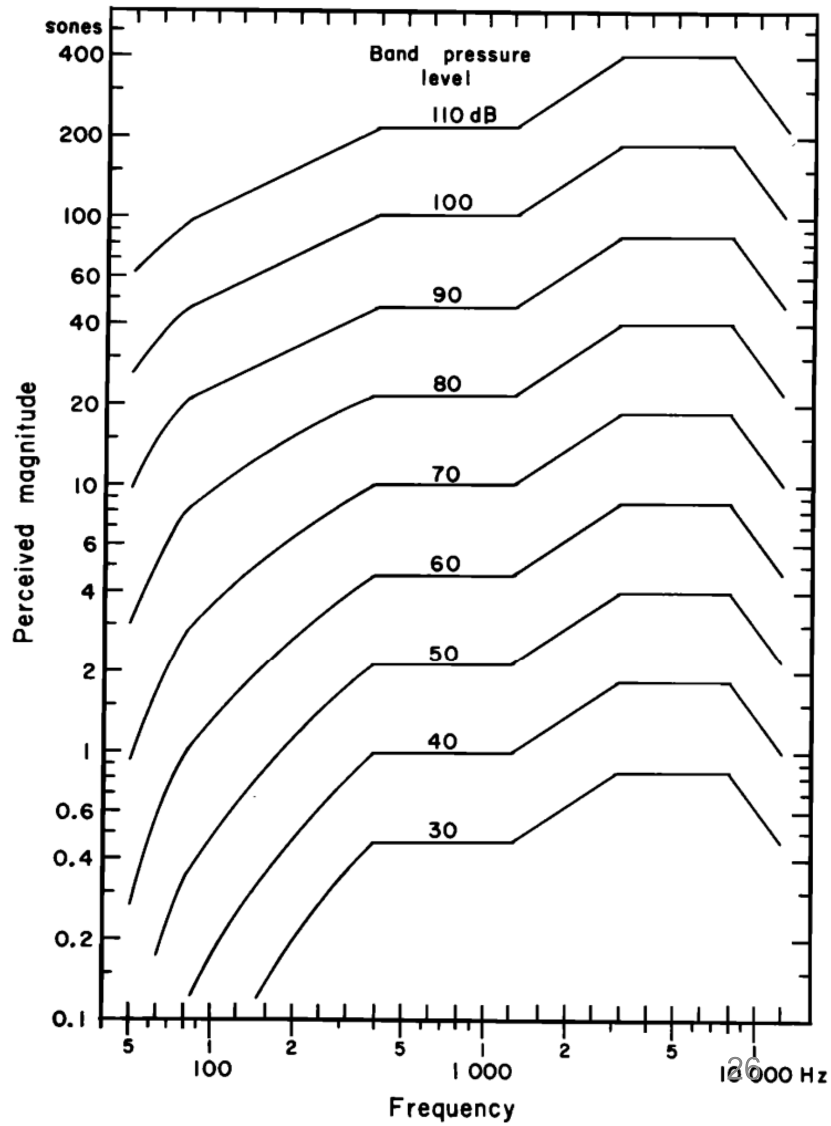
Spectrum



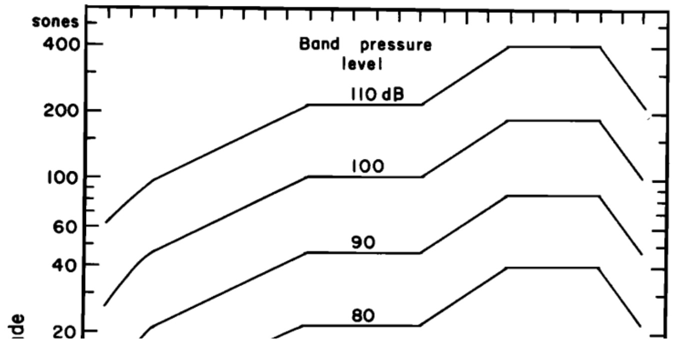
Energy Speactral Density, dB/Hz
120
100
80
60
40
20
0
-20
10^0
10^1
10^2
10^3
10^4
Frequency, Hz
Delta Wing Body
SEEB-ALR

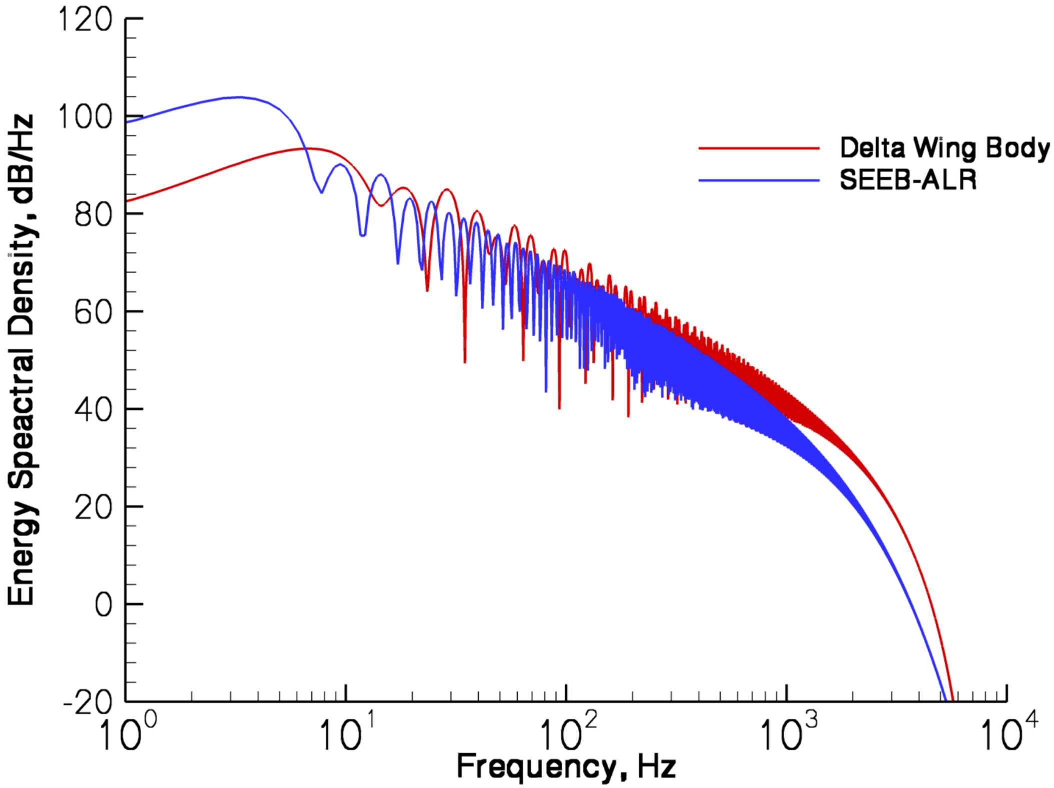
Perceived Level (PL)

- Signature is gathered into 1/3 octave bands
- Band levels are converted into sones (loudness)
- Sones from each band are combined
- Sones are converted into PL via logarithm



Noise Descriptors





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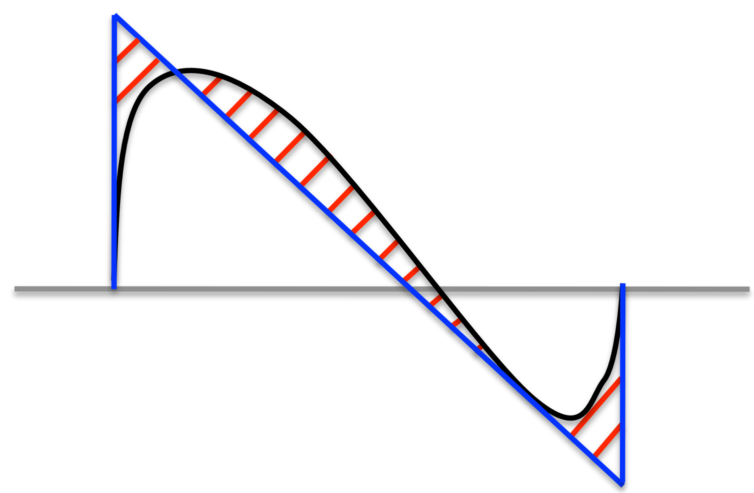


Validation Metric

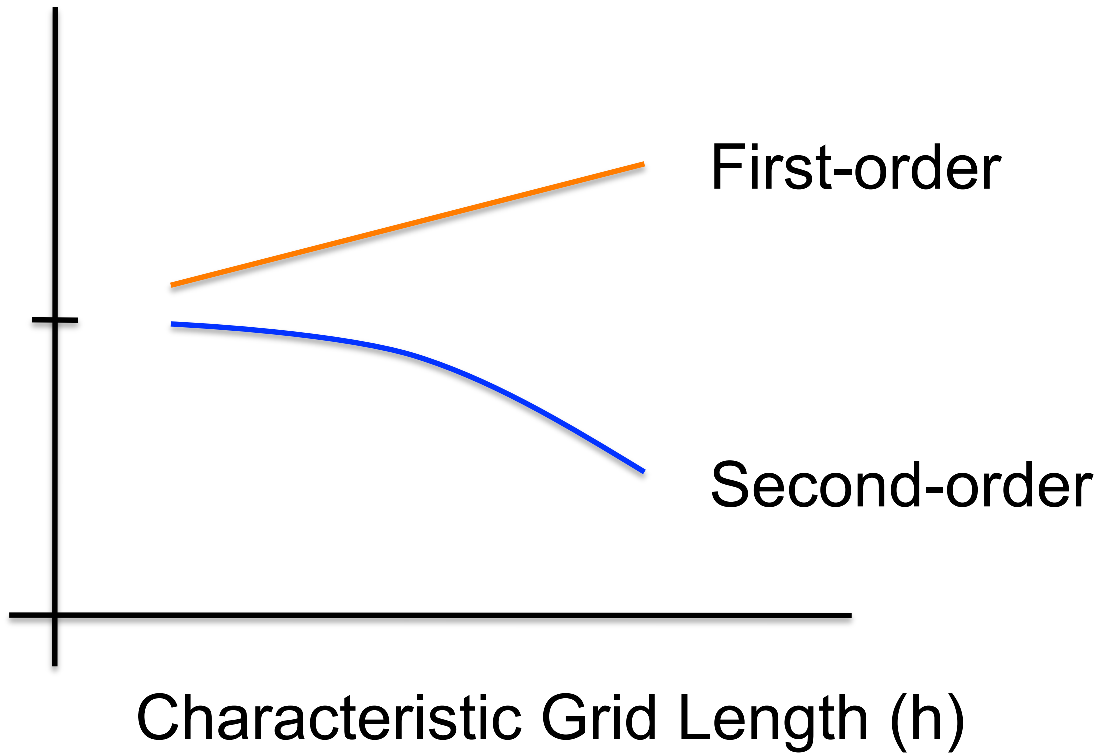
- Integral of the absolute value of the difference between the submitted signatures and wind tunnel measurement
  - Inherently imperfect (measurement is not "truth")
  - Used in validation exercises and the First AIAA Shock Boundary Layer Interaction Workshop

Statistical Method

- Goal is to identify “different” results, not “correct” or “wrong”
- Median +/- (coverage factor)*(std. dev.)
  - Assume a uniform distribution
- Small sample size with correlated results (same person, same code, refined grids)
- Used by other workshops

Expected Grid Convergence

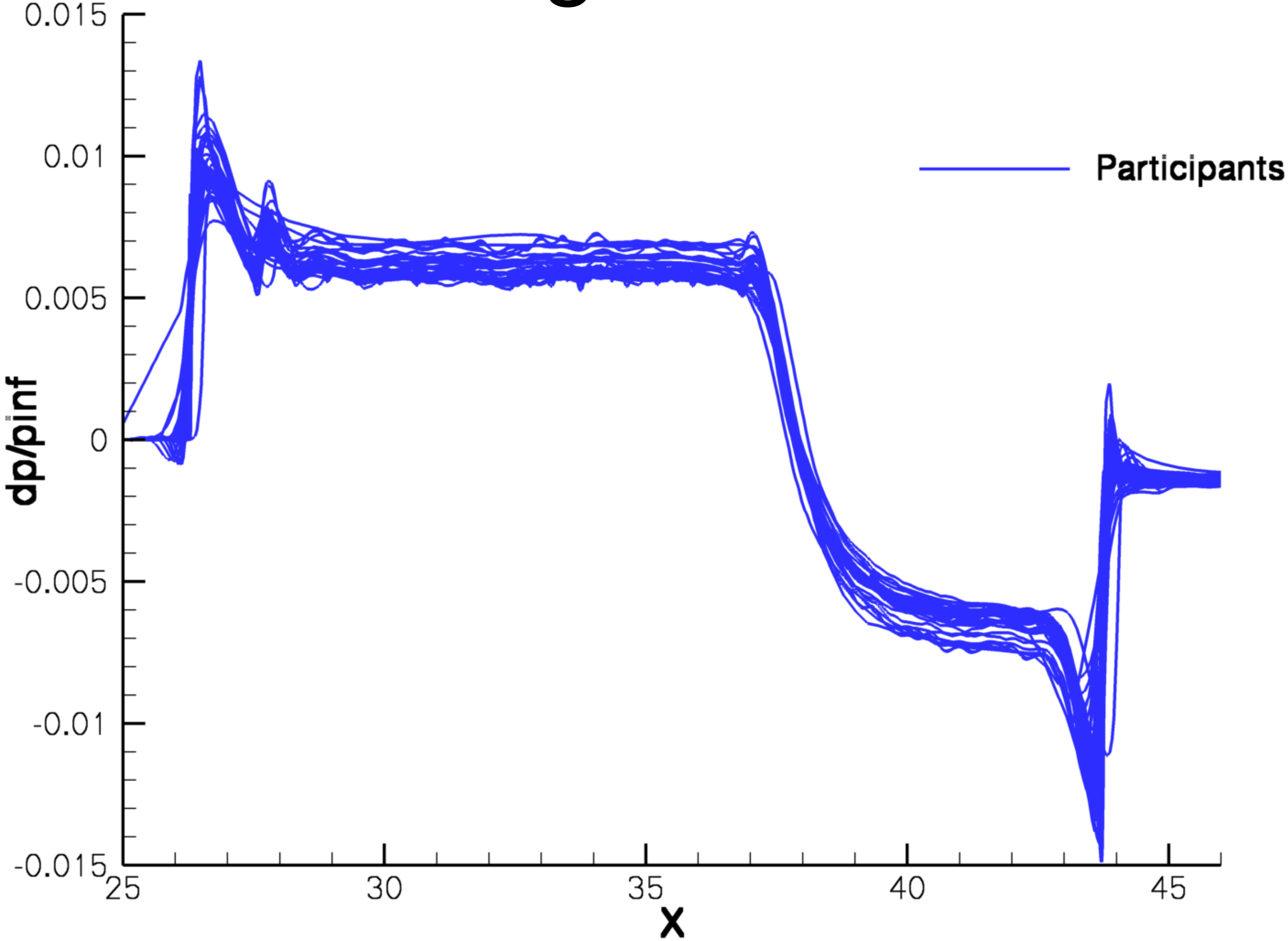
- Consistent methods should approach a value as the grid is refined to “zero” h



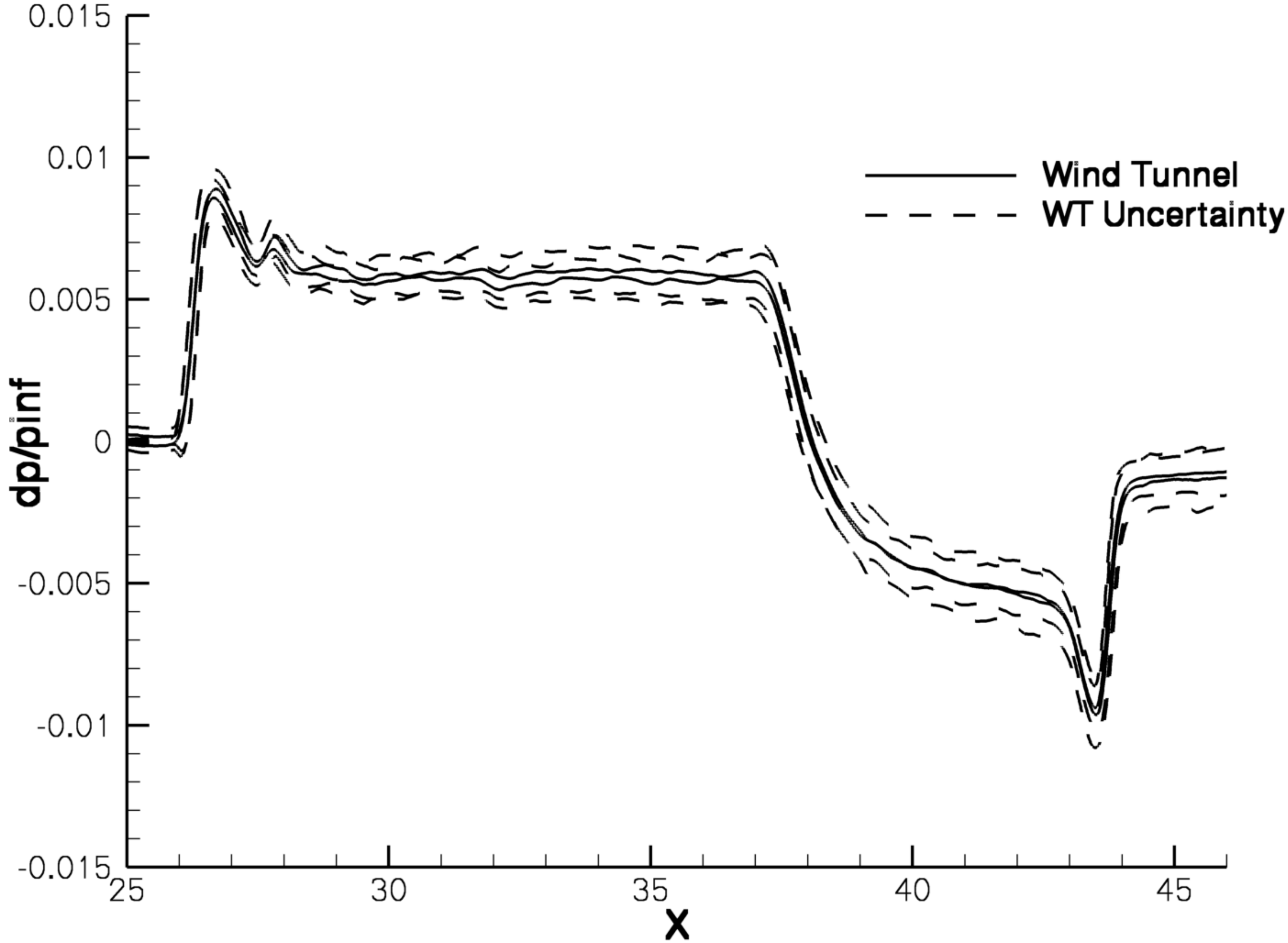
SEEB-ALR Signatures

- 61 extracted signatures (2 locations)
  - 42 workshop provided grids, 19 participant
  - 26 tetrahedral, 16 mixed, 10 structured, 4 overset, 3 Cartesian, 1 hybrid, 1 linear
  - 55 Euler, 3 SA, 1 laminar, 1 SST, 1 linear

SEEB-ALR Signatures H=21.2in



SEEB-ALR Wind Tunnel H=21.2in



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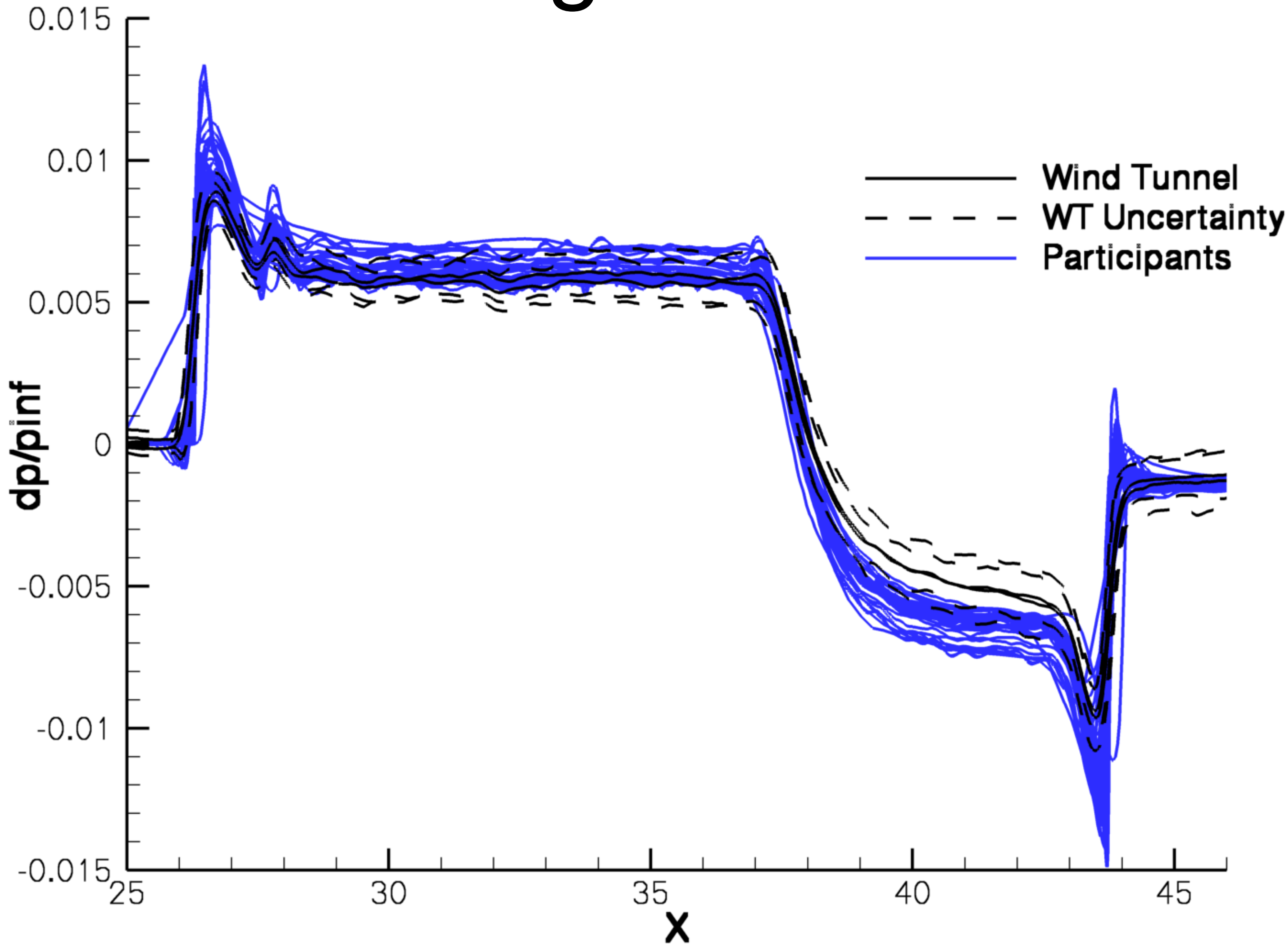
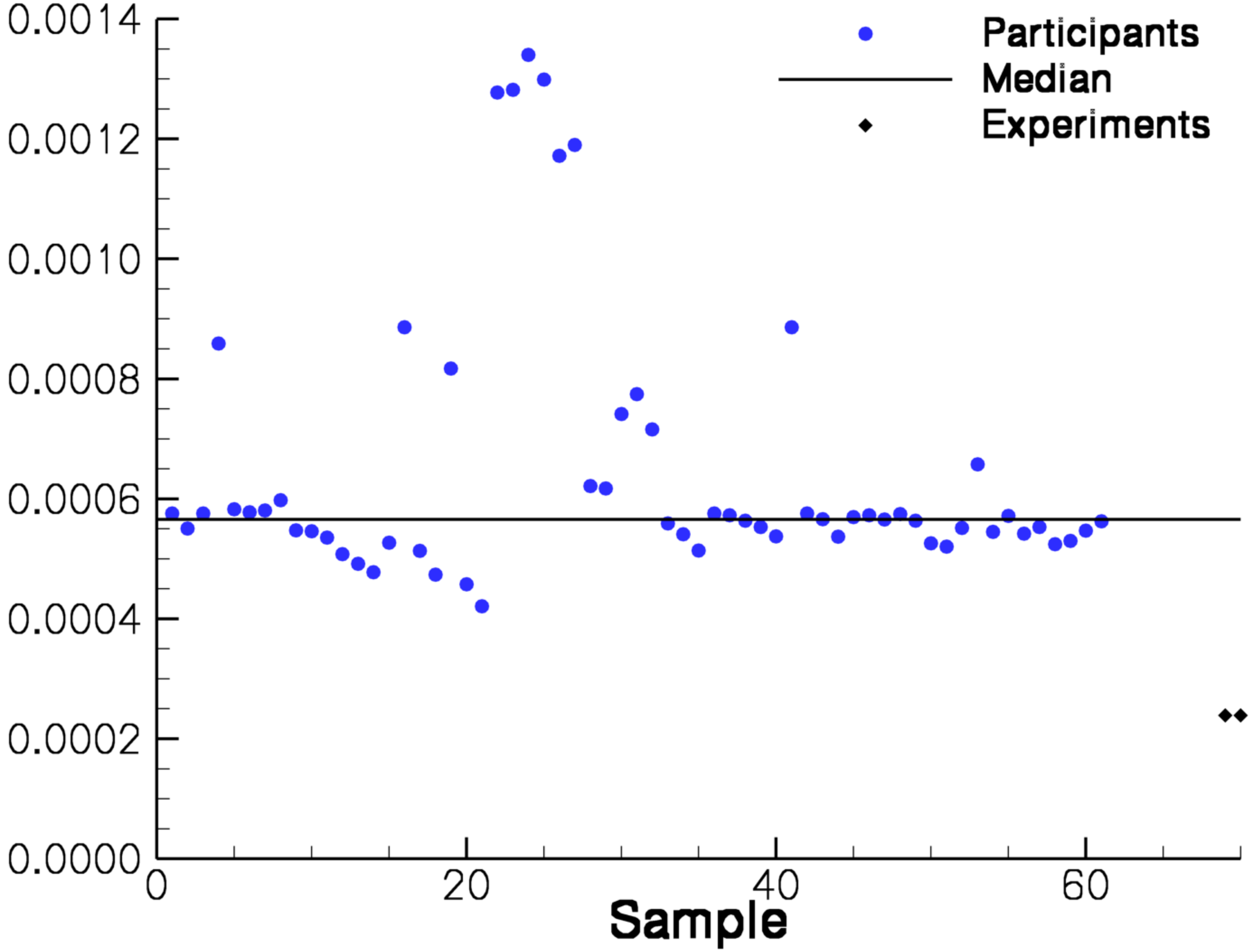
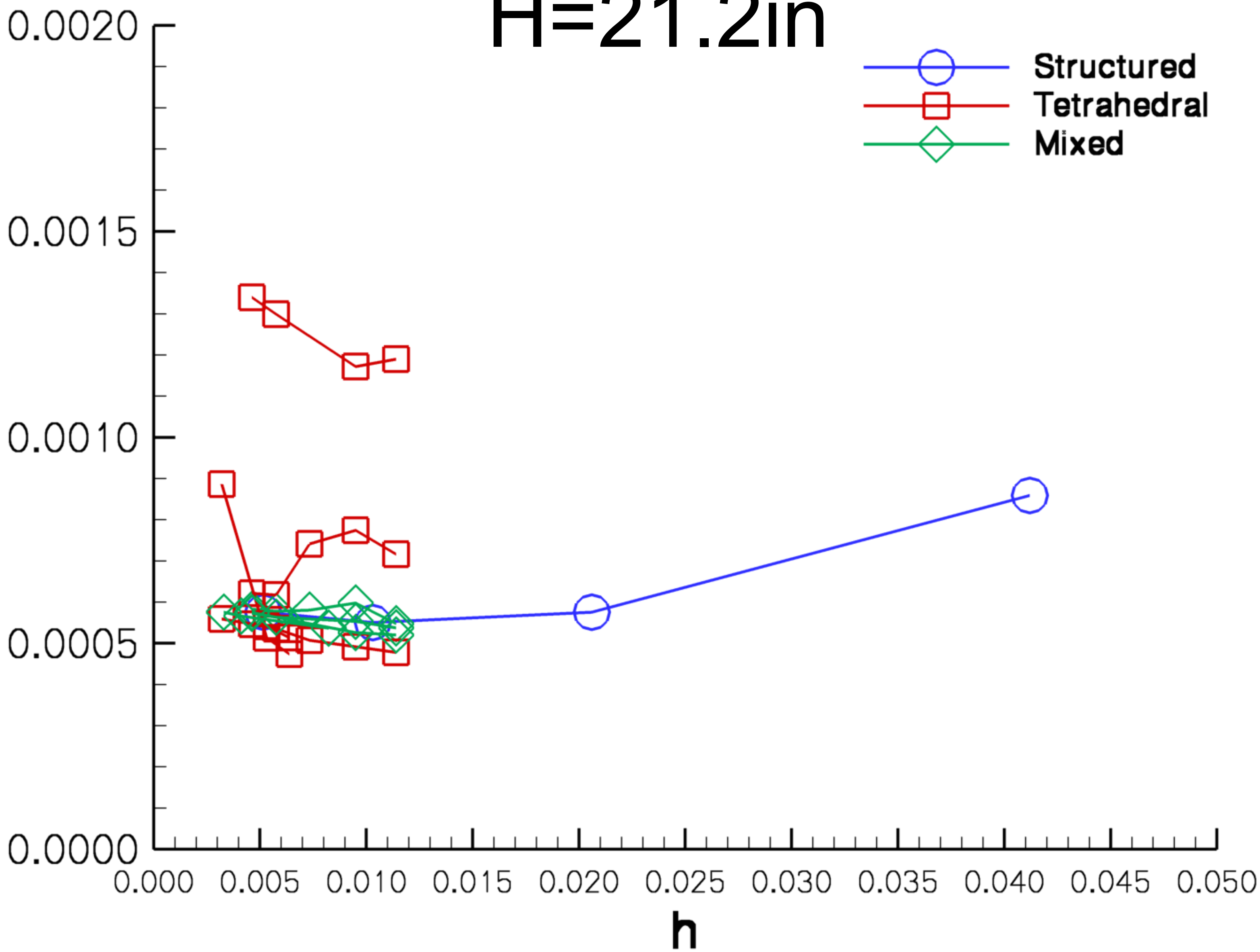


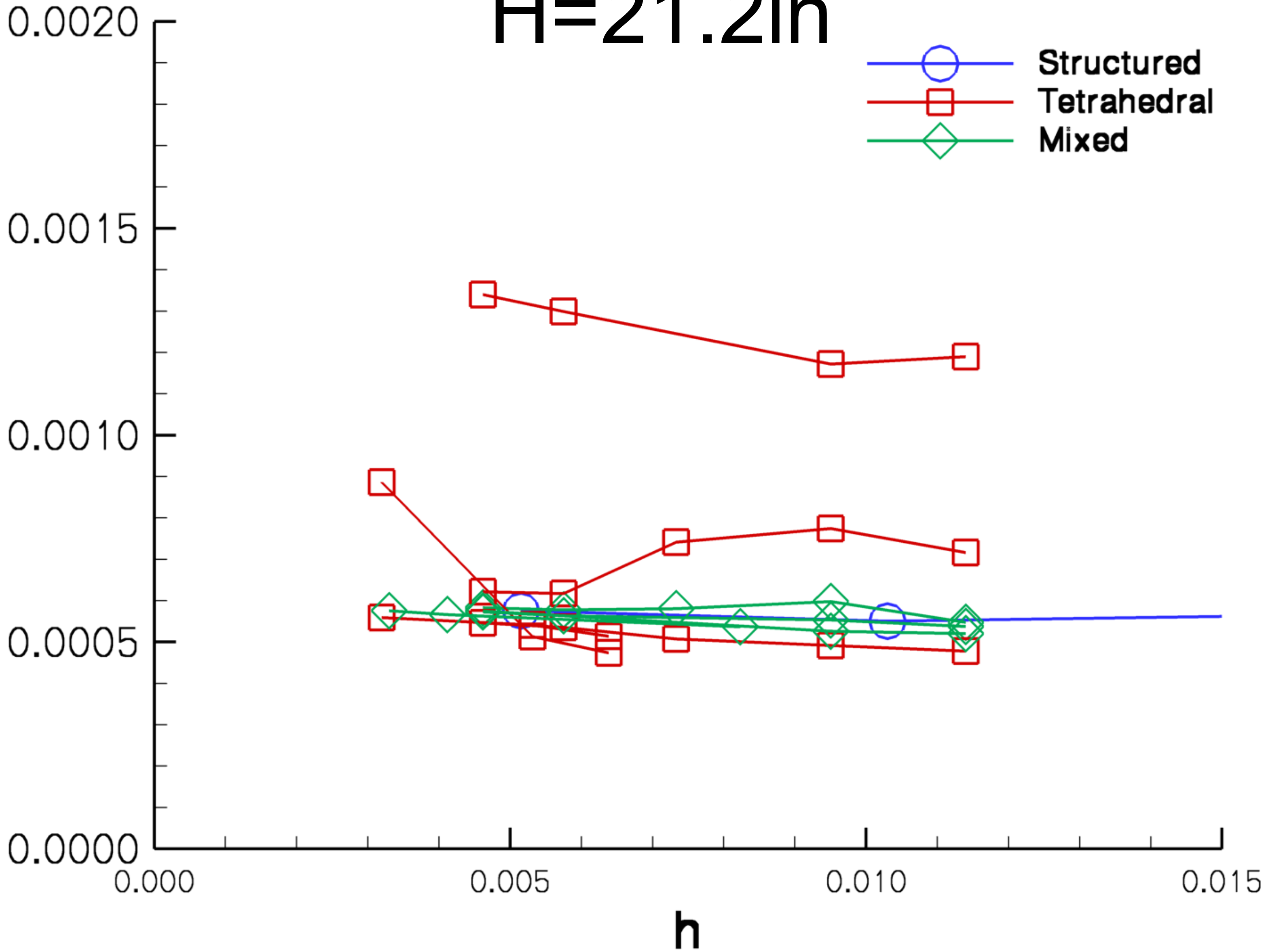
SEEB-ALR Validation Metric



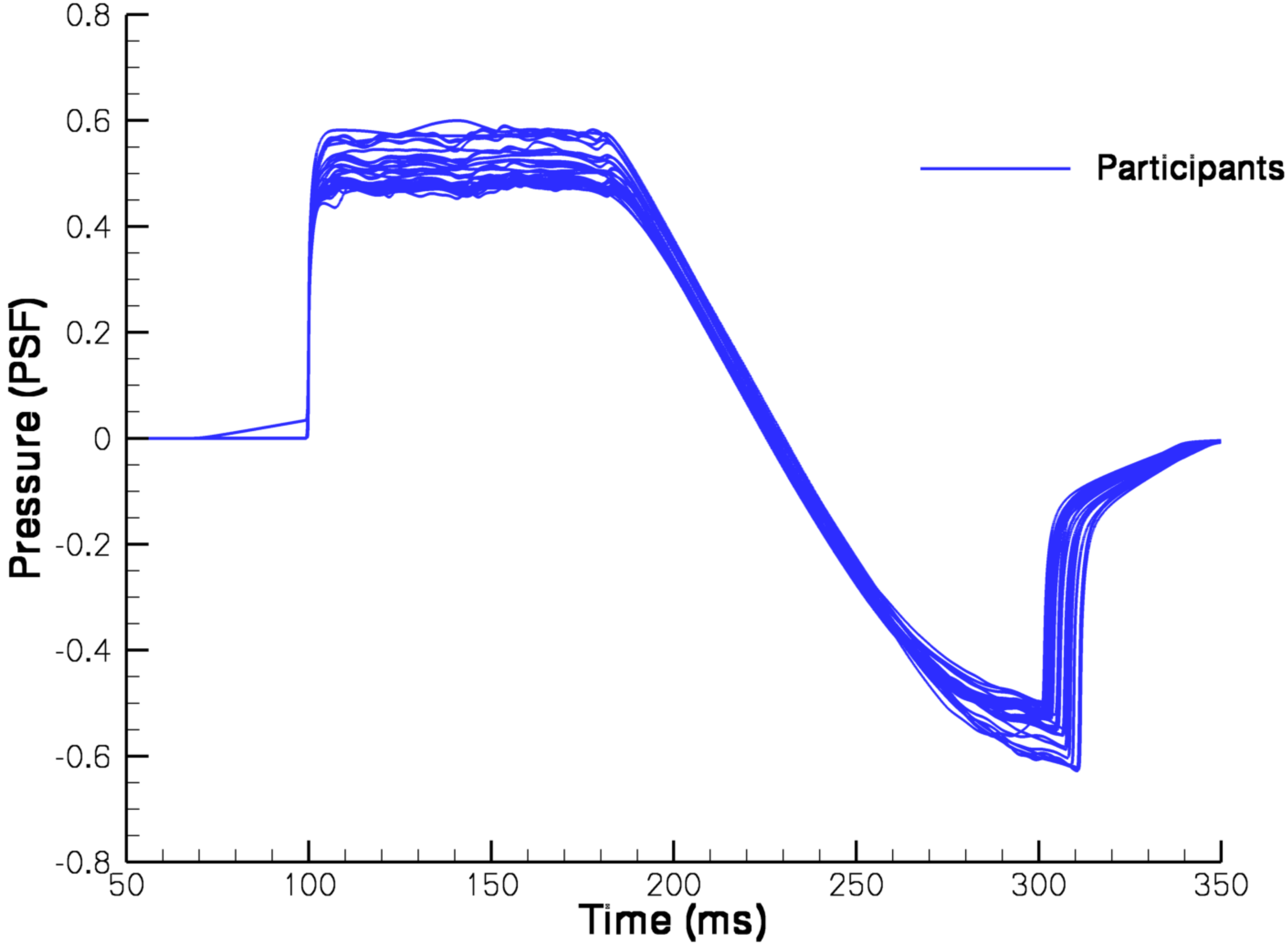
SEEB-ALR Validation Metric at H=21.2in



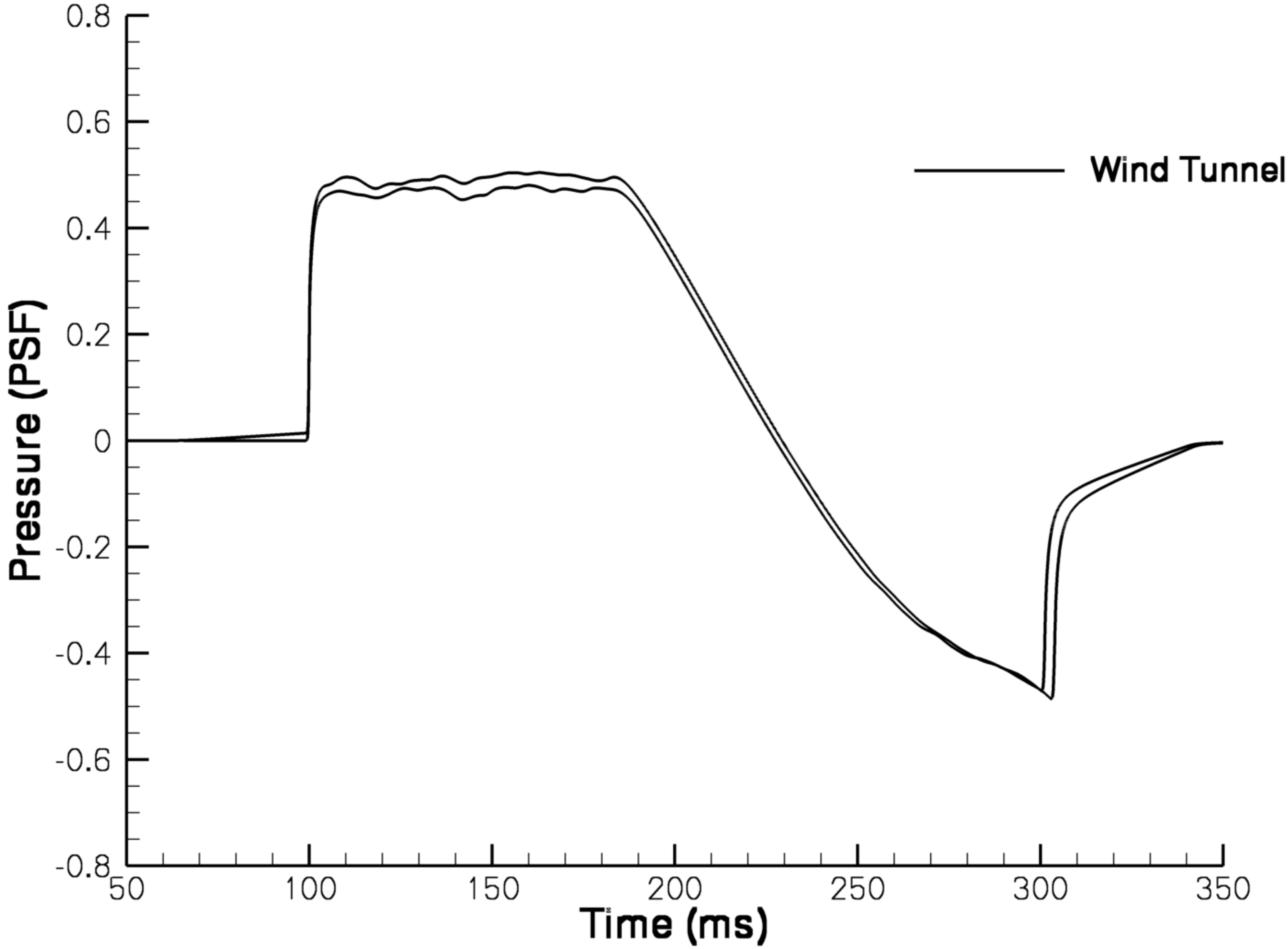
SEEB-ALR Validation Metric at H=21.2in



SEEB-ALR Ground from H=21.2in



SEEB-ALR Ground from H=21.2in



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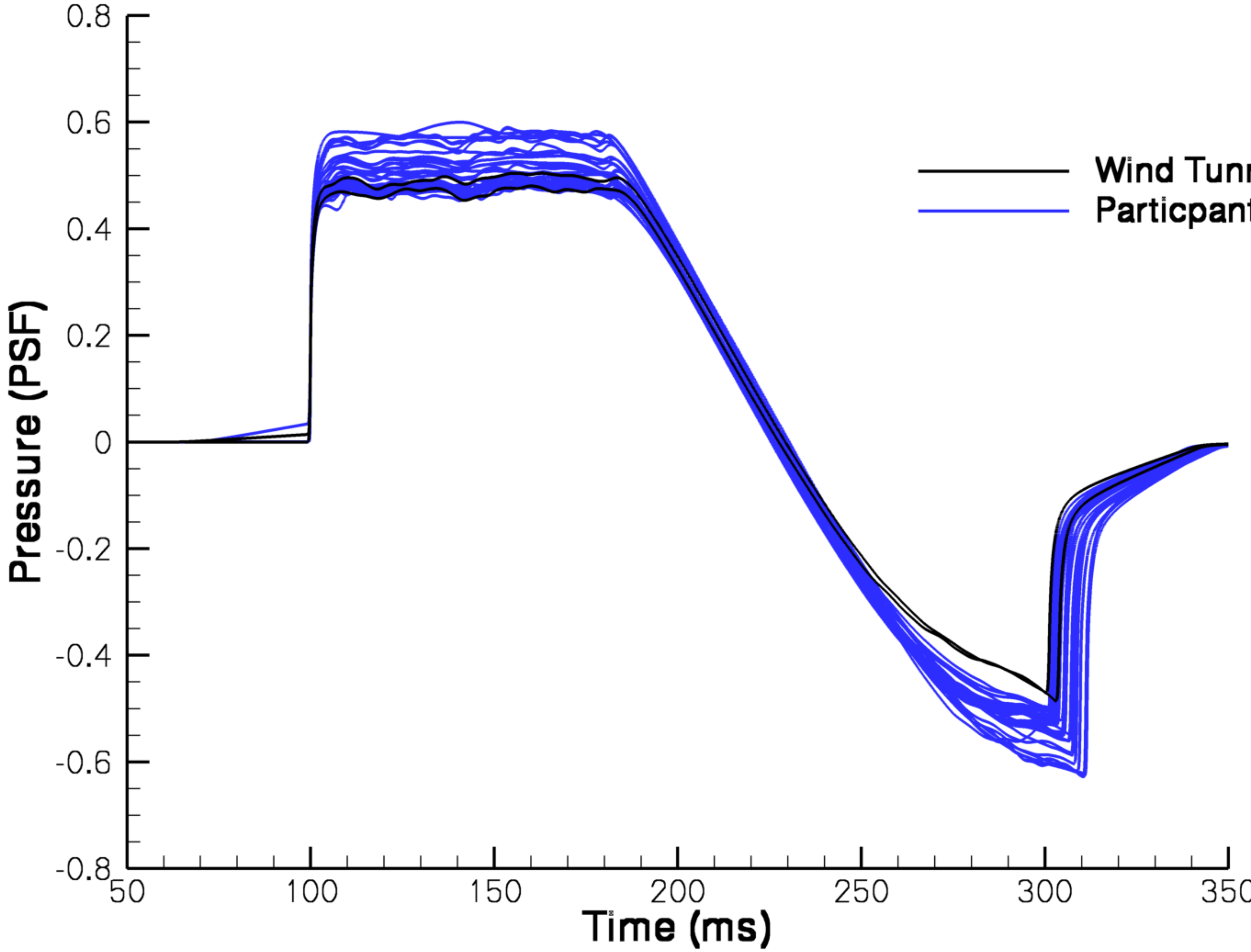
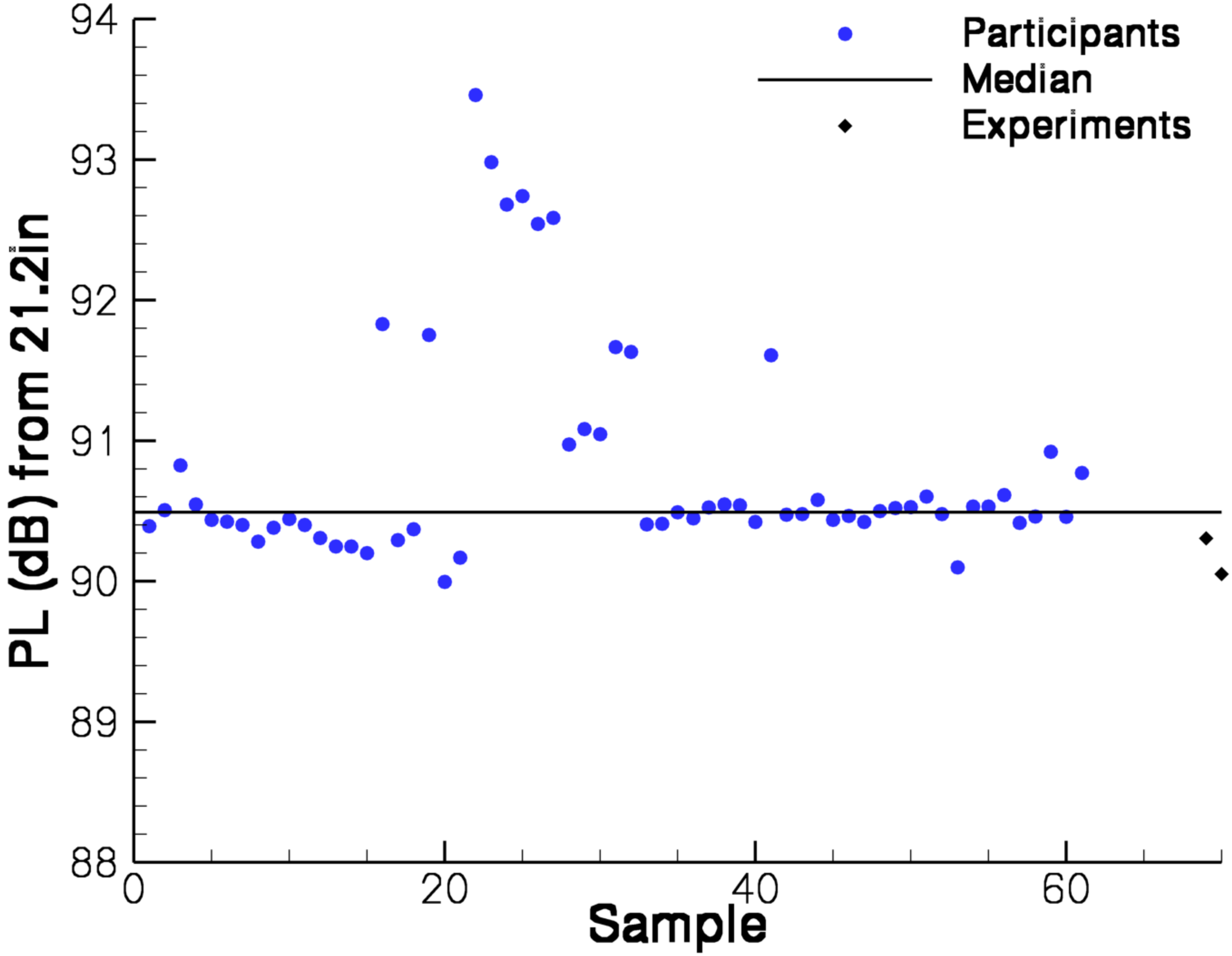
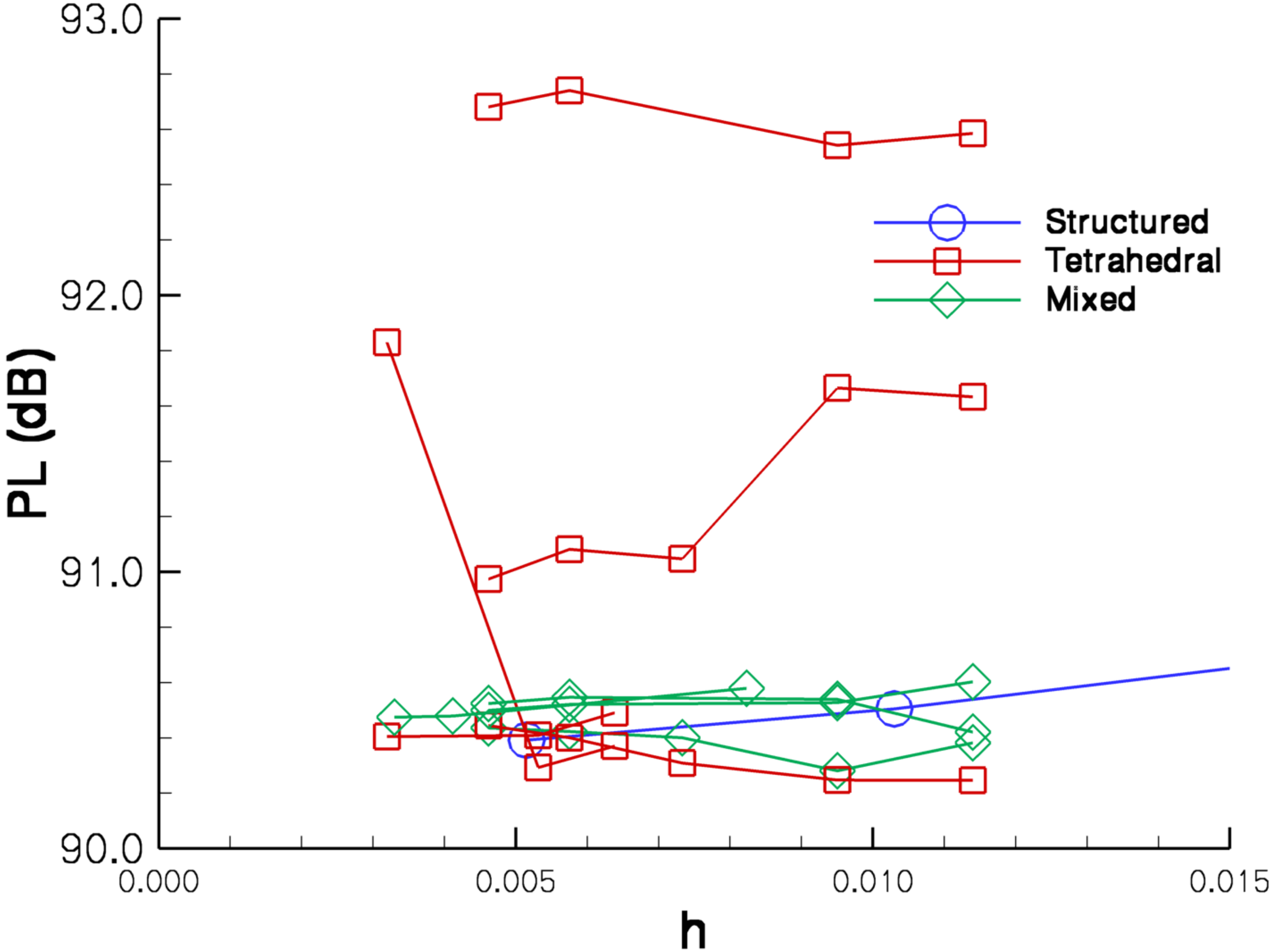


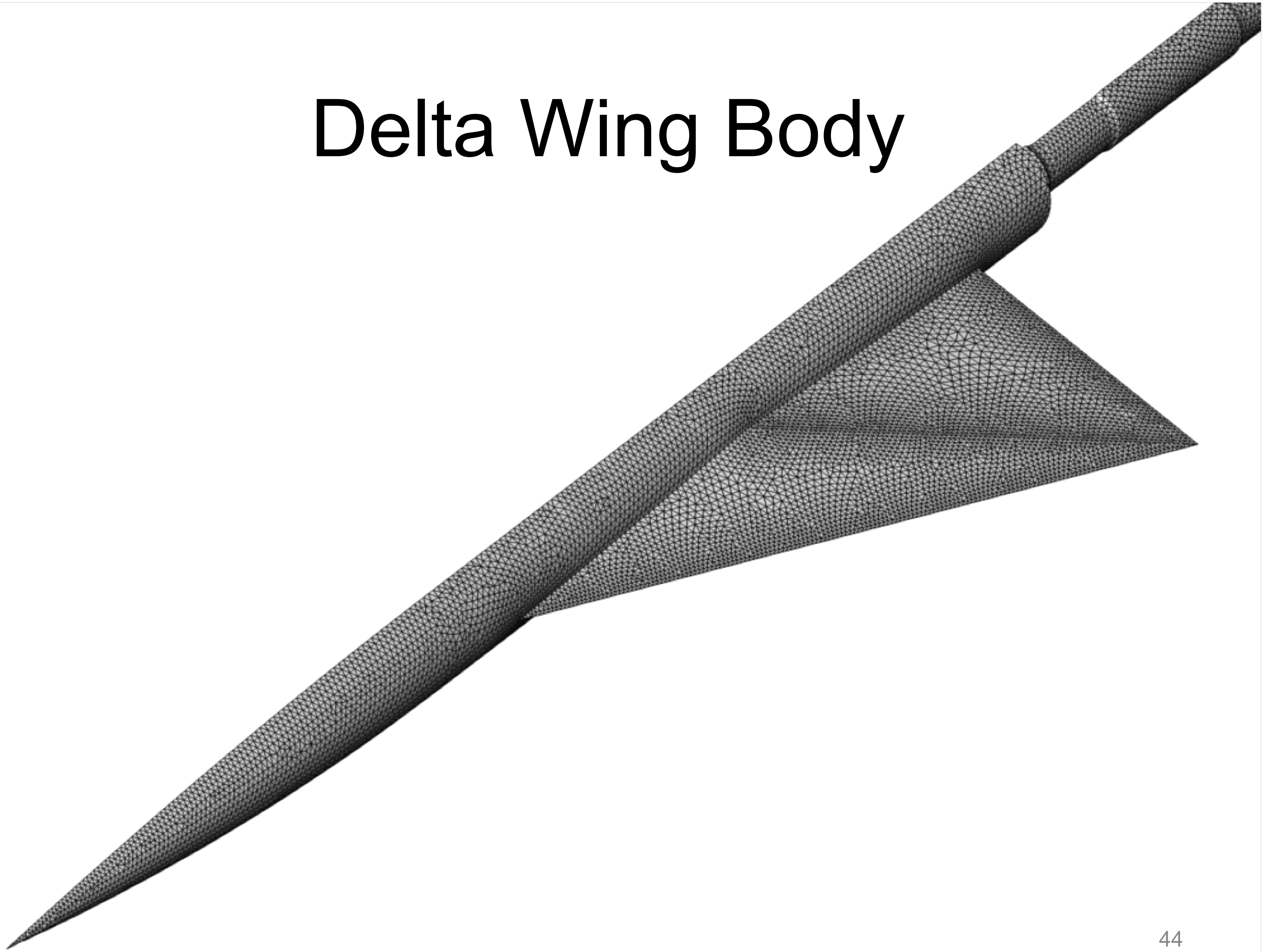
SEEB-ALR Perceived Level



SEEB-ALR Perceived Level



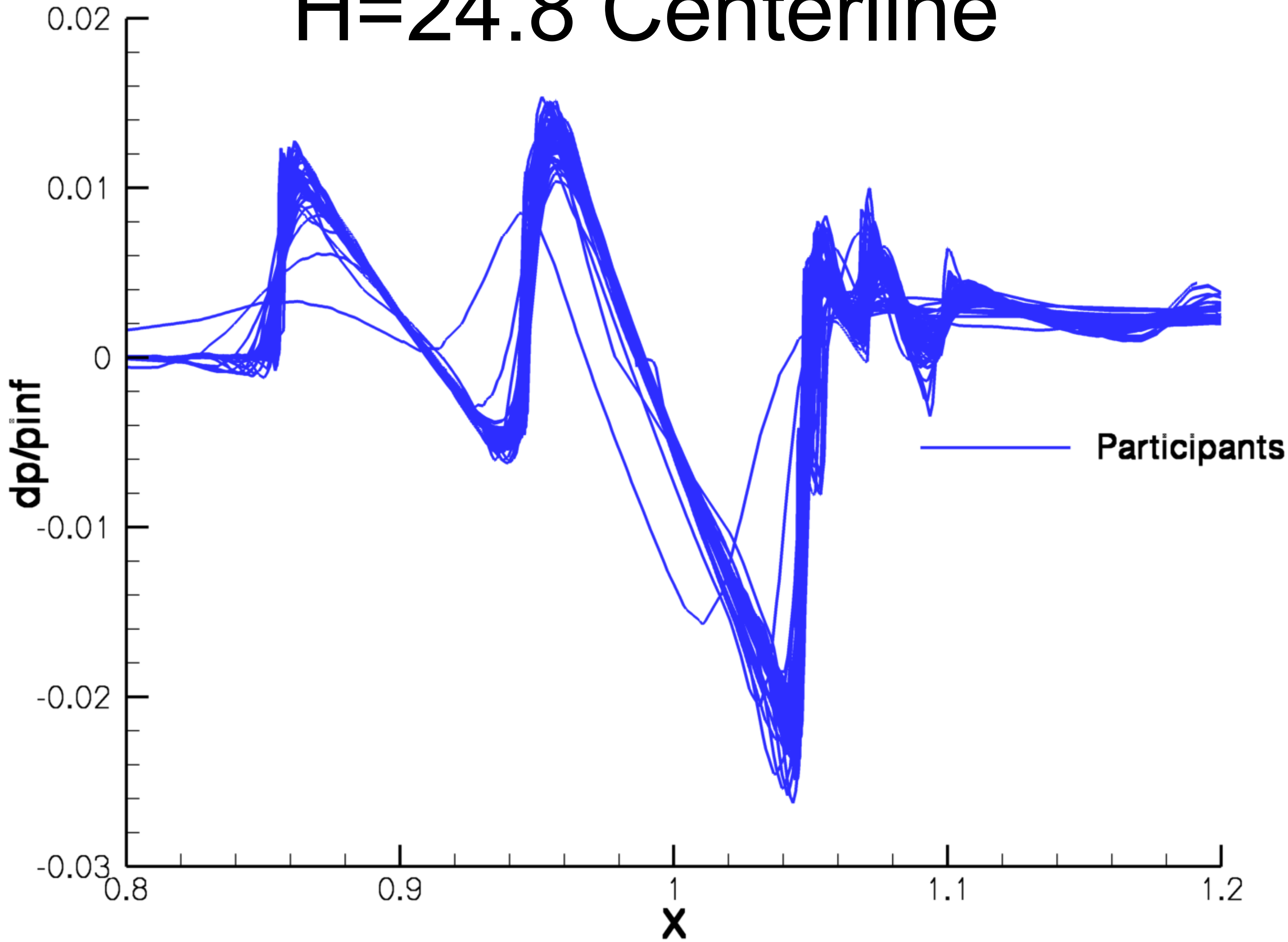
Delta Wing Body



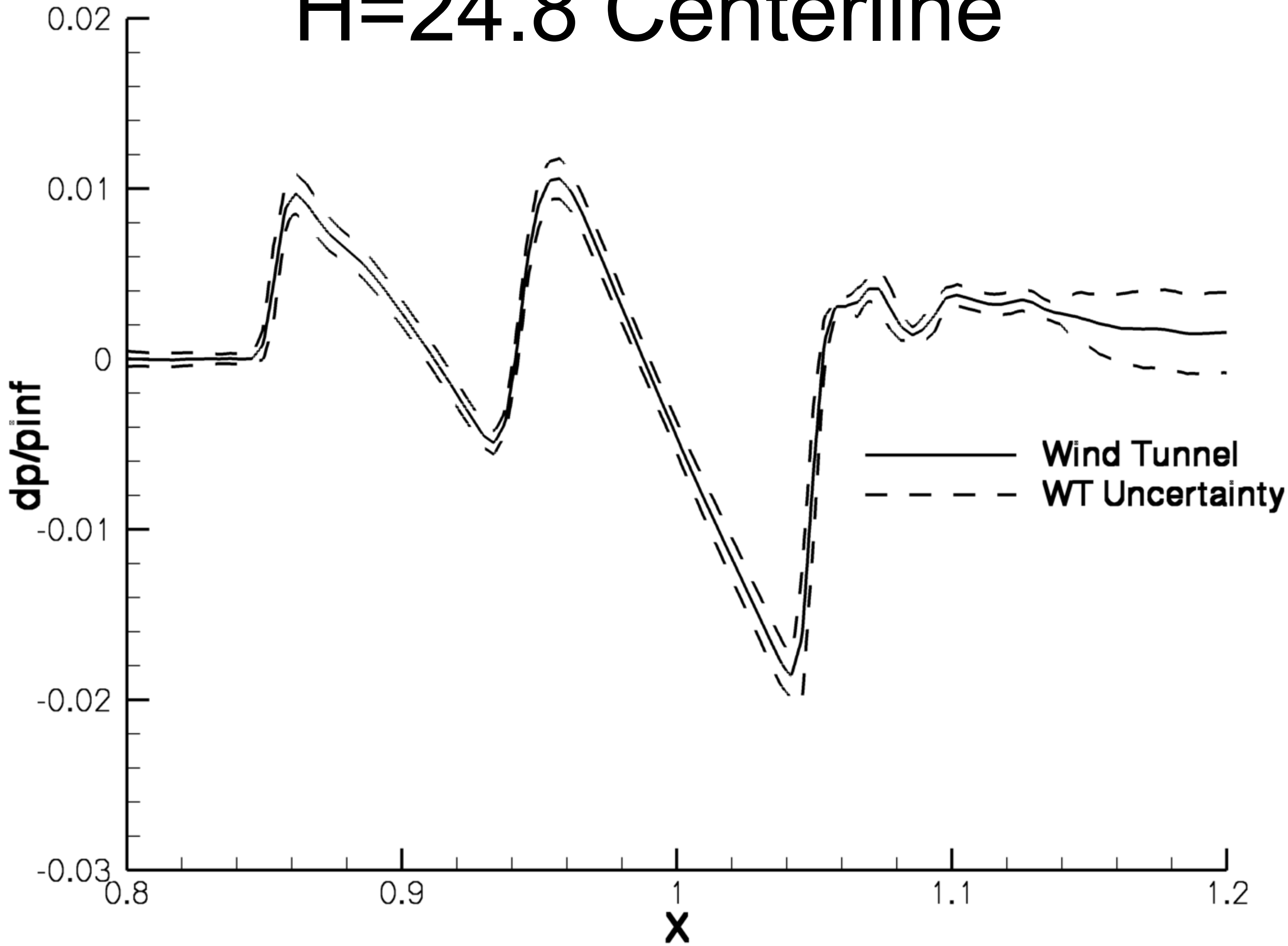
Delta Wing Body Signatures

- 58 sets of extracted signatures (10 locations)
  - 40 workshop grids, 18 participant generated
  - 24 tetrahedral,19 mixed, 8 structured, 4 Cartesian, 2 overset, 1 hybrid
  - 55 Euler, 3 SA

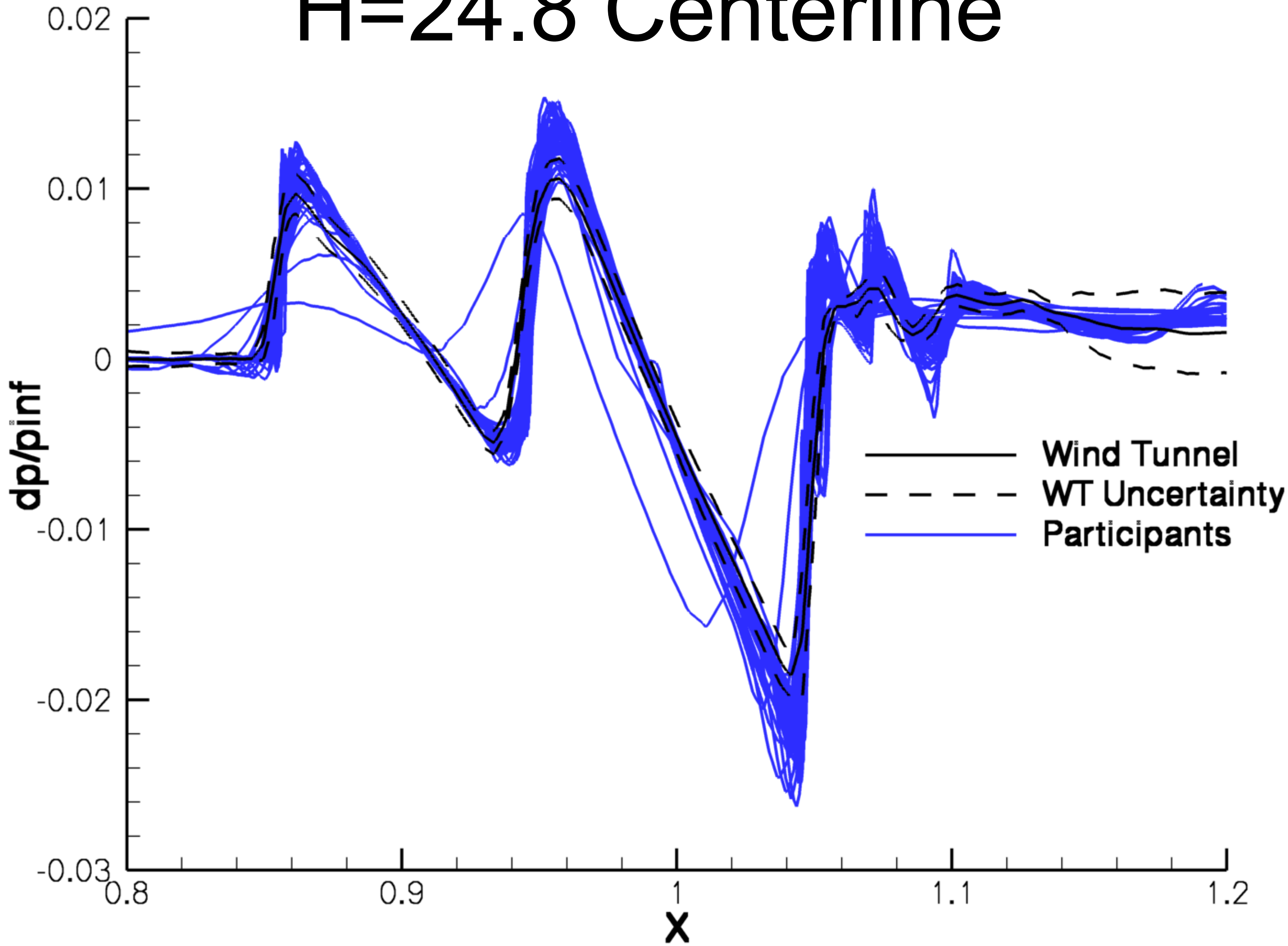
Delta Wing Body Signatures H=24.8 Centerline



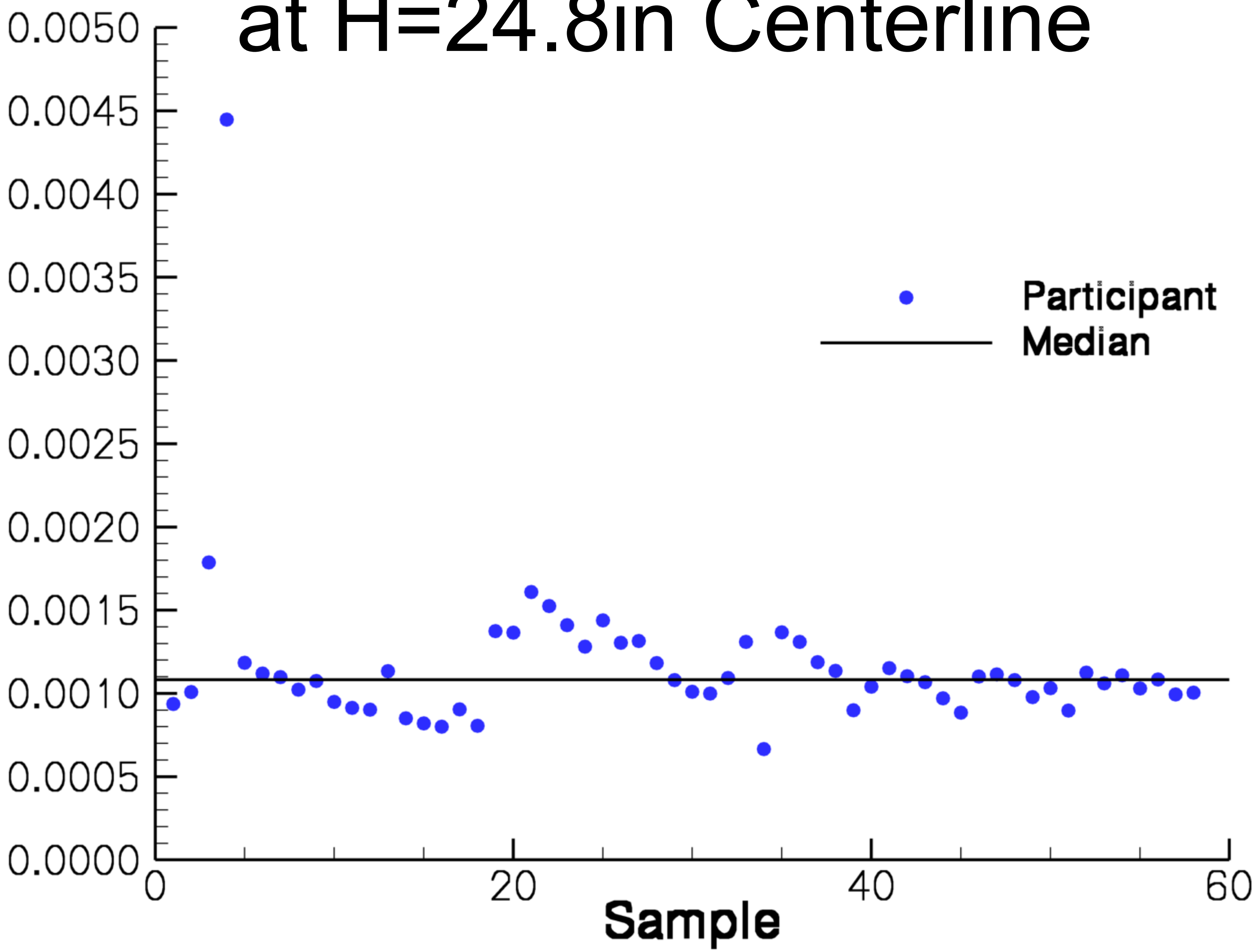
Delta Wing Body Measurement H=24.8 Centerline



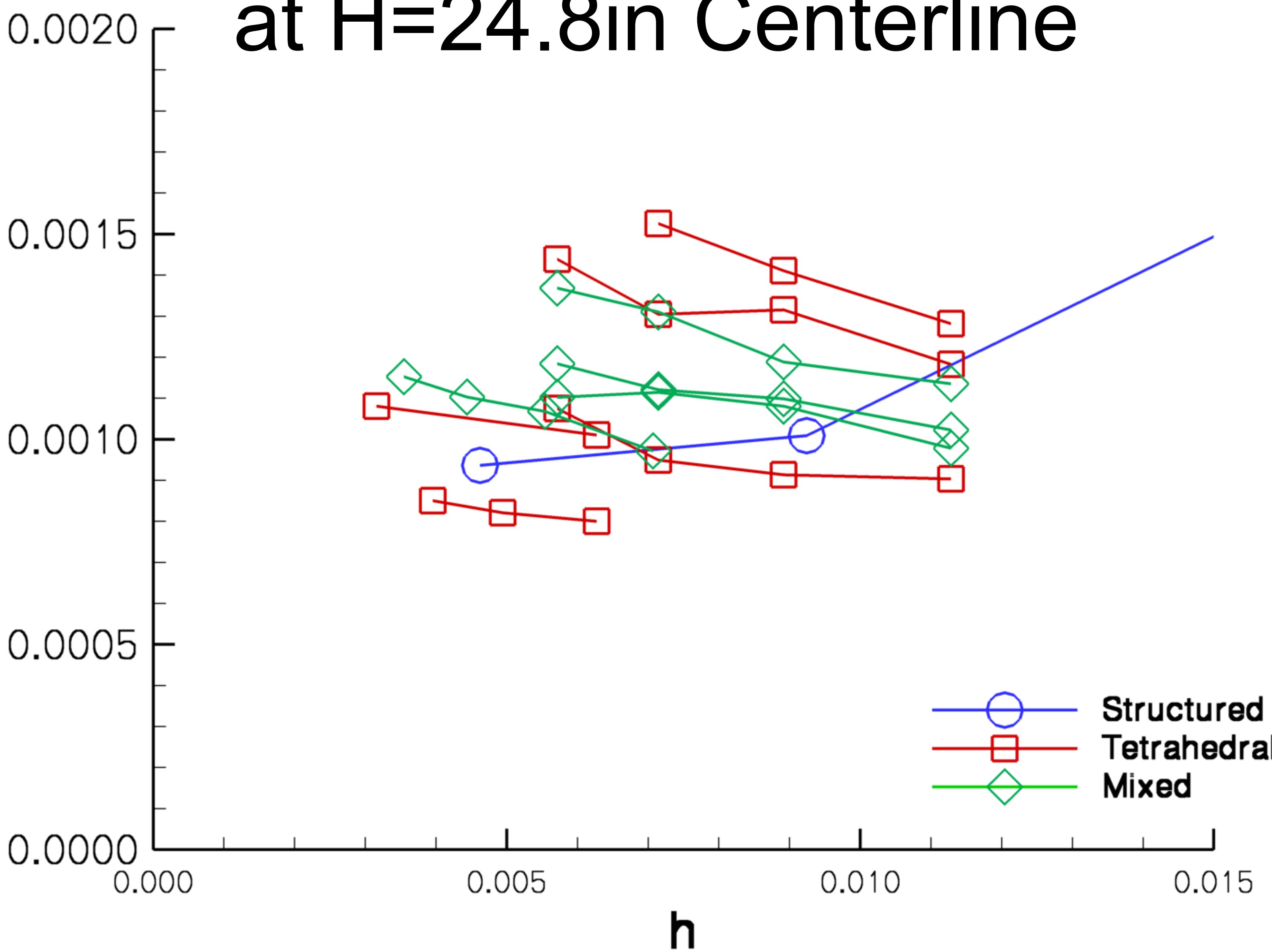
Delta Wing Body Signatures H=24.8 Centerline



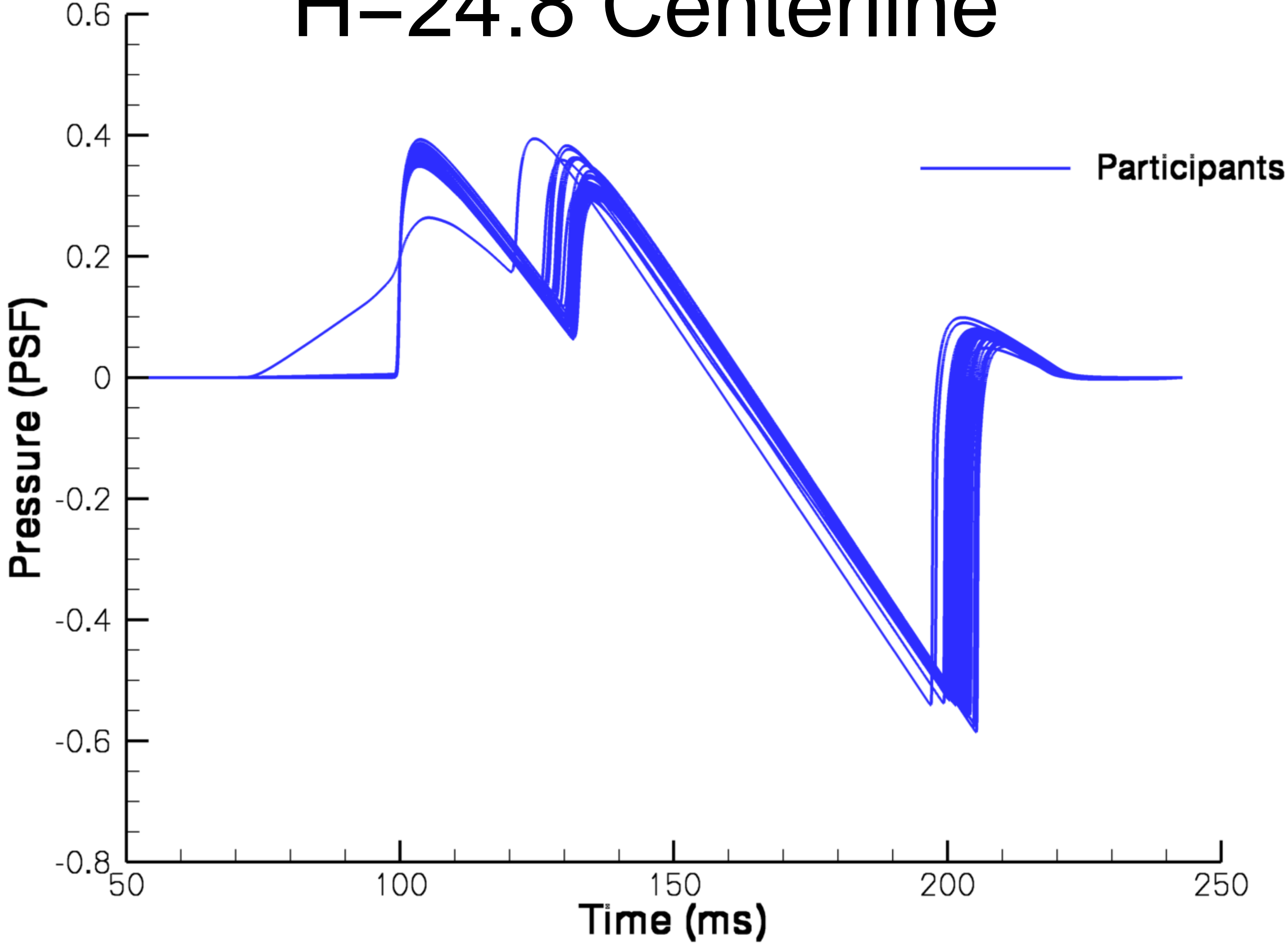
Delta Wing Body Validation Metric at H=24.8in Centerline



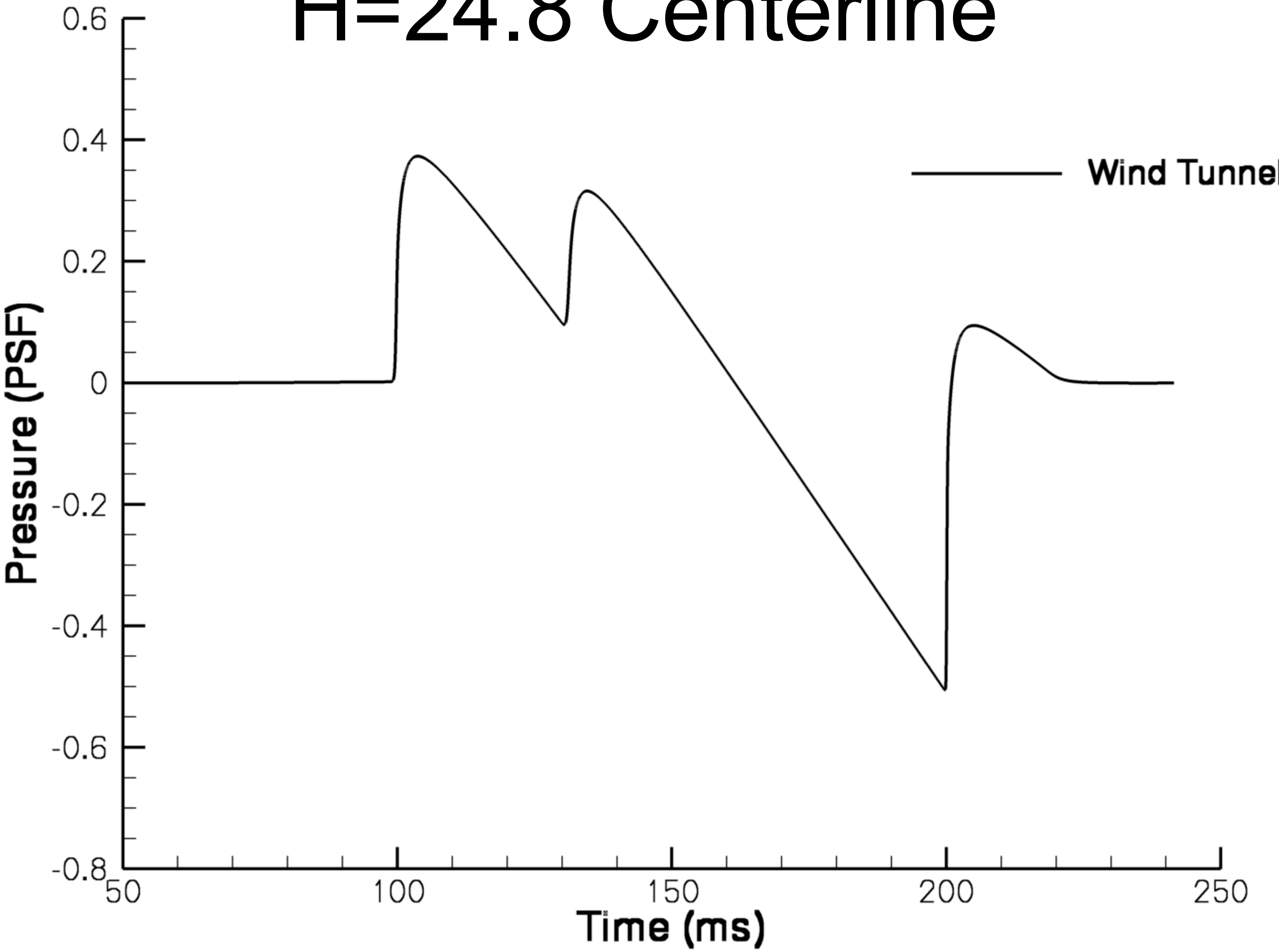
Delta Wing Body Validation Metric at H=24.8in Centerline



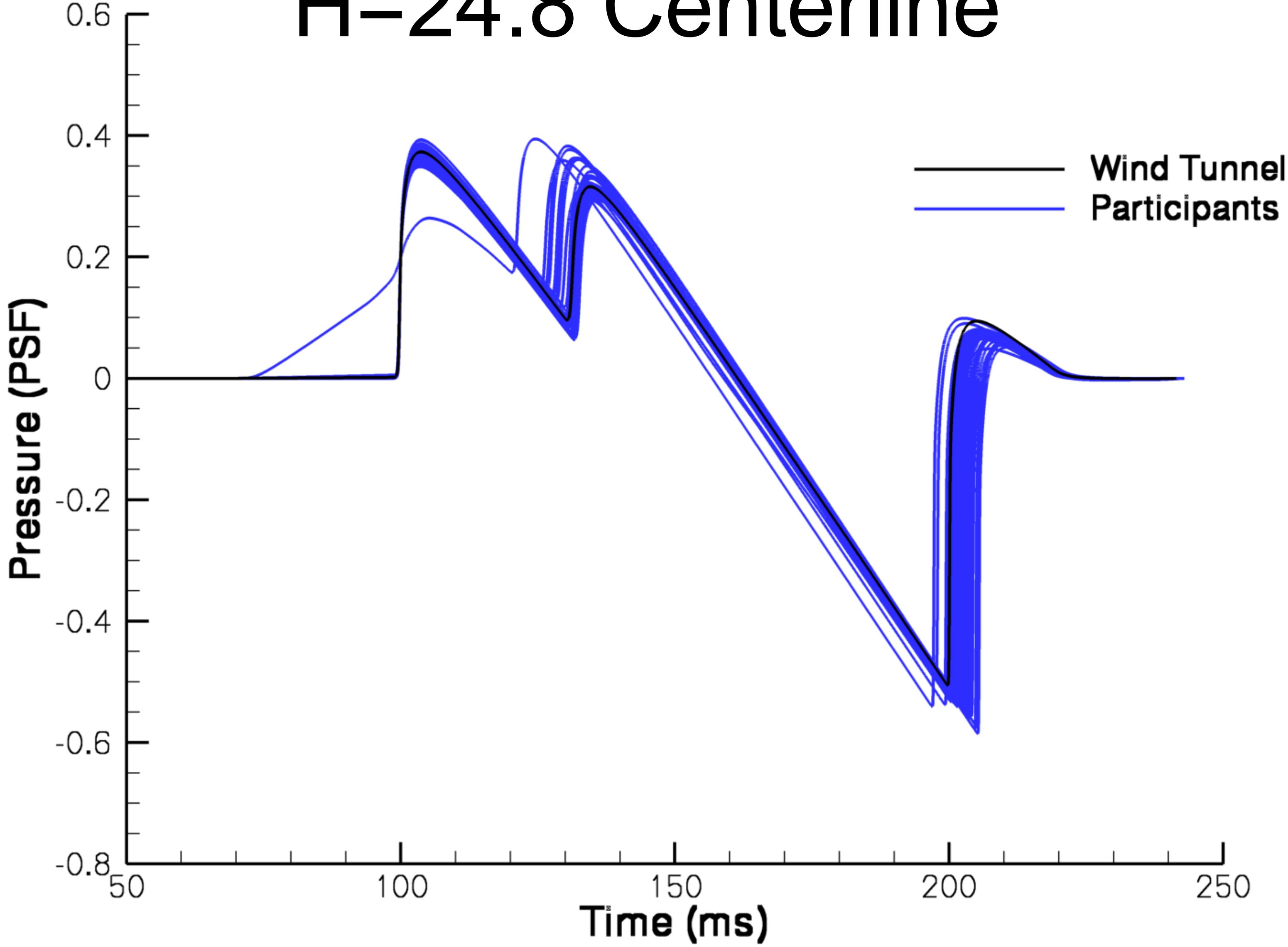
Delta Wing Body Ground from H=24.8 Centerline



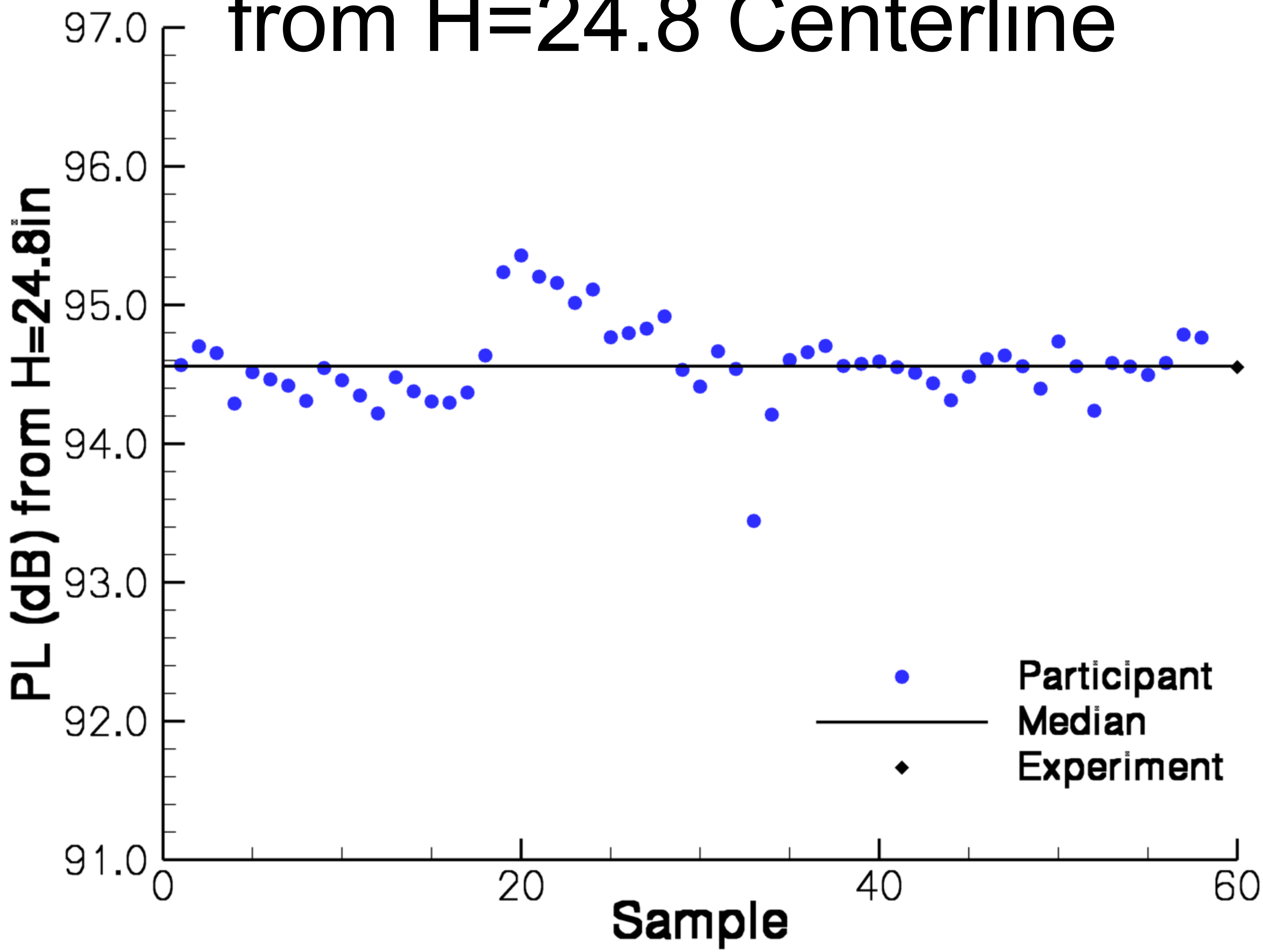
Delta Wing Body Ground from H=24.8 Centerline



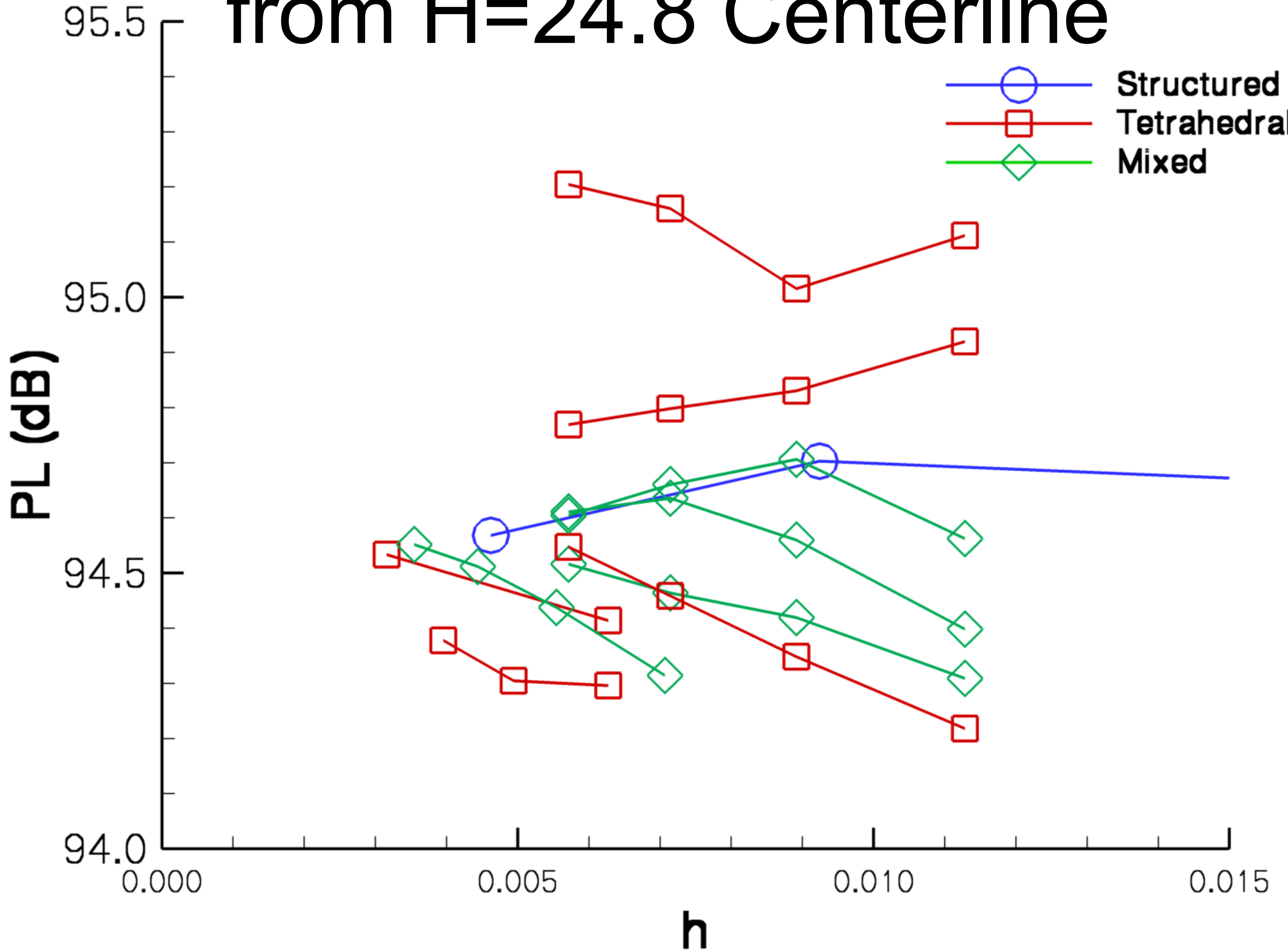
Delta Wing Body Ground from H=24.8 Centerline



Delta Wing Body Perceived Level from H=24.8 Centerline



Delta Wing Body Perceived Level from H=24.8 Centerline



Overview

- Described cases and configurations
- Described data extraction and uniform processing of submissions
  - Validation metrics, ground signatures, and noise measures
- Introduced a statistical method to find “different” submissions in the summary talk
- Introduced grid convergence expectations

Overview: Near-Field Signatures

- SEEB-ALR signatures varied mostly by pressure level
  - Same level or higher than wind tunnel flat top
  - Lower pressure than wind tunnel in expansion
- Delta Wing Body signatures in a tighter grouping with a few outliers
  - Middle expansion slope and nose expansion steeper then wind tunnel

Overview: Validation Metric

- SEEB-ALR has a number of metrics that are larger than the majority
- Delta Wing Body has one metric that was much larger than others

Overview: Ground Signatures

- SEEB-ALR ground signatures had similar shapes, but varied by pressure level
  - Higher flat top pressure and lower expansion pressure than wind tunnel measurement
- Delta Wing Body ground signatures varied by center shock location, at or ahead of wind tunnel shock location

Overview: Noise Measures

- SEEB-ALR has a quieter median 90.5 PL and more variation (asymmetrically louder)
- Delta Wing Body has a louder mean 94.6 with smaller amount of symmetric spread
- Neither is a “low boom” configuration

Overview: Grid Refinement

- SEEB-ALR has good "agreement" on grid converged values with different opinions from three participants
- Delta Wing Body has less agreement on the grid converged values for the validation metric and noise measure

Acknowledgements

- Joe Morrison and Chris Rumsey
- Alexandra Loubeau
- Sriram Rallabhandi
- Tom West, Bryan Reuter, Eric Walker, and Bil Kleb
- Organizing committee
- Fundamental Aeronautics Program High Speed Project

Summary

- More to follow after the participant talks

Backup Material

Summary of Perceived Level (PL)

- Metric for perceived level of loudness developed by S. S. Stevens[1]
  - Developed to predict behavior of human auditory system in response to sound
- Adapted for use with sonic booms by Shepherd and Sullivan[2]
- Has been shown to correlate well with human perception of sonic booms outdoors

- 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

Calculation of Perceived Level (PL)

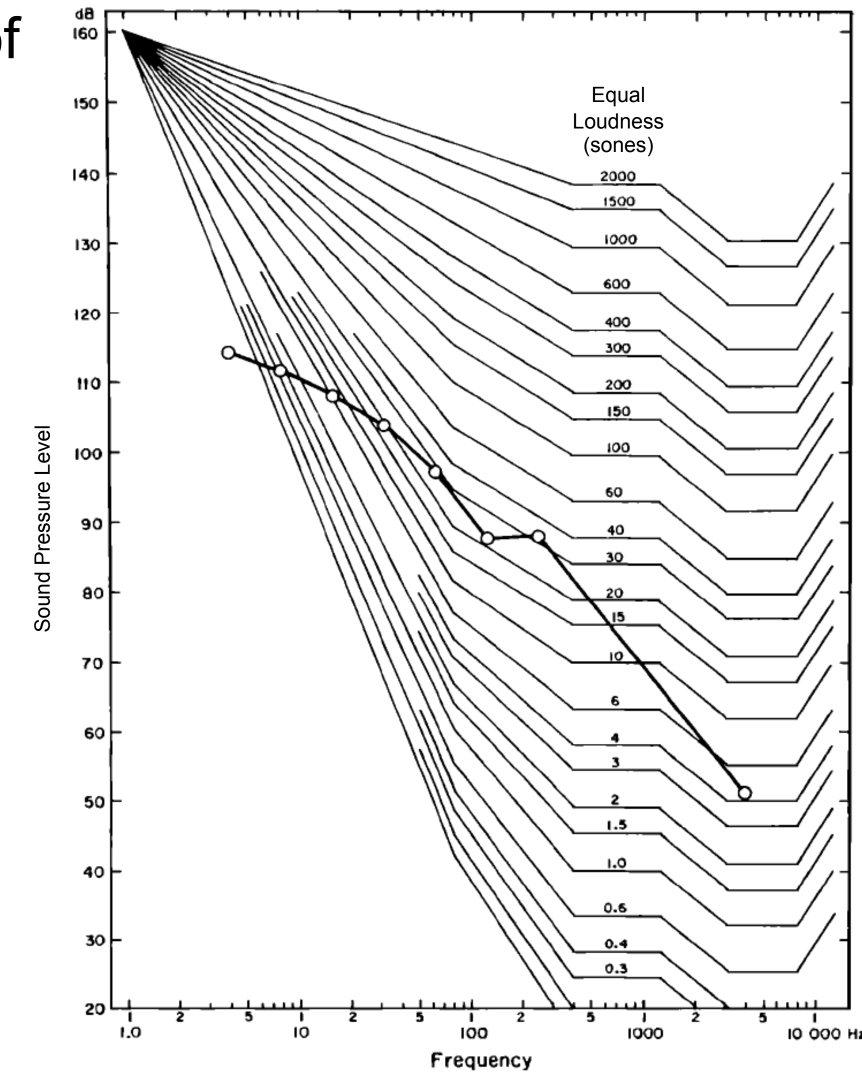
1. Calculate Sound Pressure Level of signal in 1/3-octave bands
2. Apply frequency weighting for loudness of individual bands
   - where loudness of 1 sone is referenced to 1/3-oct band of noise at 3150 Hz at 32 dB
3. Apply summation rule for total loudness

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

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

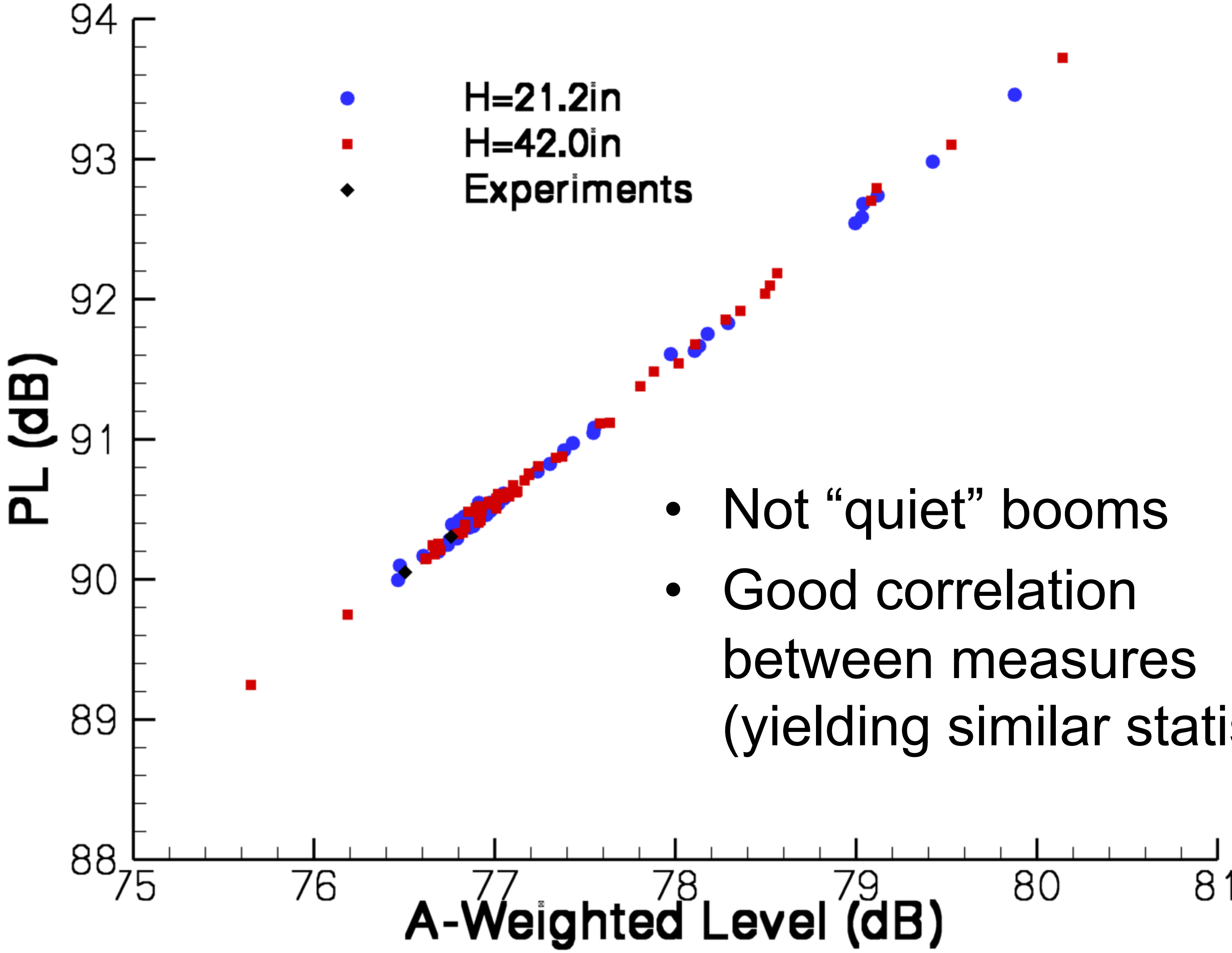
$$PL = 32 + 9\log_2(S_t)$$

4. Convert to PL in dB



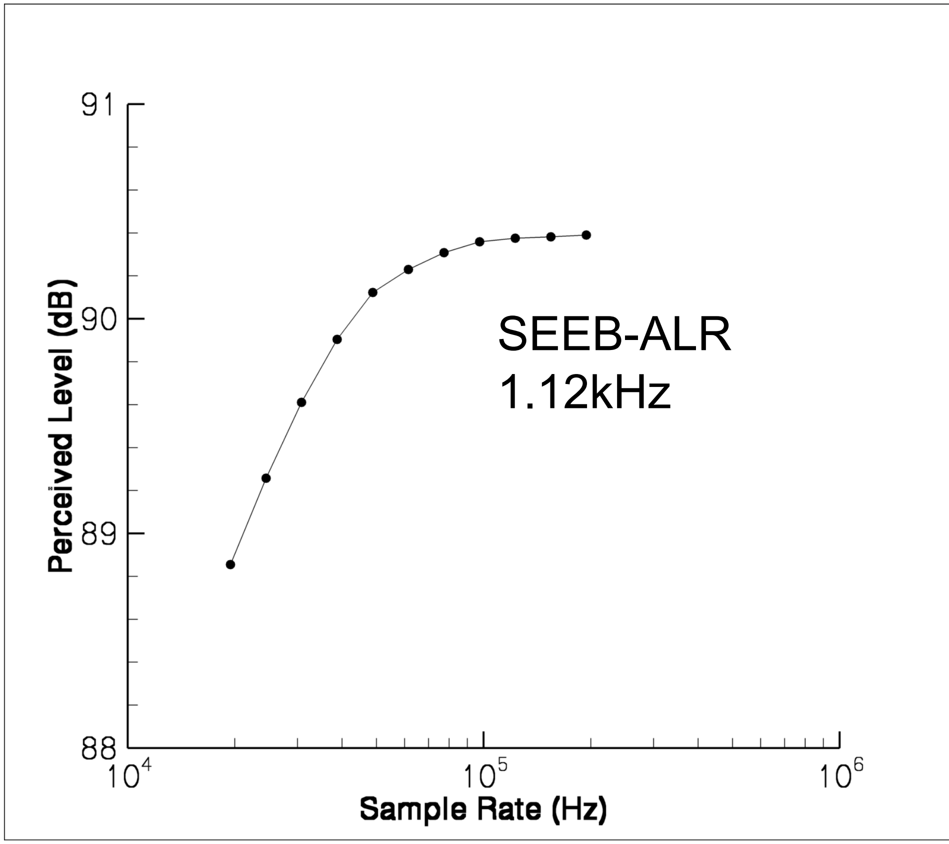
[1]S. S. Stevens. Perceived level of noise by Mark VII and decibels (E). J. Acoust. Soc. Am., 51(2):575–601, 1972.
[2]K. P. Shepherd and B. M. Sullivan. A loudness calculation procedure applied to shaped sonic booms. NASA Technical Report TP-3134, 1991.

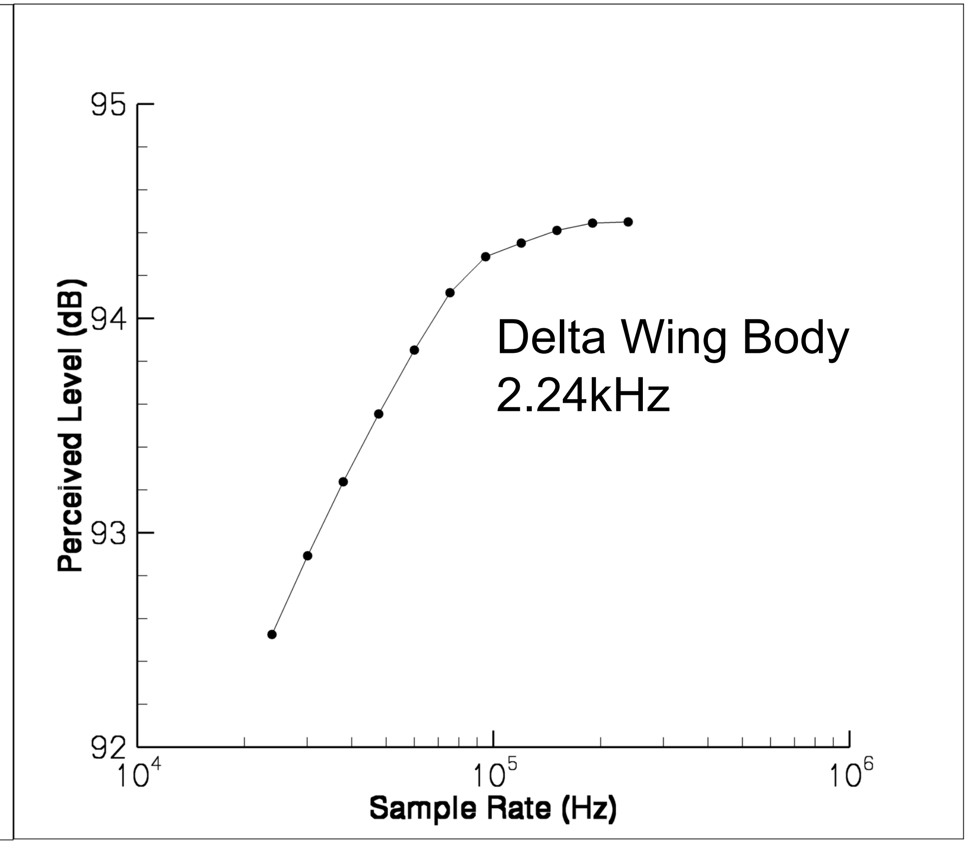
SEEB-ALR Sound Level



- Not “quiet” booms
- Good correlation between measures (yielding similar statistics)

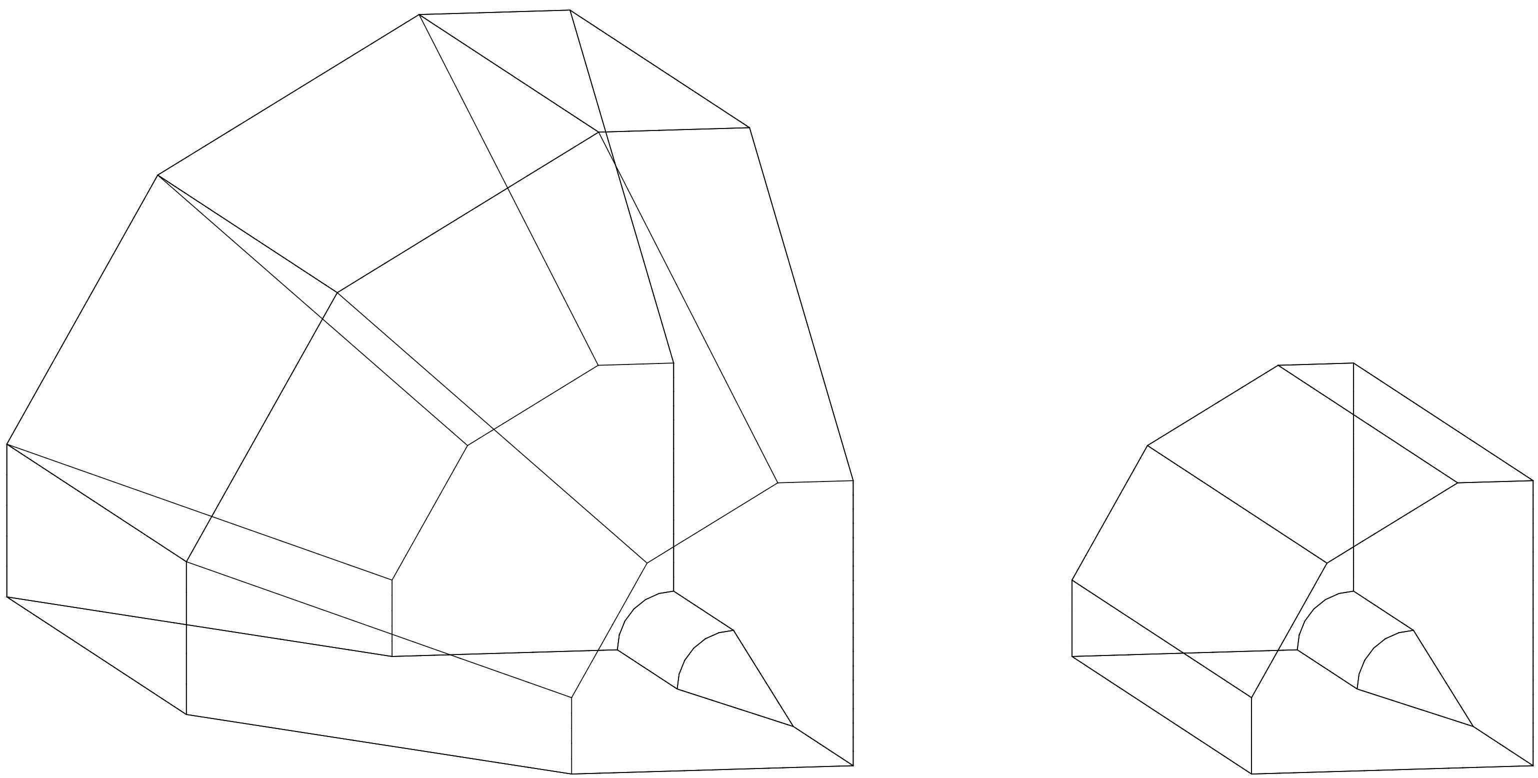
sBOOM sample rate





Inflate (Inf)

- Maintains planar surfaces for robustness



Inflate (Inf)

- Maintains planar surfaces for robustness