THIRD AIAA SONIC BOOM PREDICTION WORKSHOP NEARFIELD CFD SUMMARY

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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

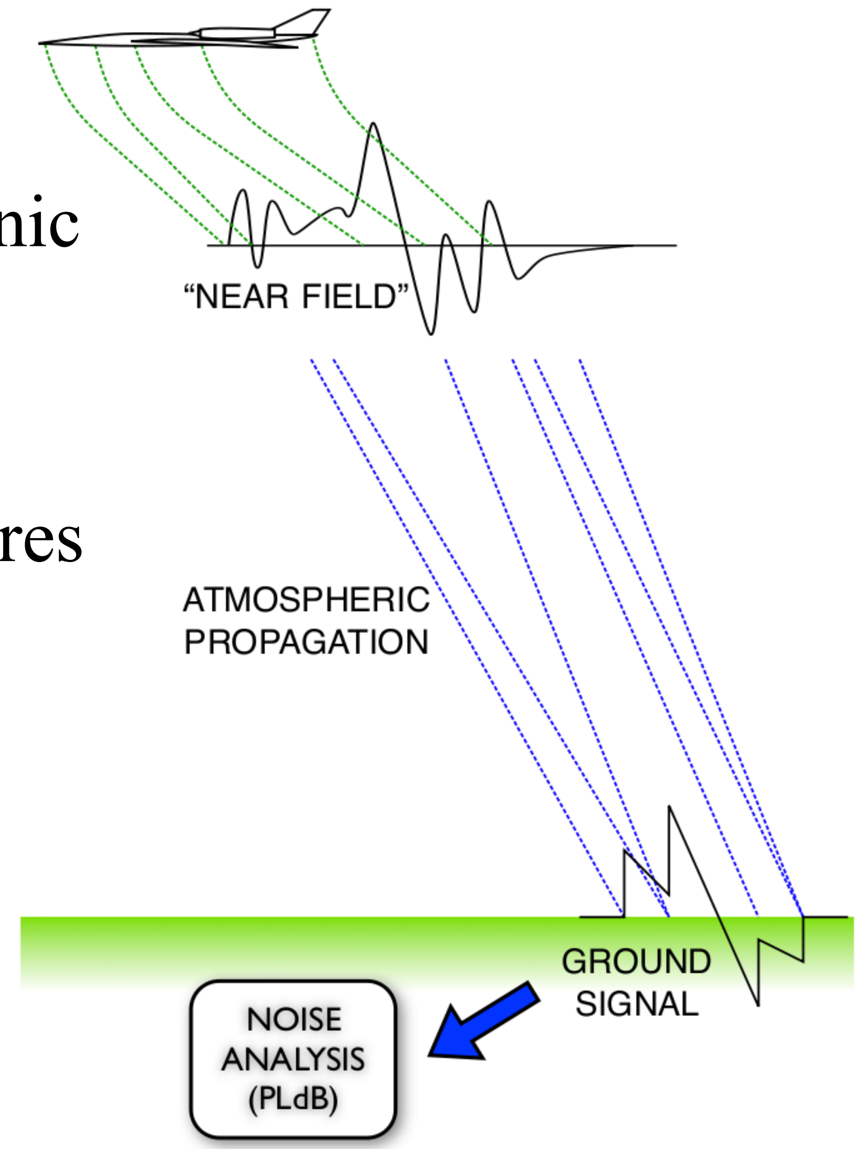
MOTIVATION

Near field CFD is part of sonic boom prediction

Explore the issues

Impartially compare signatures by uniform application of

- Near field statistics
- Propagation
- Loudness measures



WORKSHOP CULTURE

Adjectives such as good, bad, right, and wrong oversimplify issues and should be avoided

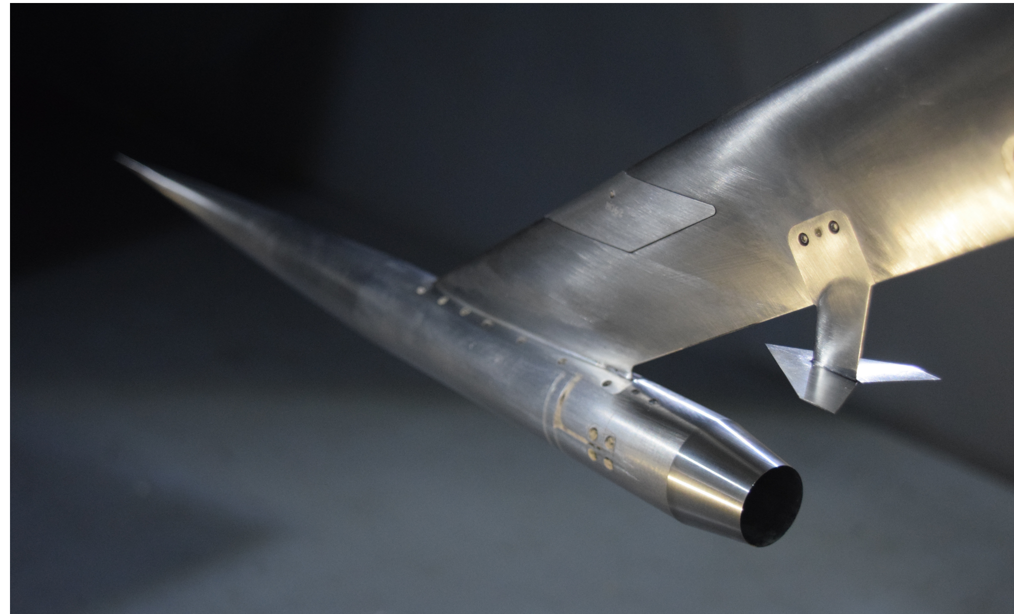
Focus on describing observed differences and communicate why things are different

MODELS AND CASES

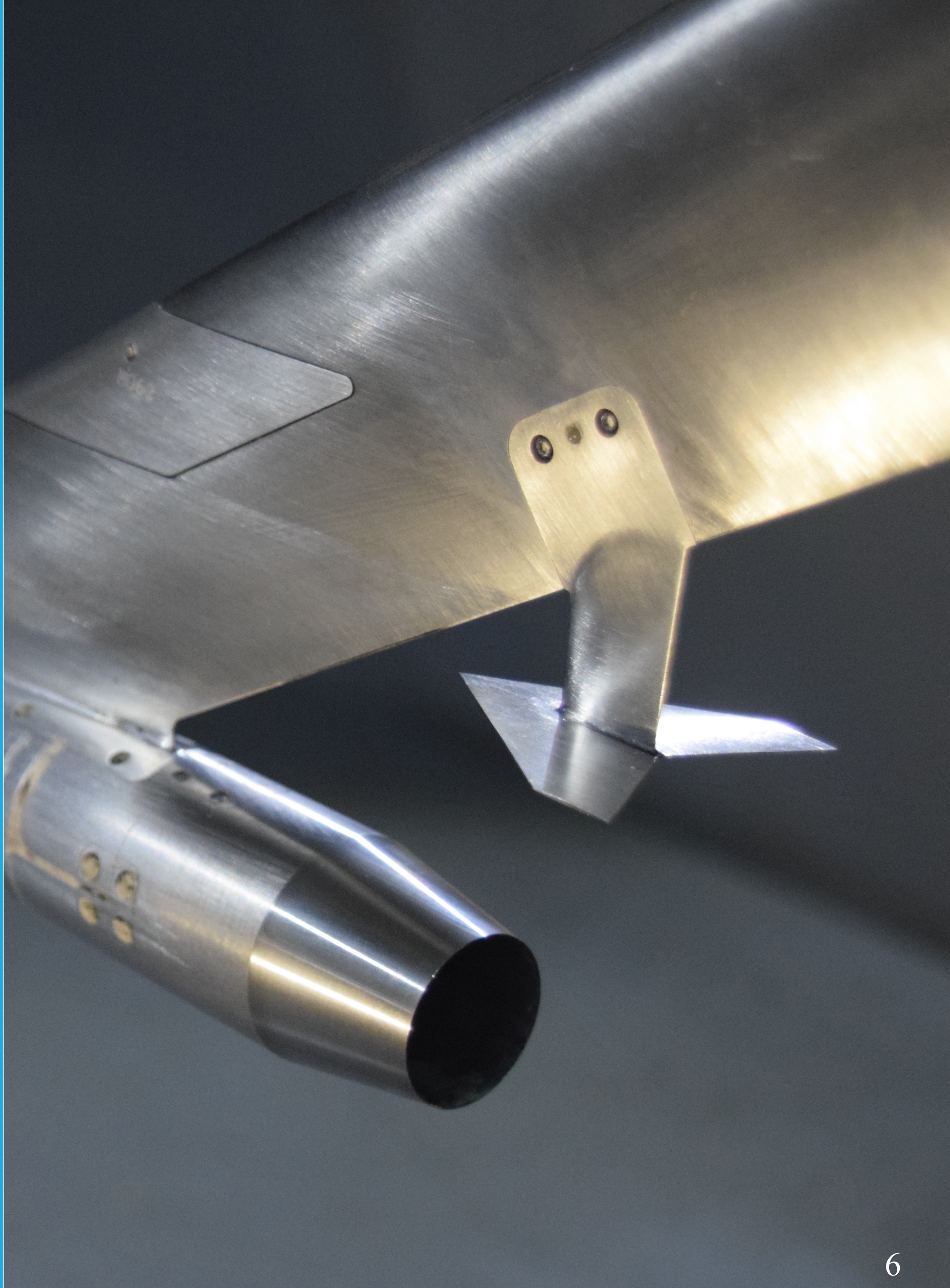
Ames 9’x7’ UPWT Biconvex Plume-Shock Interaction Case

C608, an early X-59 Prototype

IGES and STEP geometry files along with workshop generated grids provided



BICONVEX SUBMISSIONS



OUTLINE

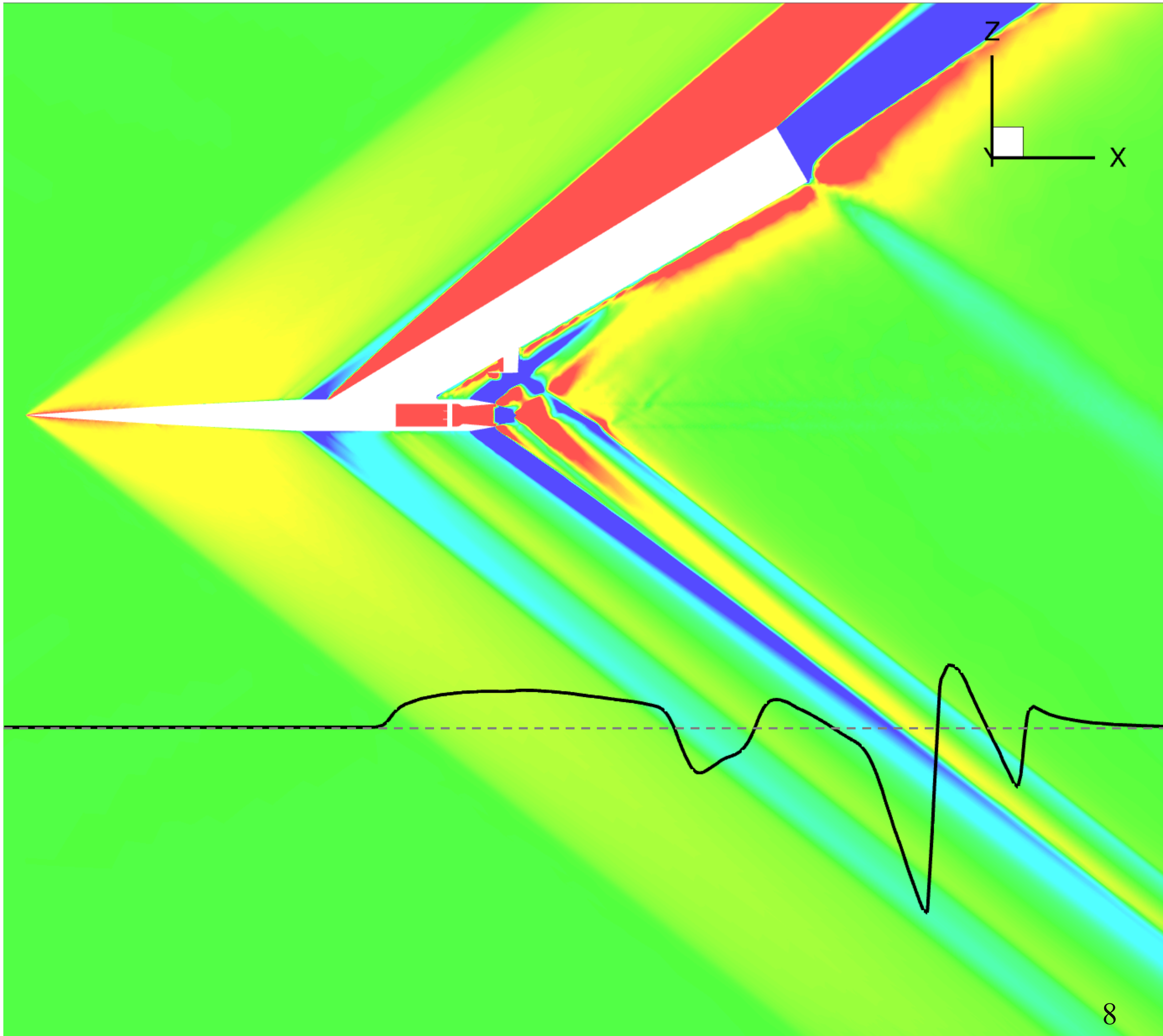
- Fine-grid nearfield pressures
  - Excluded different geometry (AE, AF) and optional case with two submissions (AD, OE)
- Compare the fine-grid ensemble pointwise standard deviation to experiment
- Identify outliners

BICONVEX dp/p_{INF}

Grid 100
Tetrahedral

USM3D
Production
code

dp/p_∞ which is the pressure disturbance normalized by freestream pressure

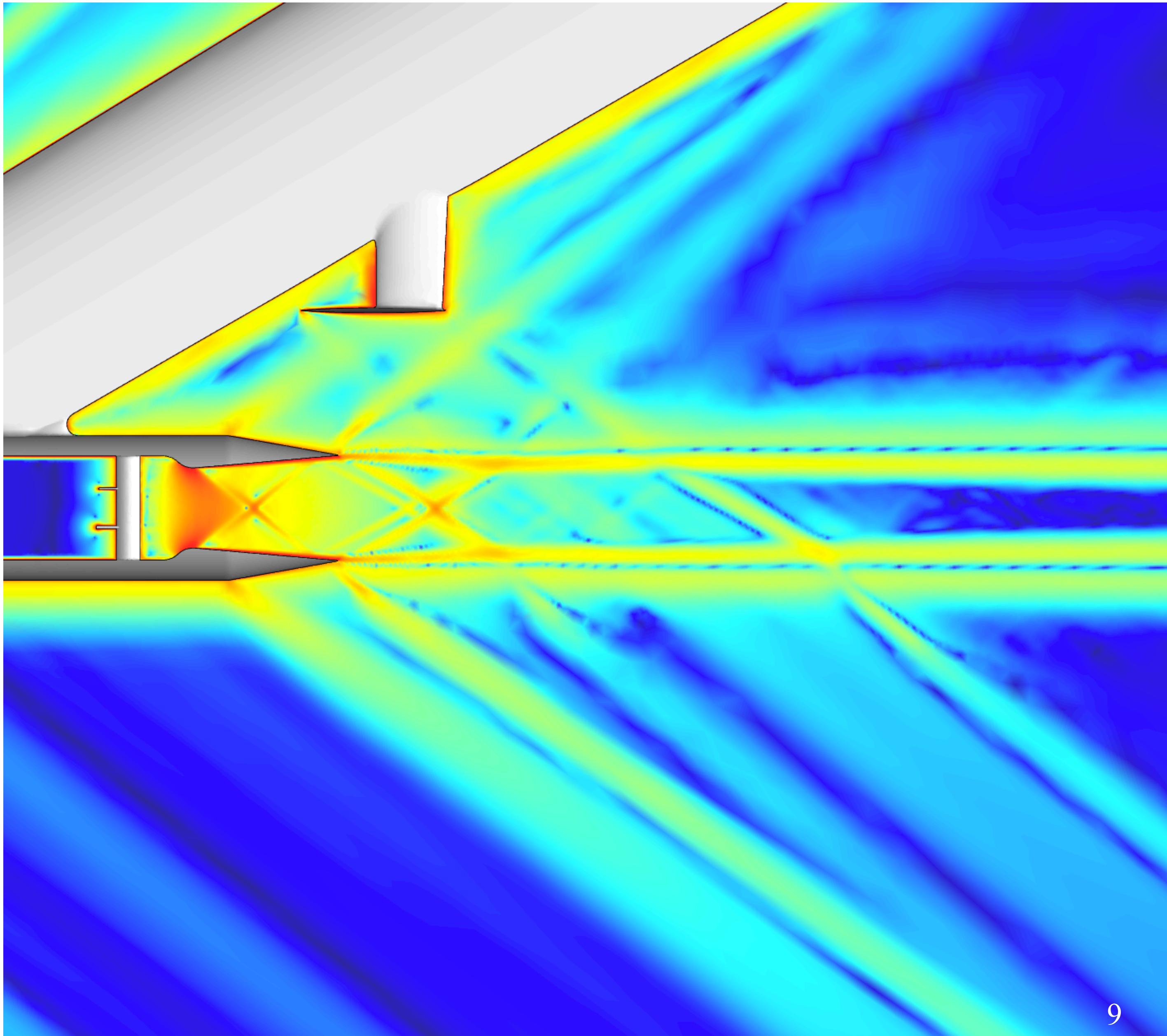


BICONVEX DENSITY GRADIENT

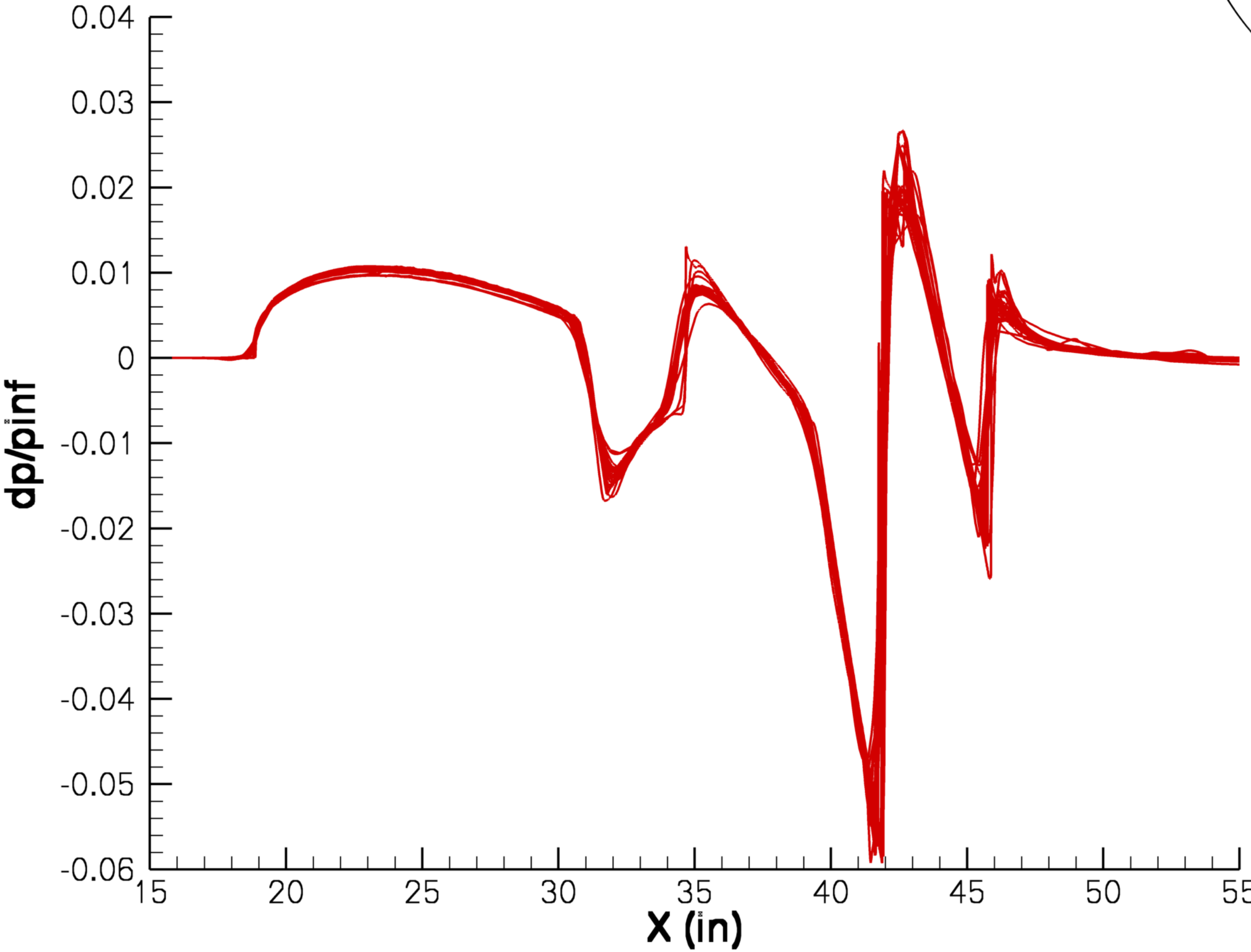
Grid 100 Tetrahedral

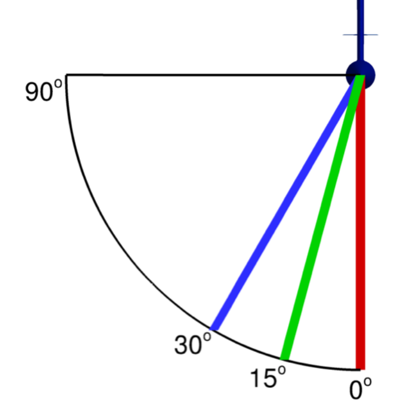
USM3D Production code

Density gradient (numerical schlieren)



BICONVEX FINE-GRID





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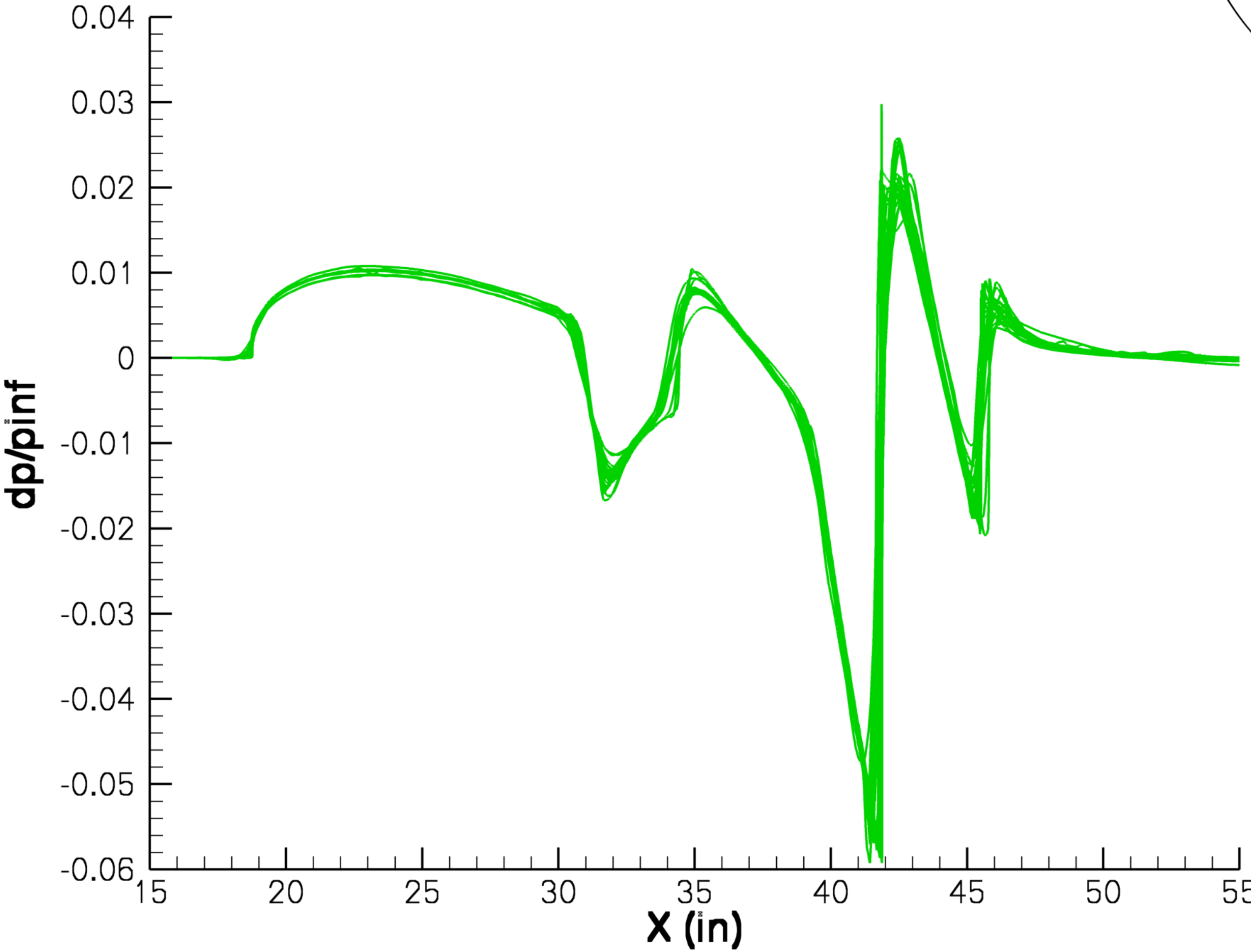
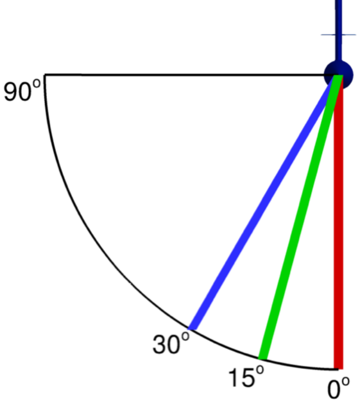
BICONVEX FINE-GRID





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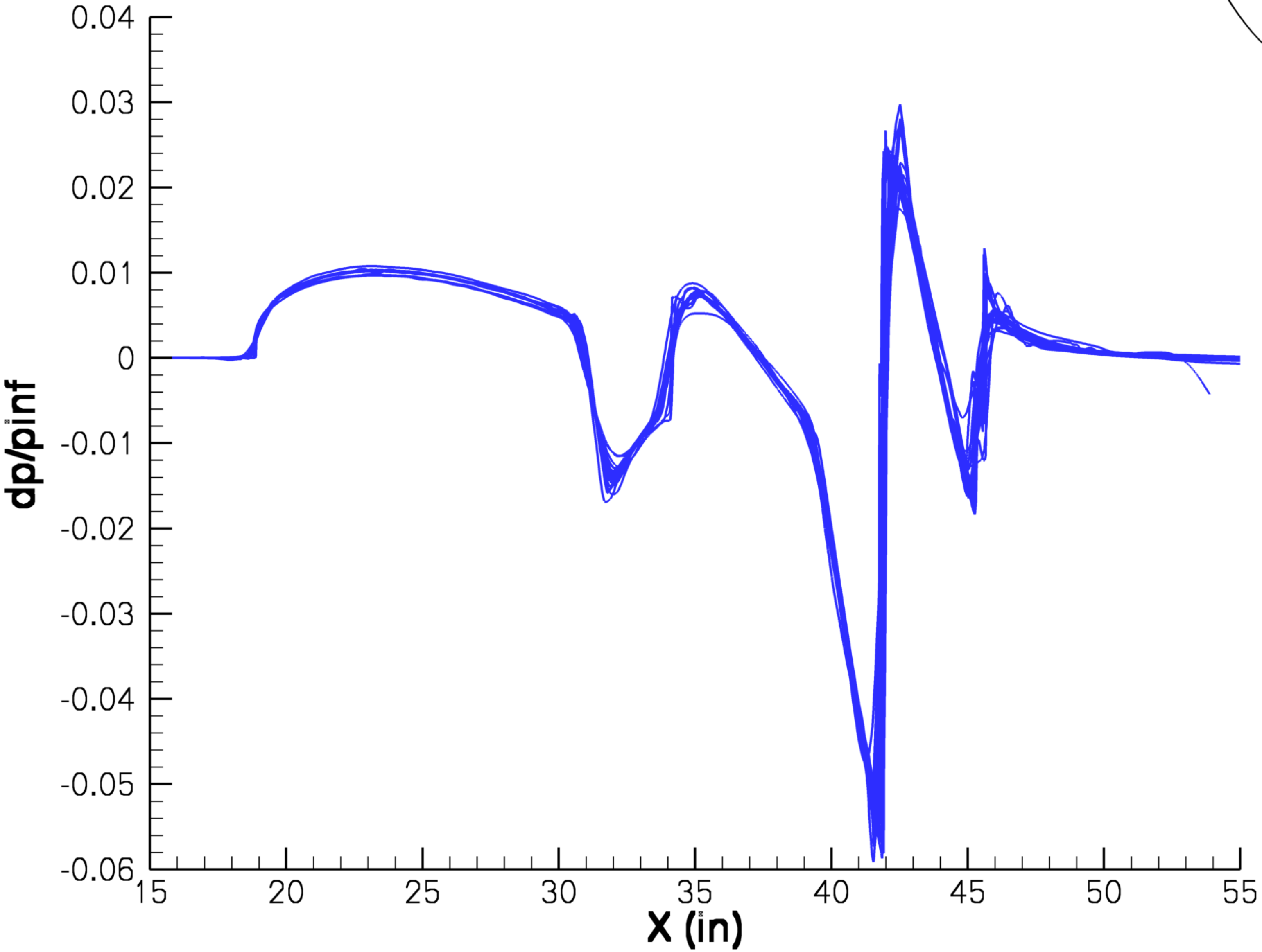

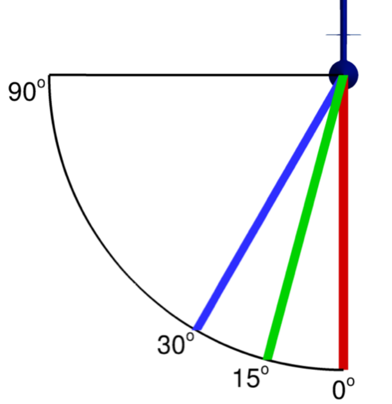

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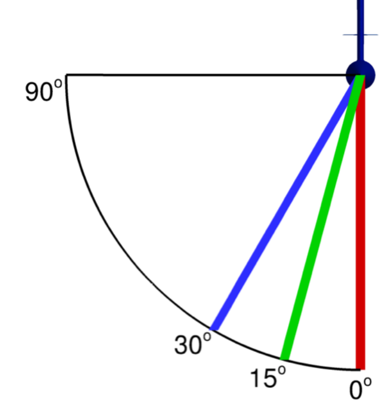
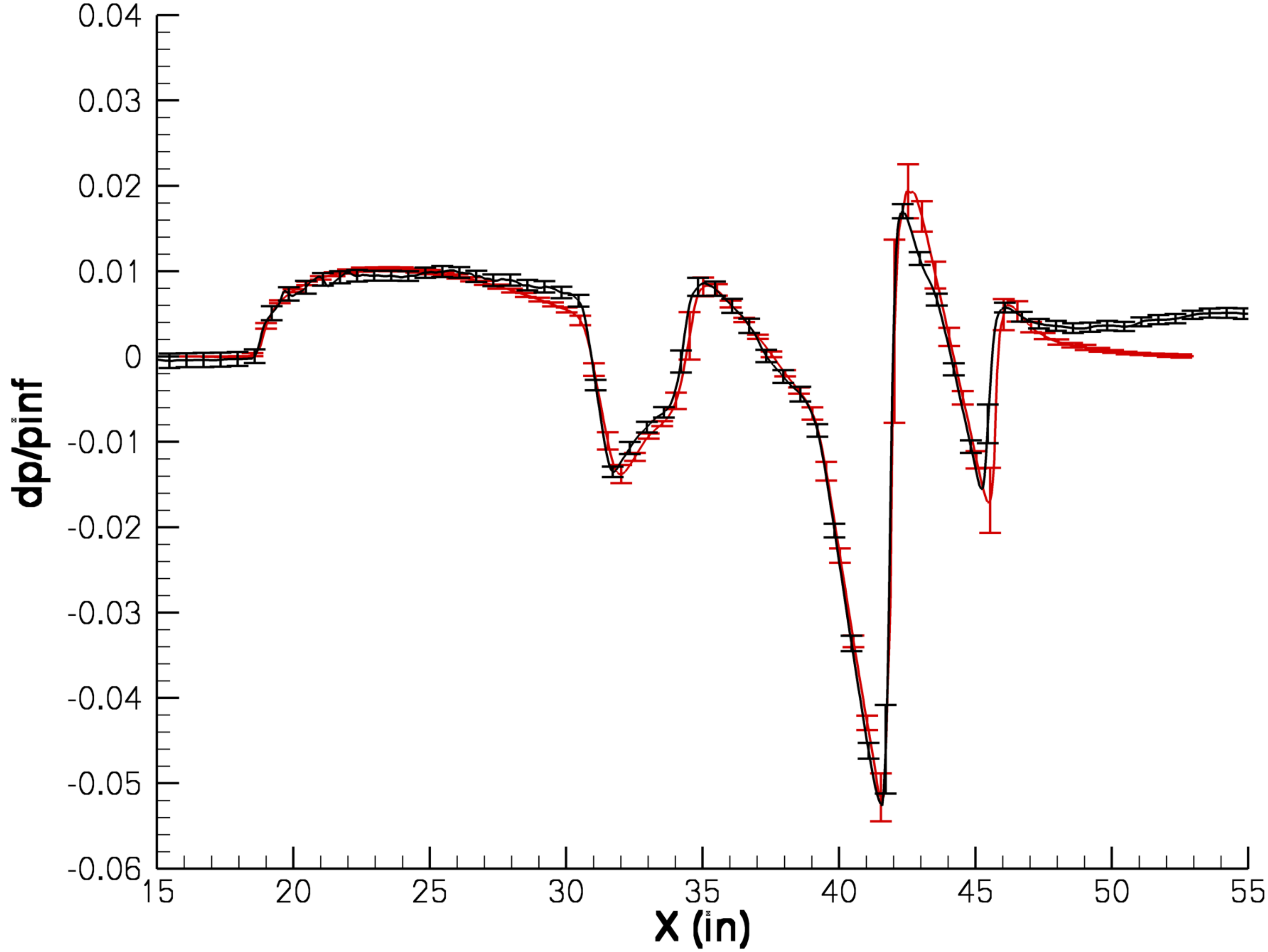
NEARFIELD SIGNATURE STATISTICS

- Pointwise population mean and standard deviation of interpolated signature every 0.05 inch (N=32)
- Analogous to wind tunnel spatial averaging
- Finest grid solution from each participant (which vary in resolution)
- Outliers impact these statistics

BICONVEX FINE-GRID ENSEMBLE COMPARISON WITH EXPERIMENT





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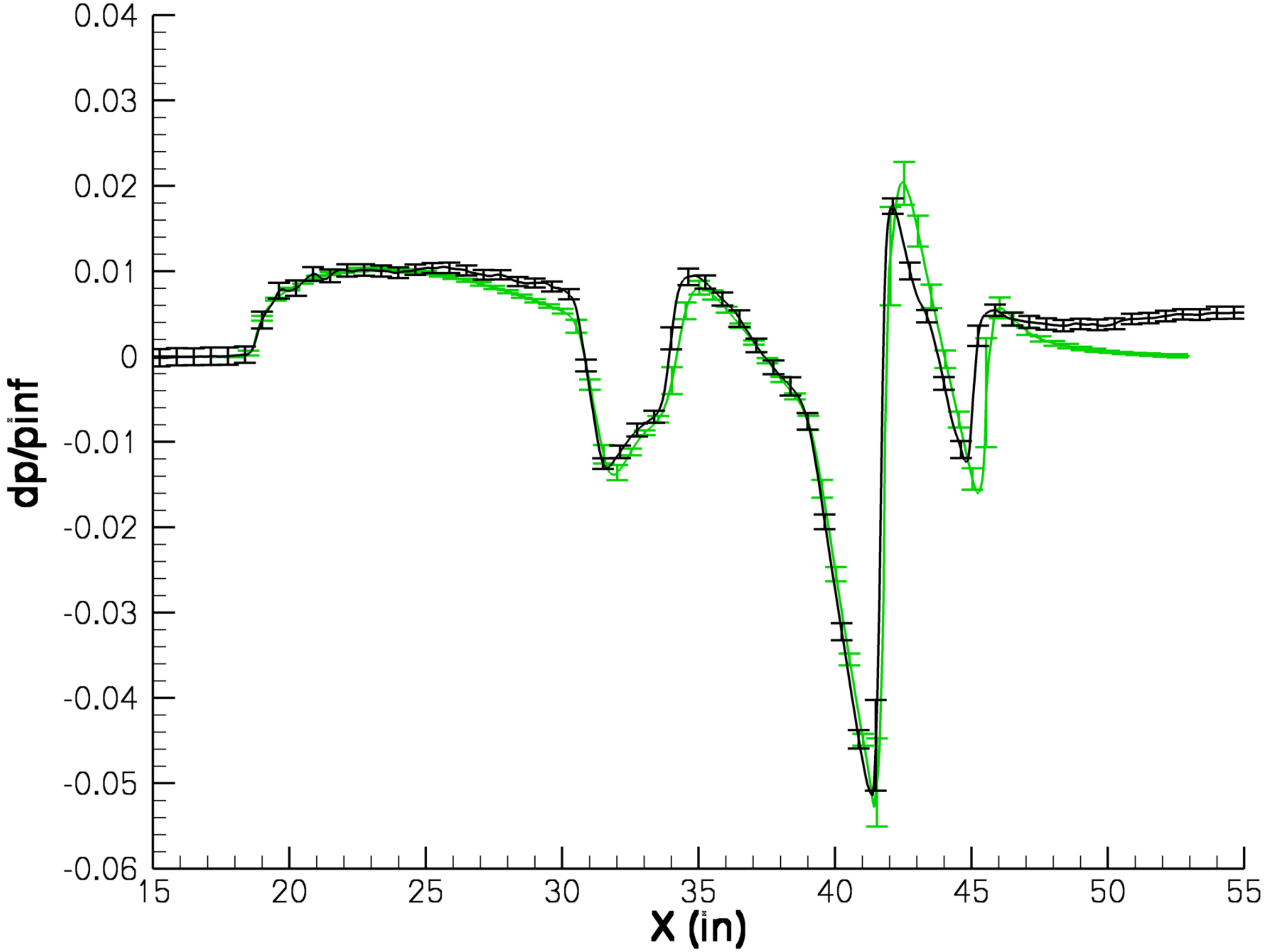

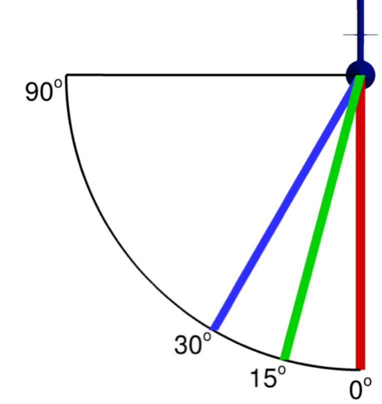

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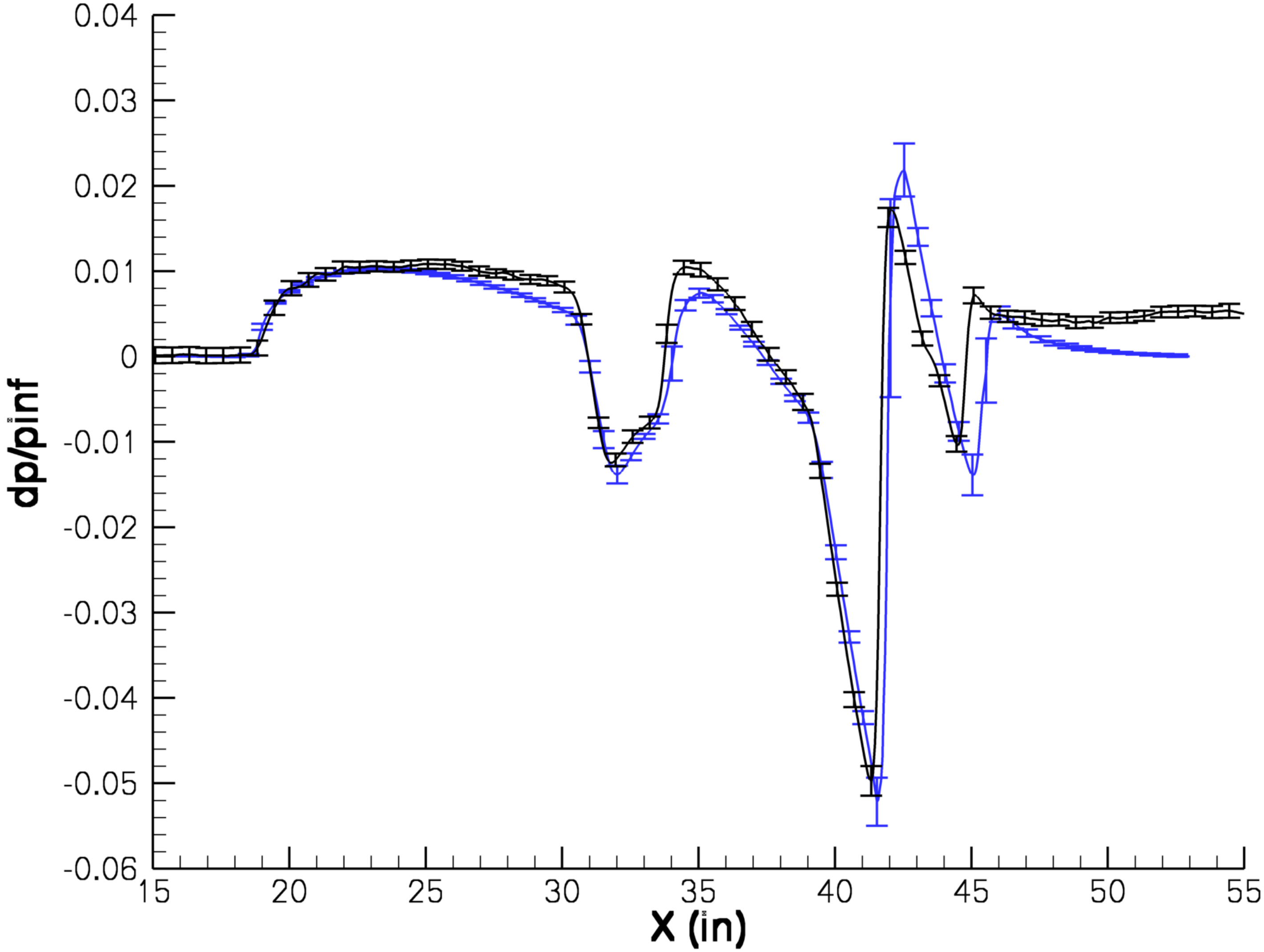
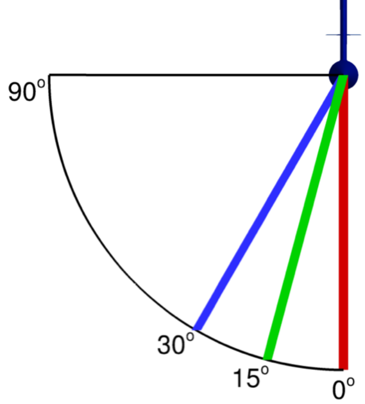
BICONVEX FINE-GRID ENSEMBLE COMPARISON WITH EXPERIMENT





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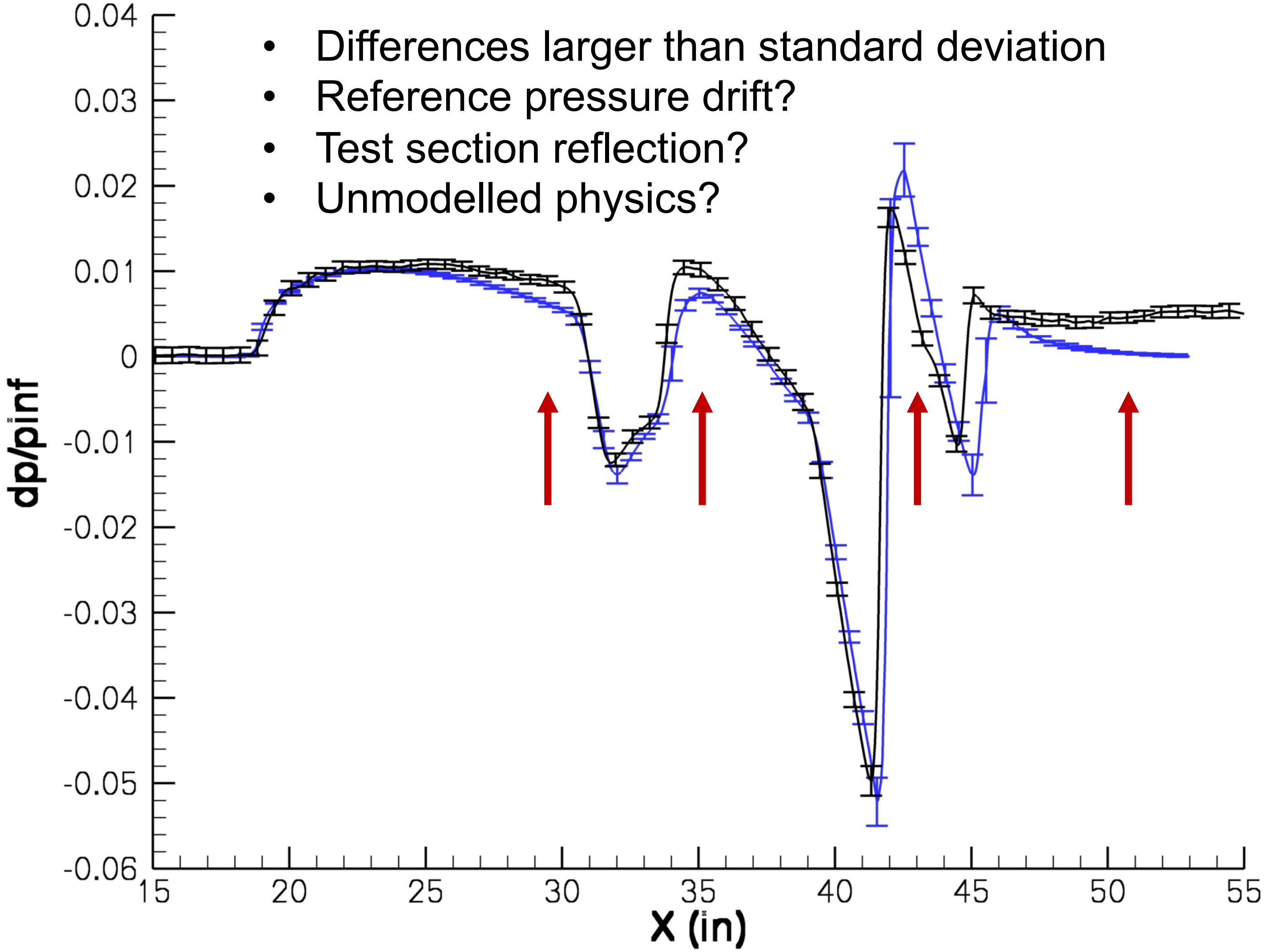
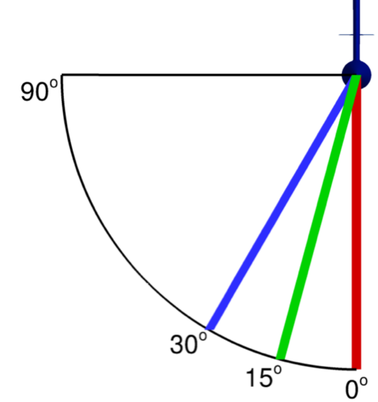
BICONVEX FINE-GRID ENSEMBLE COMPARISON WITH EXPERIMENT

- Differences larger than standard deviation
- Reference pressure drift?
- Test section reflection?
- Unmodelled physics?





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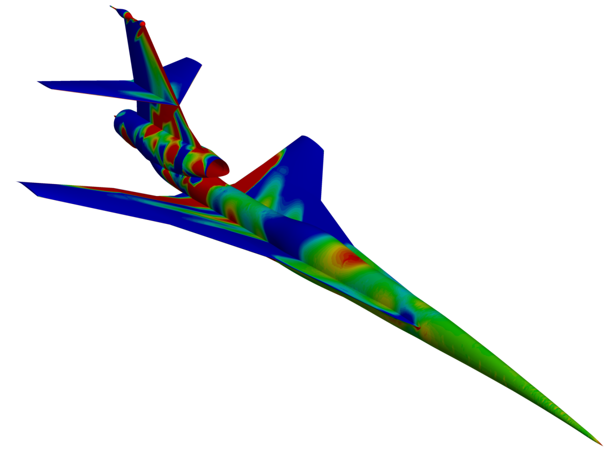
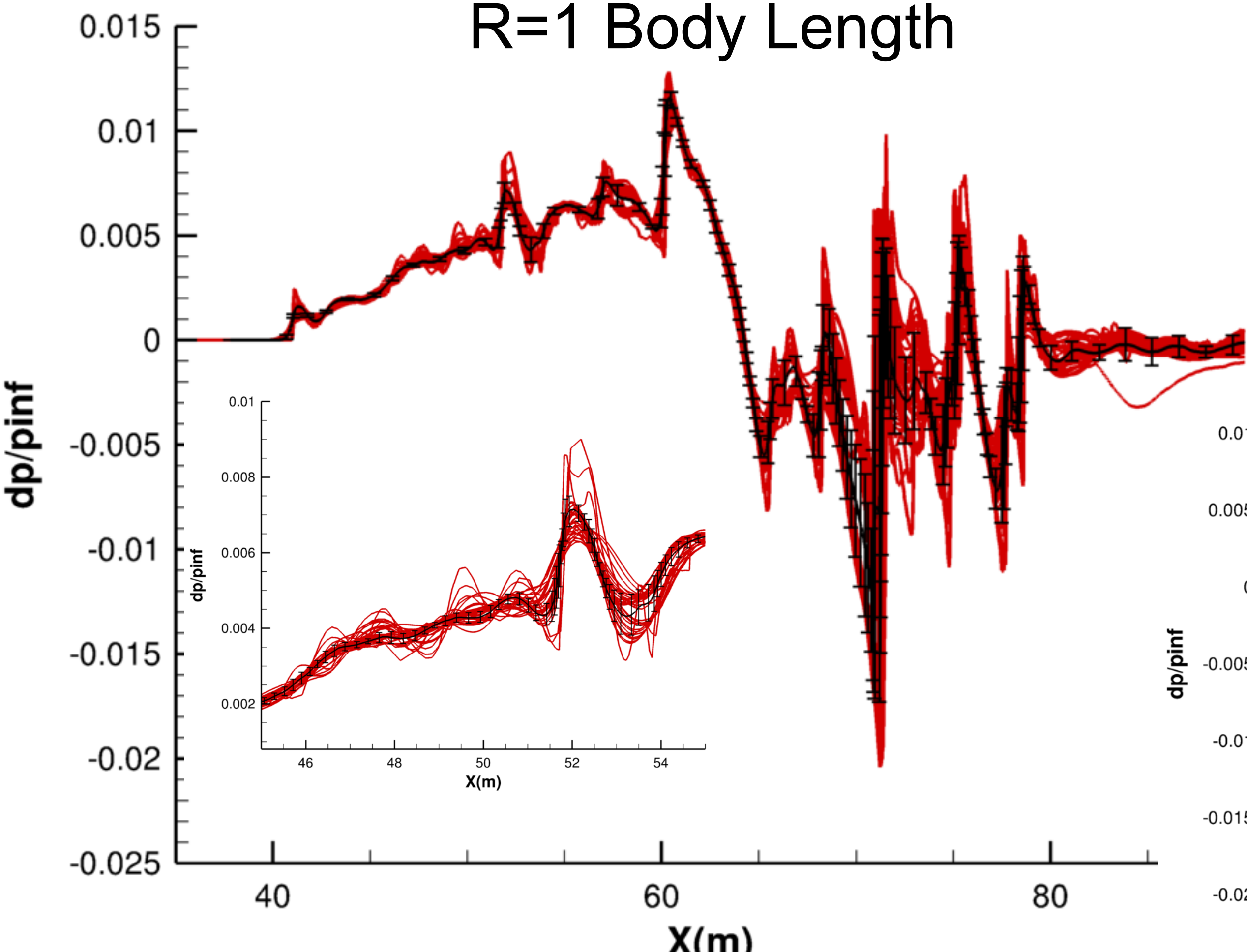
IDENTIFICATION OF OUTLIERS

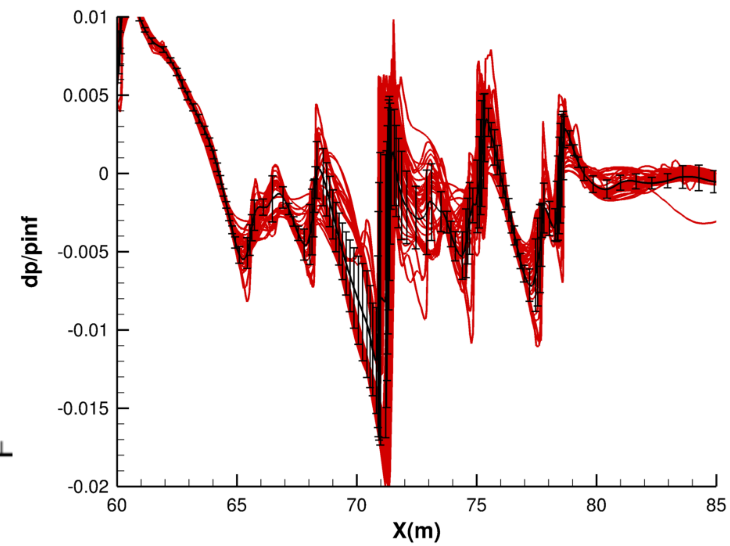
- Goal is an objective tool to identify and learn from differences in submissions
- Pointwise standard deviation is an imperfect tool
  - Not suited to small sample size
  - Distribution of submissions is not normal
  - Should use Functional Data Analysis (FDA) for shape as well as magnitude outlier identification
- Previous workshop used box and whisker plots with an effective coverage factor of 2 (exceed 95% likelihood)
- Coverage factor of 1 (exceed 68% likelihood) used here
- Focus on submissions exceeding 1 standard deviation for forebody and plume (avoid shocks)

SBPW2 C25P CONTEXT

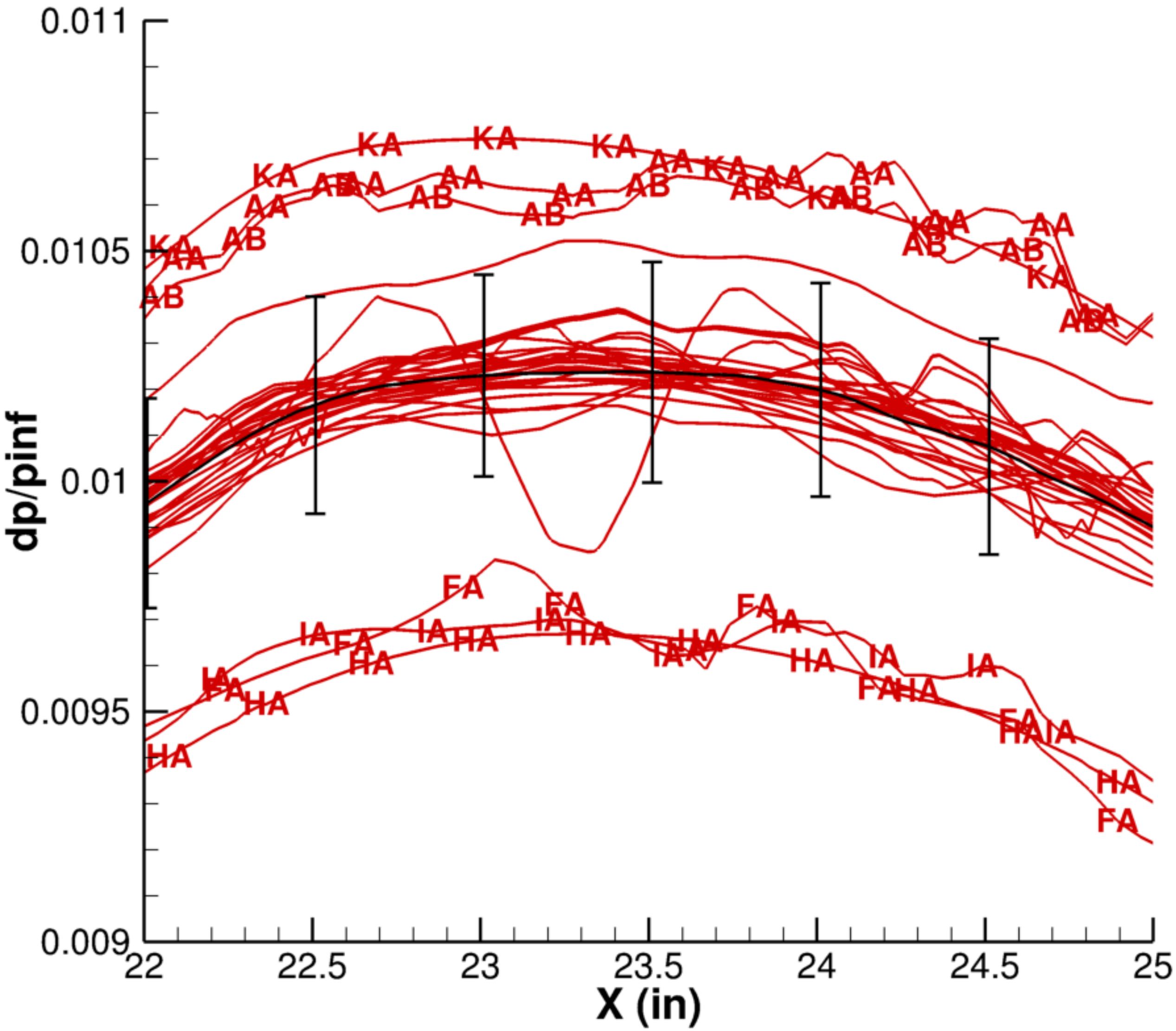


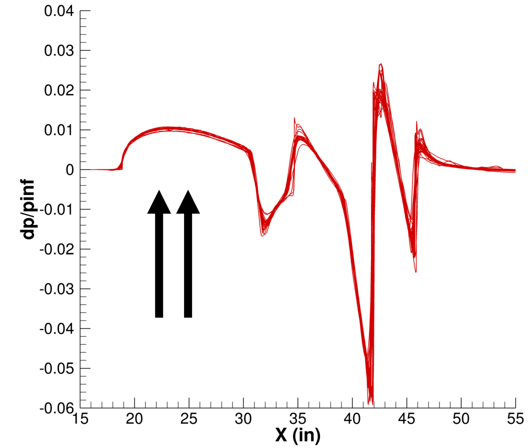
PHI=00
R=1 Body Length





BICONVEX FOREBODY





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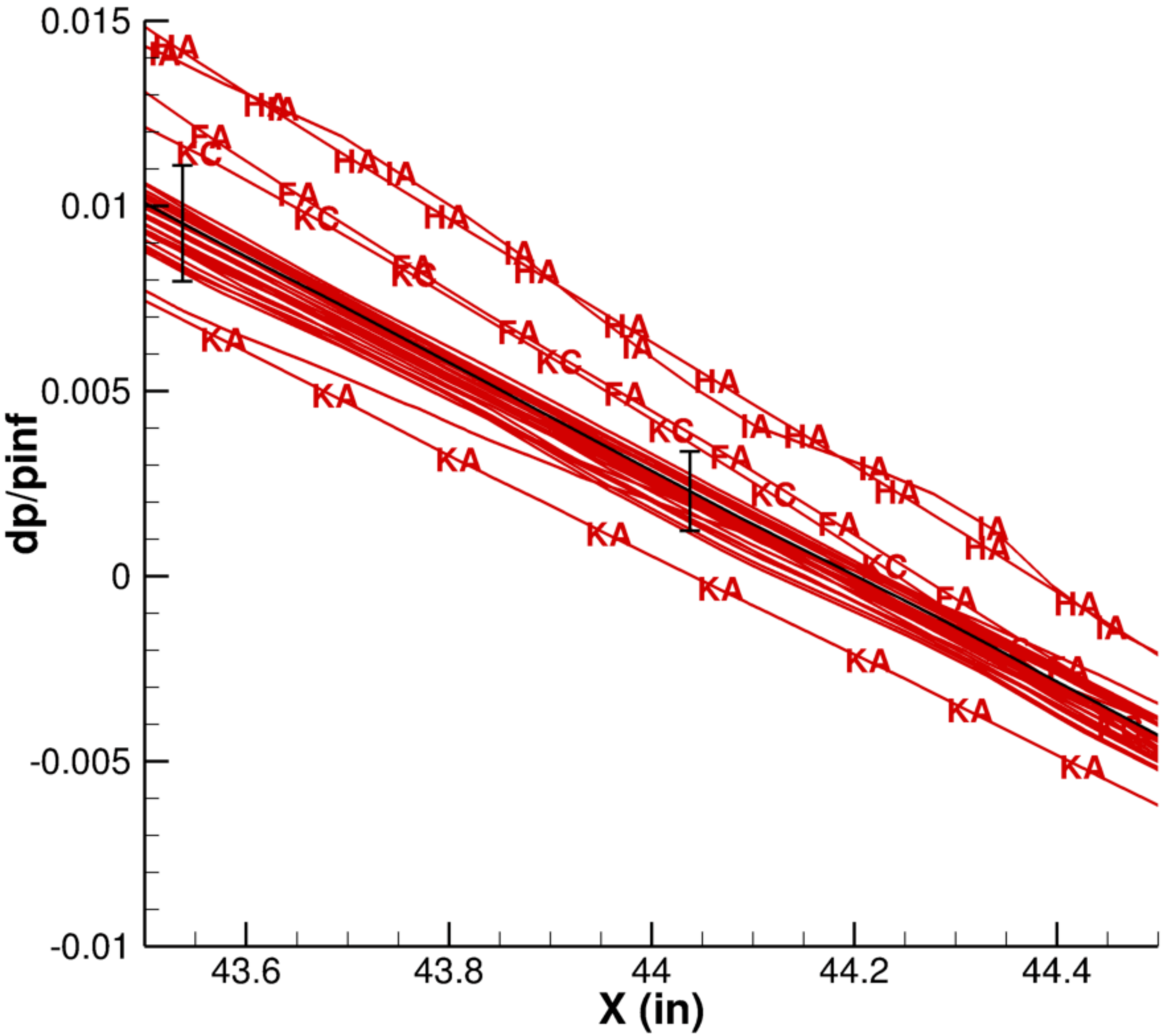
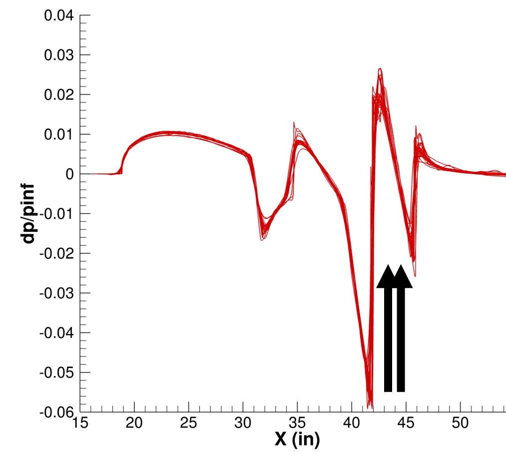
BICONVEX PLUME





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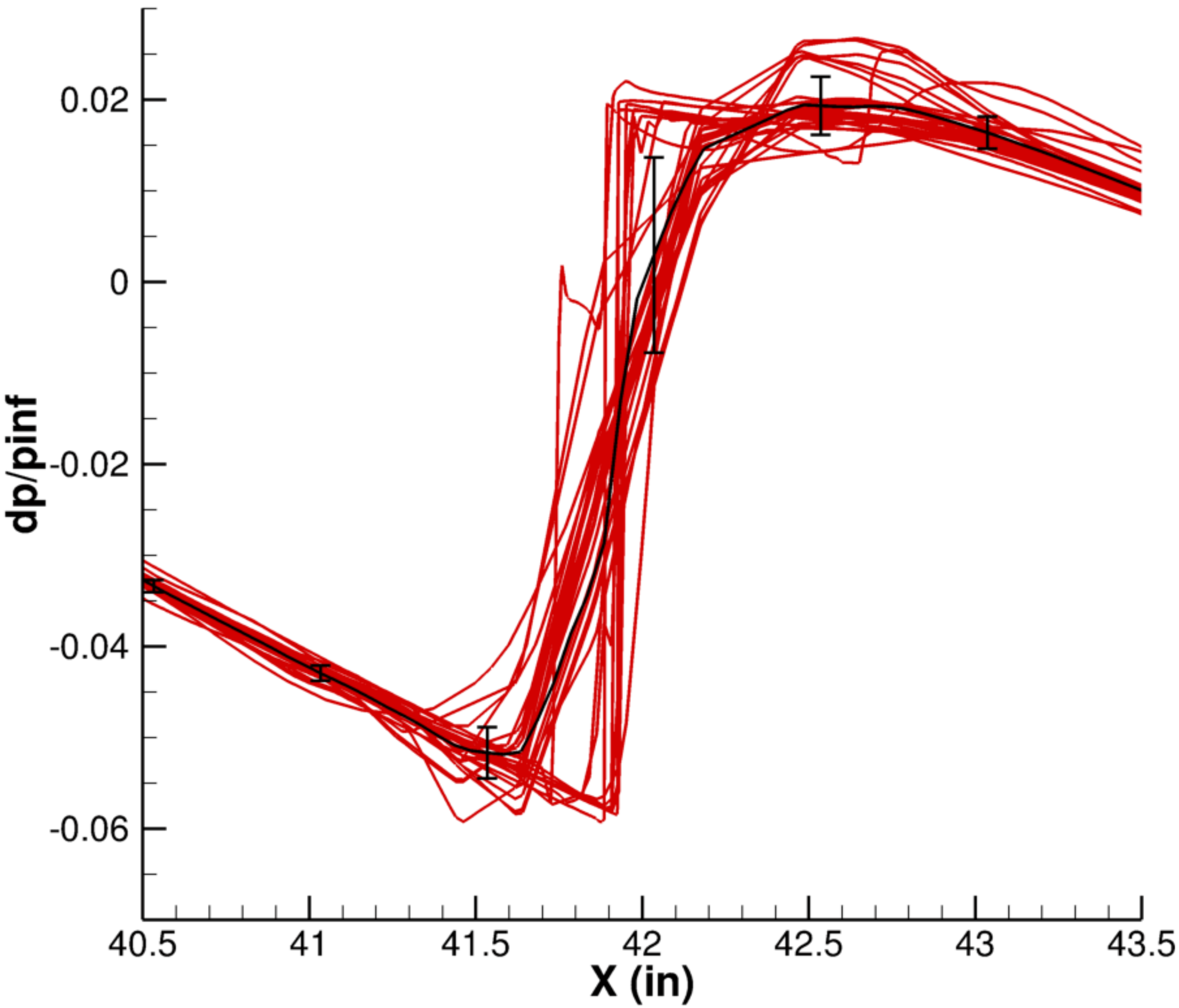
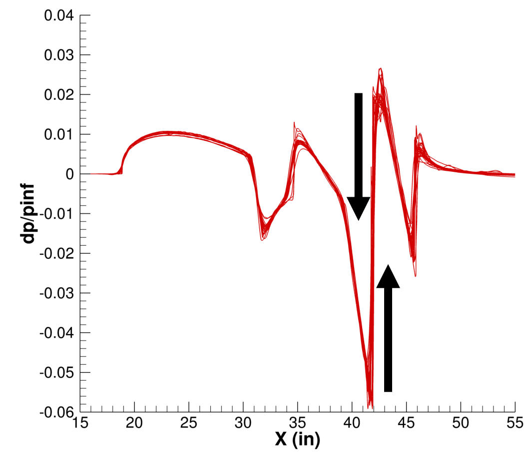
BICONVEX LIP SHOCK





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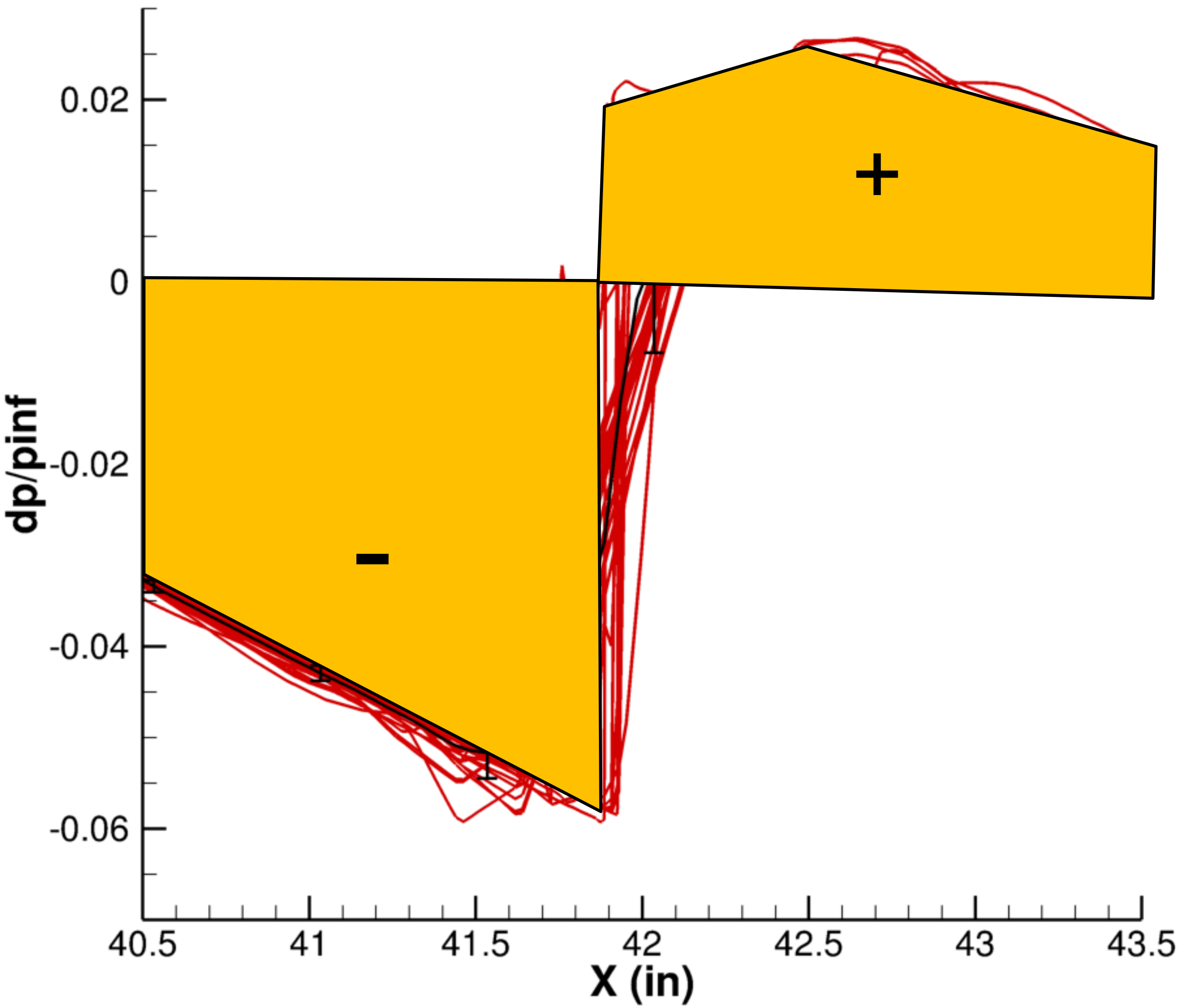
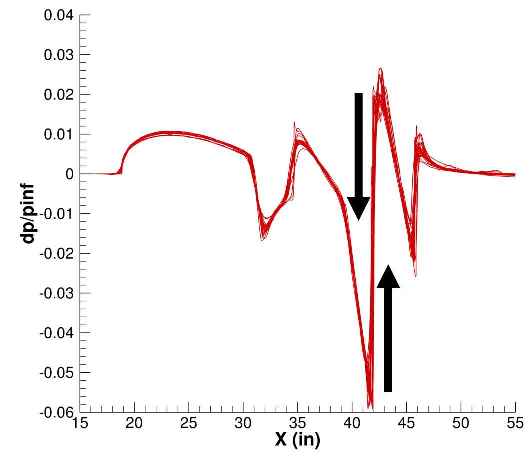
BICONVEX LIP SHOCK PRESSURE INTEGRAL CALCULATION CARTOON





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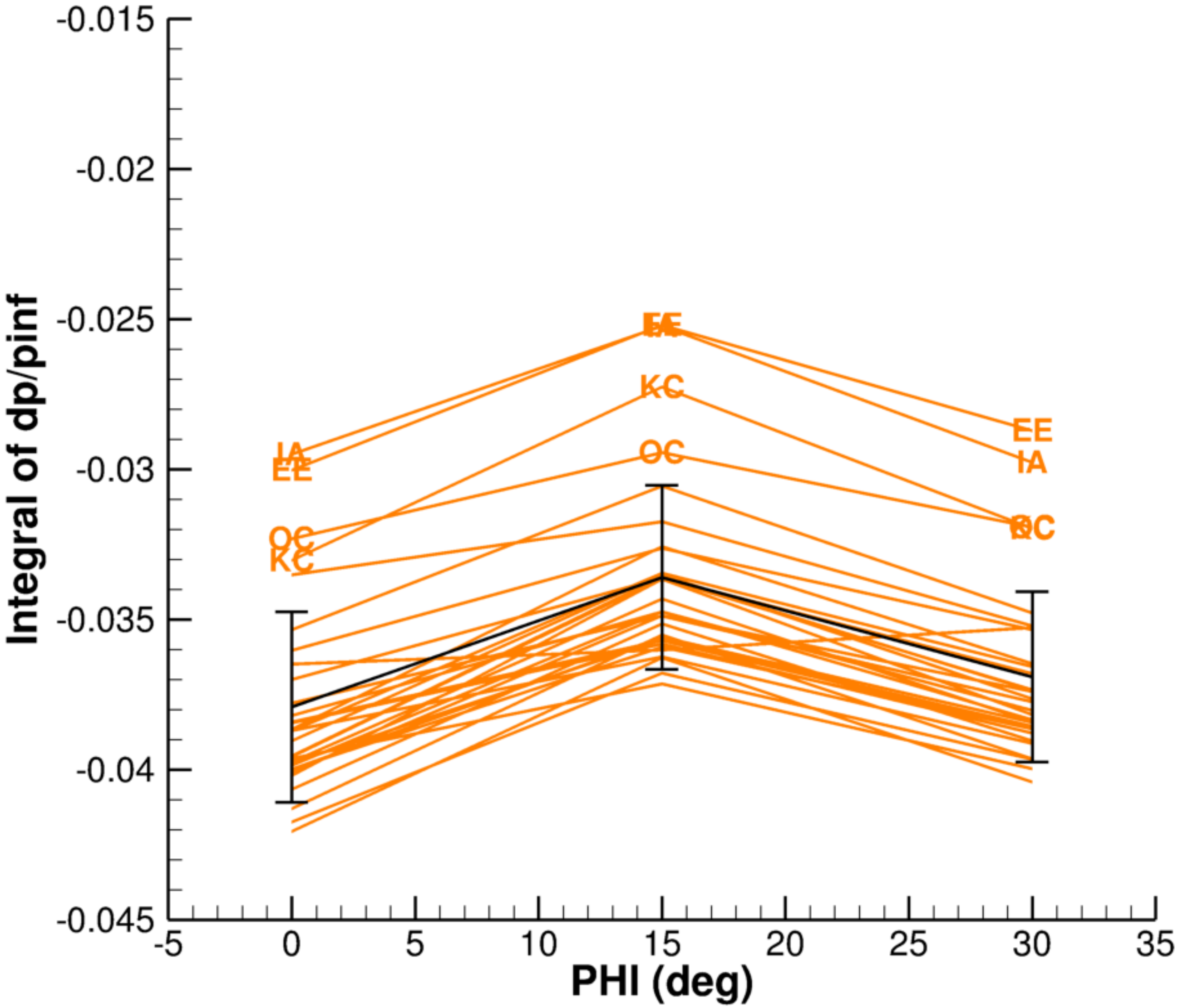
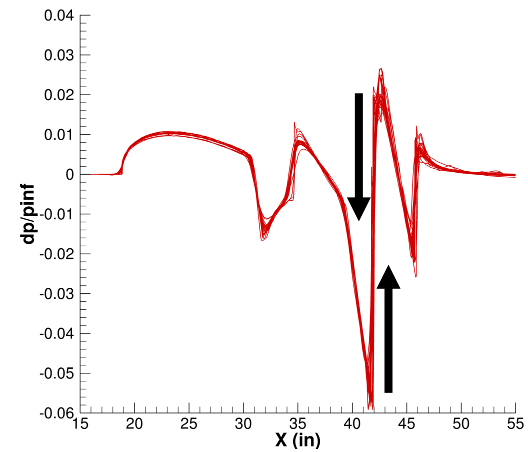
BICONVEX LIP SHOCK INTEGRAL OUTLIERS





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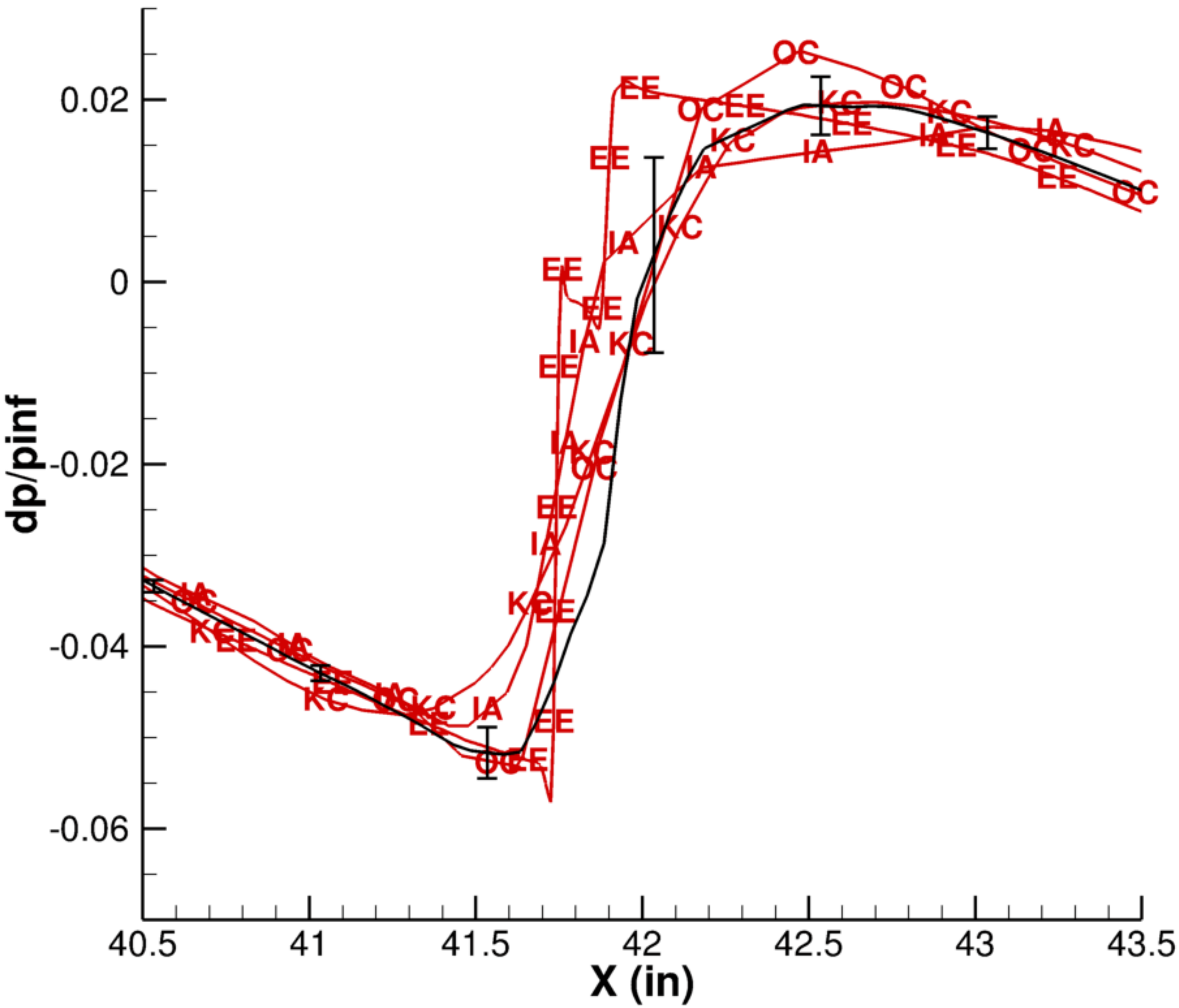
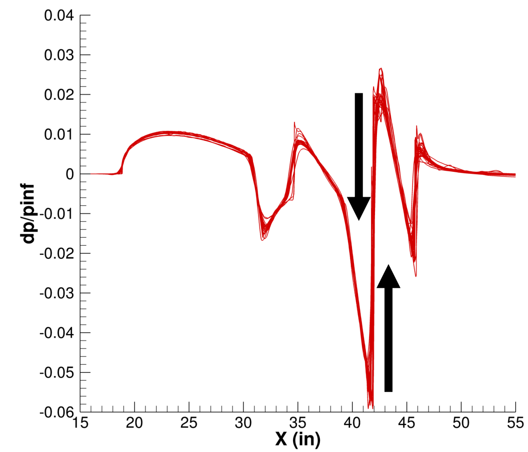
BICONVEX LIP SHOCK INTEGRAL OUTLIERS





PHI=00

BICONVEX SUMMARY

- Participant submissions tightly grouped and strict criteria required to identify outliners
- Experiment and participant submissions (displayed as mean and standard deviation) have low variation but do not overlap in multiple locations
  - Possible reference pressure drift in experiment
  - Test section reflection missing from simulation
  - RANS (and Euler) may provide an incomplete simulation of shock-plume interaction physics
  - Simplified boundary conditions may be insufficient

BICONVEX SUMMARY

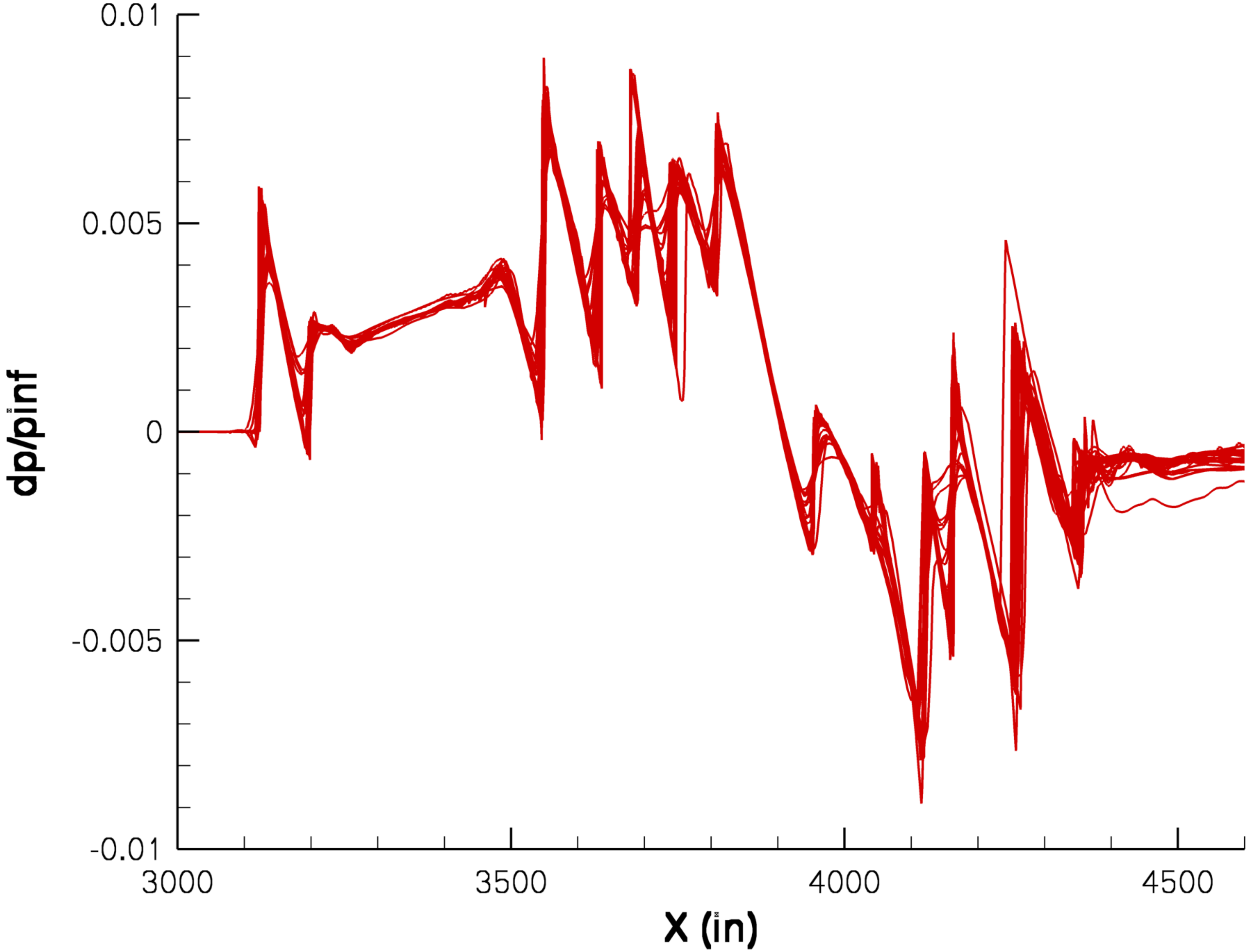
- Pressure magnitude used as identifier in smooth regions and pressure integral used as identifier in nonsmooth region with shock
- Many outliers were identified in multiple regions: forebody, lip shock, and plume
  - Forebody outliers were equally high and low
  - Lip shock outliers had forward shock location
  - Plume outliers were high, except one

C608, AN EARLY X-59 PROTOTYPE, SUBMISSIONS

OUTLINE

- Near field statistics
- Boom carpets
- Grid convergence
- Pointwise standard deviation of boom carpet
  - Identify outliners
- Details on outliners
  - Nearfield
  - Ground
- Compare to previous workshop for context

C608 FINE-GRID ENSEMBLE

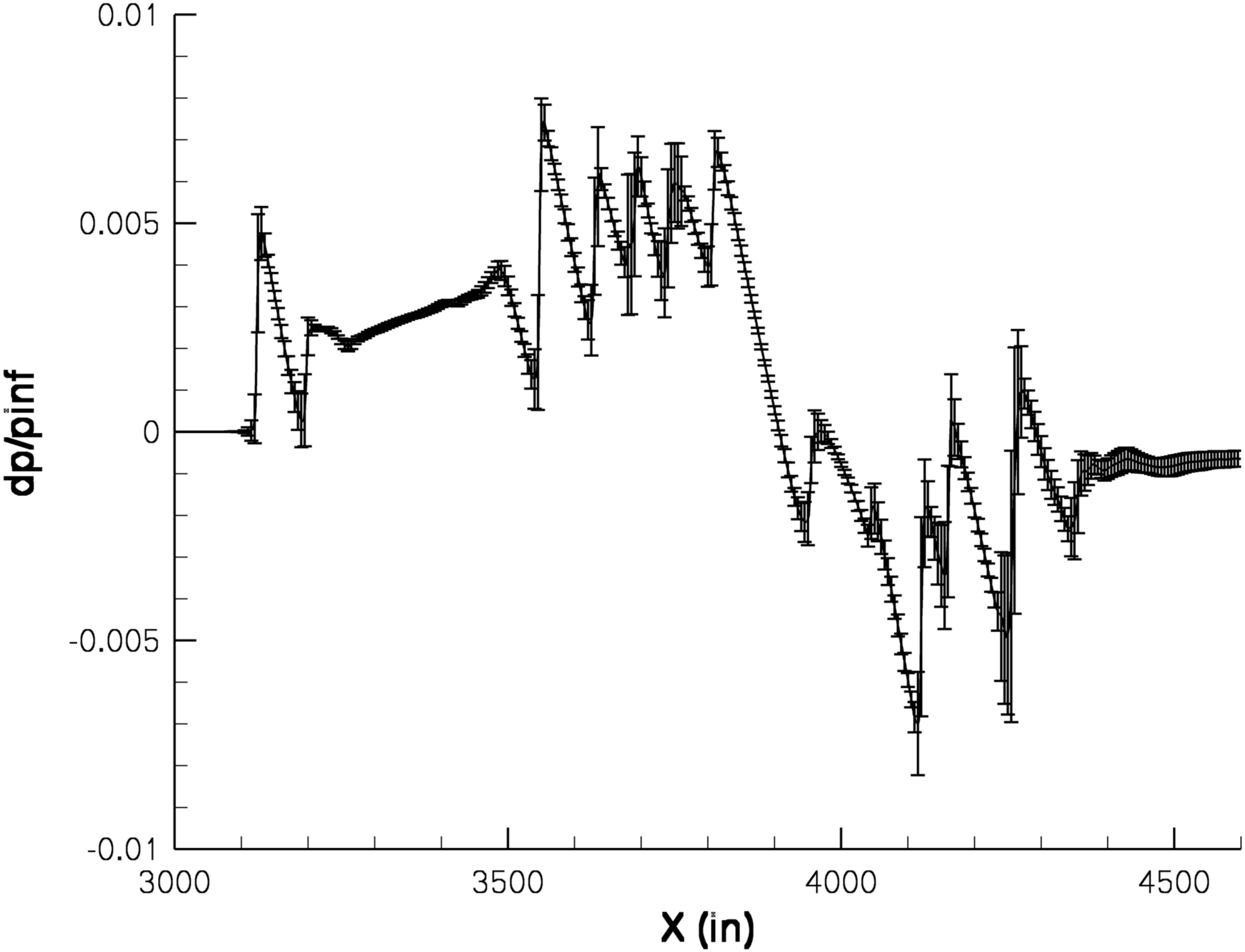


PHI=00
N=27

NEARFIELD SIGNATURE STATISTICS

- Pointwise population mean and standard deviation of interpolated signature every half inch
- Analogous to wind tunnel spatial averaging
- Finest grid solution from each participant (which vary in resolution)
- Outliers impact these statistics

C608 FINE-GRID ENSEMBLE



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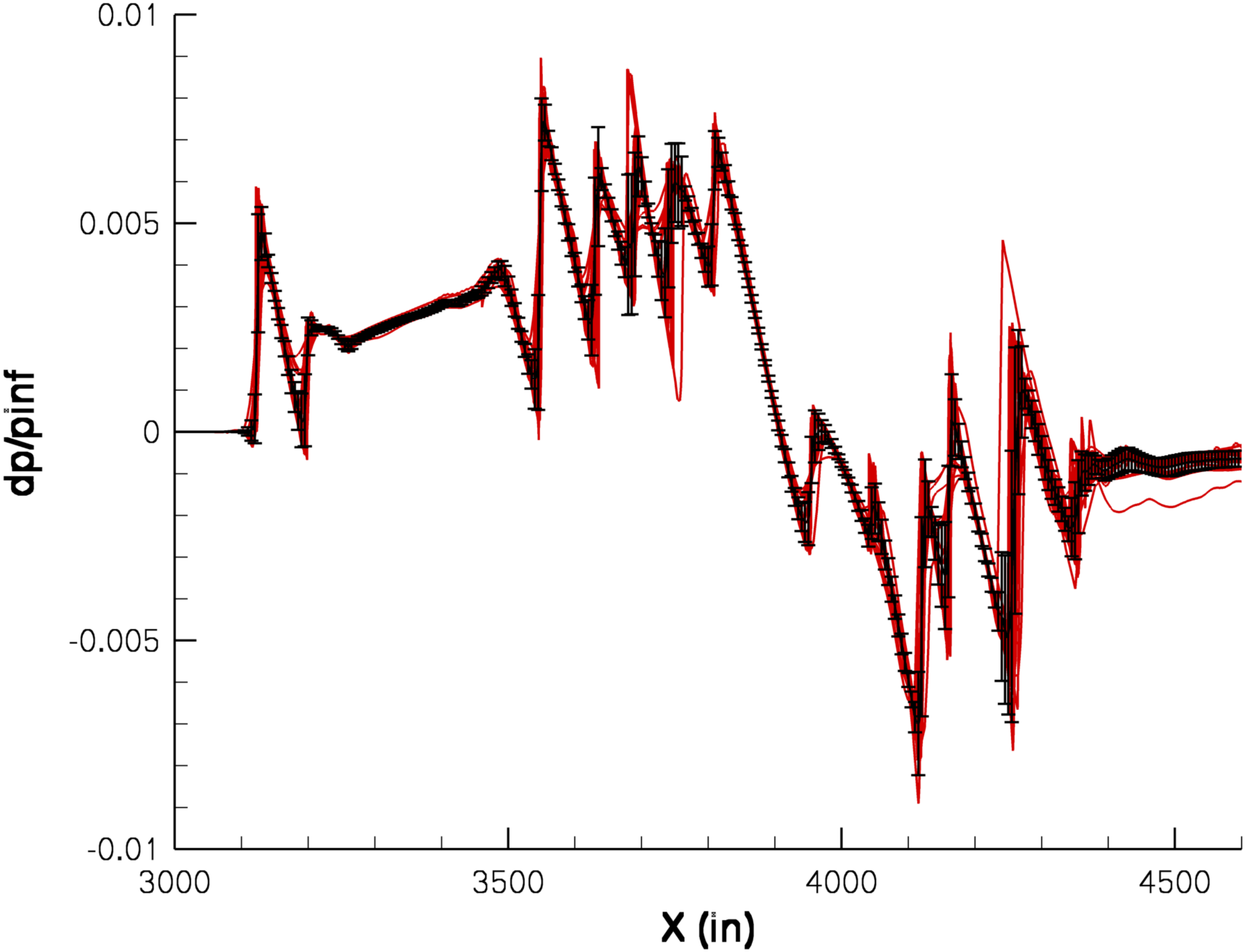
C608 FINE-GRID ENSEMBLE



PHI=00
N=27

GROUND PROPAGATION

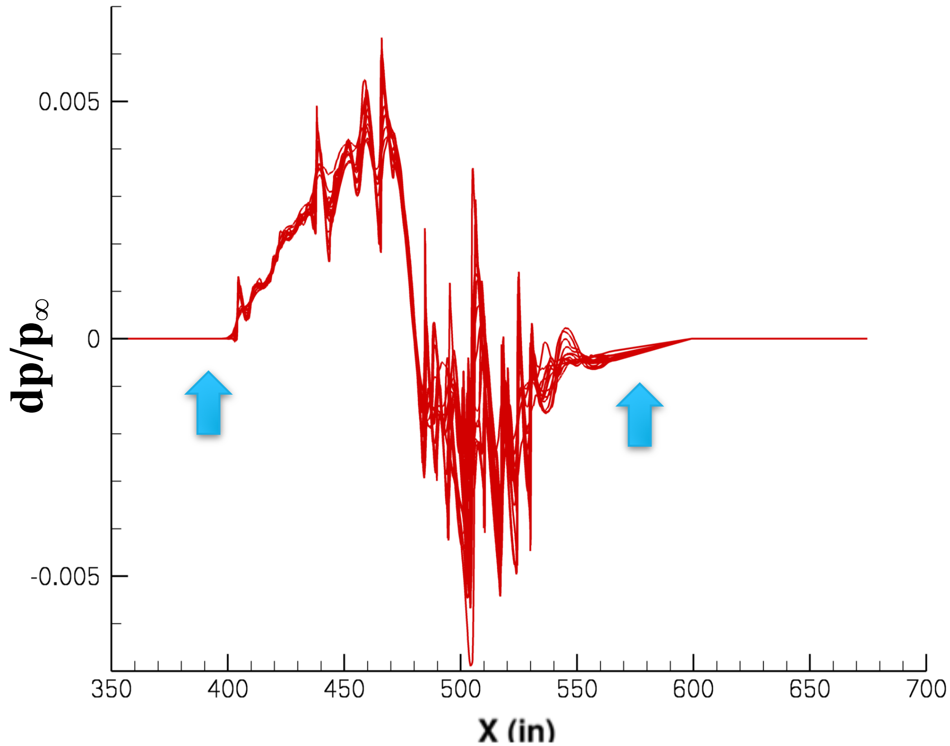
- Geometry and grids provided in "full-scale"
- US Standard atmosphere and ANSI S1.26 Annex C relative humidity from 53200 ft. altitude
- sBOOM version 2.82 (Rallabhandi)
    - Burgers' equation with molecular relaxation
- Submissions are windowed with fore and aft ramps

NEARFIELD WINDOW FOR PROPAGATION

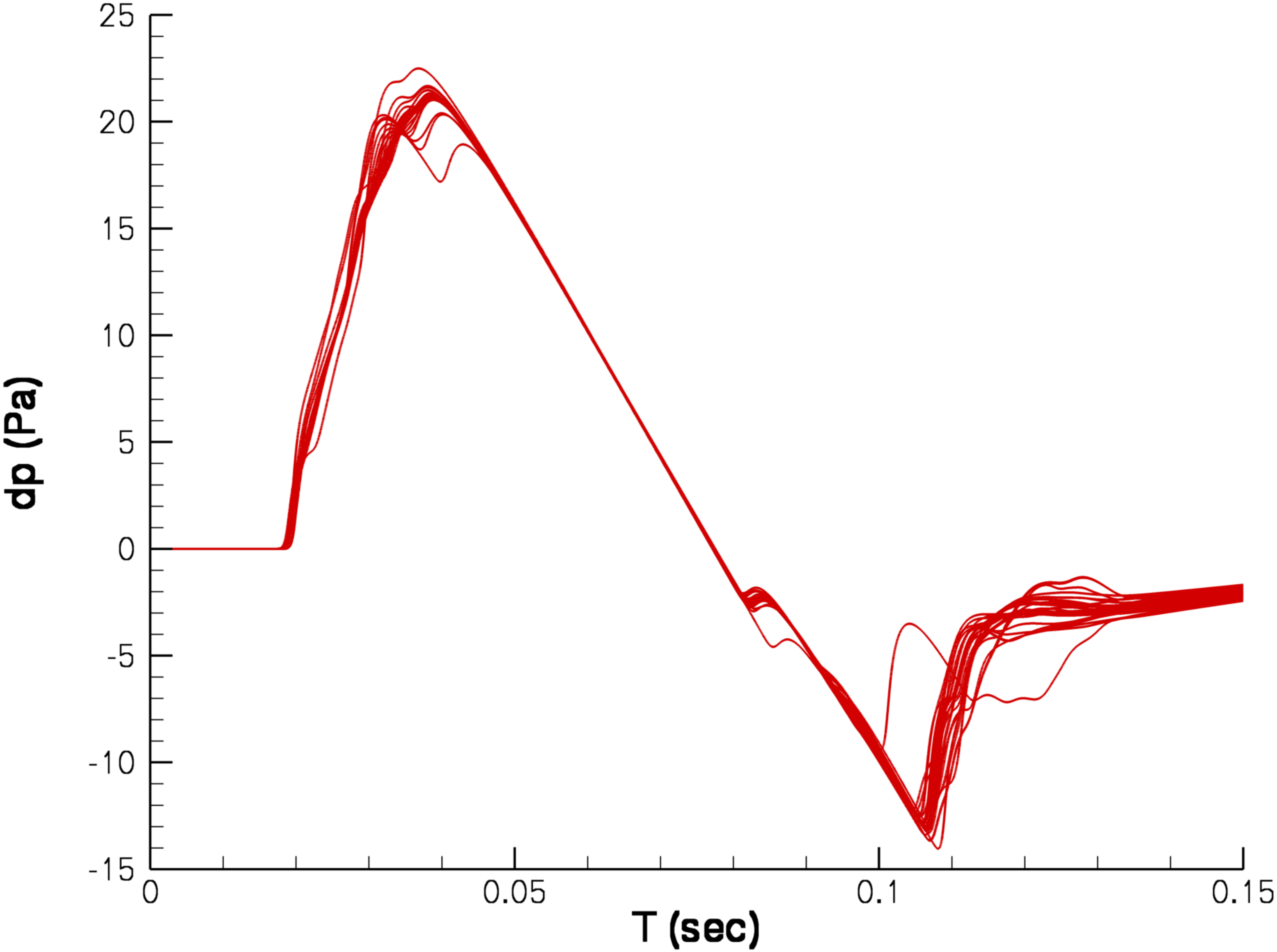
Nearfield submission is ramped to zero

- [2960,3070] ahead of signature
- [4790,5870] aft of signature

Signature is zero-padded outside of that range



C608 FINE-GRID GROUND



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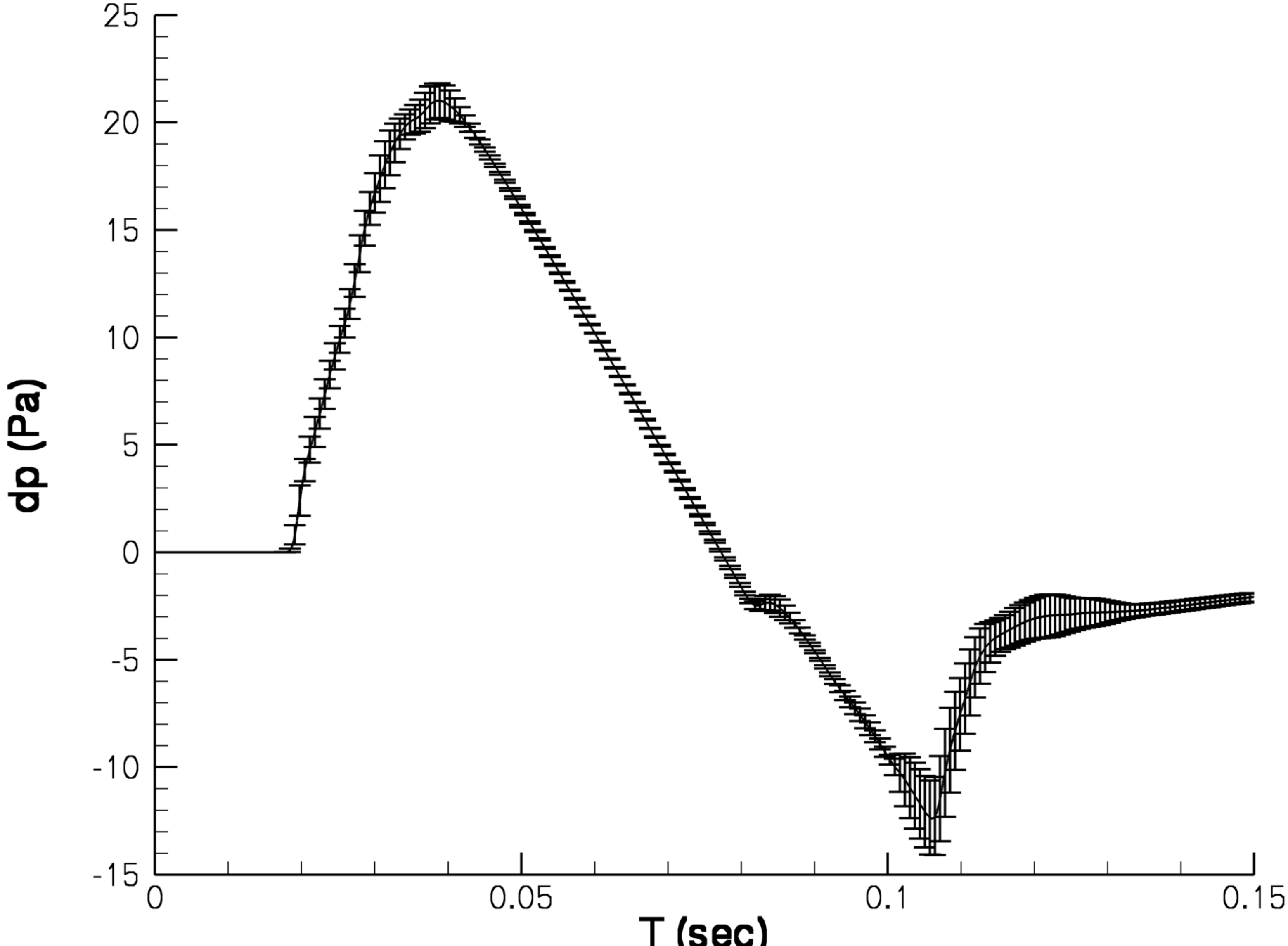
C608 FINE-GRID GROUND



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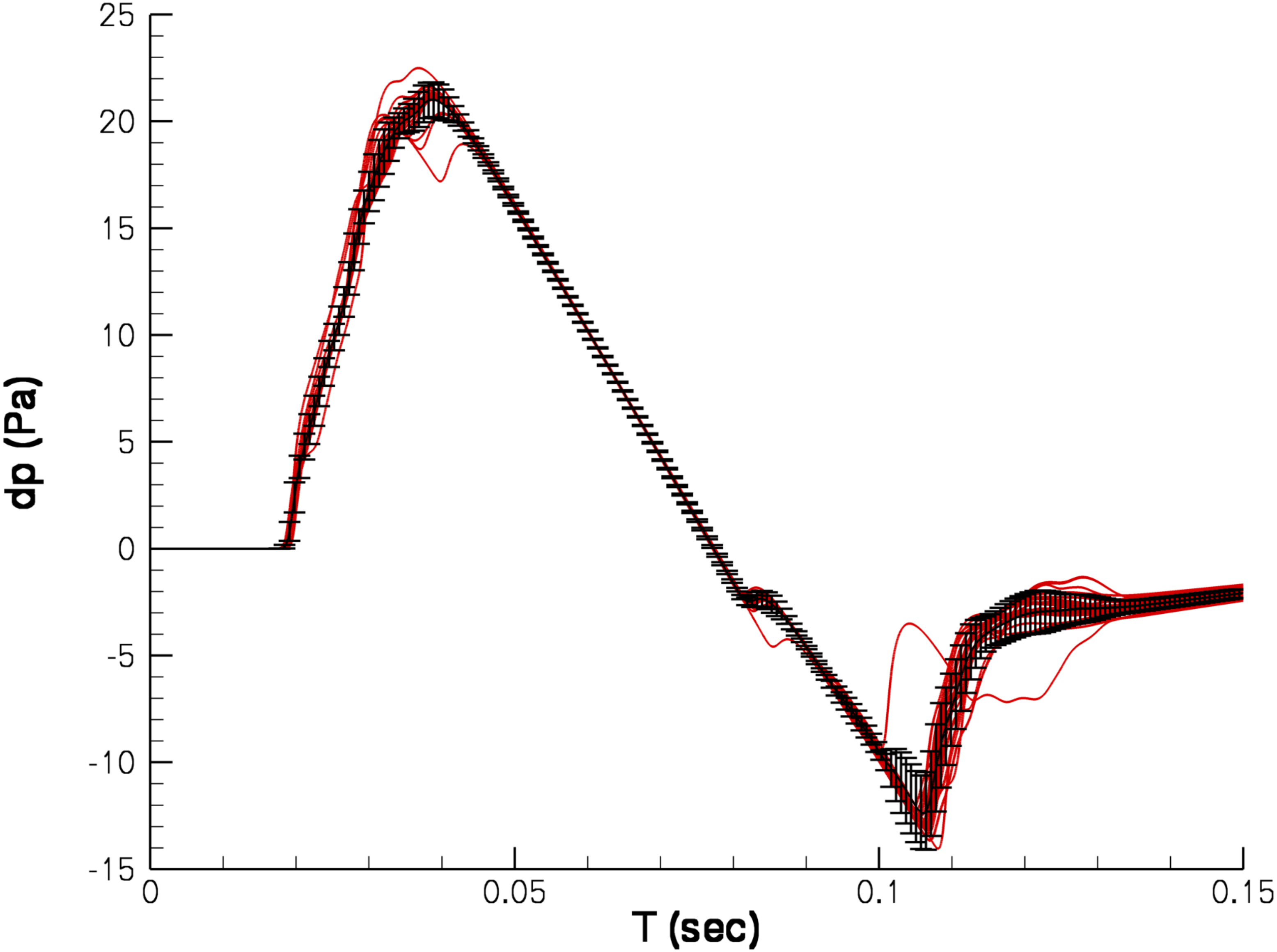
C608 FINE-GRID GROUND



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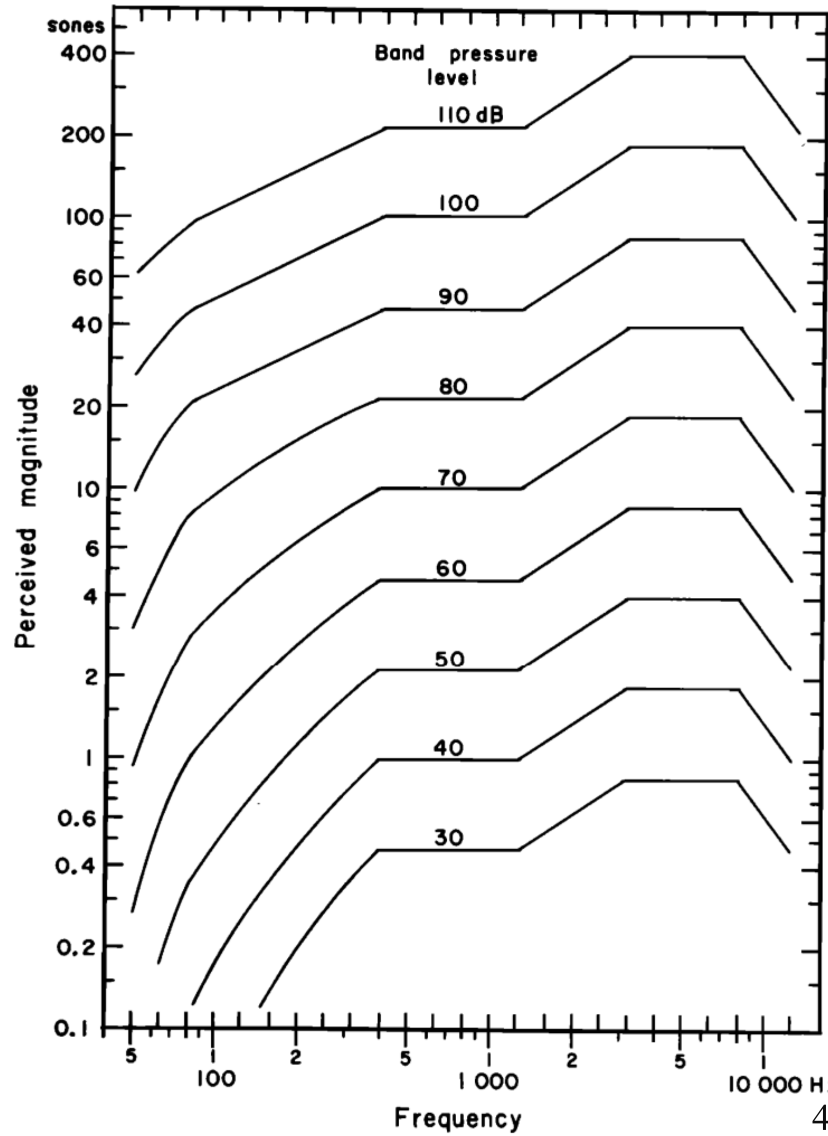
LOUDNESS AND ANNOYANCE

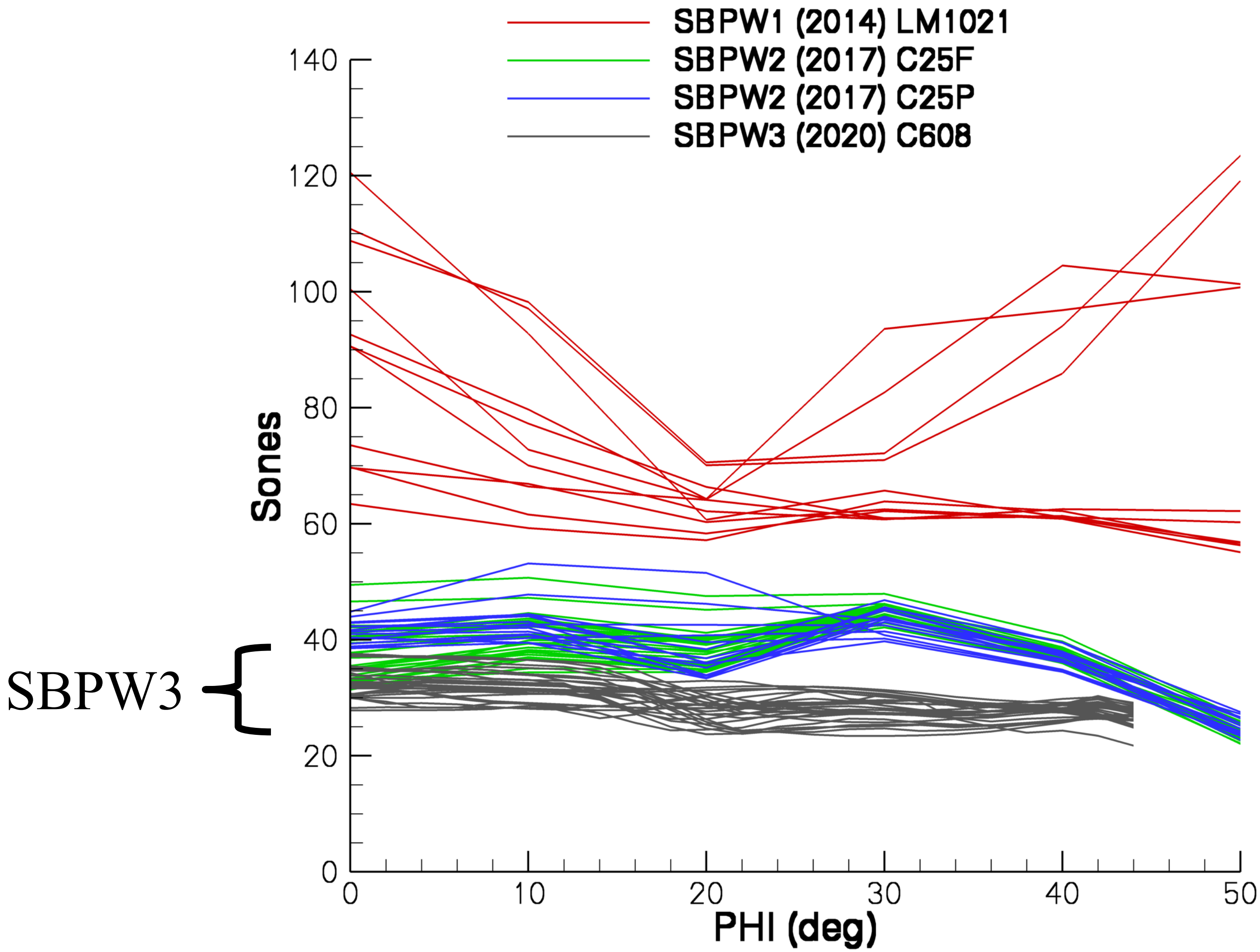
- Subjective metrics
- These human experiences are correlated to noise descriptors through experiments
  - Leatherwood et al. JASA 2002
  - Stevens Mark VII Perceived Level (PL)
  - Loubeau et al. 2nd International Sonic Boom Forum 2015 meta-study

PERCEIVED LEVEL (PL)

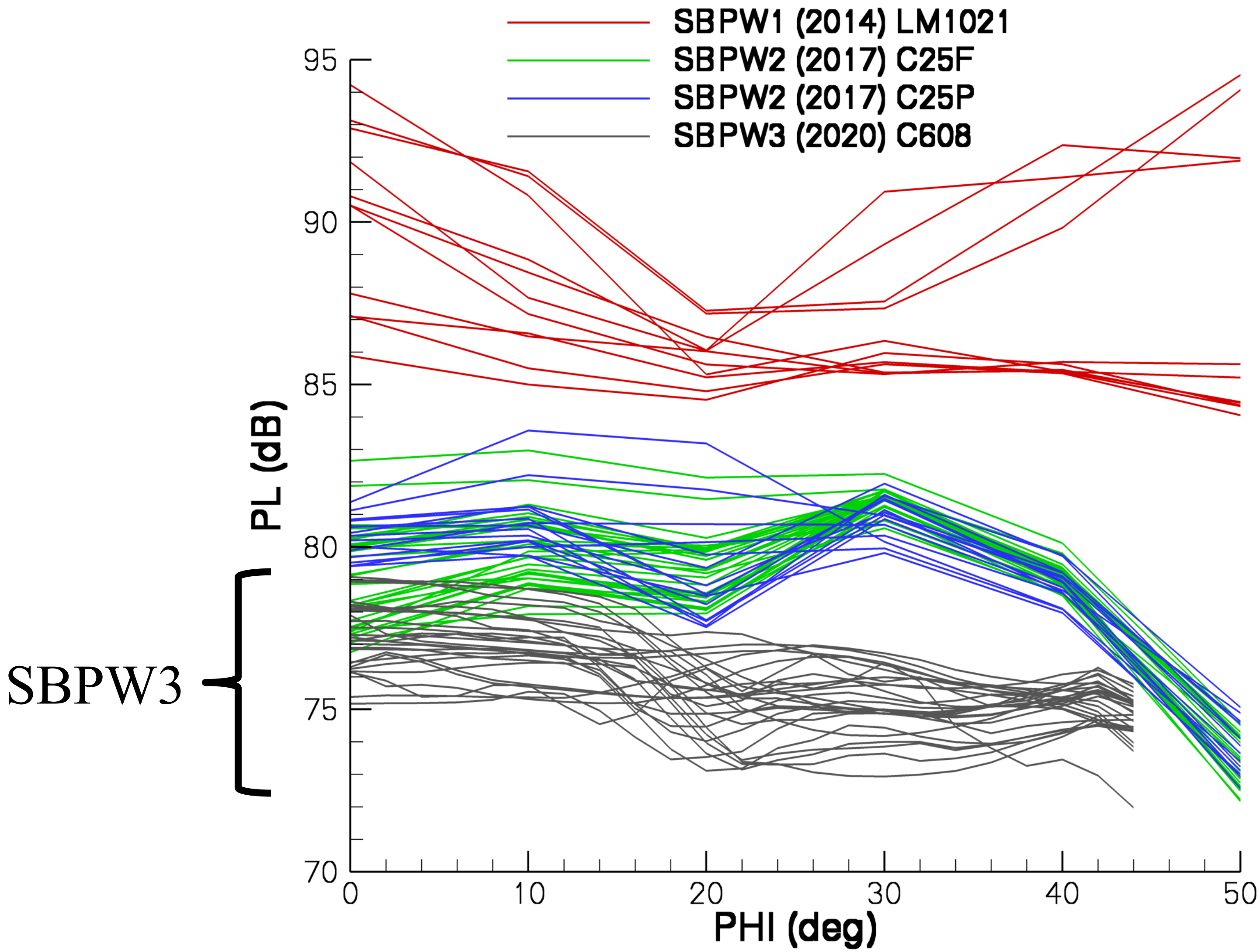
- Signature sound pressure level is gathered into 1/3 octave bands
- Band levels are converted from db into sones (based on subjects perceived loudness)
- Sones from each band are combined
- Sones are converted into PL via logarithm



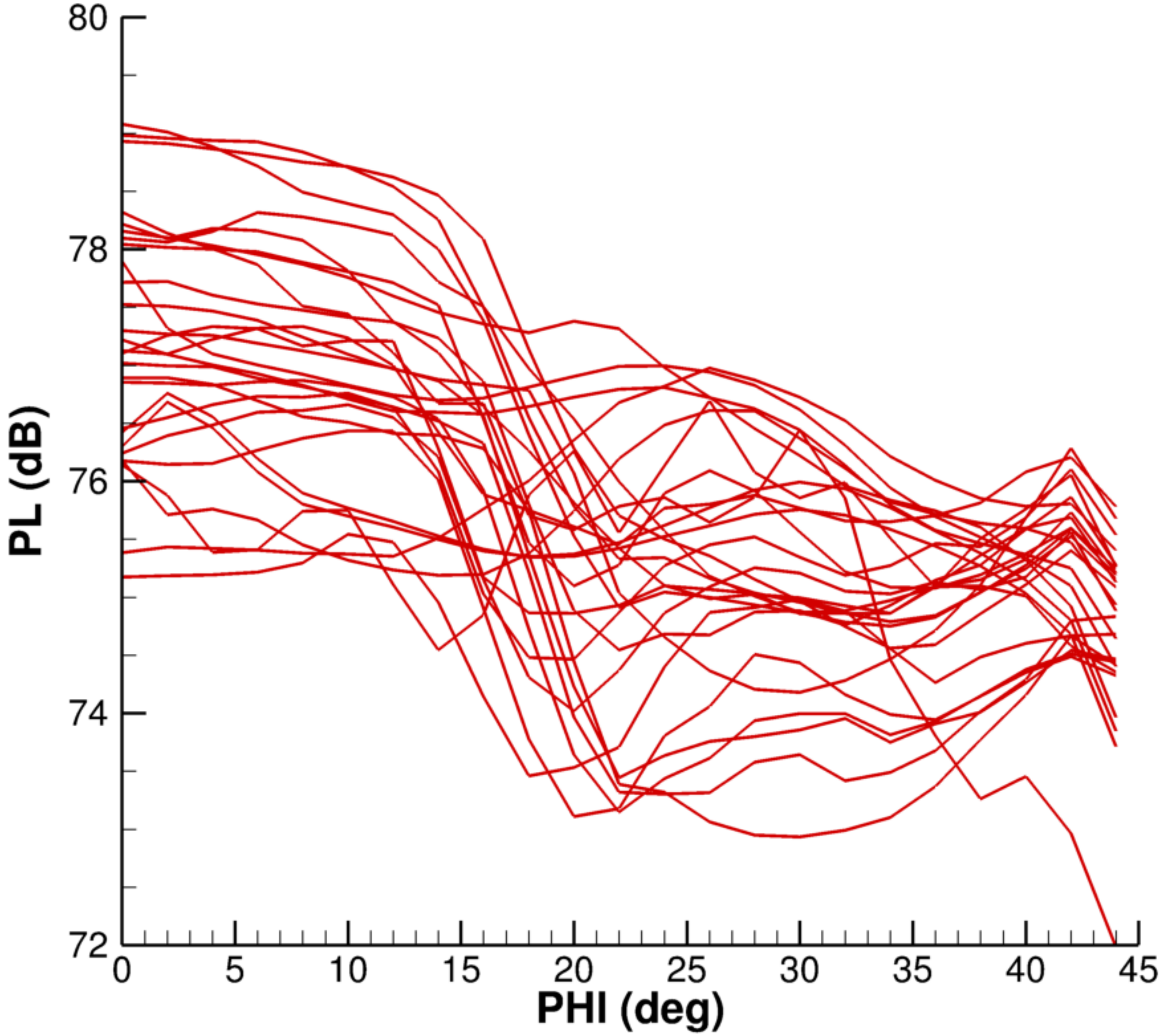
SBPW FINE-GRID LOUDNESS (SONES) CARPET



SBPW FINE-GRID PL CARPET



C608 FINE-GRID PL CARPET



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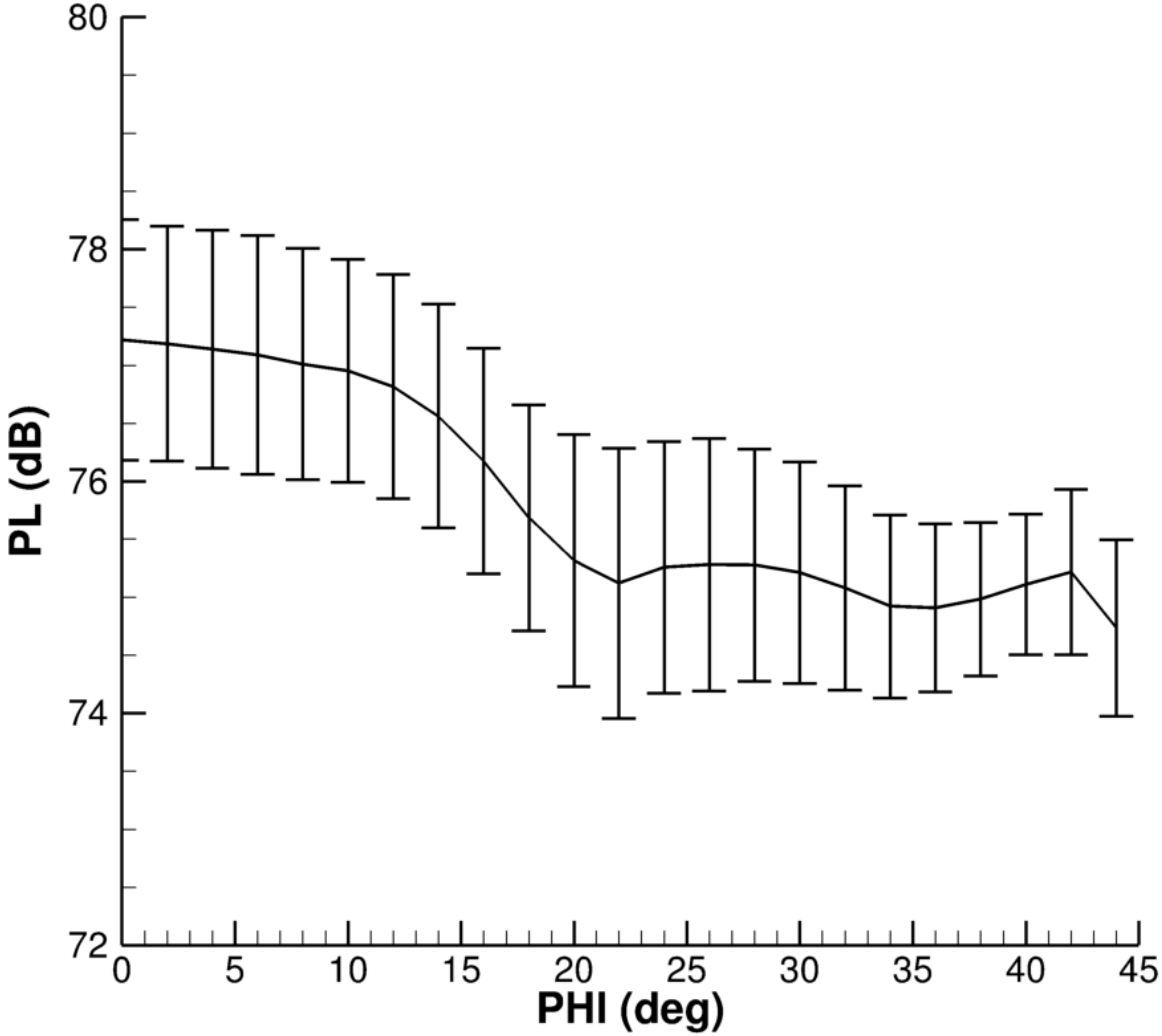

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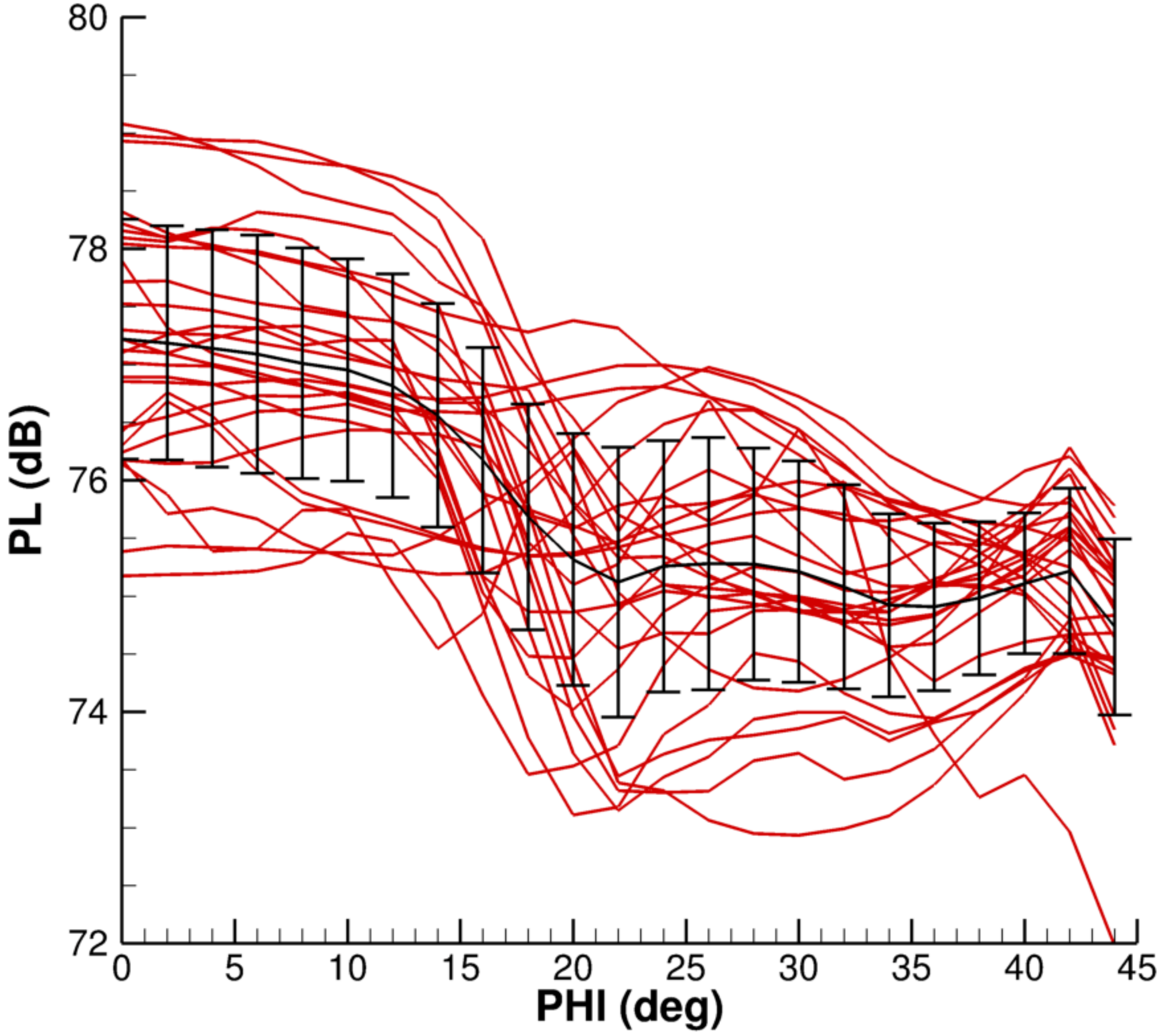
C608 FINE-GRID PL CARPET



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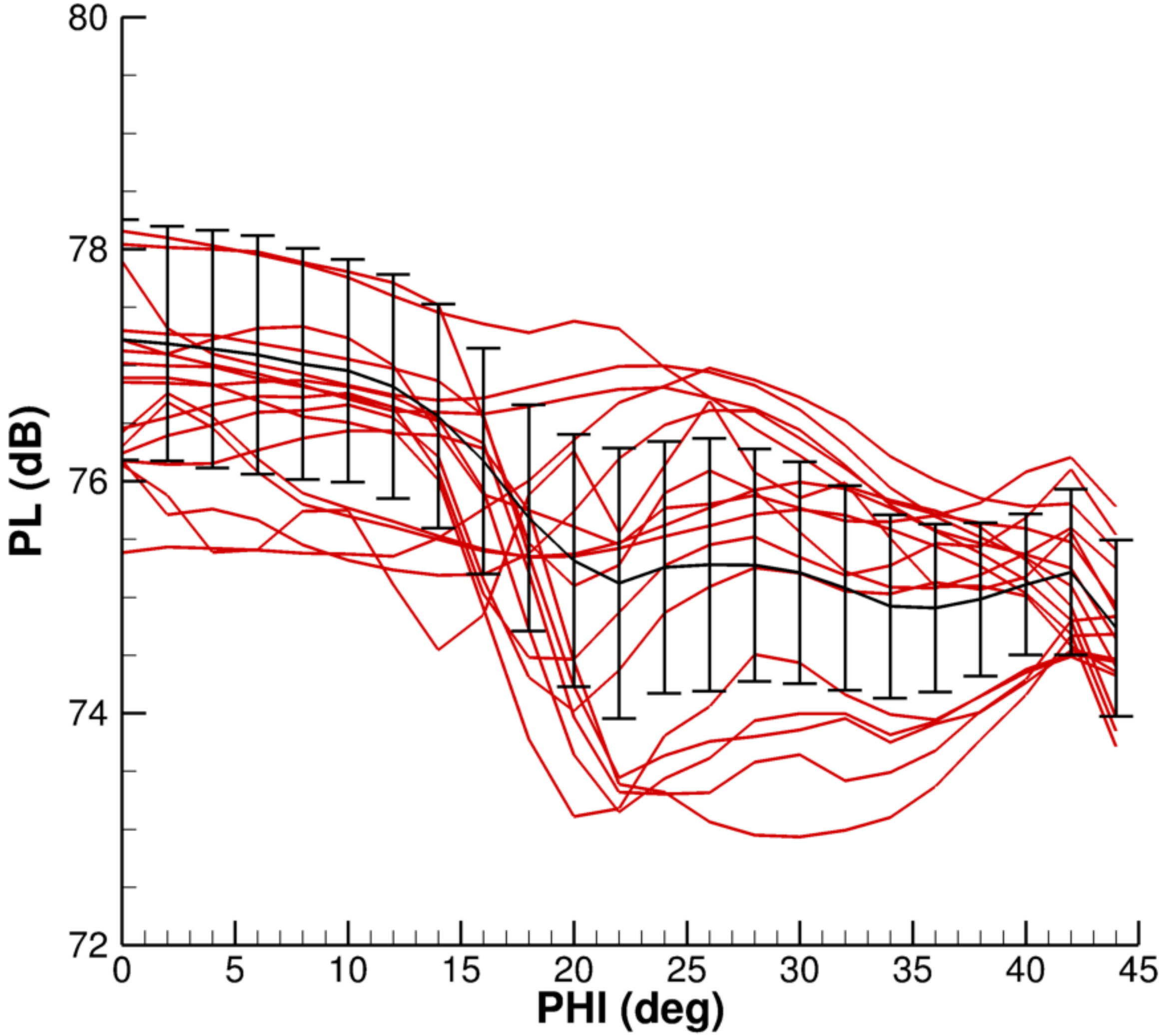
C608 WORKSHOP PROVIDED FINE-GRID PL



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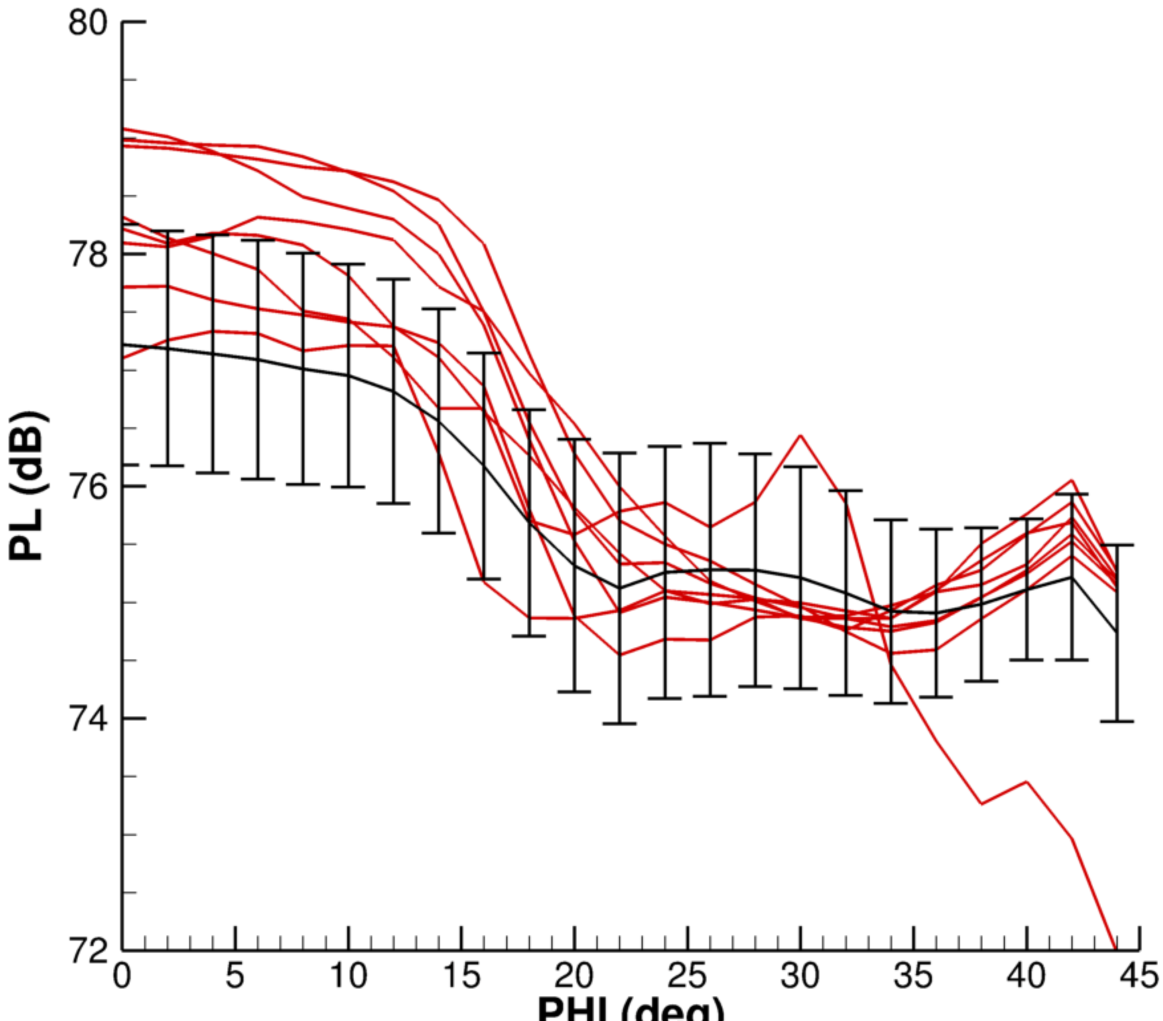
C608 PARTICIPANT GENERATED FINE-GRID PL



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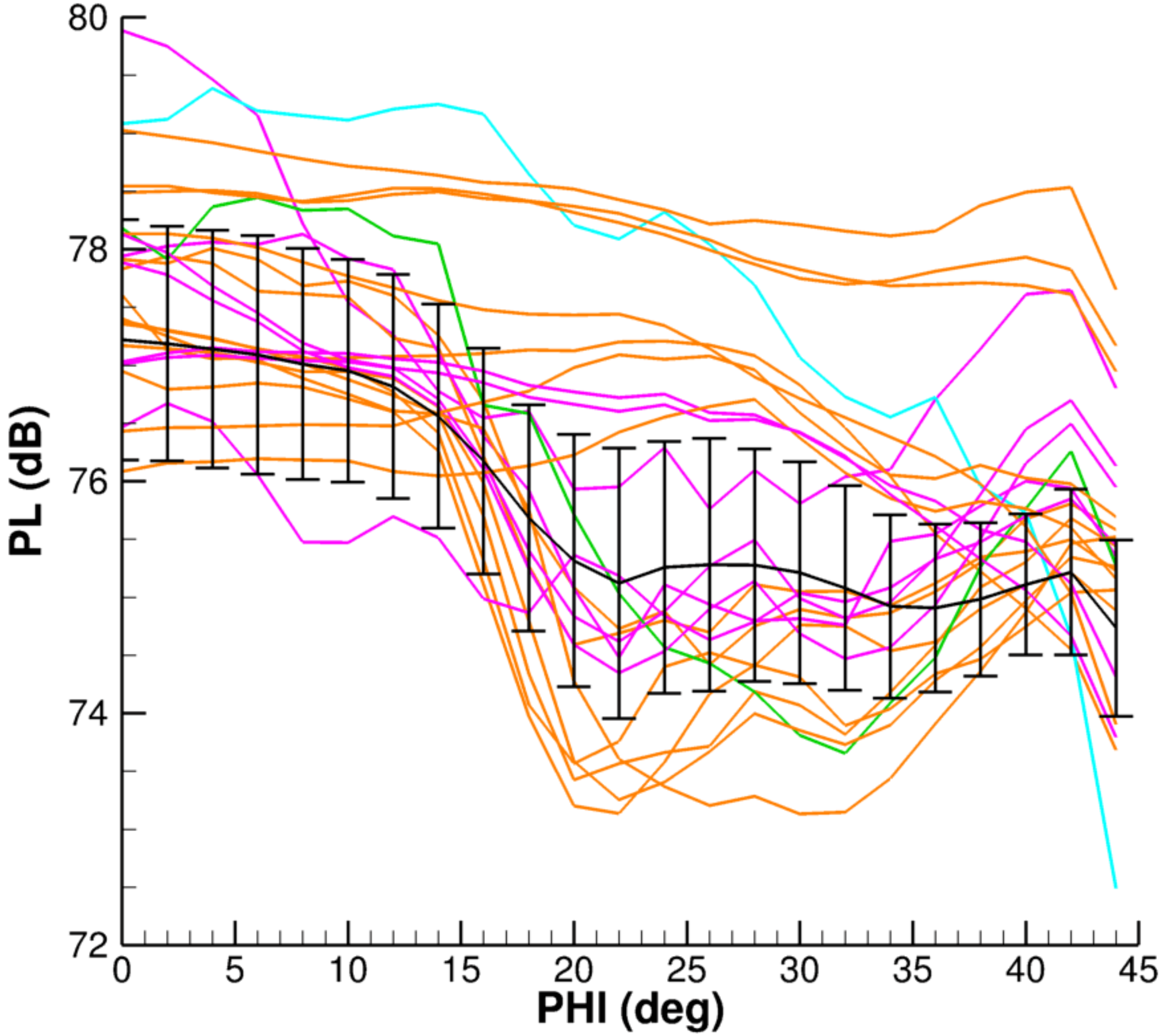
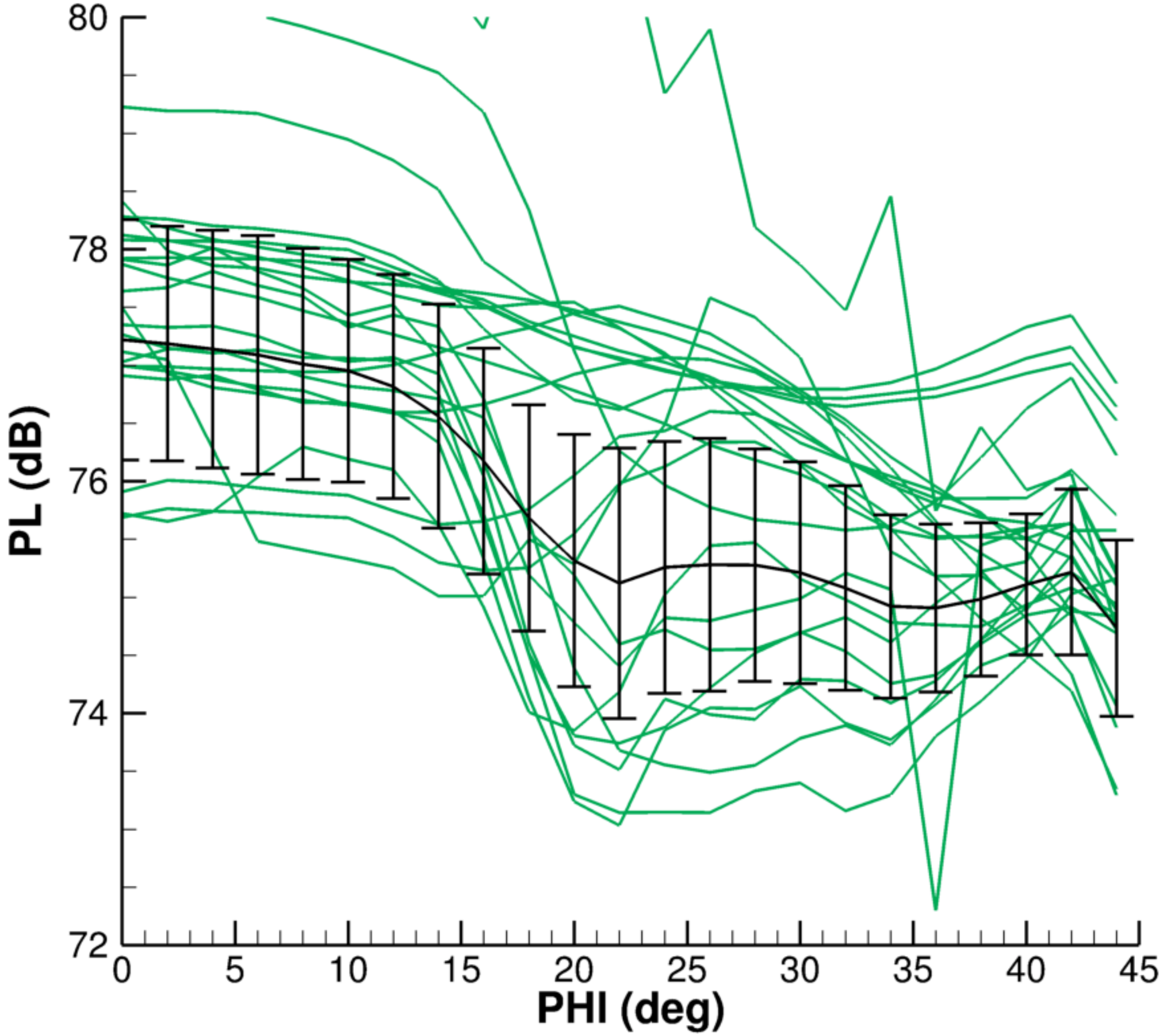
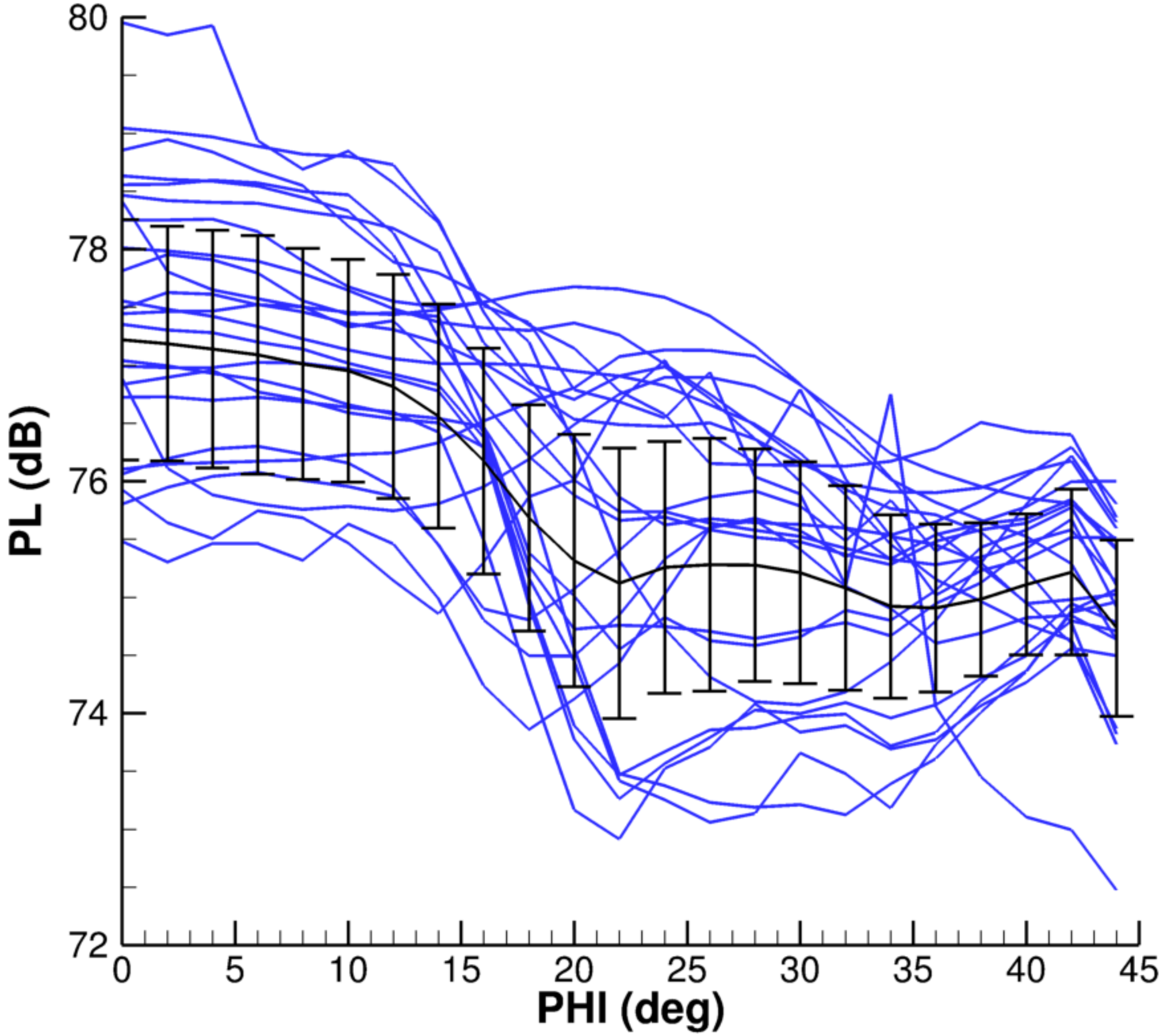
C608 TINY-GRID PL



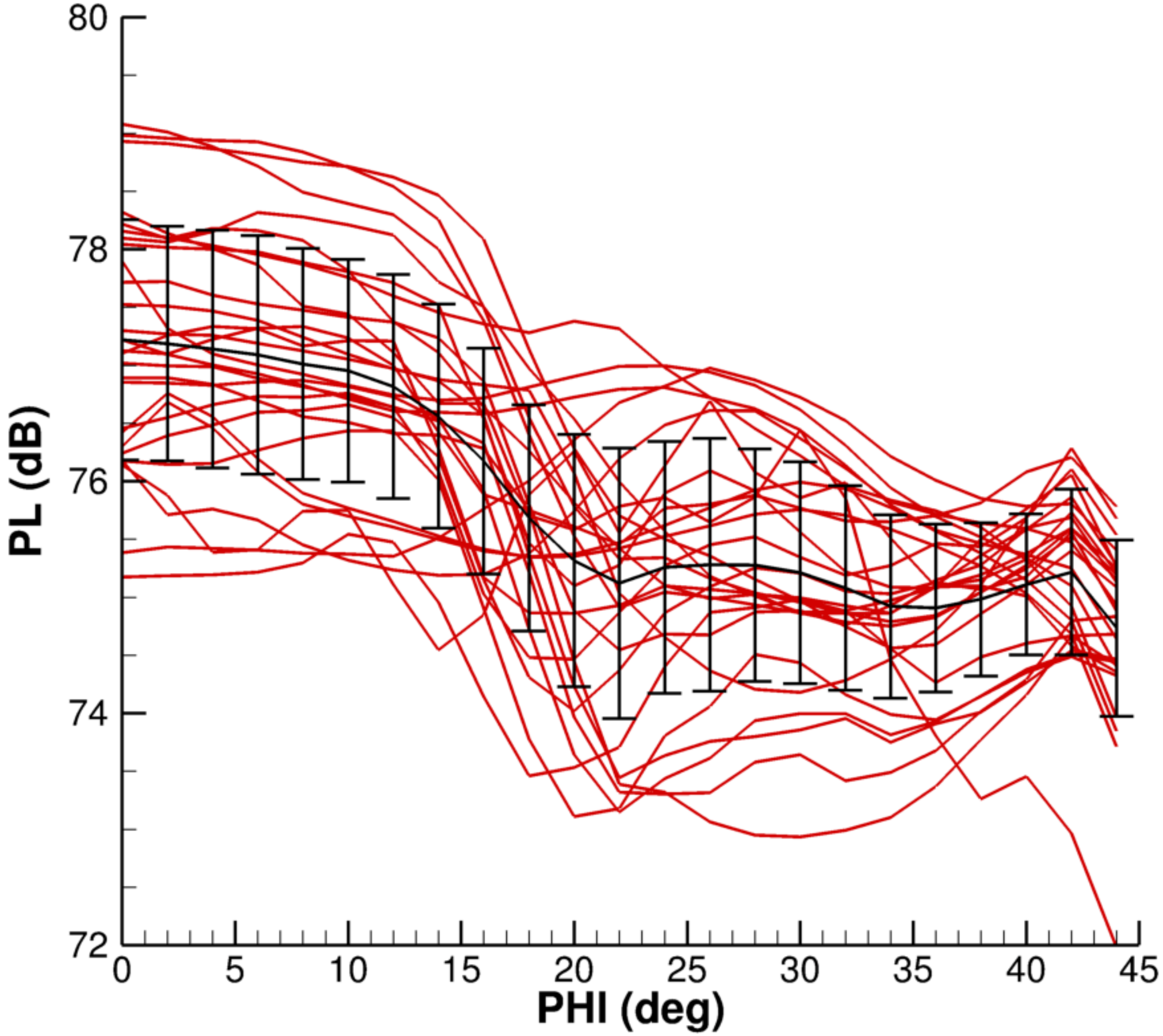
C608 COARSE-GRID PL



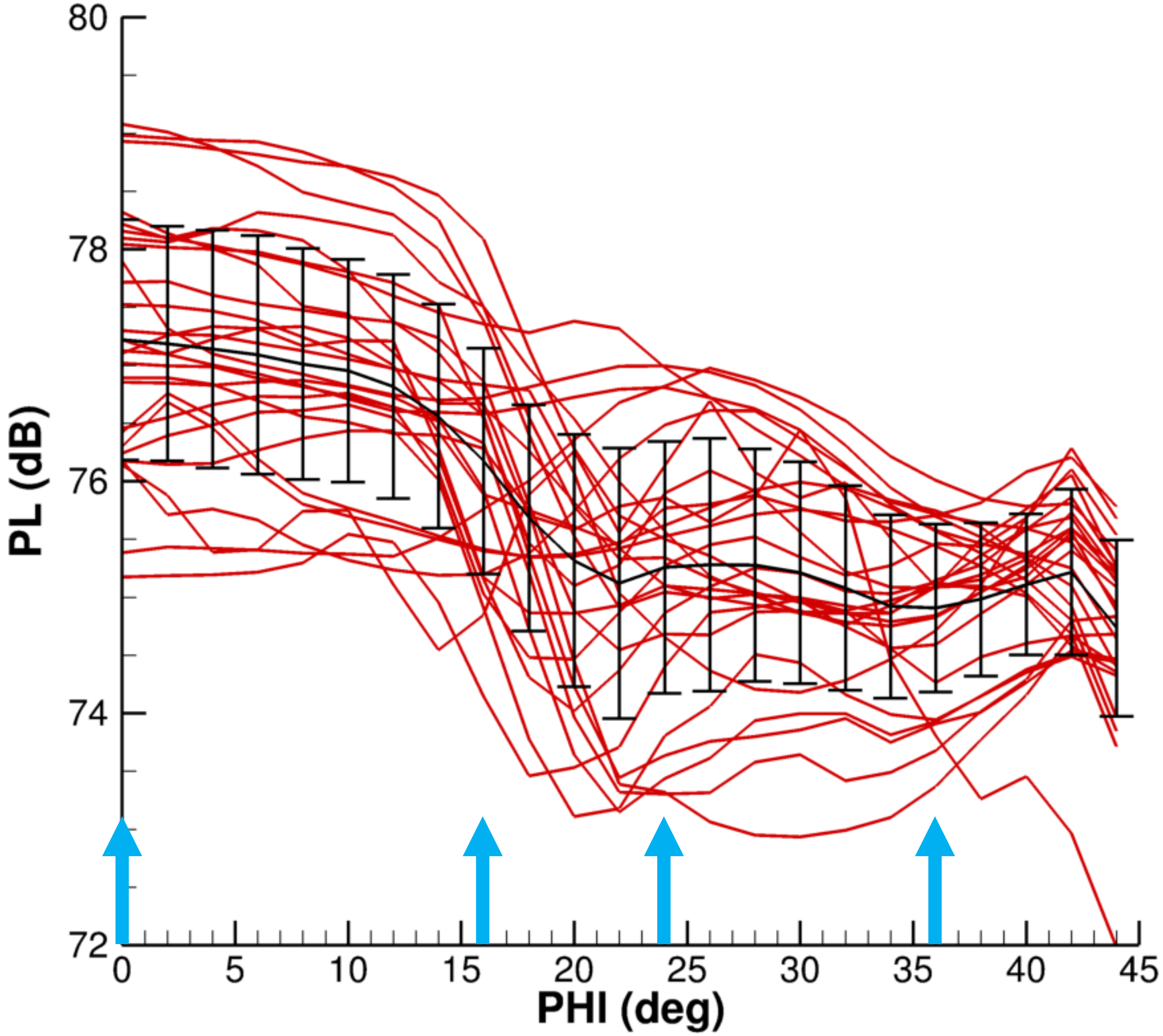
C608 MEDIUM-GRID PL



C608 FINE-GRID PL



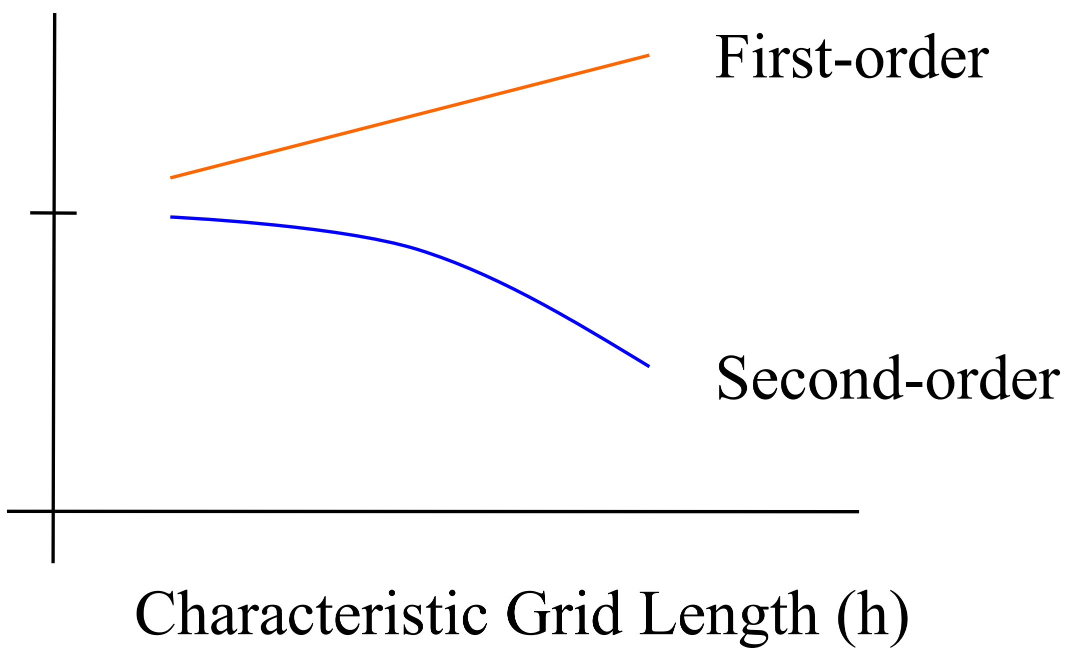
C608 FINE-GRID PL



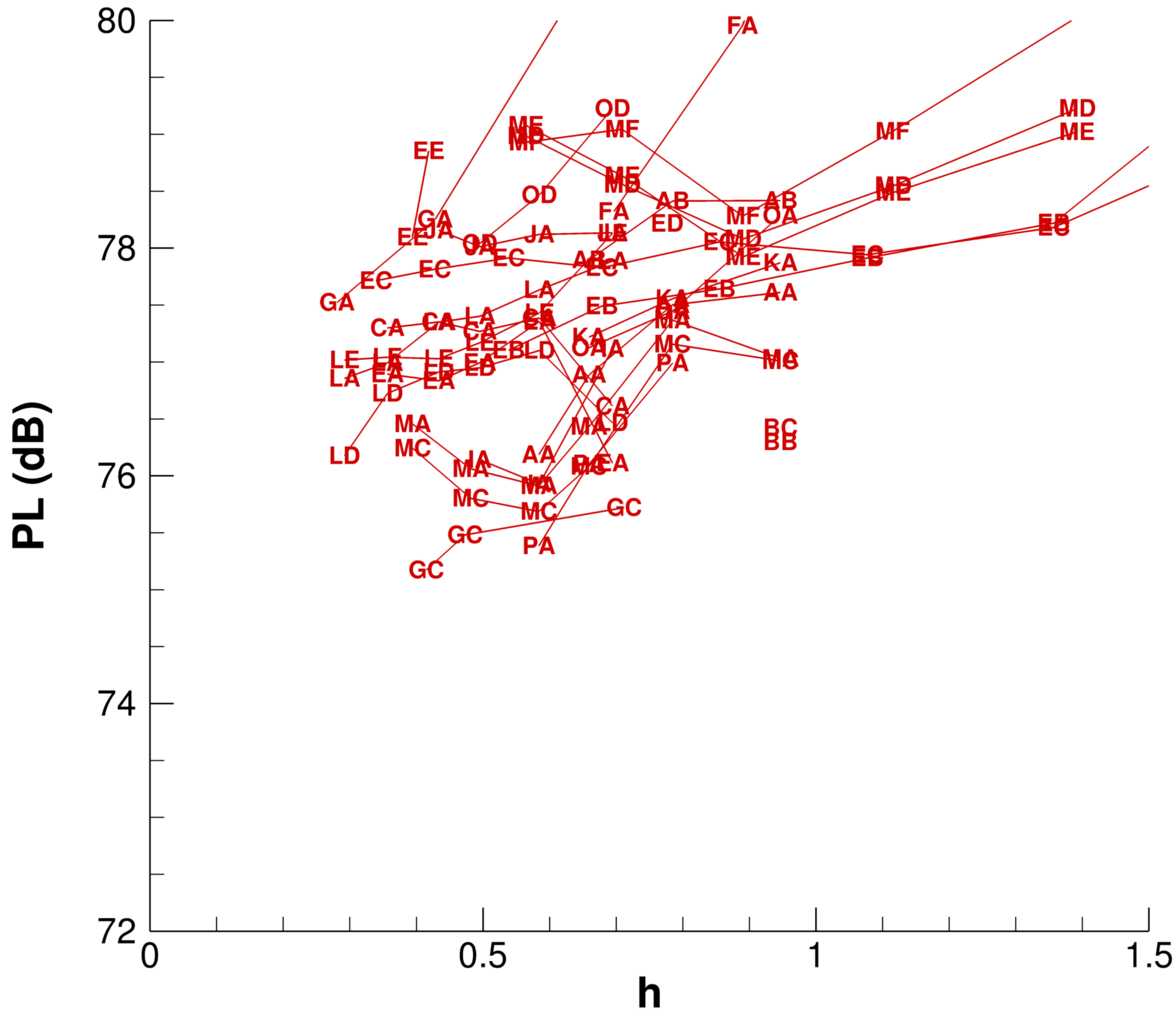
EXPECTED GRID CONVERGENCE

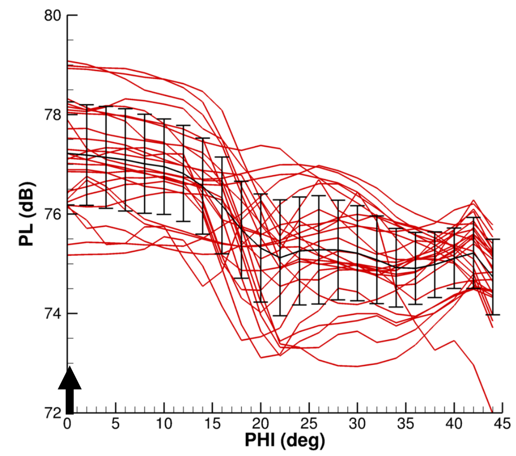
Consistent methods should approach a value as the grid is refined to “zero” h

Ten million control volumes is h=1



C608 PL GRID CONVERGENCE





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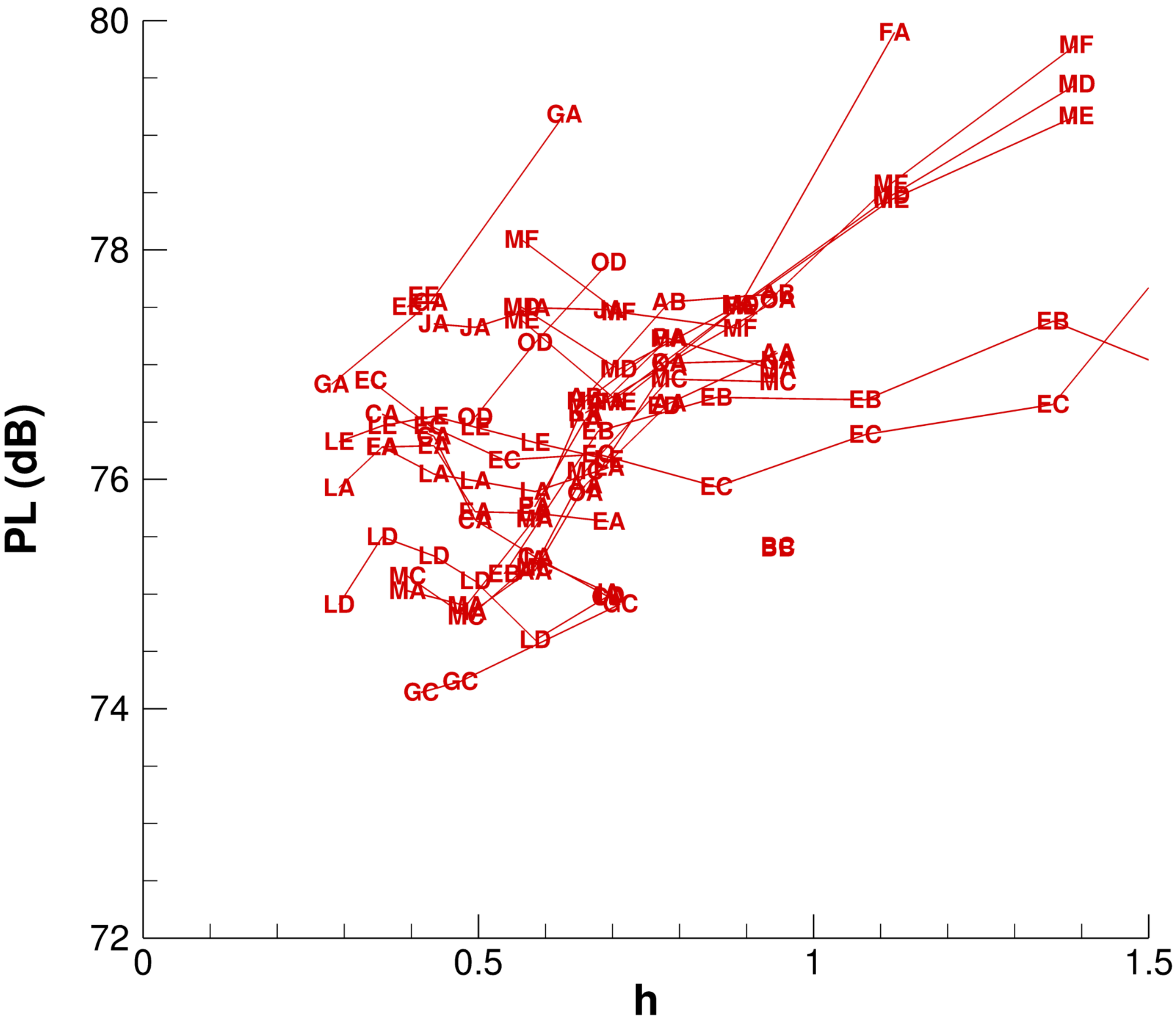
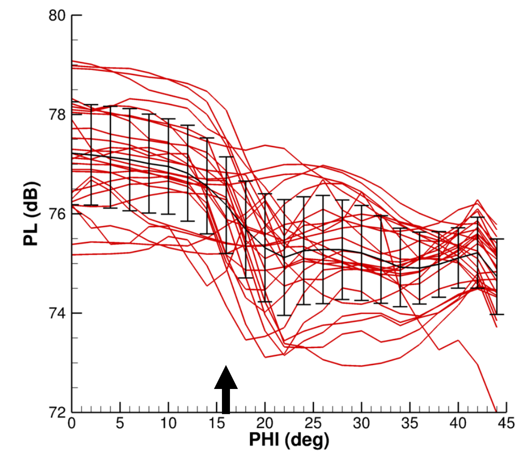
C608 PL GRID CONVERGENCE





PHI=16

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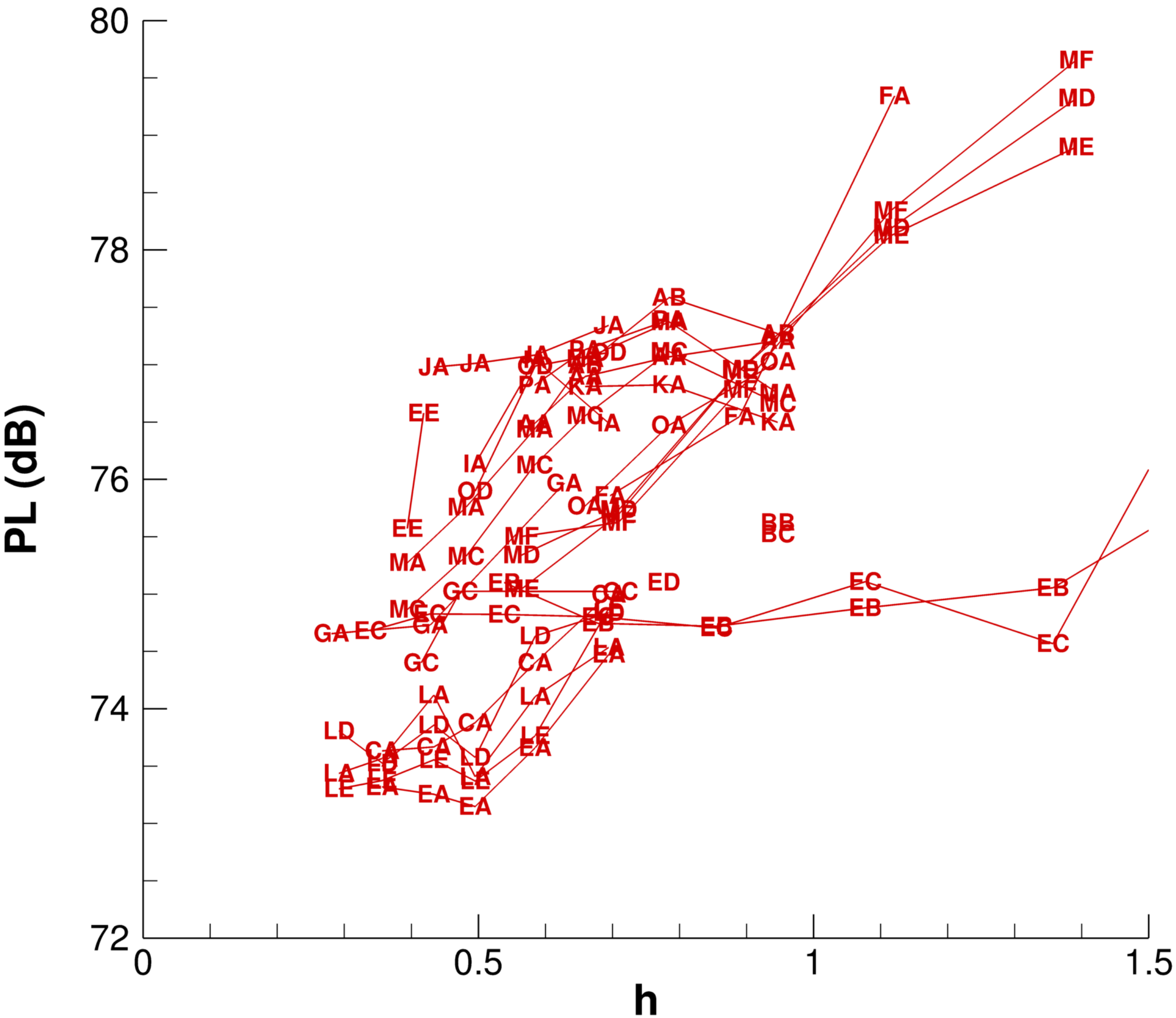

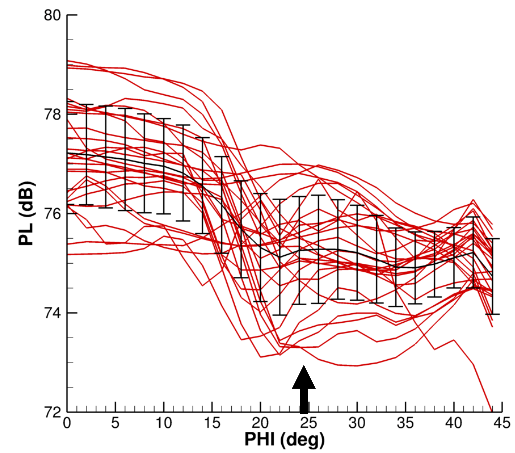

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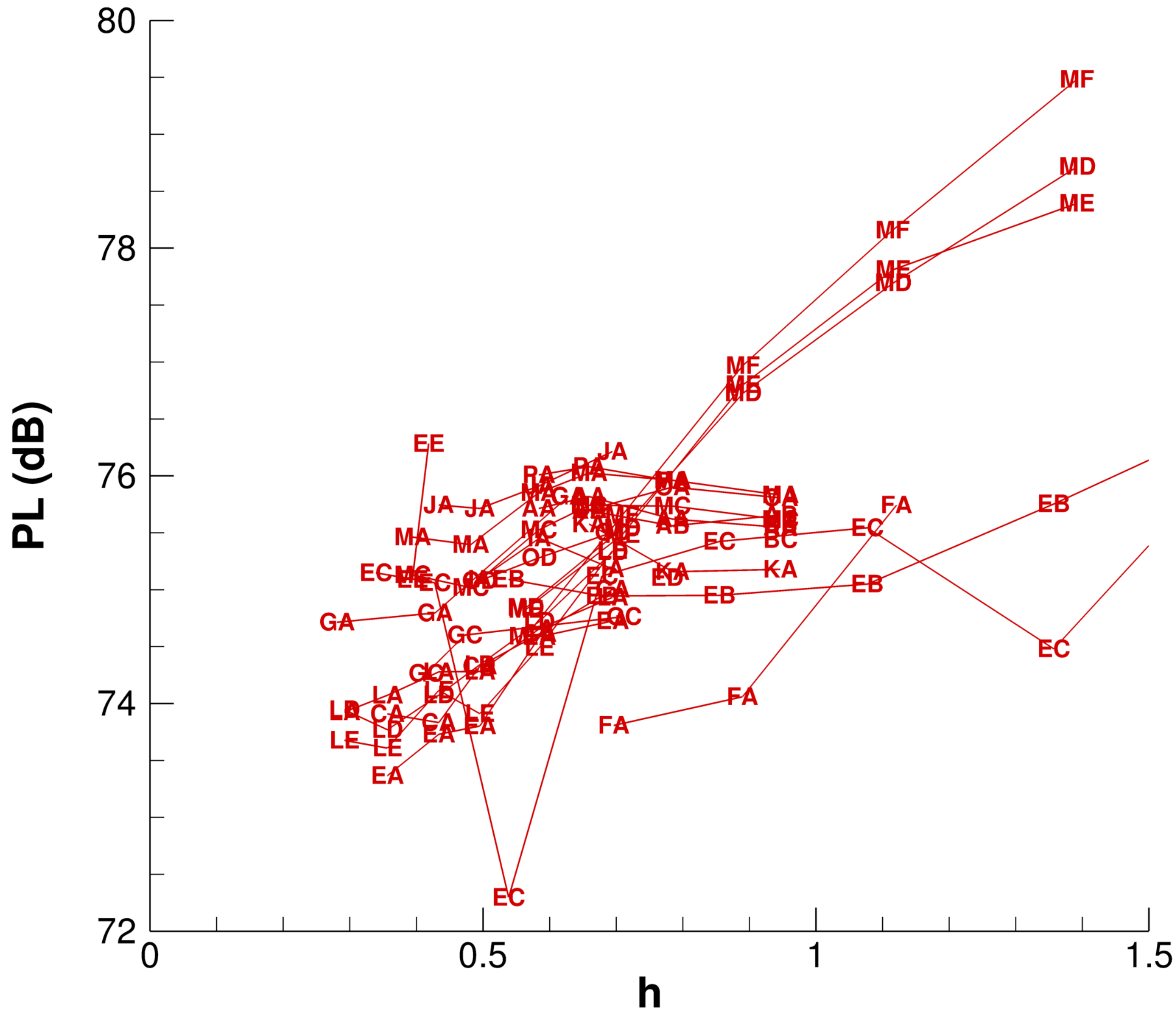
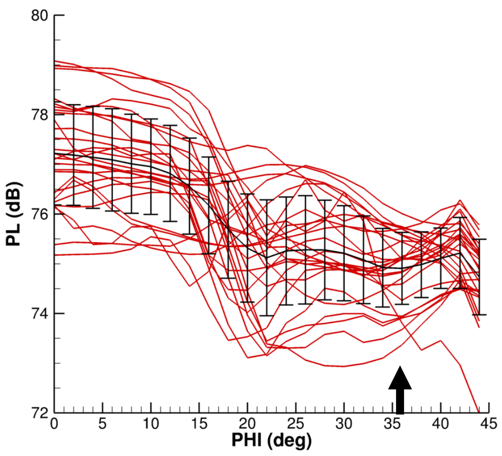


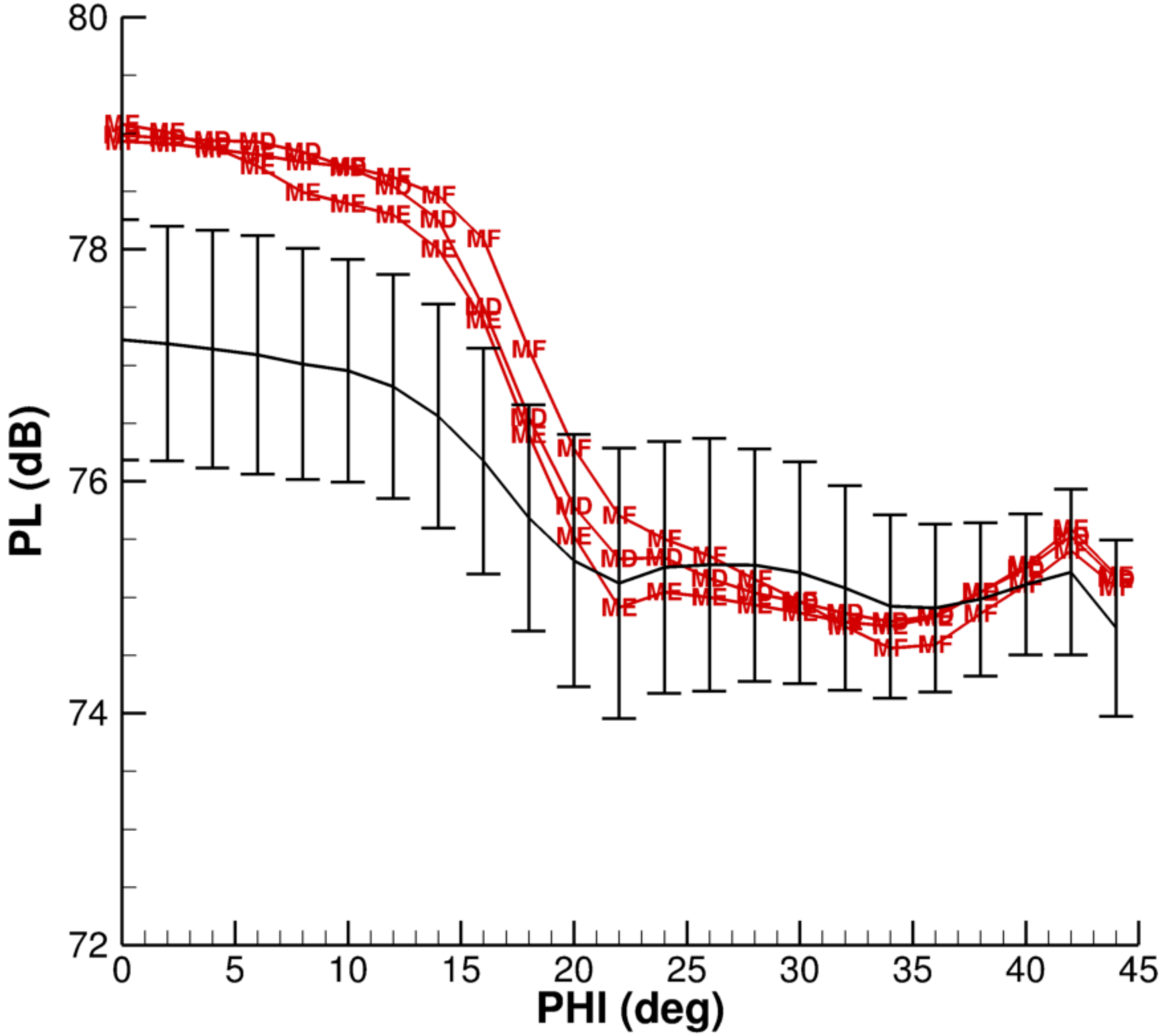


PHI=36

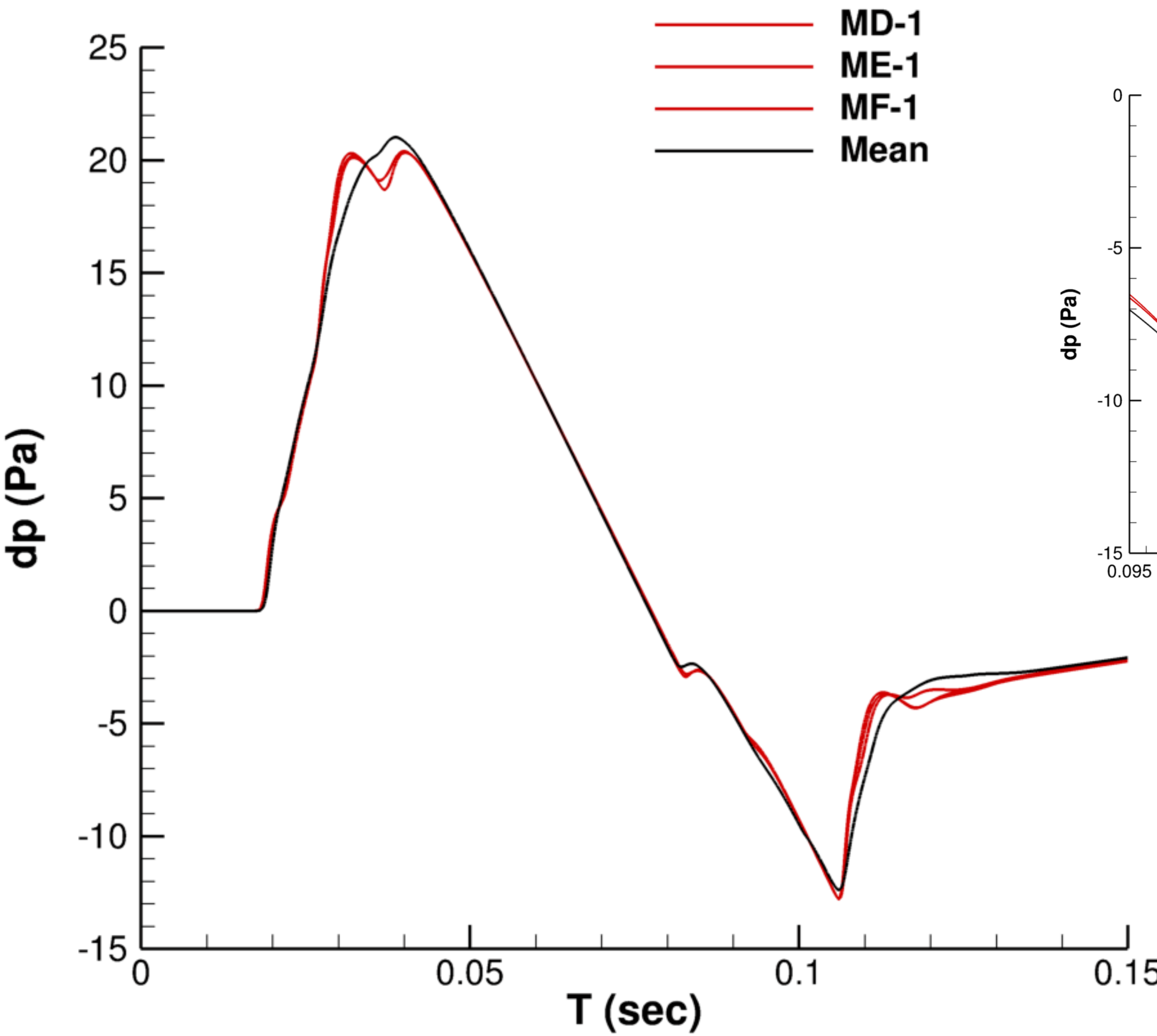
IDENTIFICATION OF OUTLIERS

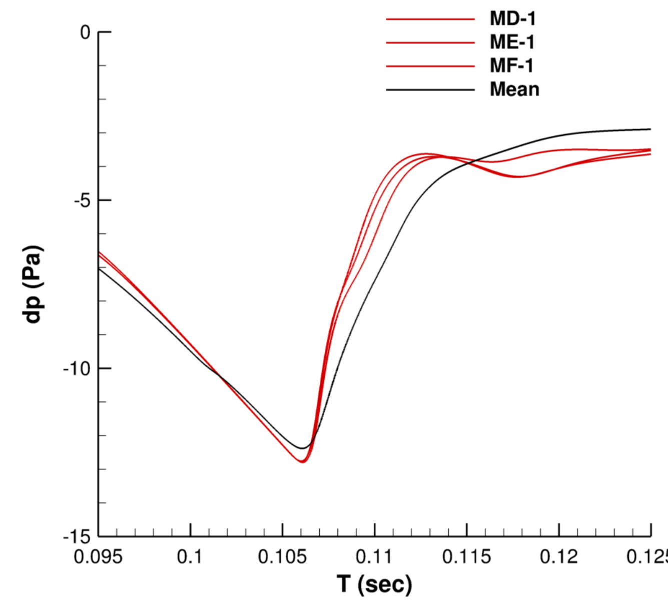
- Goal is an objective tool to identify and learn from difference in submissions
- Pointwise standard deviation is an imperfect tool
  - Not suited to small sample size
  - Distribution of submissions is not normal
  - Should use Functional Data Analysis (FDA) for shape as well as magnitude outlier identification
- Previous workshop used box and whisker plots with an effective coverage factor of 2 (exceed 95% likelihood), but 1 (exceed 68% likelihood) used here
- Focus on submissions exceeding 1 standard deviation for PHI < 15

C608 PL HIGH OUTLIERS



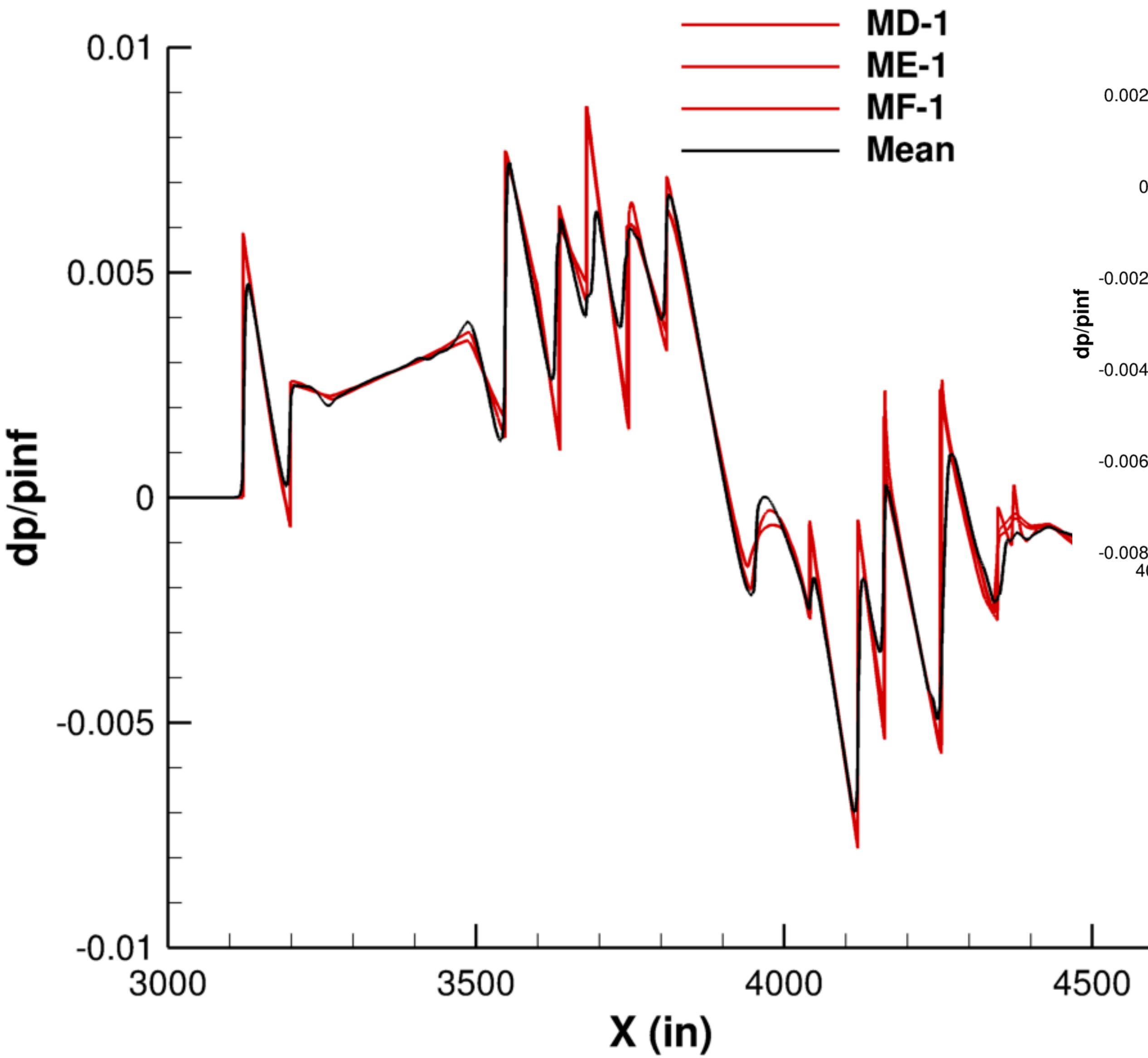
C608 MD, ME, MF GROUND

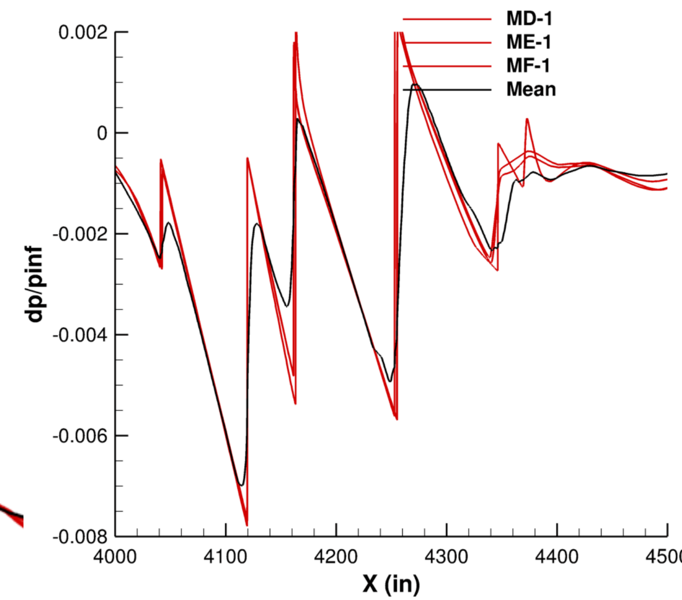




PHI=0

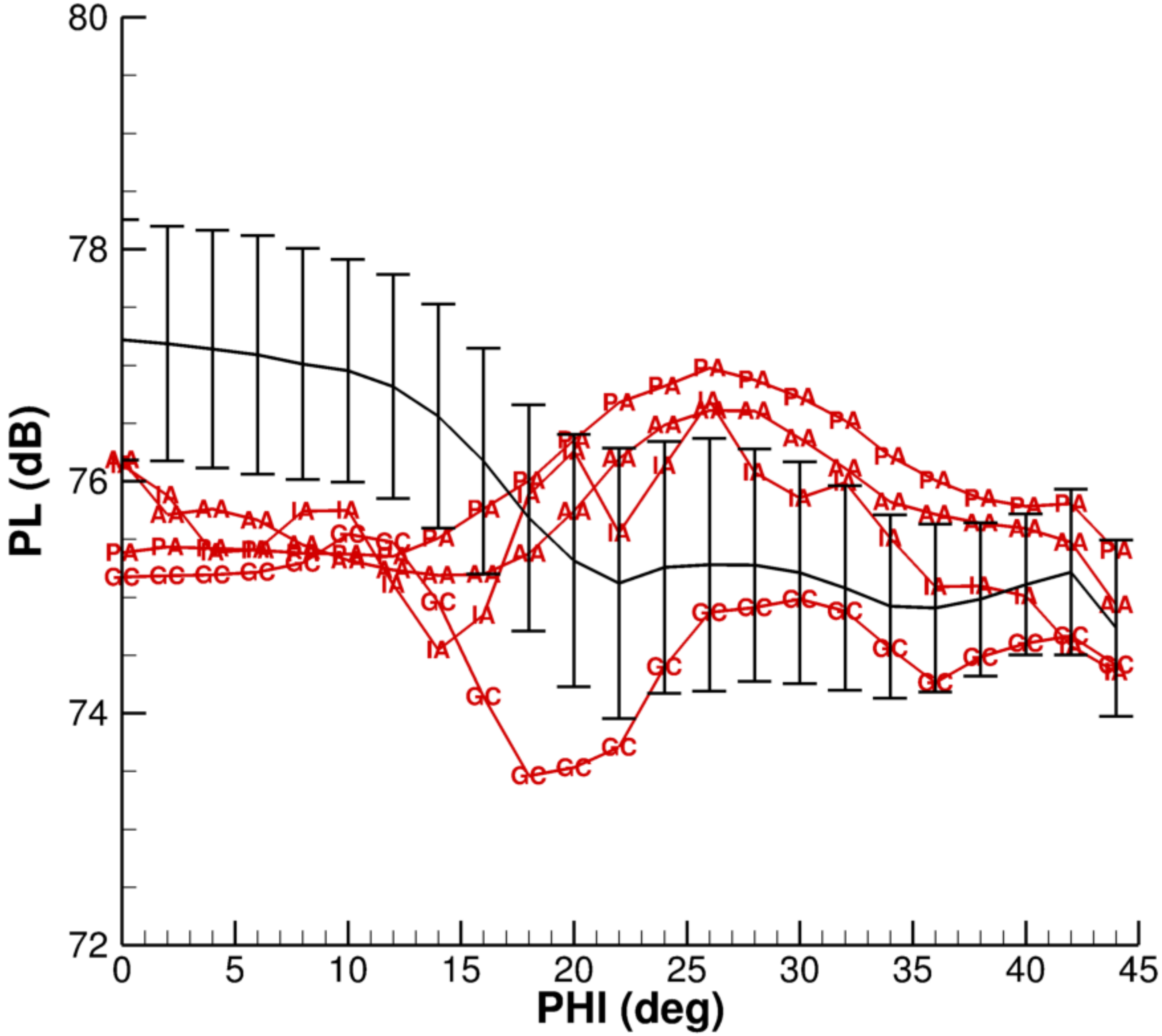
C608 MD, ME, MF NEARFIELD



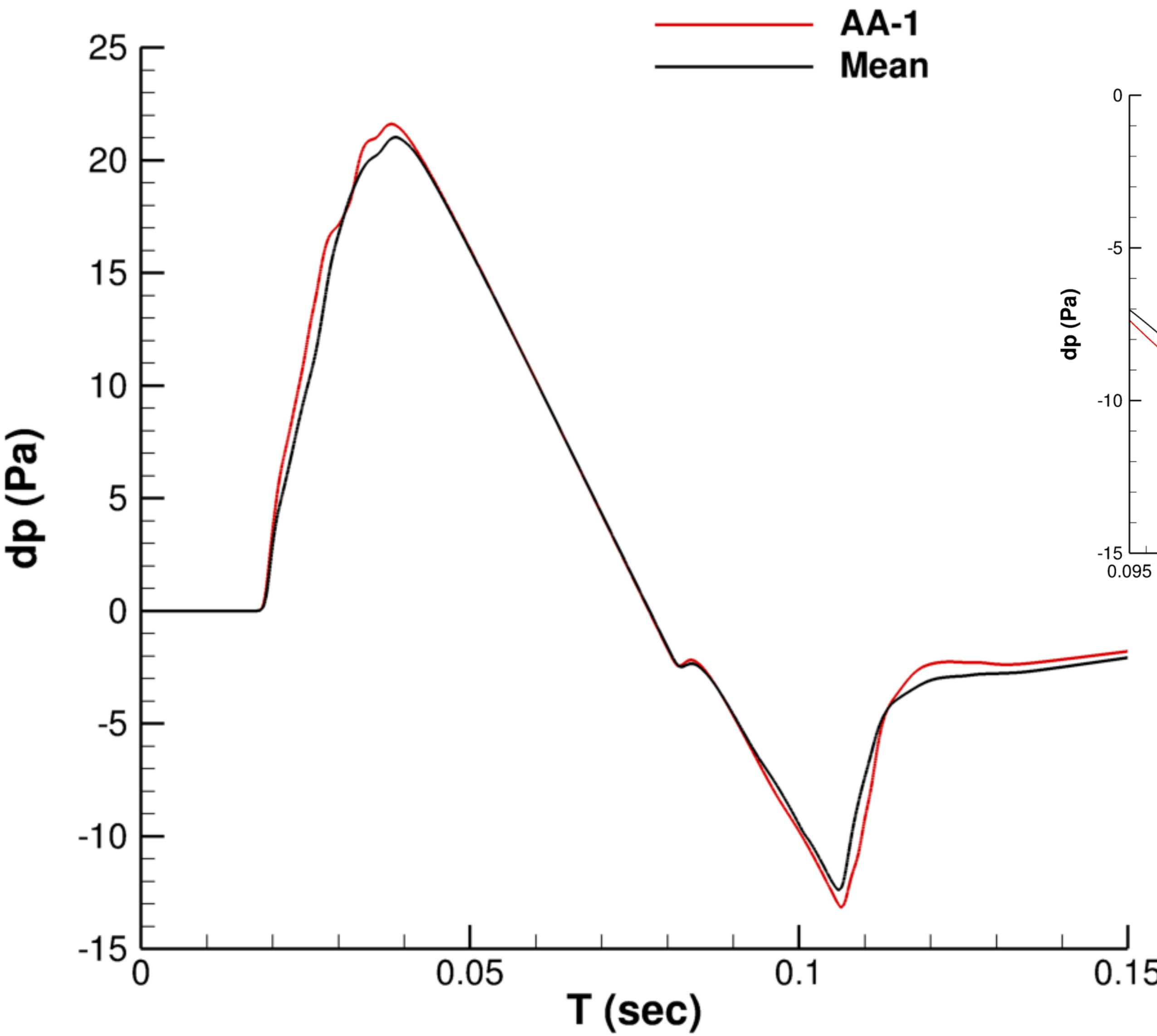


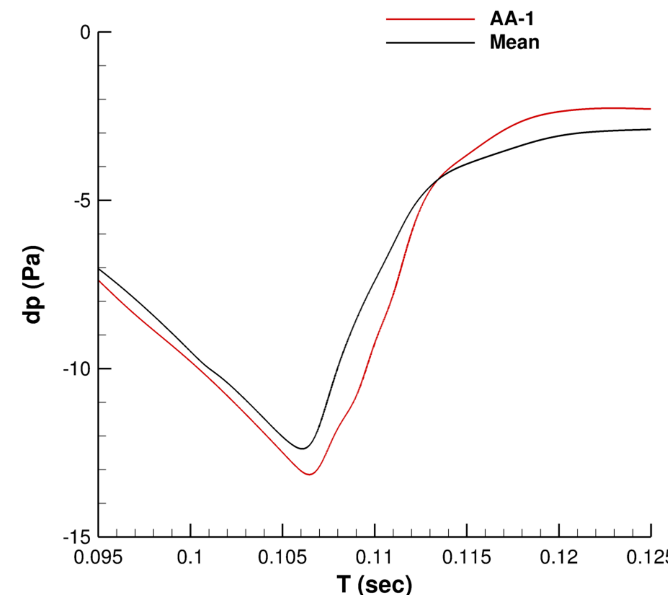
PHI=0

C608 PL LOW OUTLIERS



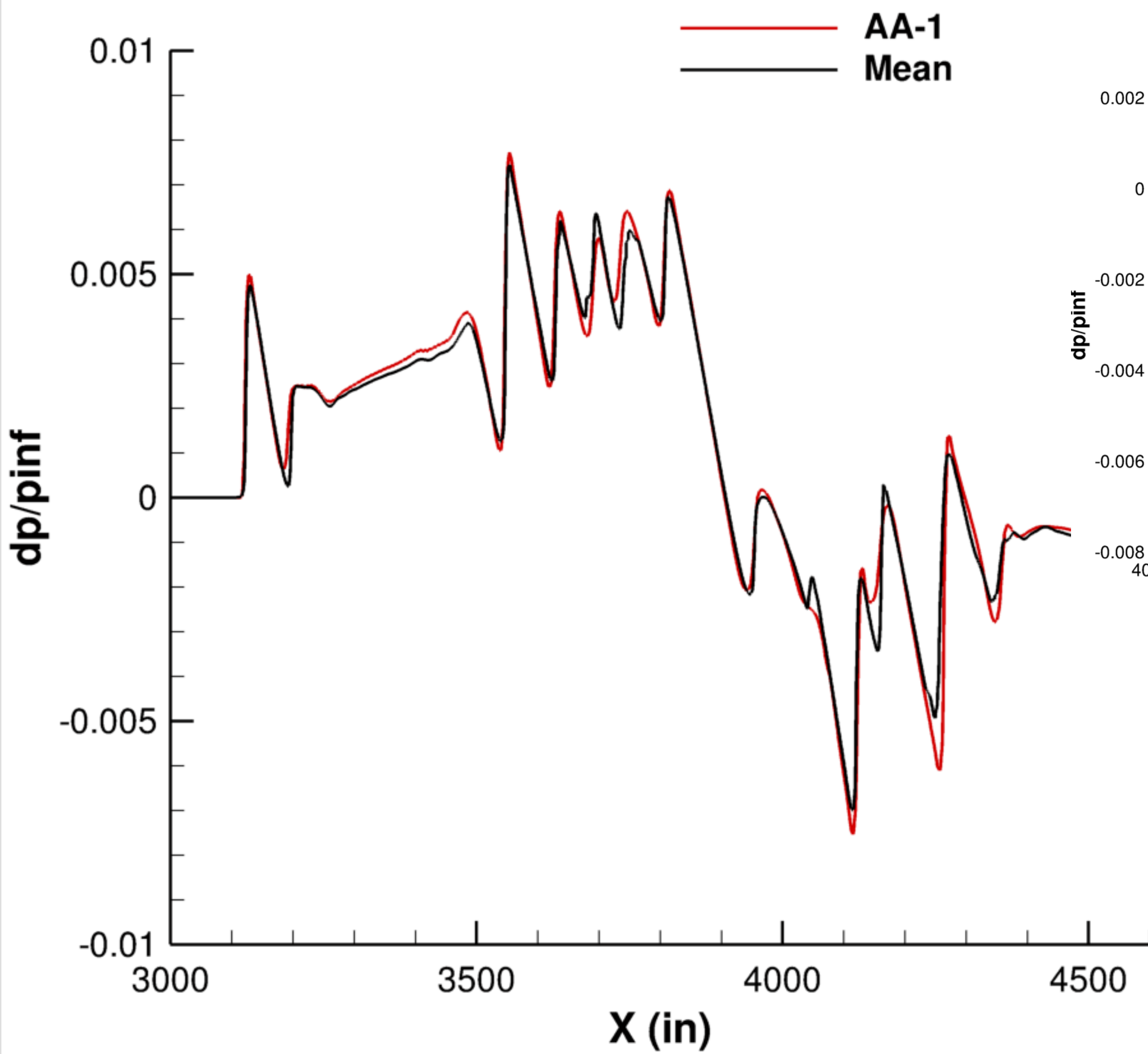
C608 AA GROUND

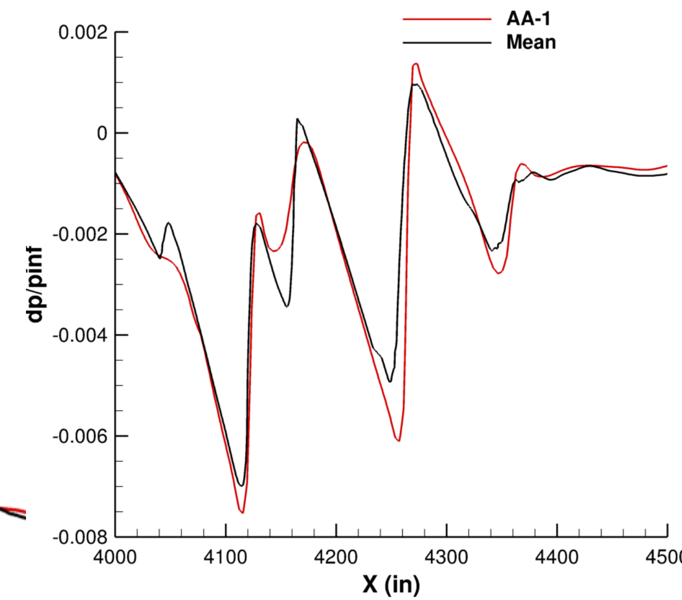




PHI=0

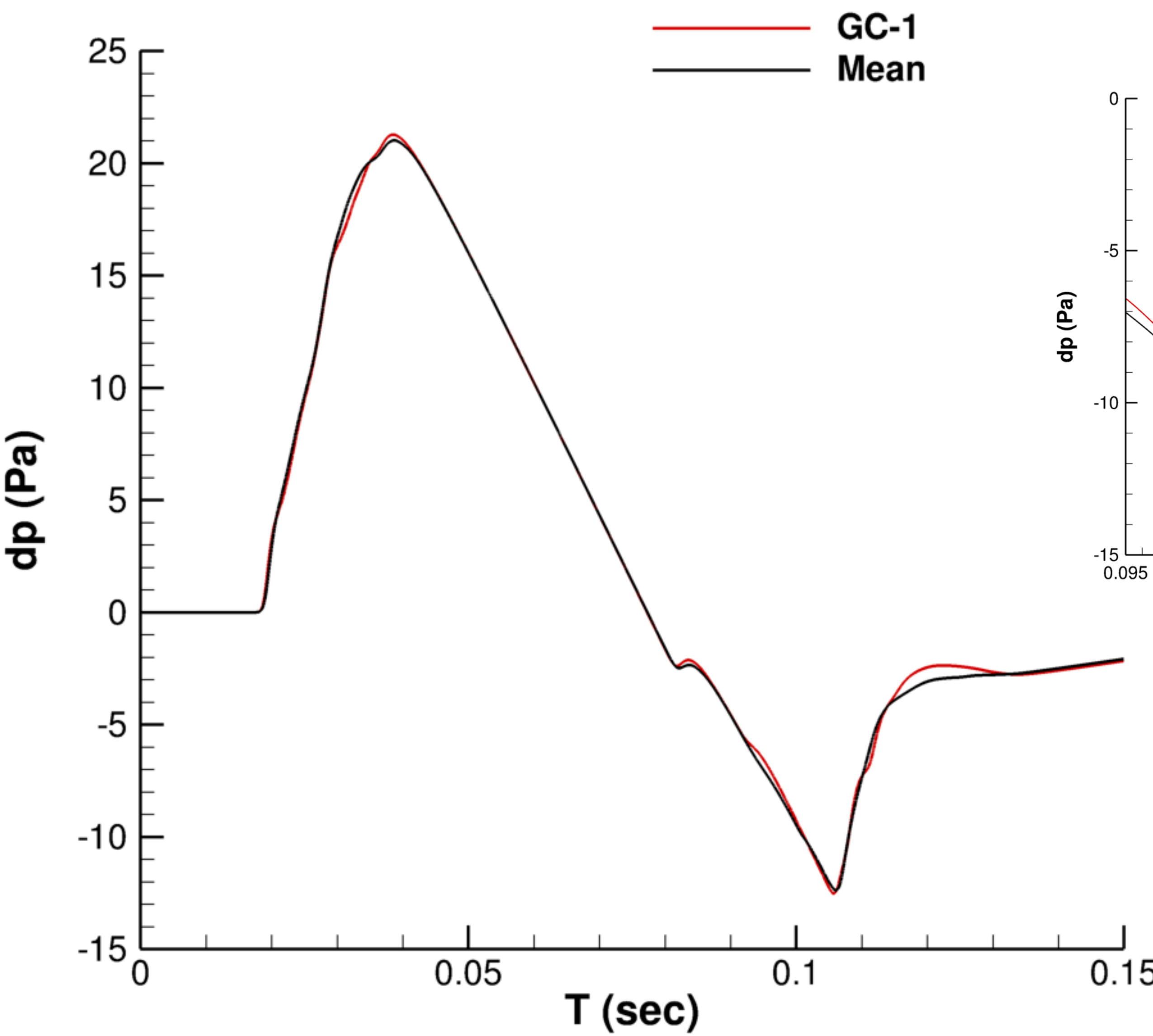
C608 AA NEARFIELD

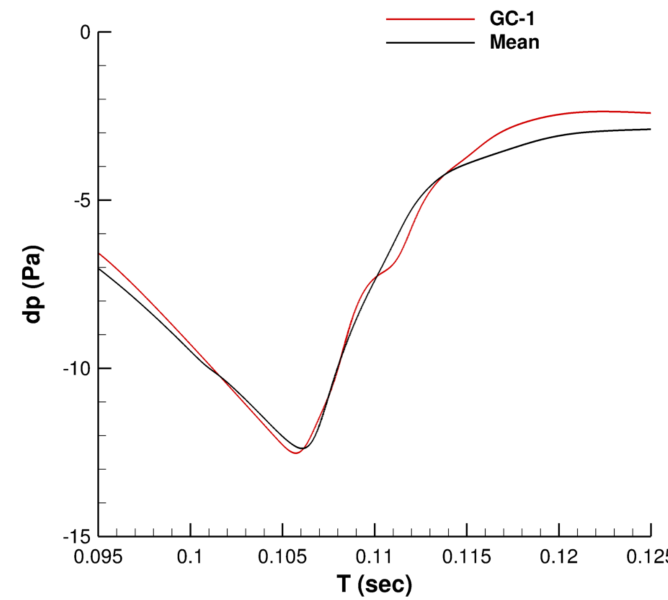




PHI=0

C608 GC GROUND





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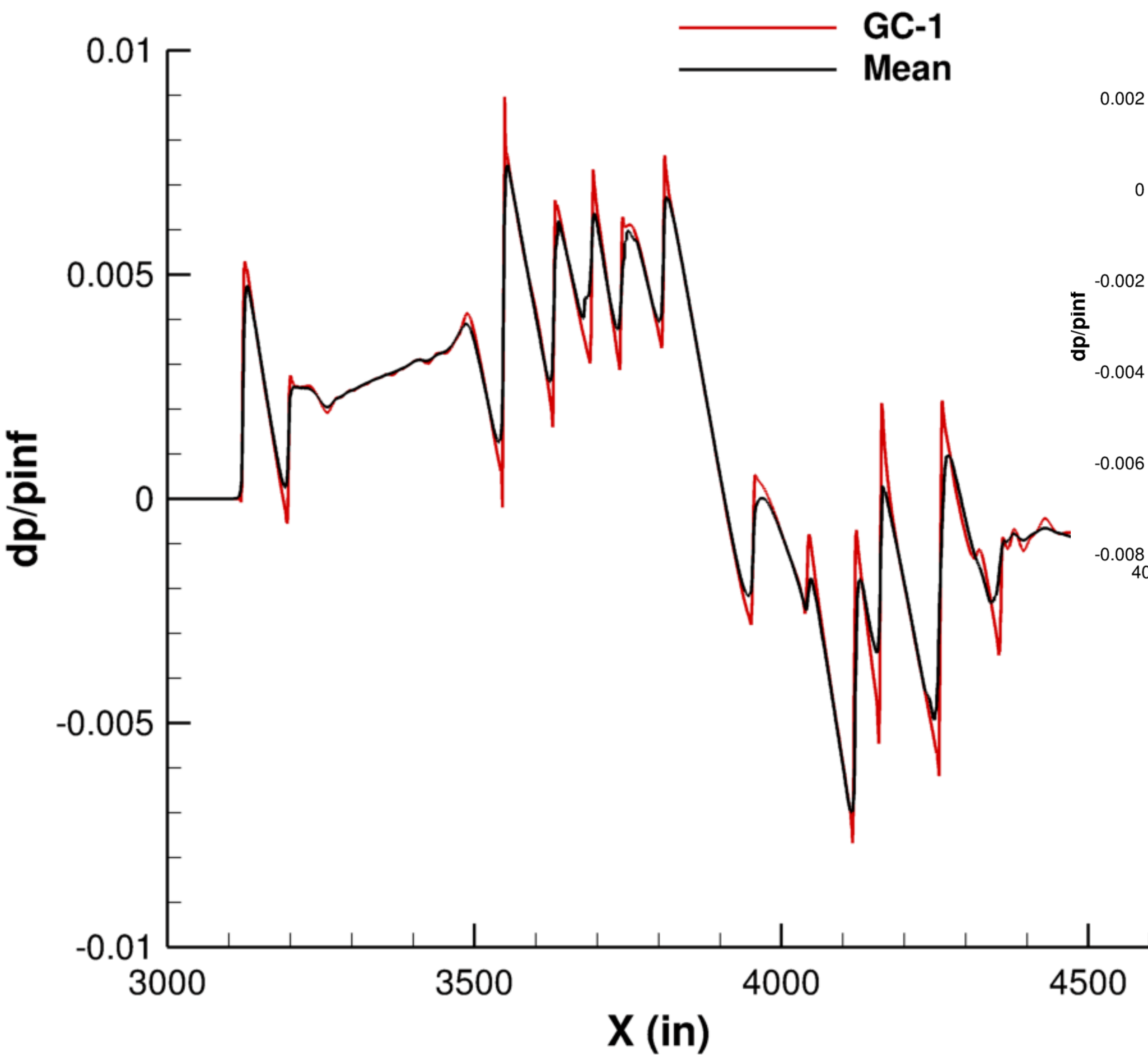
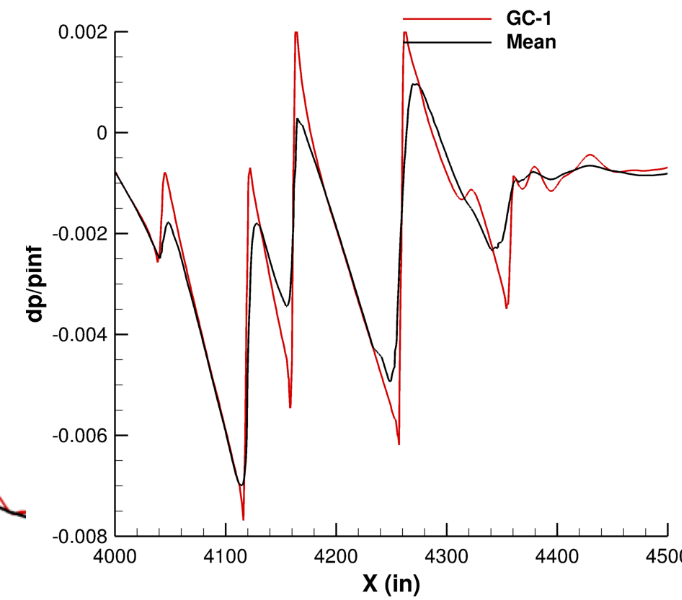
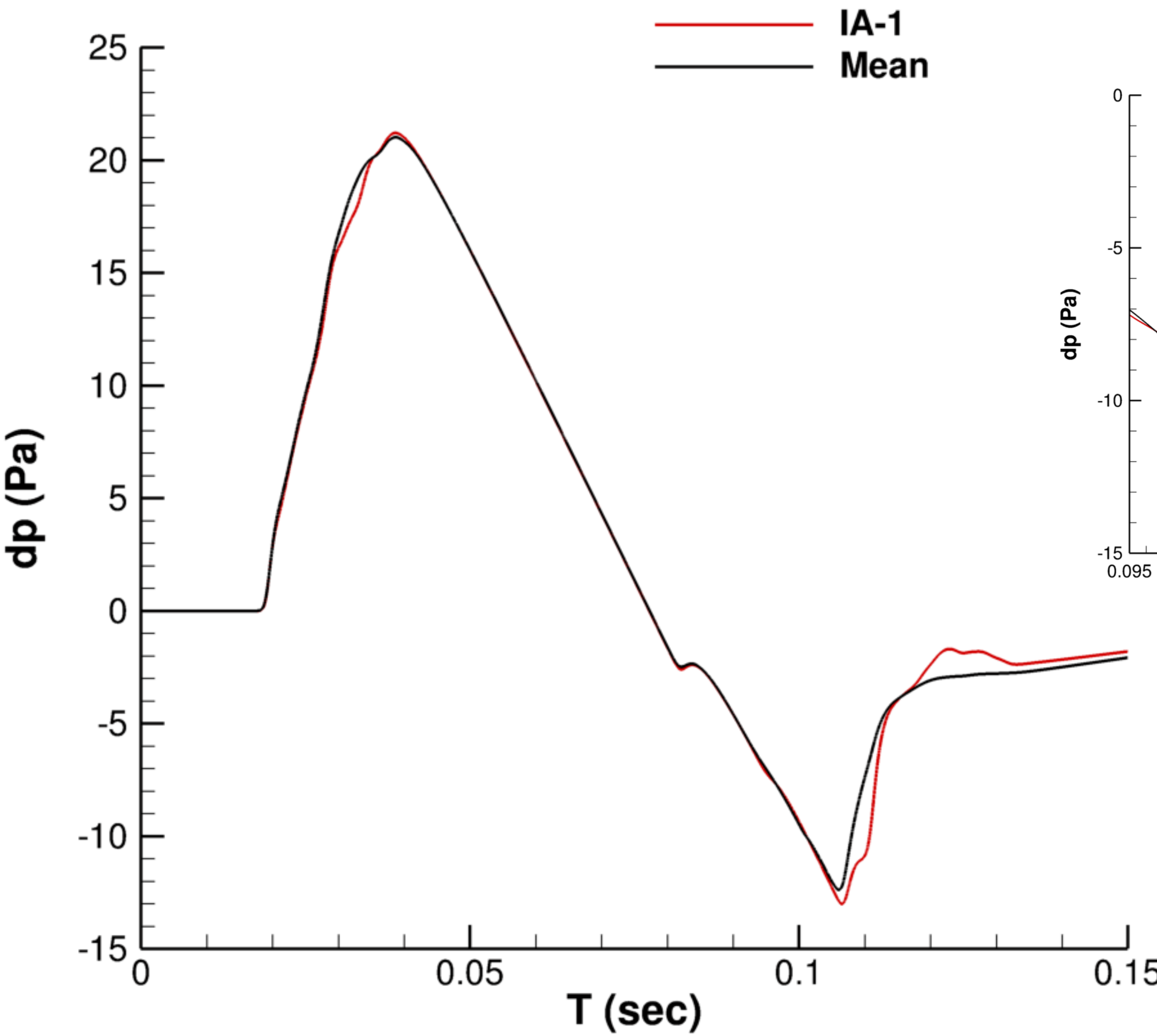
C608 GC NEARFIELD

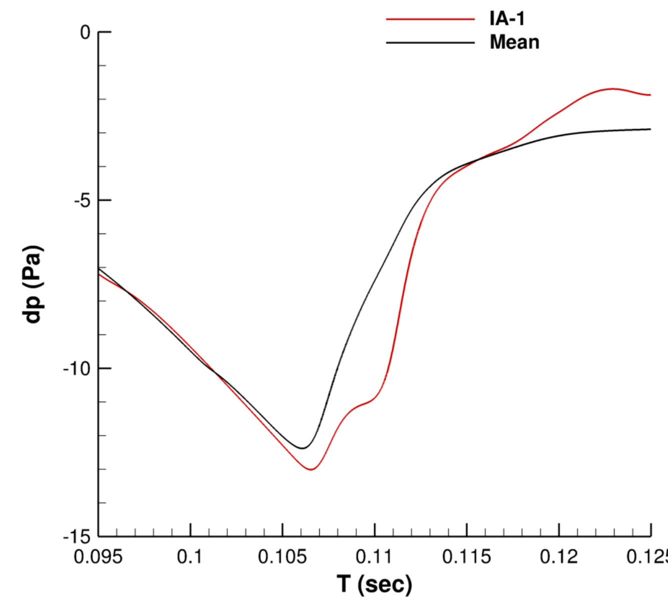




PHI=0

C608 IA GROUND





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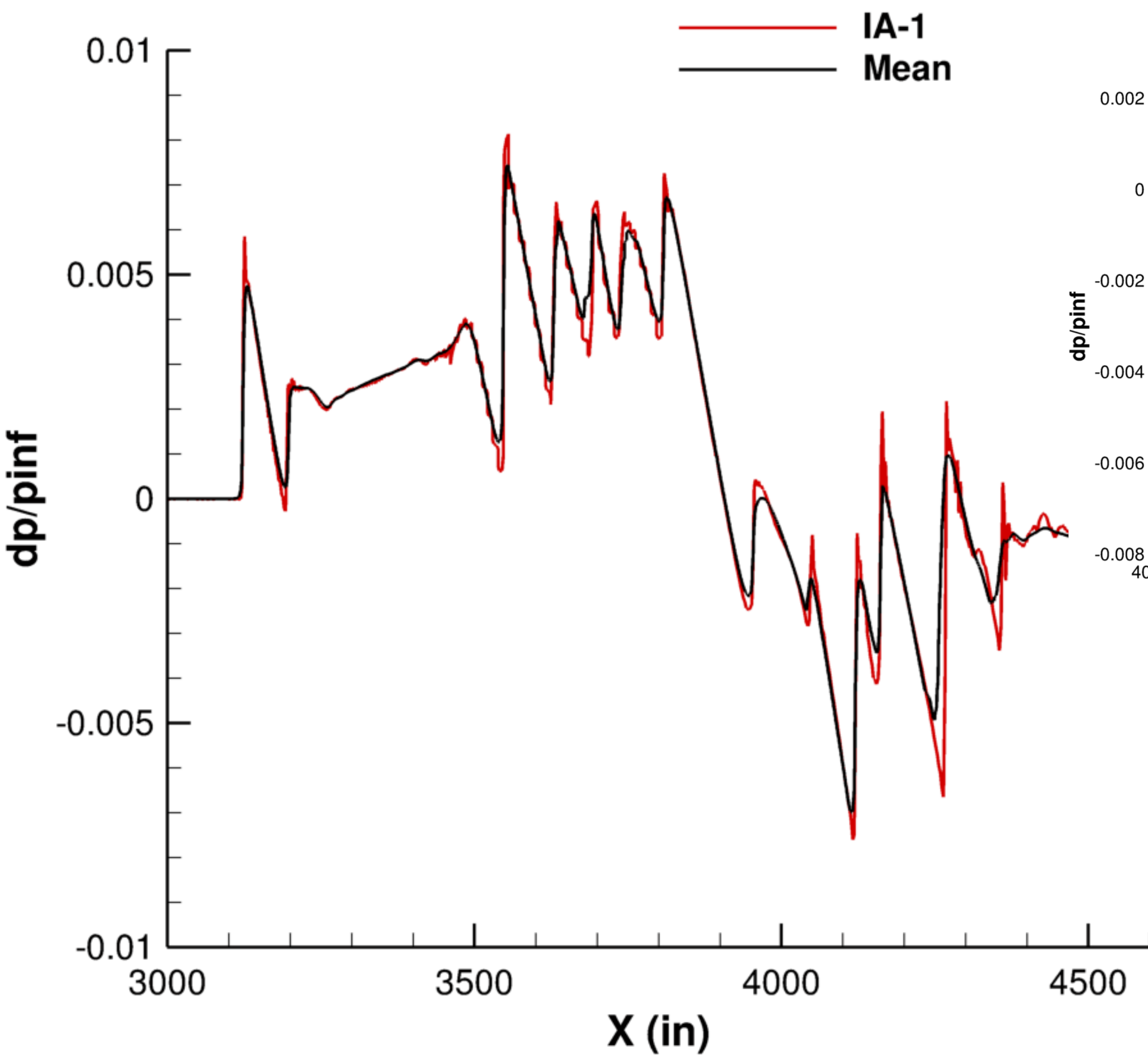
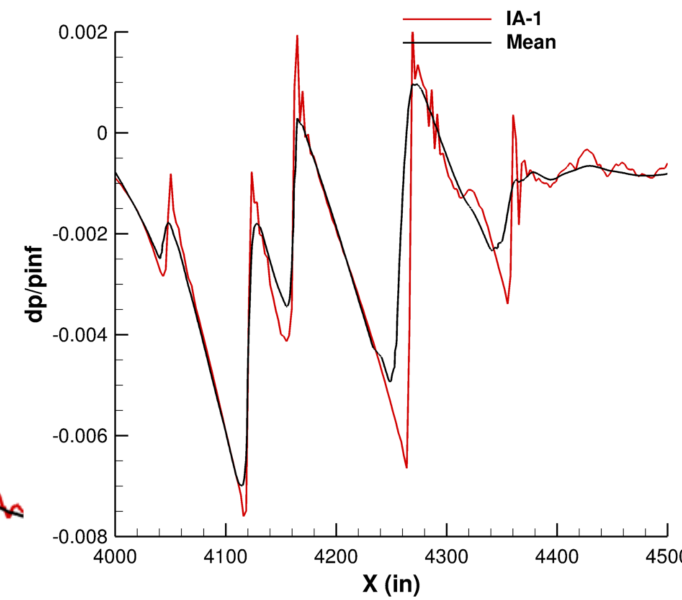
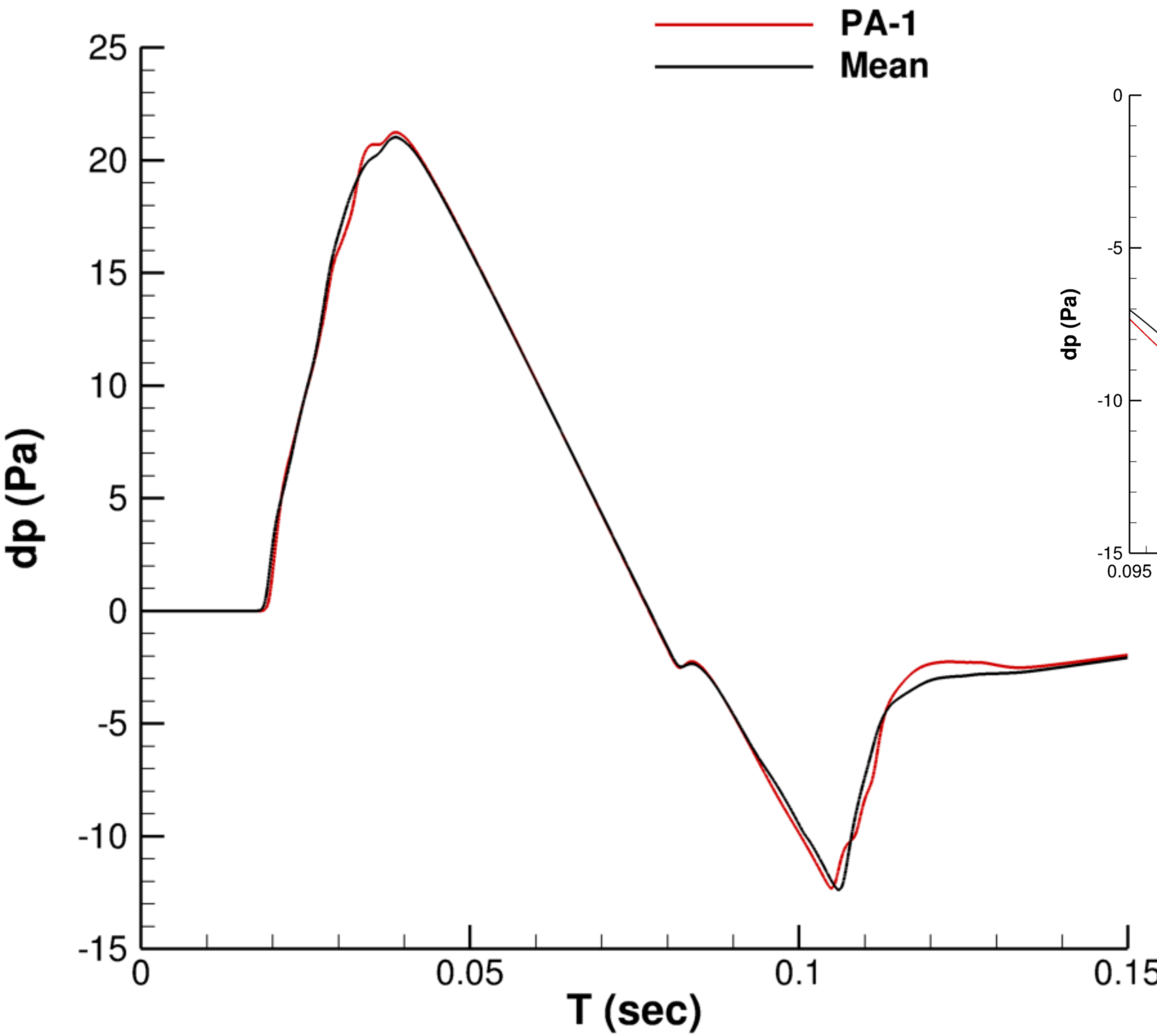
C608 IA NEARFIELD

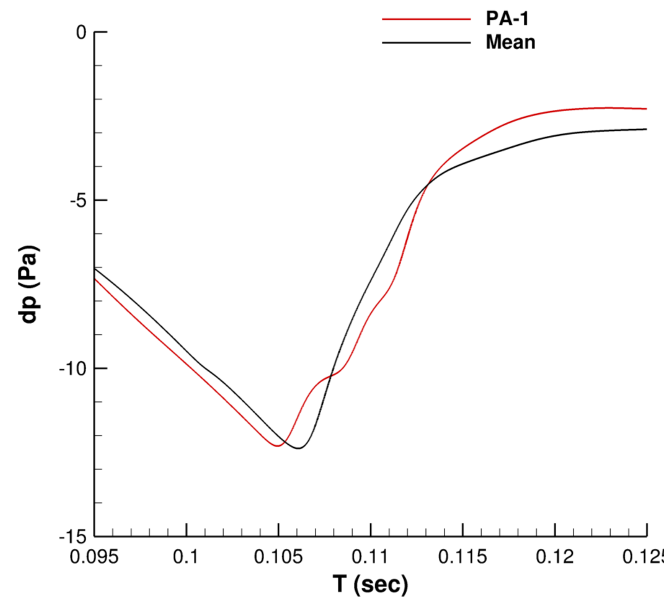




PHI=0

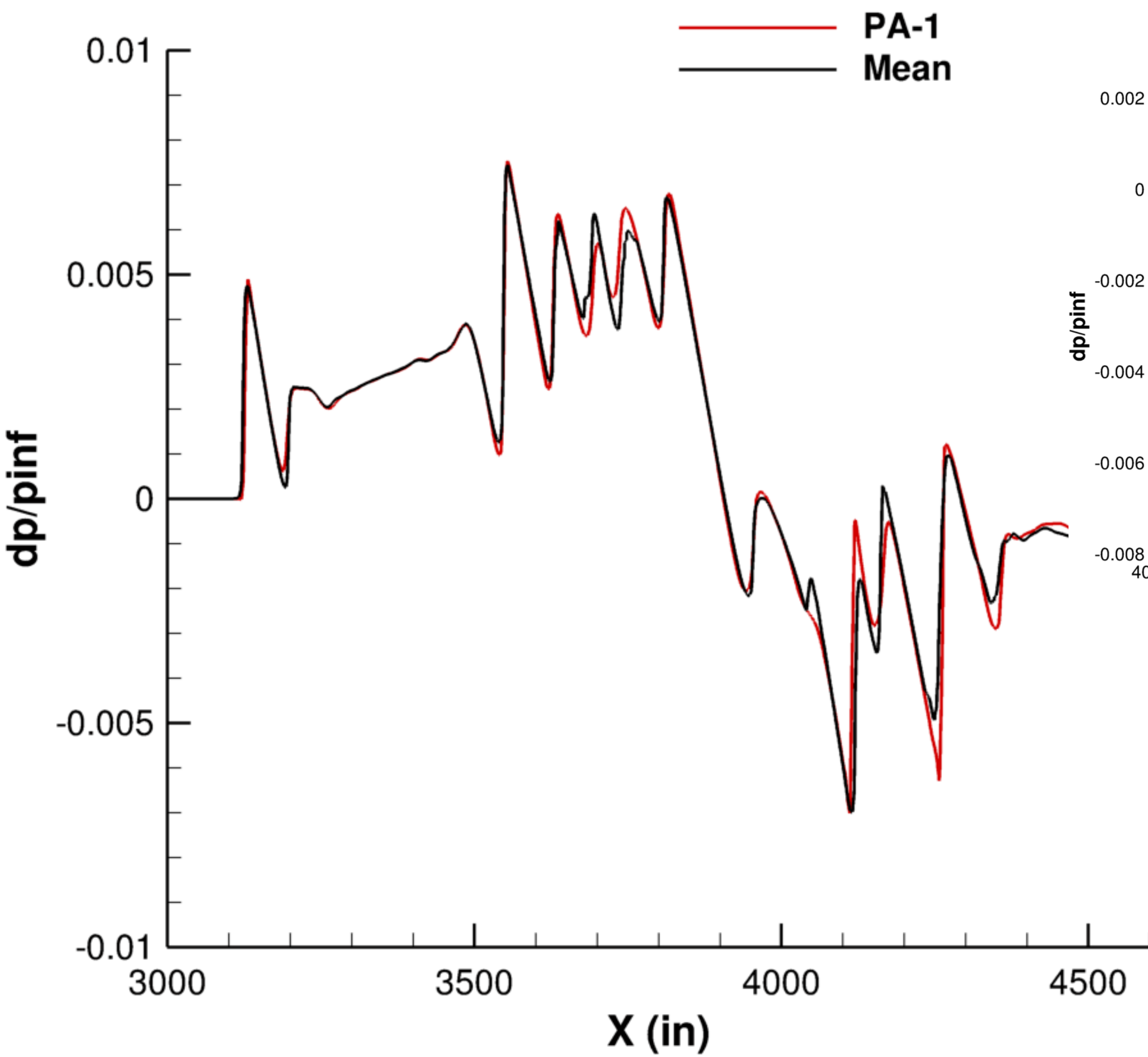
C608 PA GROUND

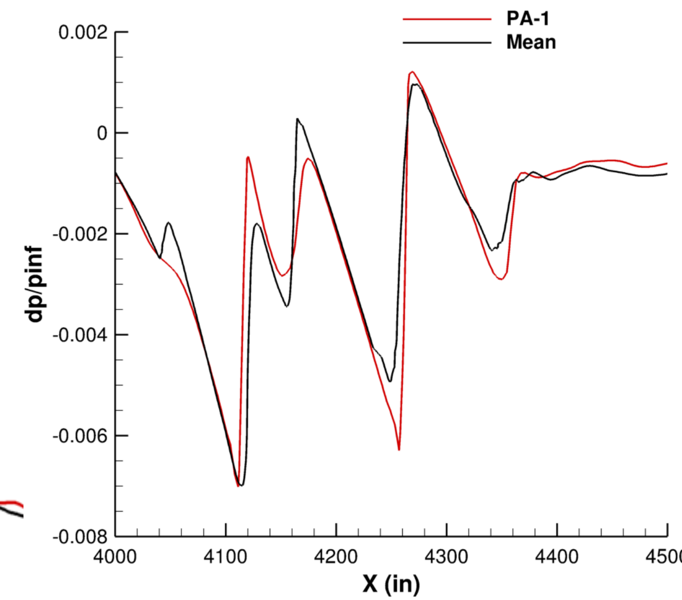




PHI=0

C608 PA NEARFIELD





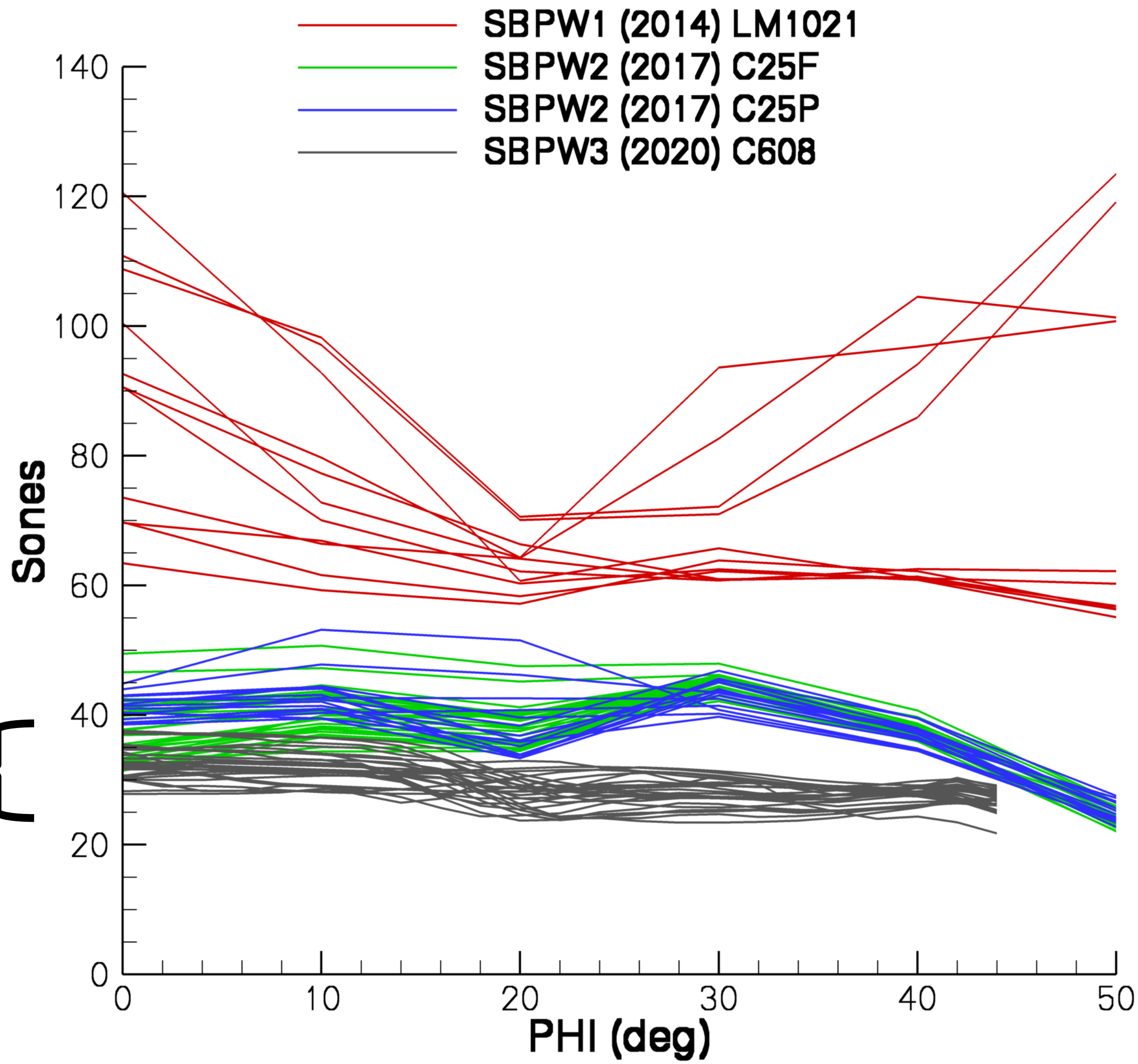
PHI=0

SUMMARY

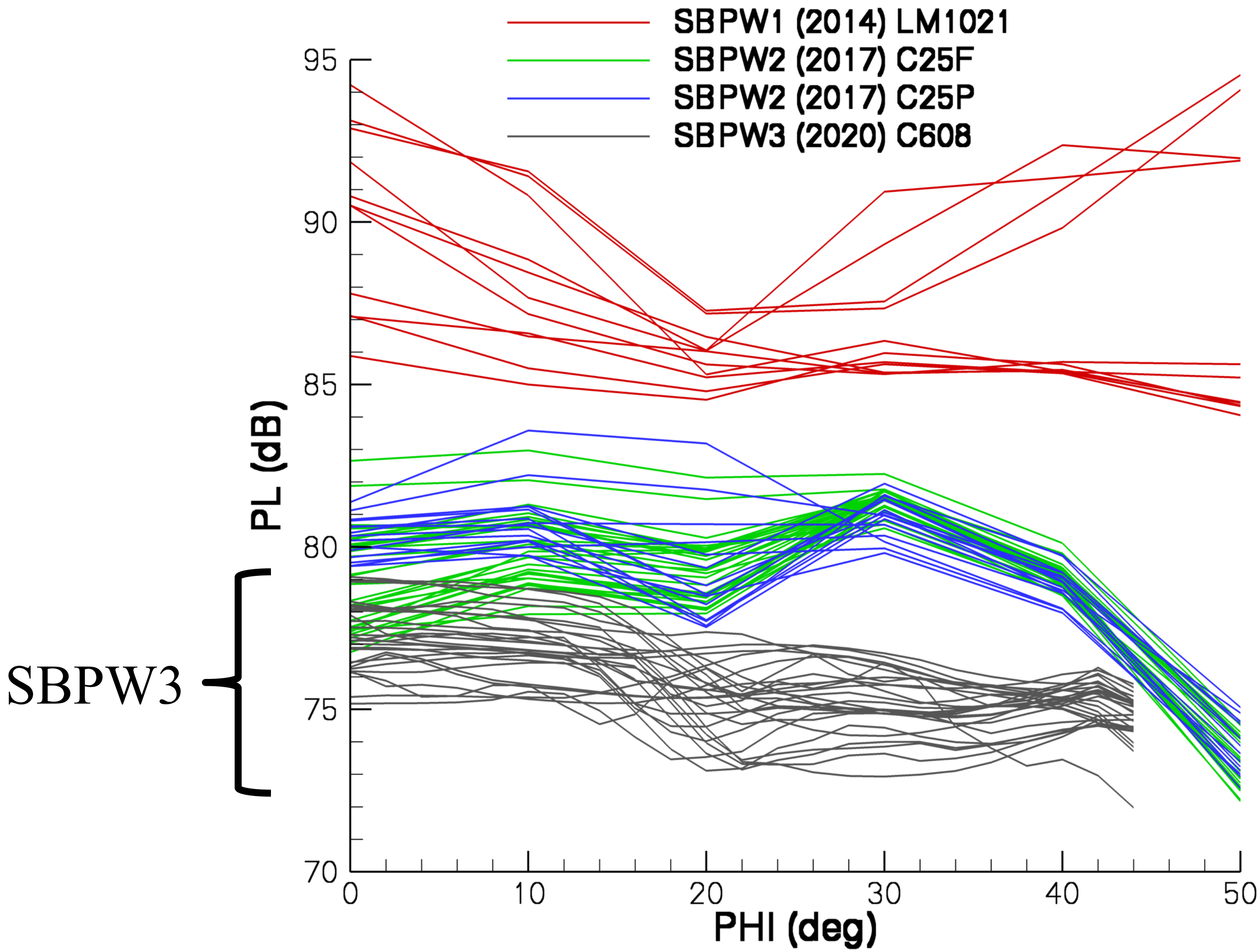
- C608 is the quietest (and therefore, the hardest to predict) C608 includes propulsion boundary conditions and a representative level of geometry complexity
- Variation of the aft deck lip shock and other tail shocks has the largest impact on PL
- The variation is lowest of SBPW with the strictest criterion for outliers
  - A coverage factor of one was used (outliers exceed 68% likelihood) via sample mean and standard deviation
  - SBPW-2 coverage factor of two (outliers exceed 95% likelihood) via box and whisker plots

SBPW FINE-GRID LOUDNESS (SONES) CARPET

SBPW3



SBPW FINE-GRID PL CARPET



CONCLUSIONS

- Sincere thank you to all the participants!
- These cases included propulsion boundary conditions and realistic geometry making them the hardest attempted in the workshop series
- The variation is lowest of SBPW, requiring a stricter criterion to identify outliers
  - A coverage factor of one was used (outliers exceed 68% likelihood) via sample mean and standard deviation
  - SBPW-2 coverage factor of two (outliers exceed 95% likelihood) via box and whisker plots

OPTIONAL CASE PARTICIPATION

How to encourage more participation during or after workshop

- Uncertainty Quantification (UQ) run matrix
- Multiscale Mach adapted grids

NEXT STEPS

- Participant submission updates (10-FEB-2020)
- Further analysis based on feedback (some surface and volume solutions available)
- AVIATION papers and AIAA Journal of Aircraft Special Section
  - Provide participant submissions and ensemble data to AVIATION authors for comparison plots and independent analysis
- Enable a foundation for research
  - Midfield space marching solver
  - Propagation including over the top or secondary boom
  - Other opportunities?