Summary and Statistical Analysis of the First AIAA Sonic Boom Prediction Workshop

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Overcoming the Barriers to Practical High Speed Vehicles

Environmental Barriers

Sonic Boom

- Design for low noise sonic boom
- Understand Community Response

Airport Noise

- Noise levels not louder than subsonic aircraft at appropriate airports

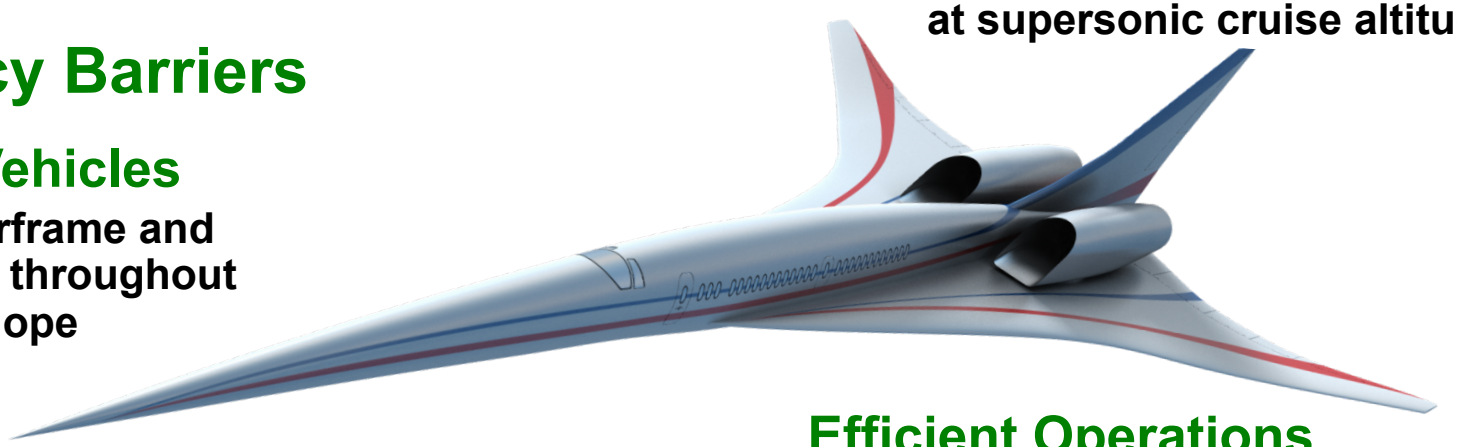
High Altitude Emissions

- No or minimal long term impact at supersonic cruise altitudes

Efficiency Barriers

Efficient Vehicles

- Efficient airframe and propulsion throughout flight envelope



Light Weight, Durable Vehicles

- Low airframe and propulsion weight in a slender flexible vehicle operating at supersonic cruise temperatures

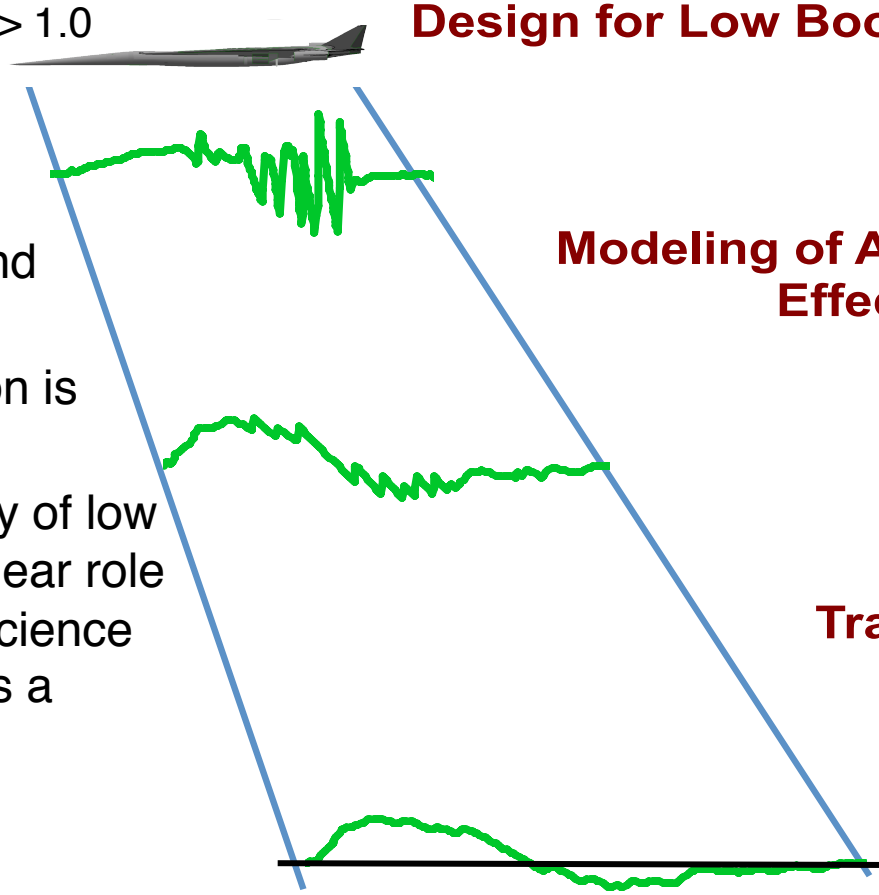
Efficient Operations

- Airspace-Vehicle interaction for full utilization of high speed

Solutions to Barriers Drive the Selection of NASA Research Themes

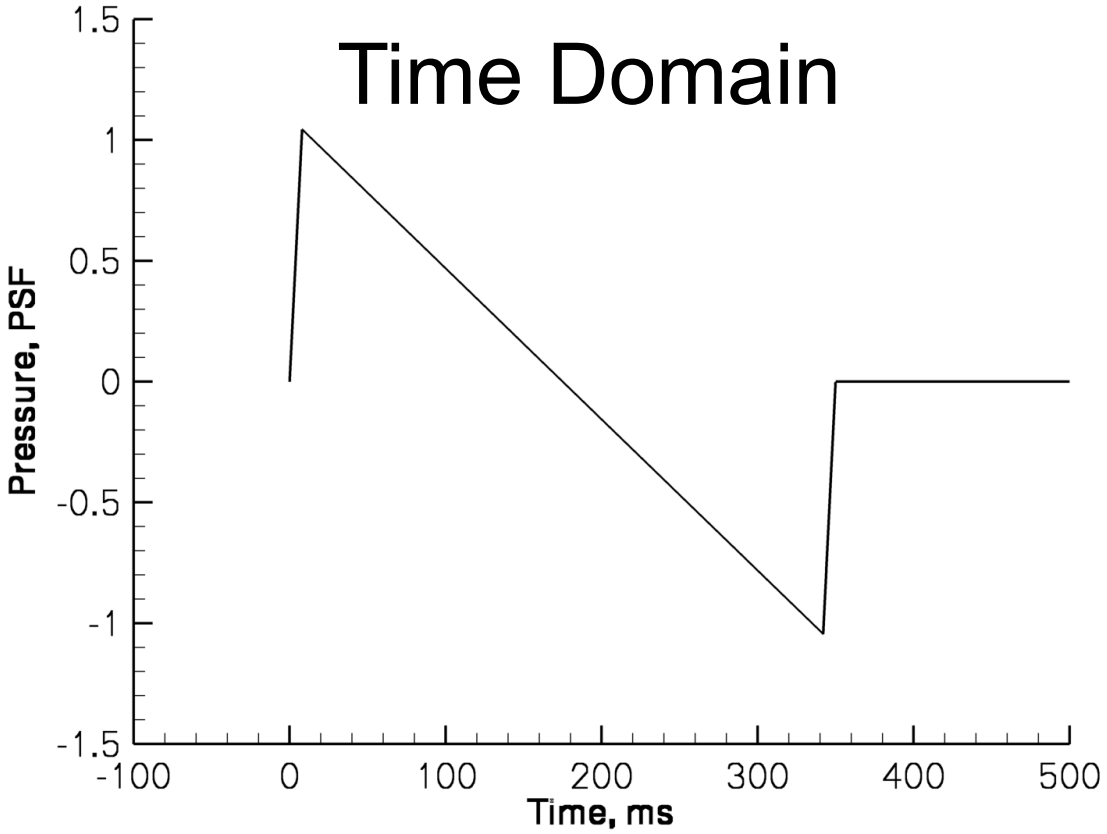
Overland Supersonic Flight

- Most significant barrier to opening new markets for supersonic civil aircraft
  - FAA: No flight at Mach > 1.0
  - ICAO: No sonic boom disturbance
- Rule change driven by improved technology and industry interest
- International cooperation is required
- NASA has a long history of low boom research and a clear role in the technology and science behind a rule change as a national laboratory



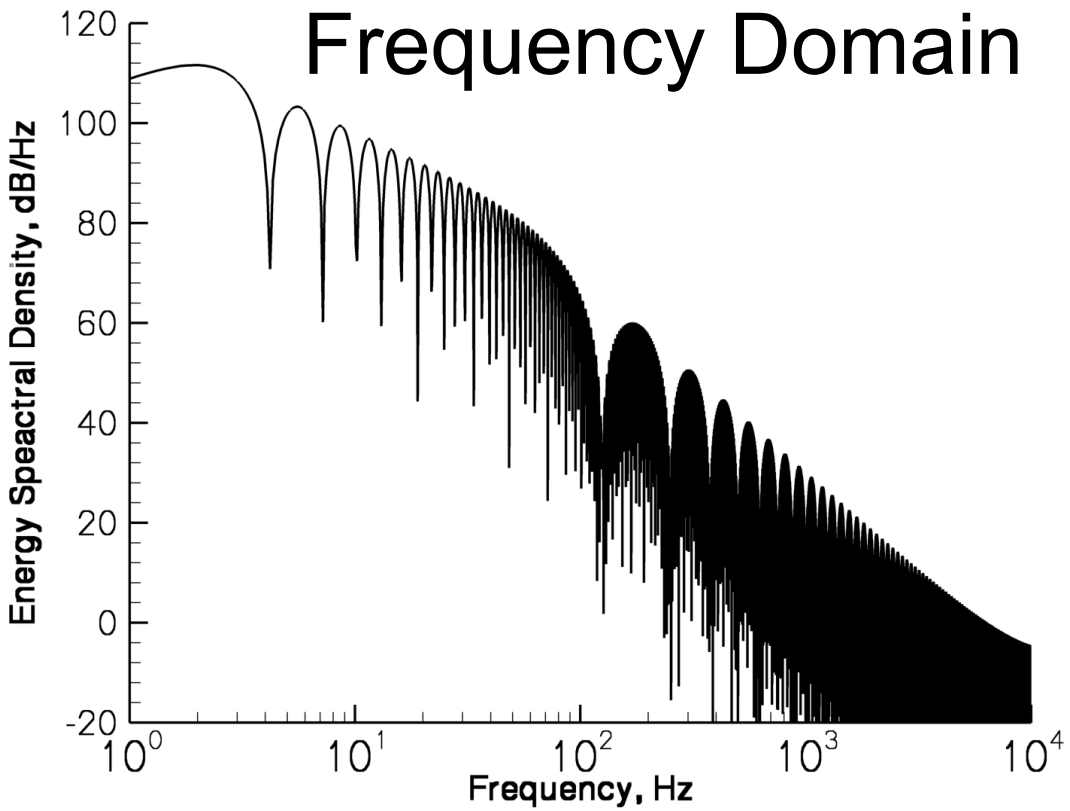
Background on Mitigation

- Sonic waves from existing aircraft coalesce into an N-wave sonic boom
- Durations less than a second
  - Impulsive noise



Background on Mitigation

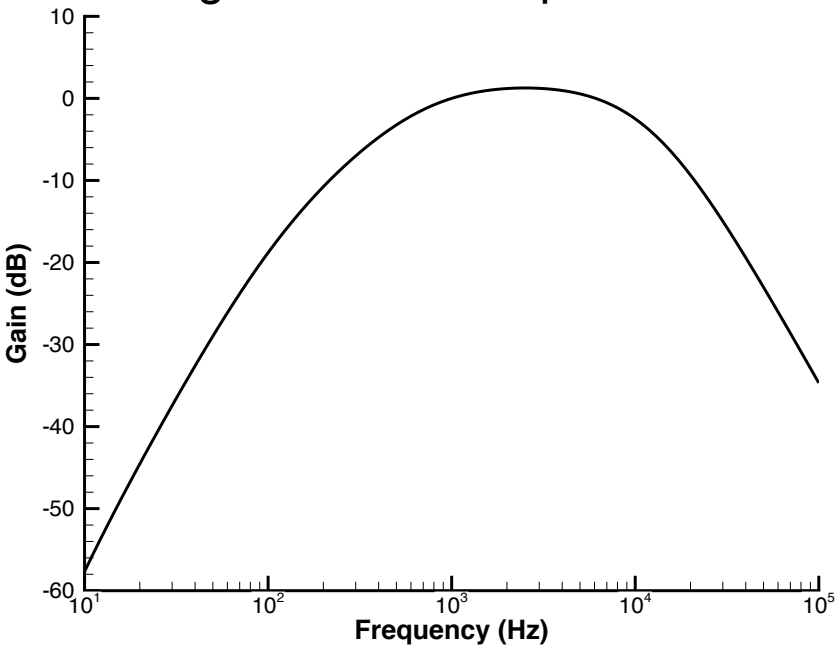
- N-waves have significant energy at frequencies that humans perceive well



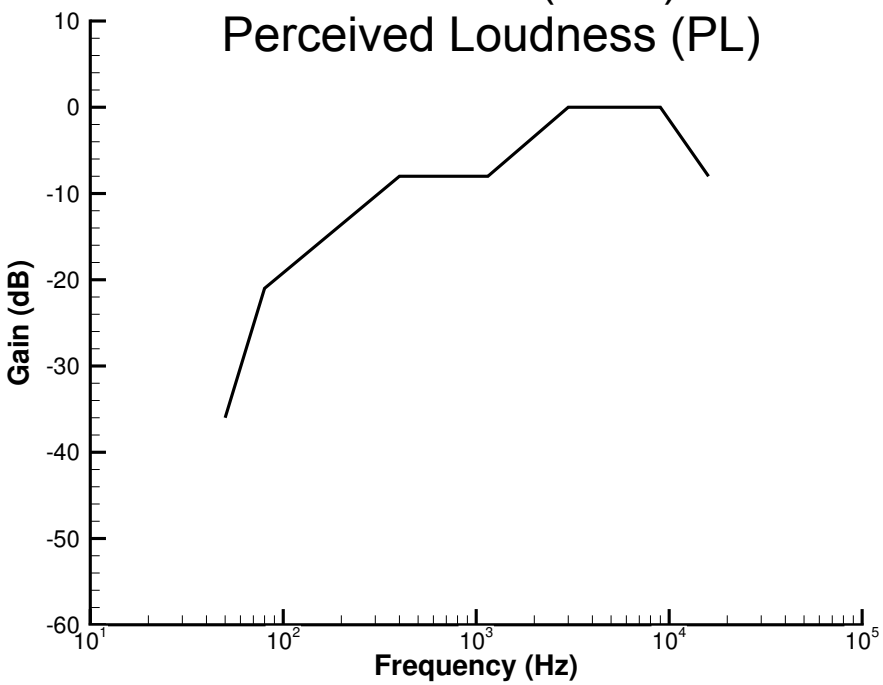
Background on Noise Measures

- Multiple models have been developed and evaluated in experiments
- Humans perceive noises to be louder if they are 600 Hz to 10,000 Hz

A-Weighted Sound Exposure Level

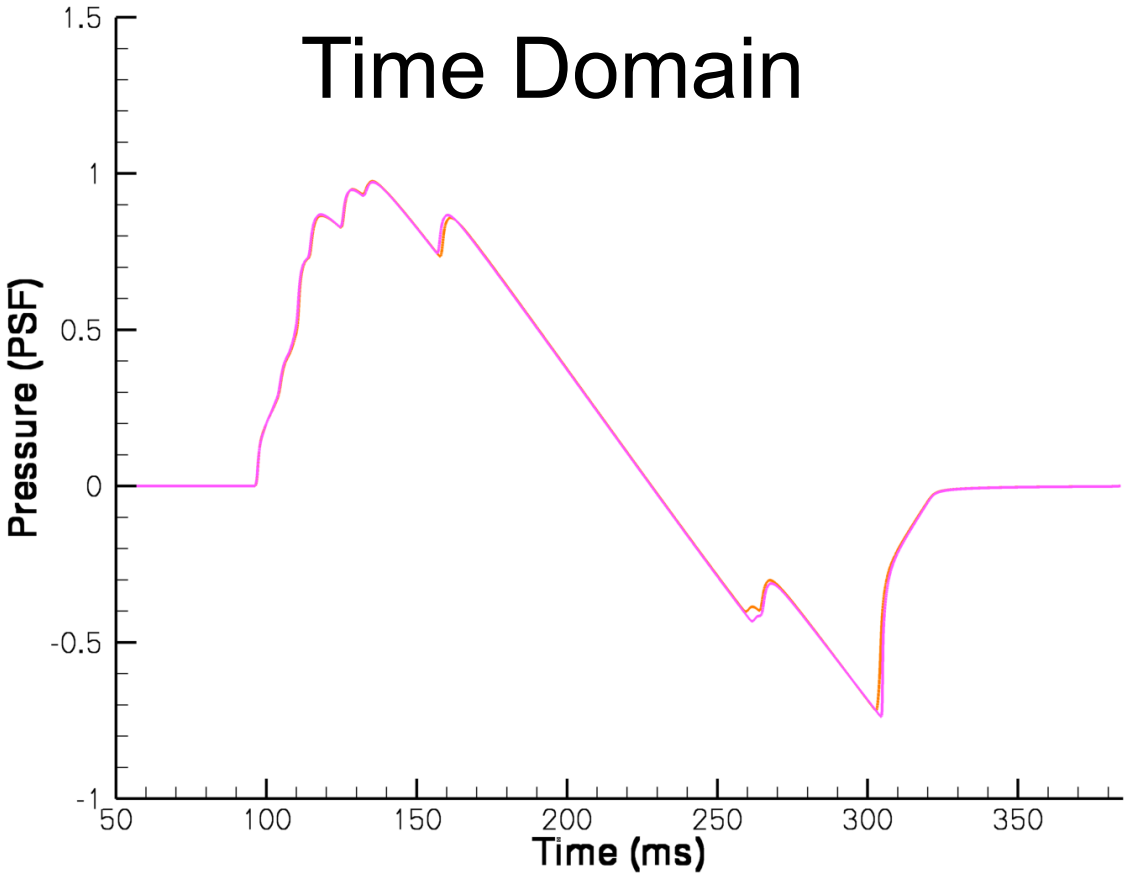


Stevens JASA (1971)
Perceived Loudness (PL)



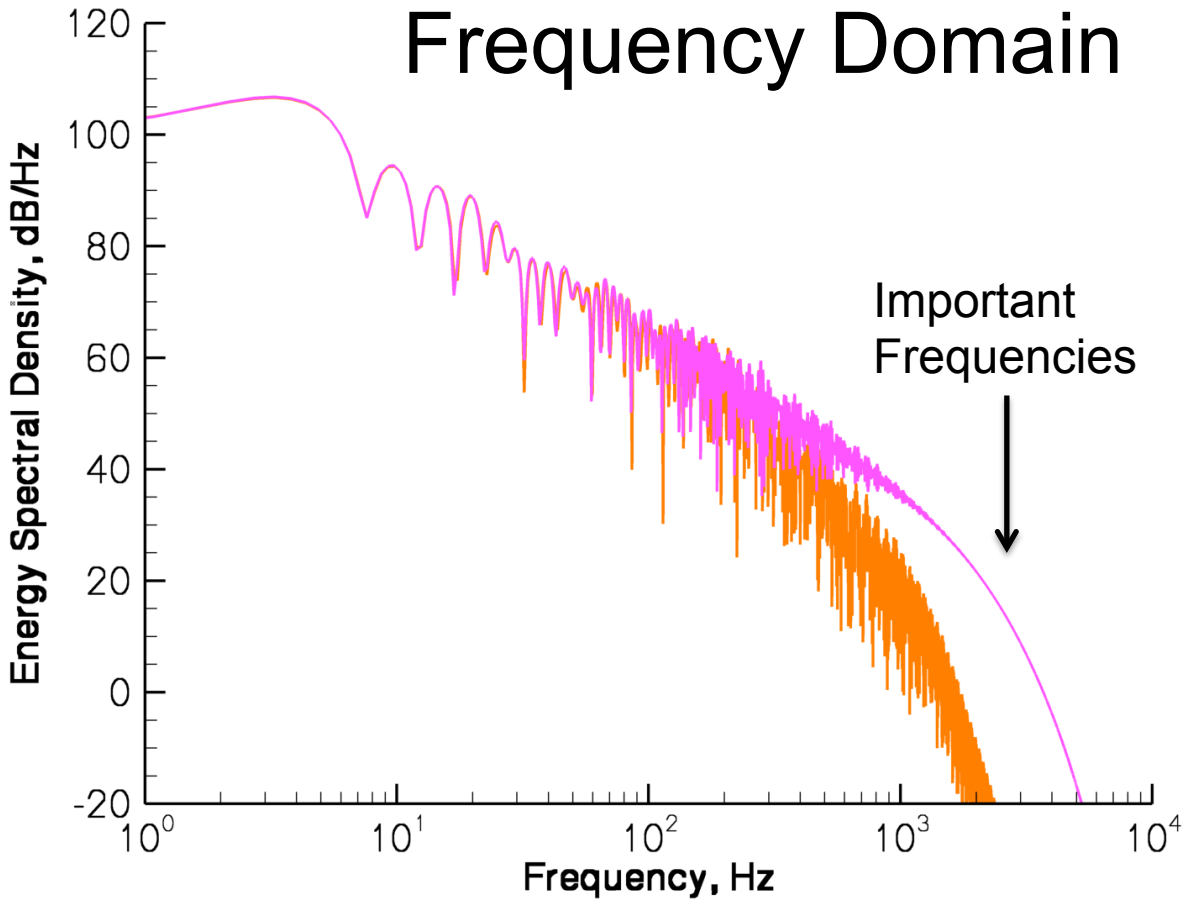
Background on Mitigation

- Current low-boom designs prevent coalescence



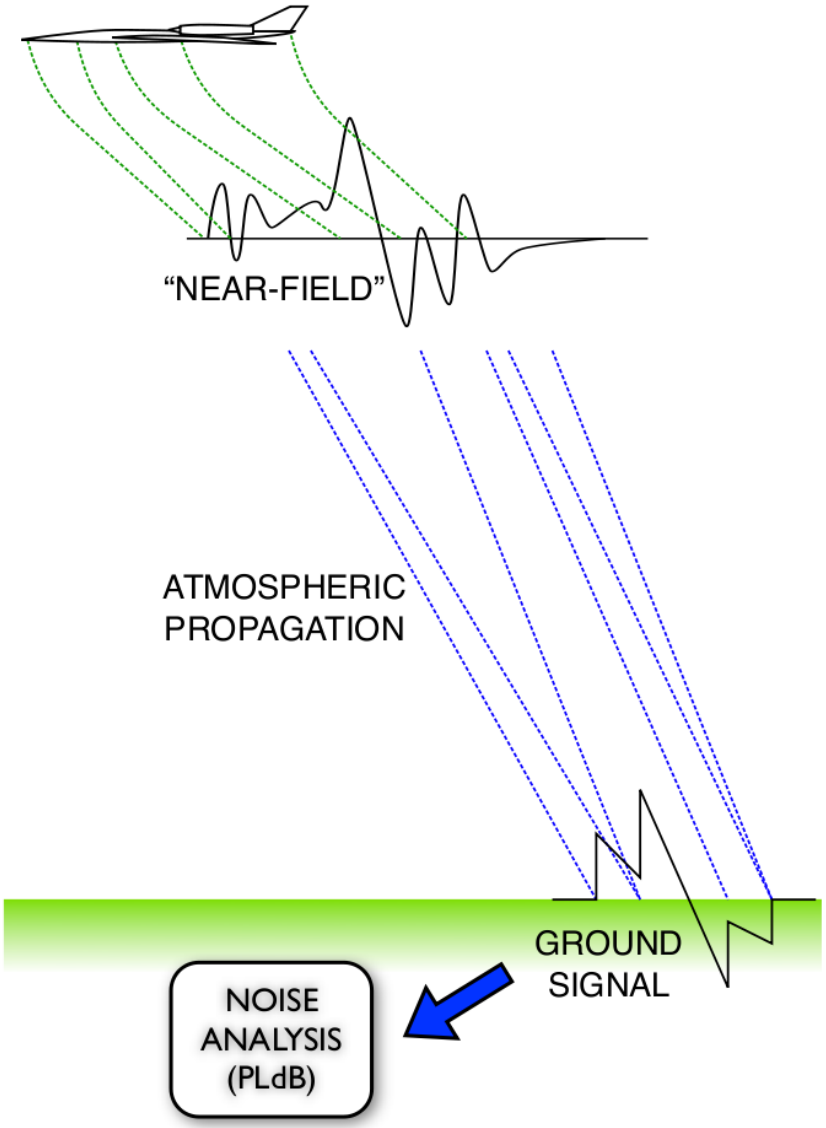
Background on Mitigation

- Which significantly reduce energy at these important frequencies



Prediction of Loudness (Annoyance)

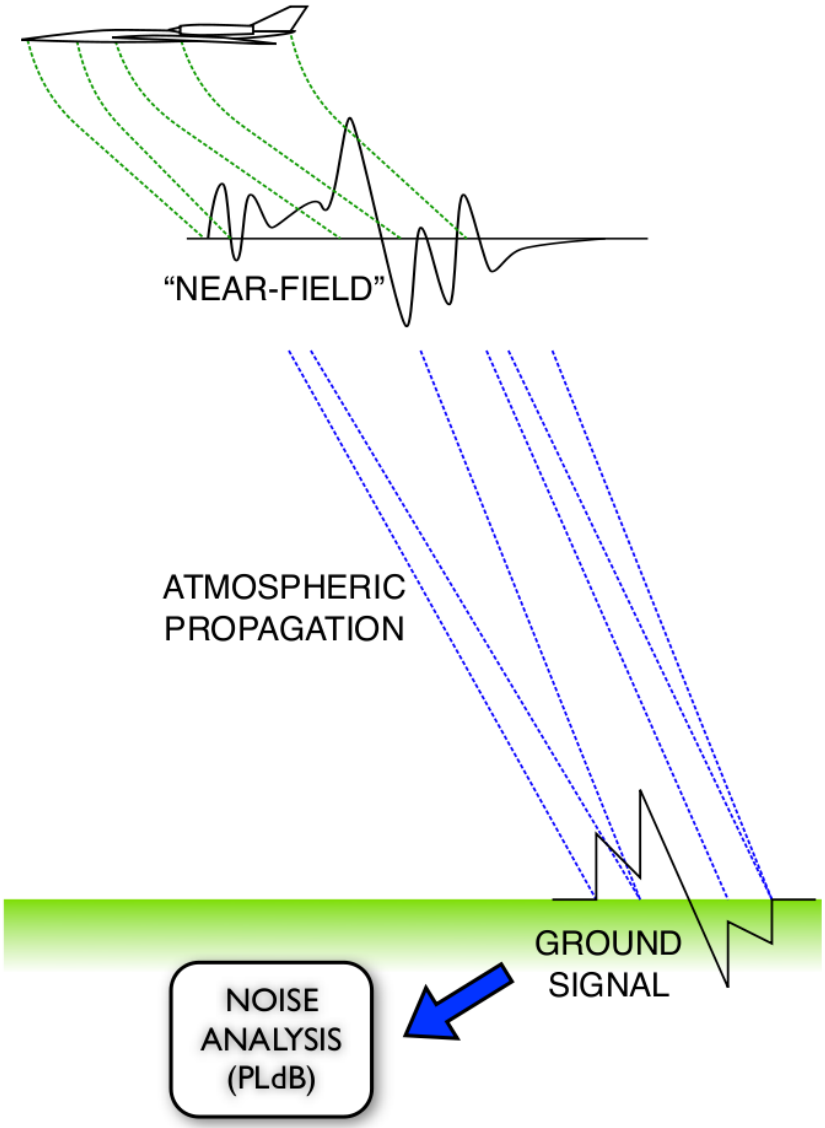
- Generation of the acoustic disturbances
- Propagation through real atmosphere
  - Winds, temperature variation, molecular relaxation, and maneuvering aircraft
- Atmospheric turbulence
- Response of structures (typically below 10 Hz)
- Perception of noise and annoyance correlated to noise measures through experiments



[image: Mathias Wintzer]

First AIAA Sonic Boom Workshop

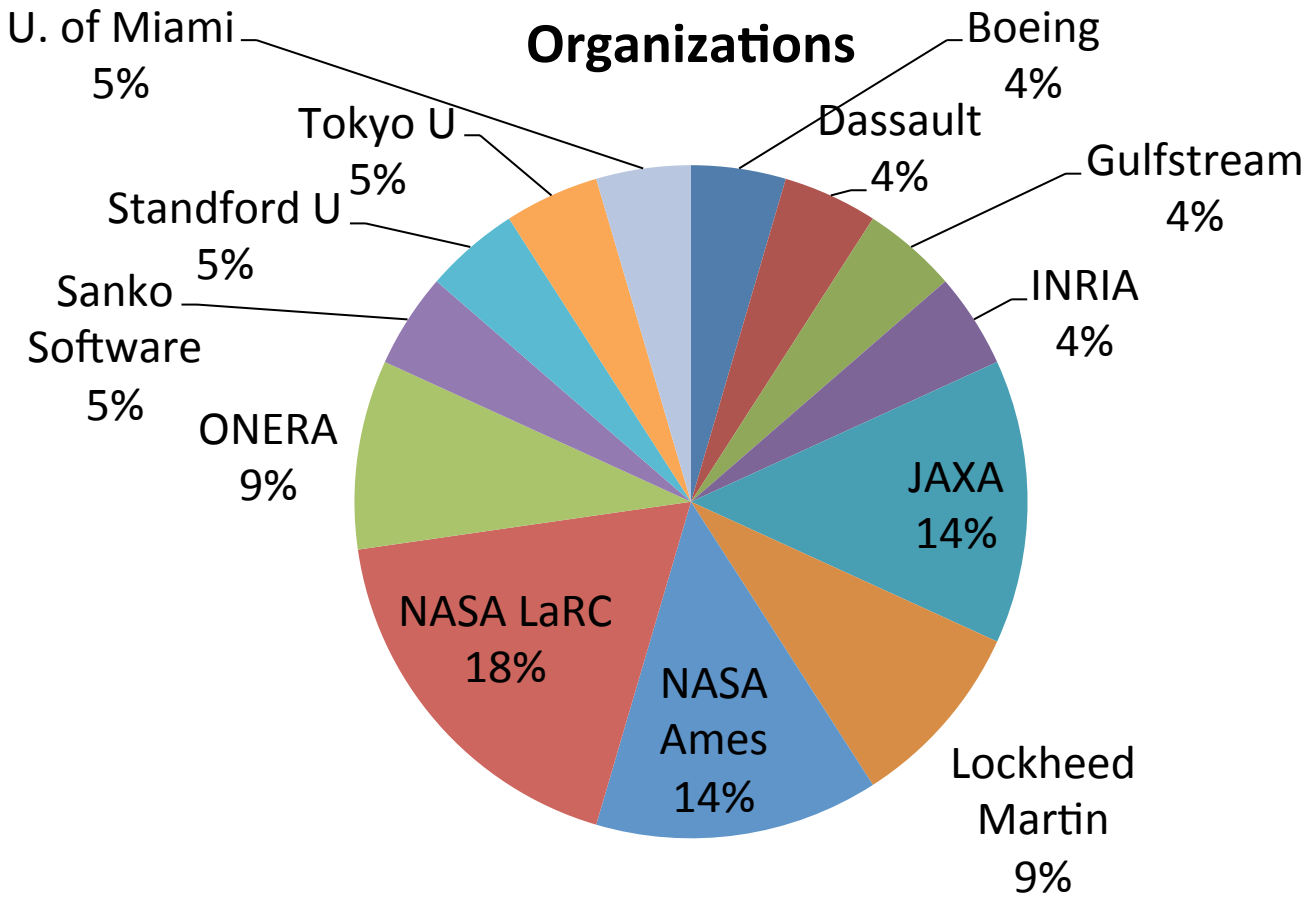
- Assess state-of-the-art near-field CFD as part of sonic boom prediction
- One-day workshop before American Institute of Aeronautics and Astronautics (AIAA) SciTech January 2014 conference
- Impartially compare relevant measures of near-field signatures to each other and wind tunnel measurements
- Following successful AIAA workshop model



[image: Mathias Wintzer]

AIAA Sonic Boom Workshop Participants

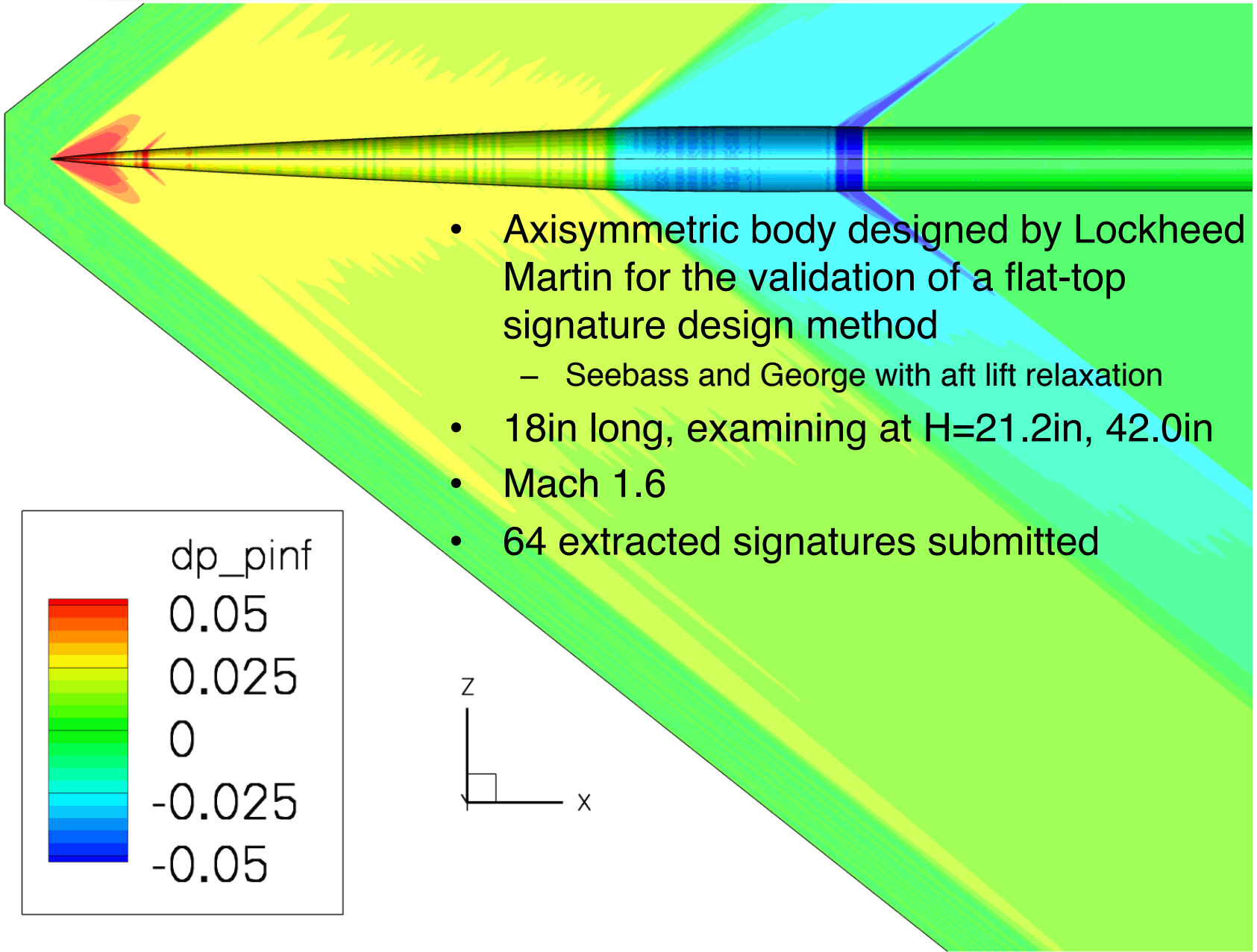
- 19 groups
  - Individuals and collaborations of up to 5 people
  - 13 US, 3 France, and 3 Japan
  - 10 Government, 5 Companies, 4 University



AIAA Sonic Boom Workshop Models

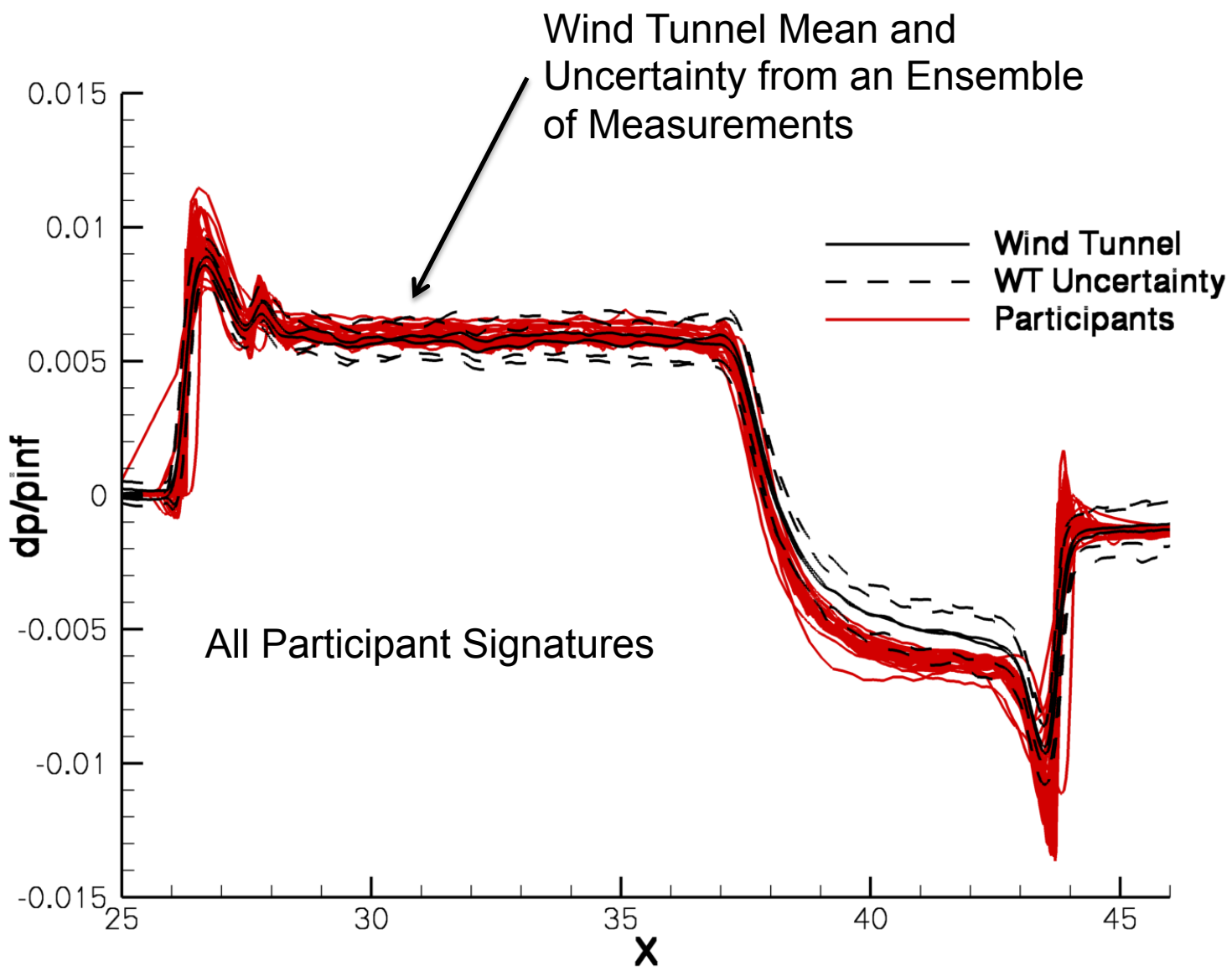
[image: Aftosmis, Nemec AIAA-2014-558]

SEEB-ALR Near-Field Pressure

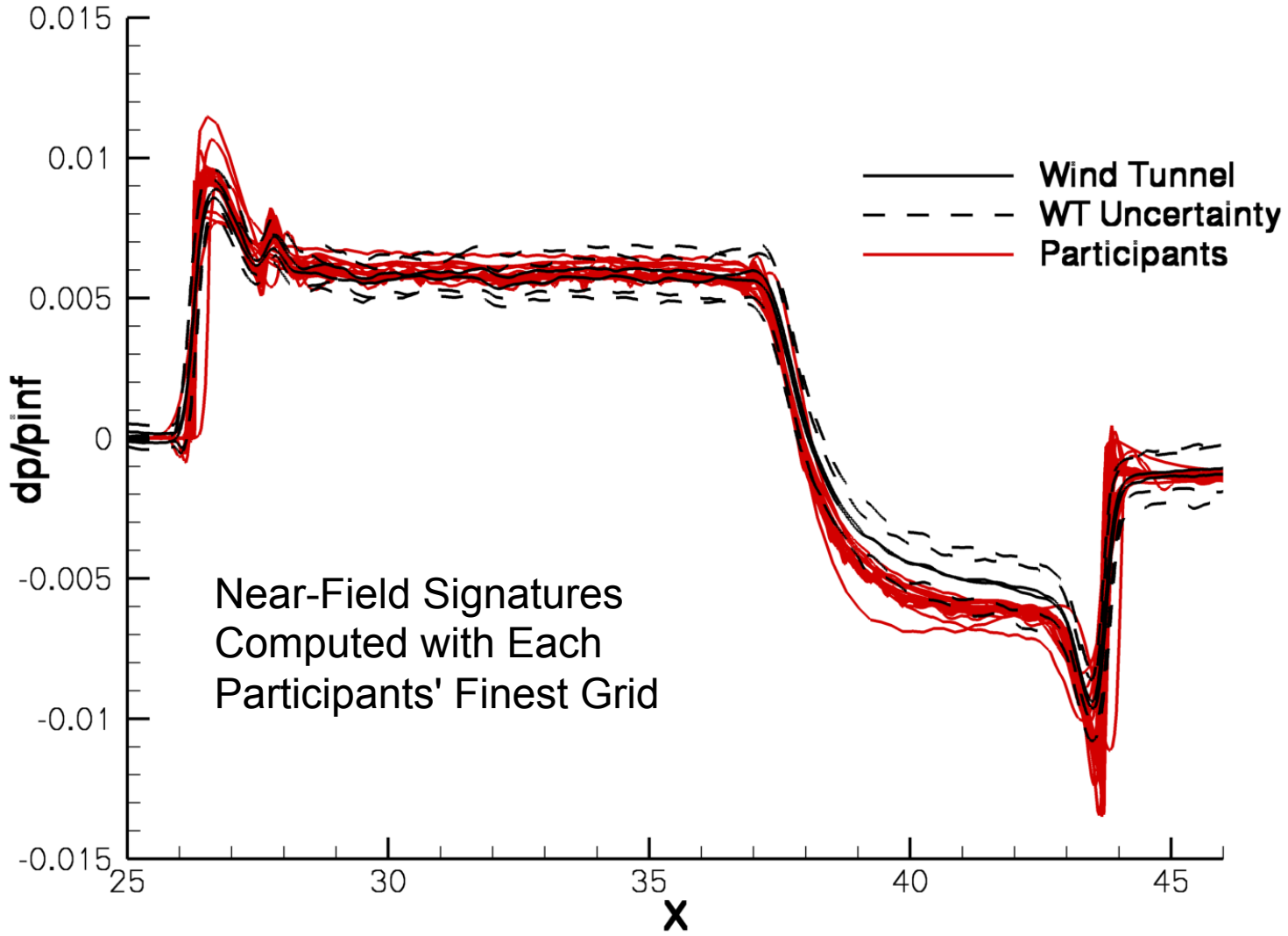


- Axisymmetric body designed by Lockheed Martin for the validation of a flat-top signature design method
  - Seebass and George with aft lift relaxation
- 18in long, examining at H=21.2in, 42.0in
- Mach 1.6
- 64 extracted signatures submitted

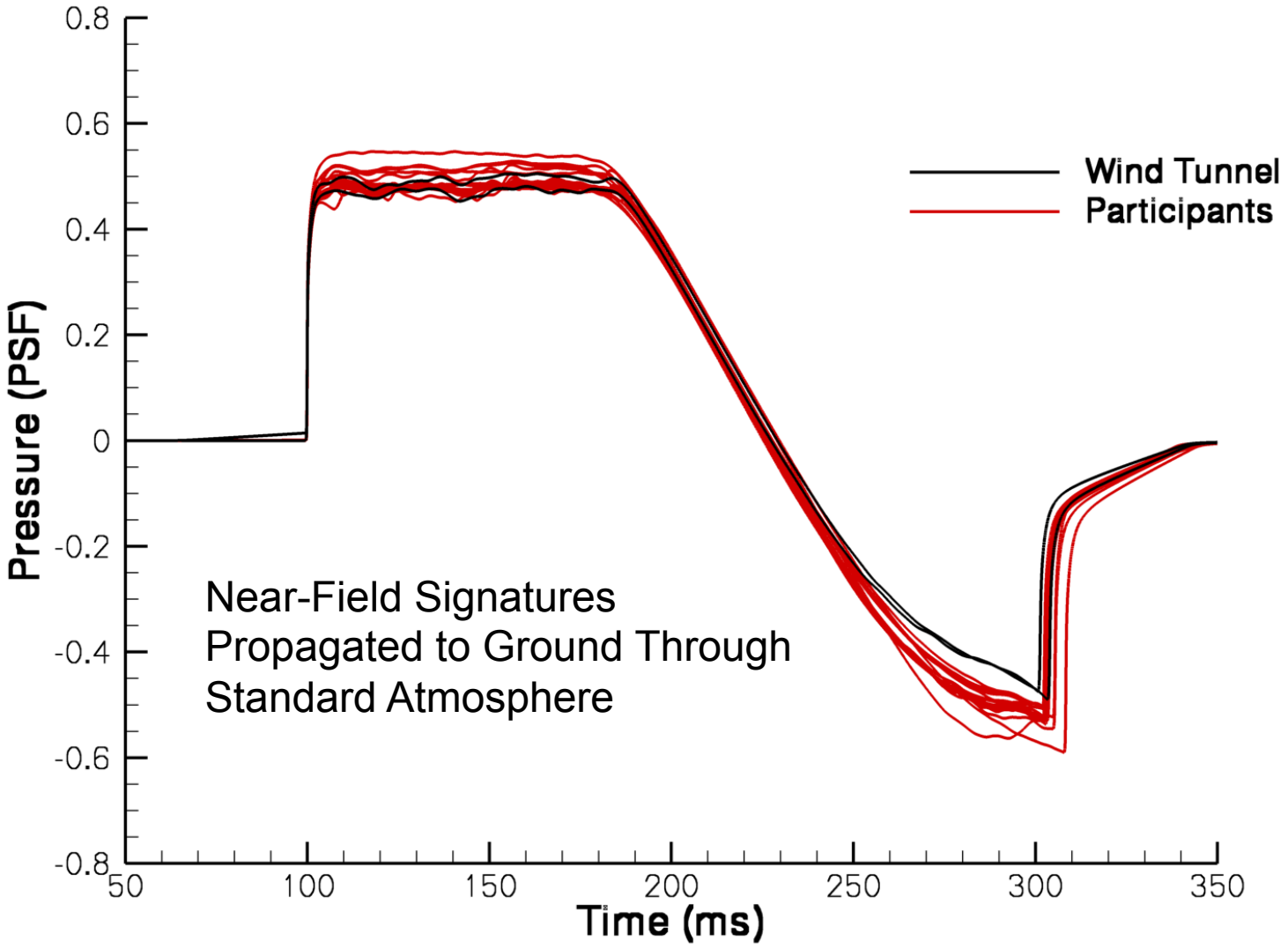
All SEEB-ALR Near-Field Signatures



Fine-Grid SEEB-ALR Near-Field Signatures



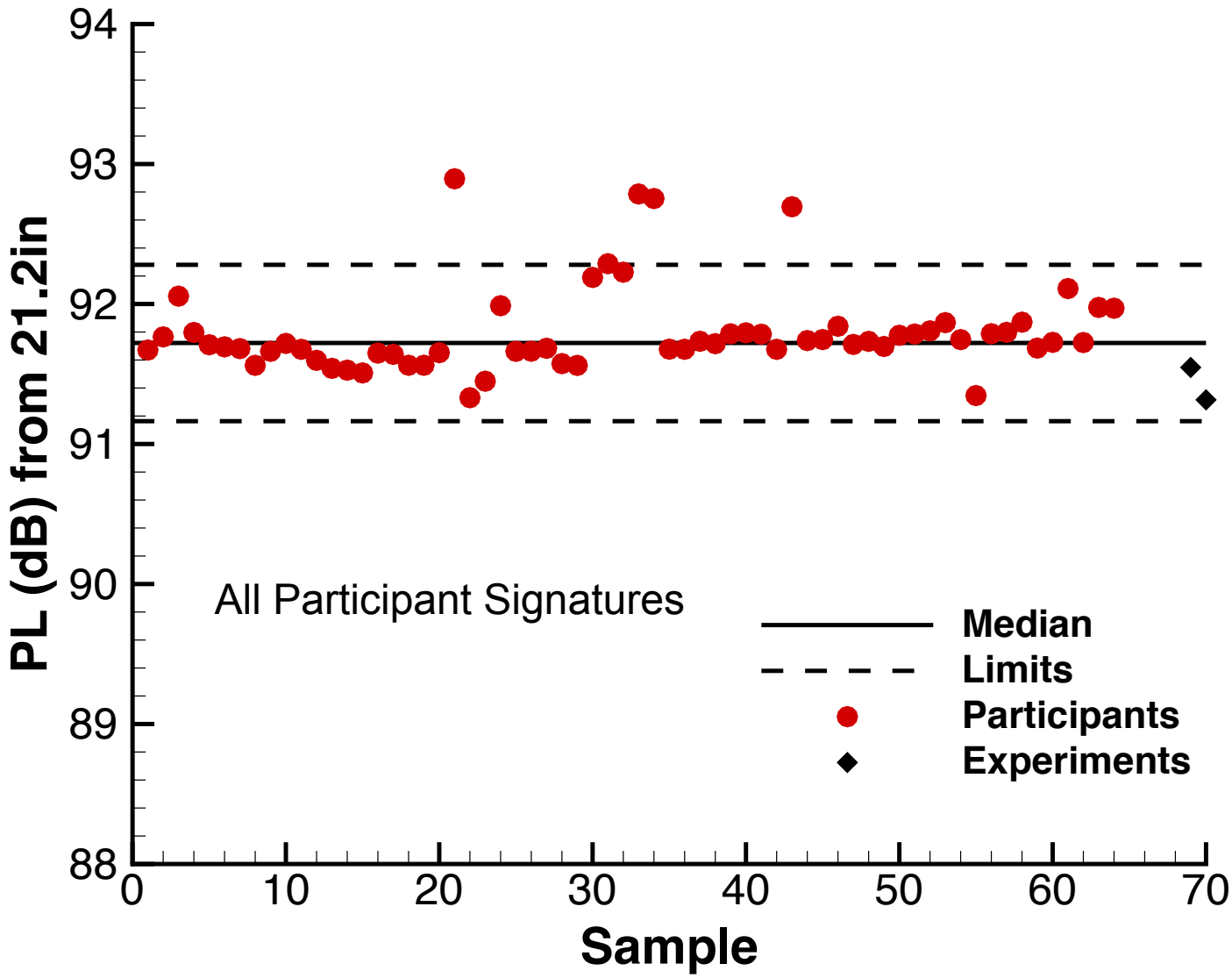
Fine-Grid SEEB-ALR Ground Signatures



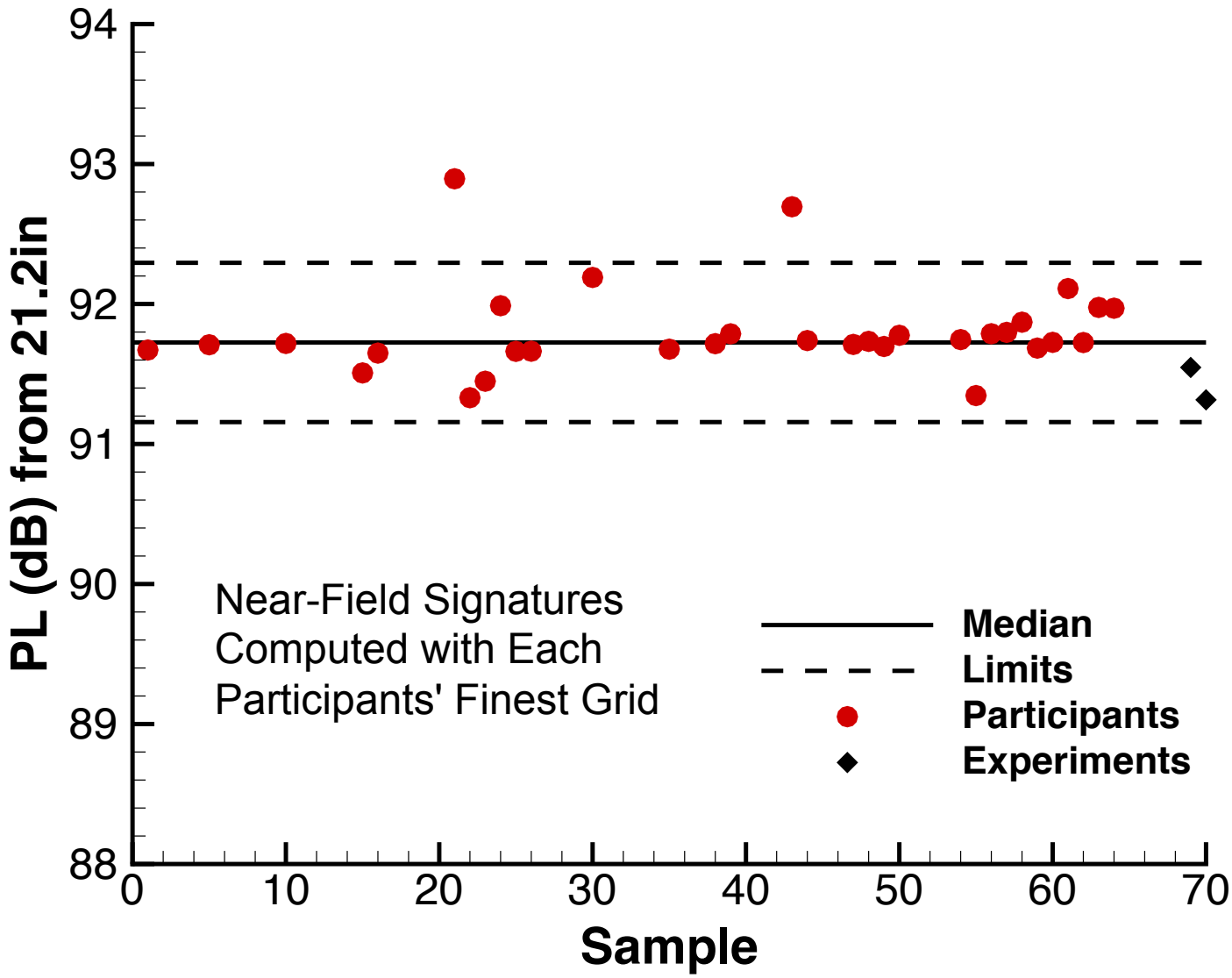
Statistical Method

- Goal is to identify “different” results, not “correct” or “wrong”
- Median +/- (1.7 coverage factor)*(standard deviation)
  - Assume a uniform distribution
- Small sample size with correlated results (same person, same code, different grid)
- Used by other AIAA workshops (e.g., Drag Prediction, High Lift)

All SEEB-ALR Perceived Level

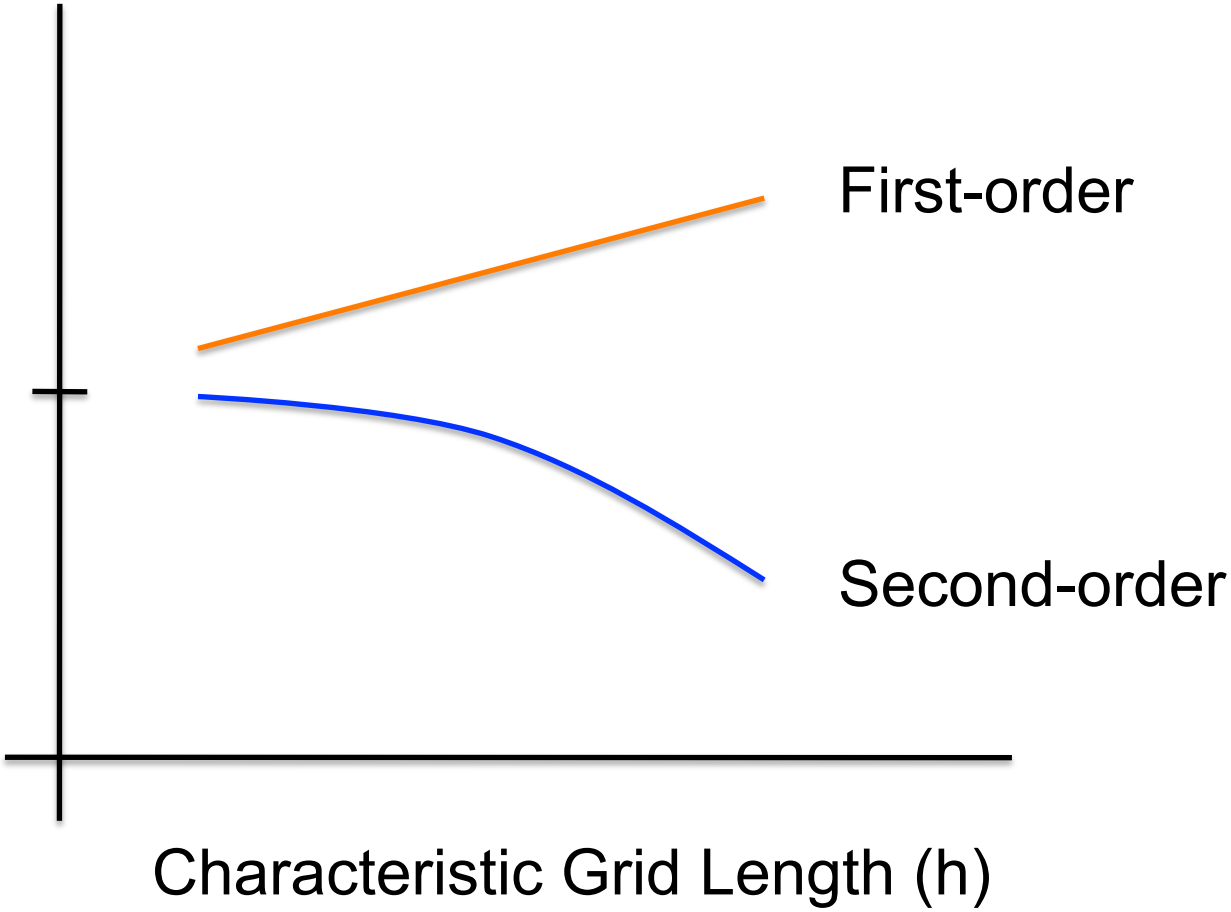


Finest-Grid SEEB-ALR Perceived Level

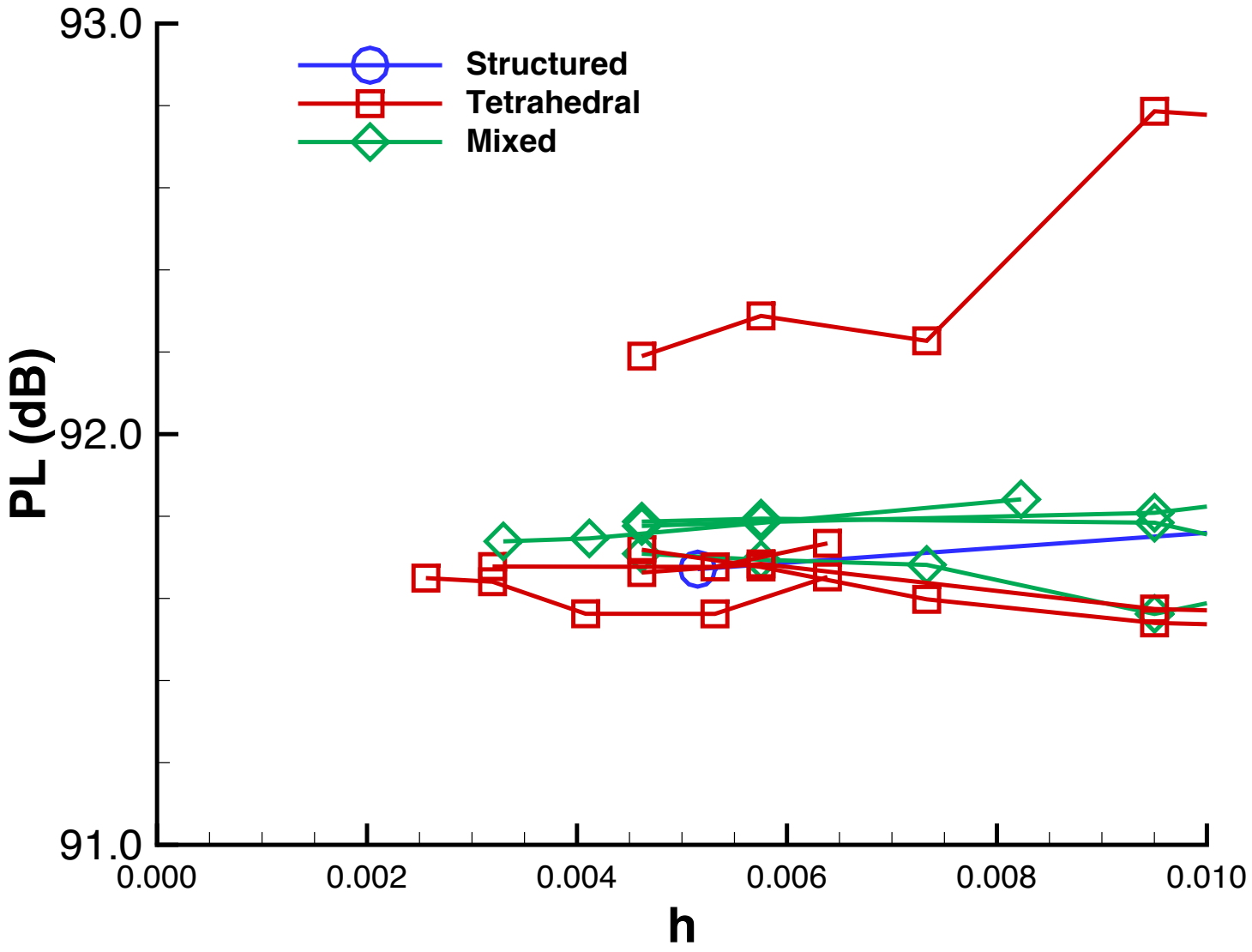


Expected Grid Convergence

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

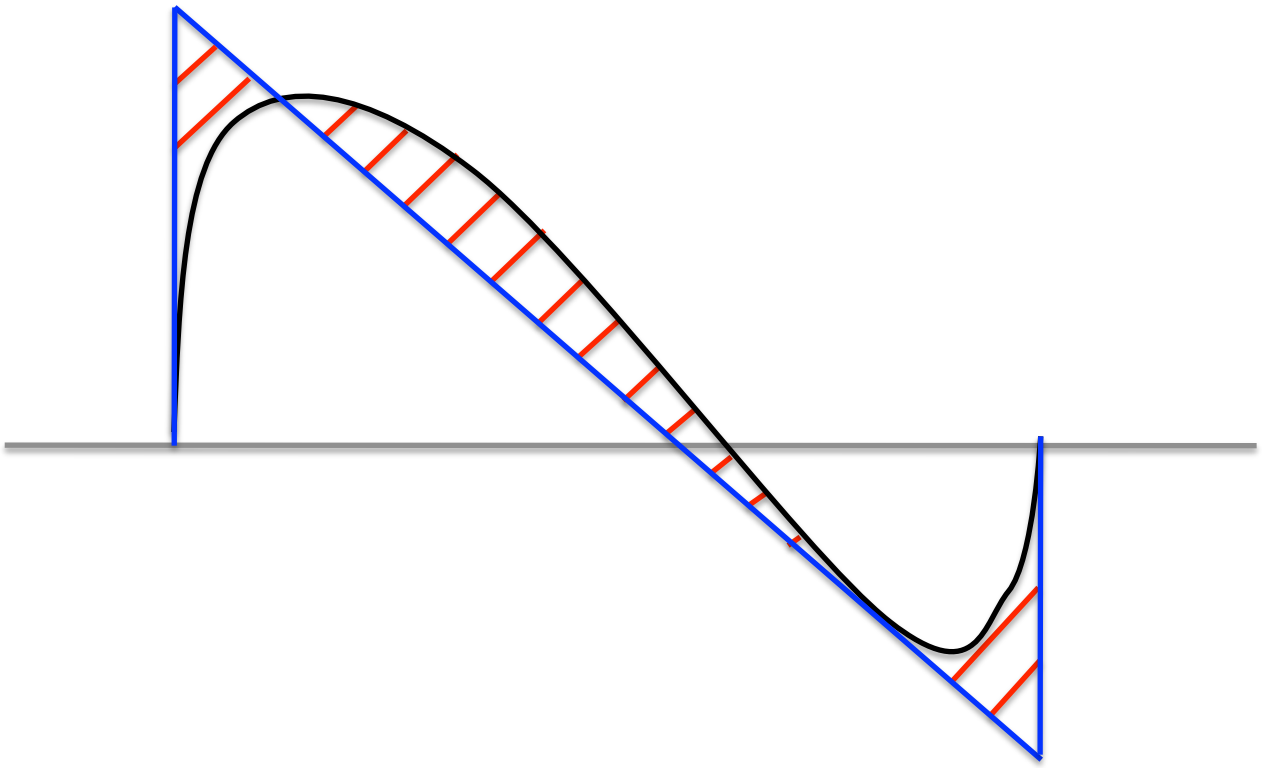


SEEB-ALR Perceived Level Grid Convergence

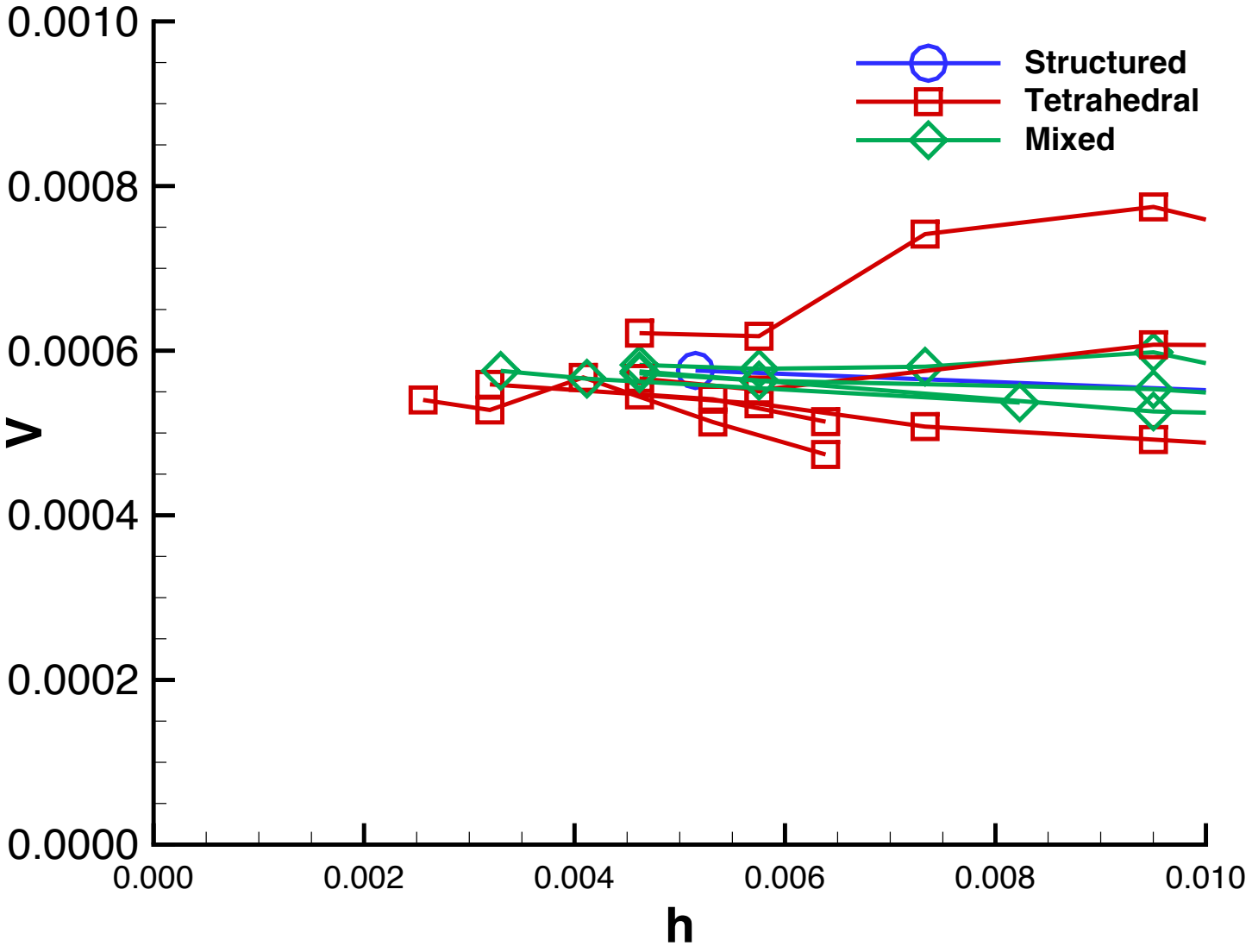


Validation Metric

- 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



SEEB-ALR Validation Metric

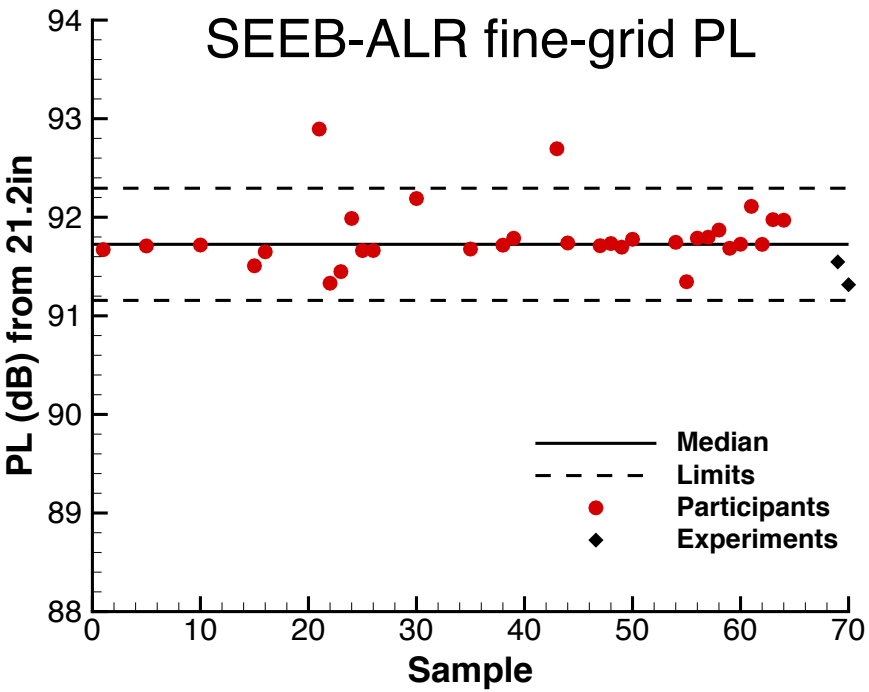


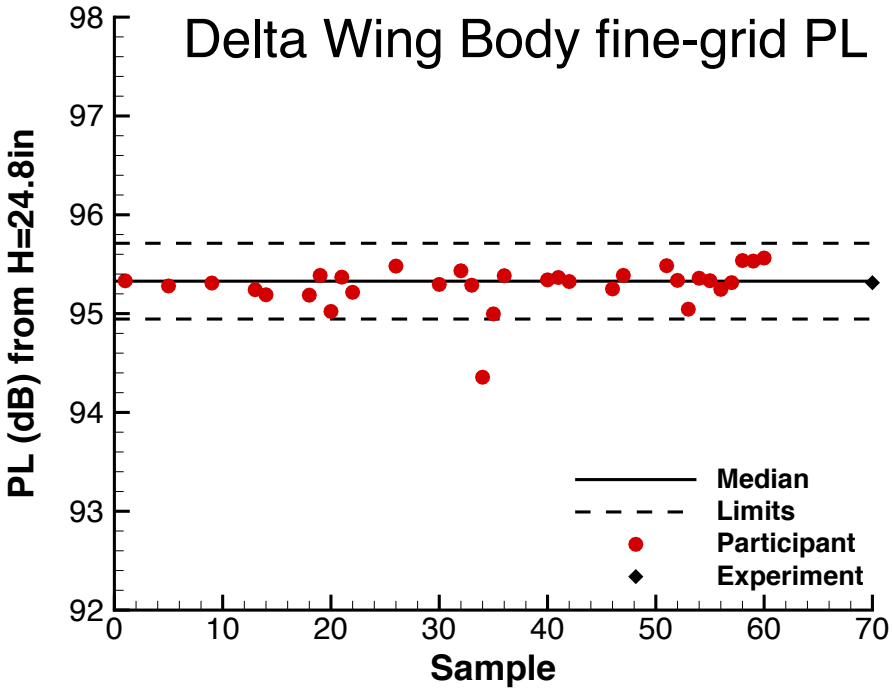
AIAA Sonic Boom Workshop Models

[image: Aftosmis, Nemec AIAA-2014-558]

Delta Wing Body

- Very similar statistics to the SEEB-ALR
- Uniform grid refinement did not converge to as tight a range
  - Stronger stocks





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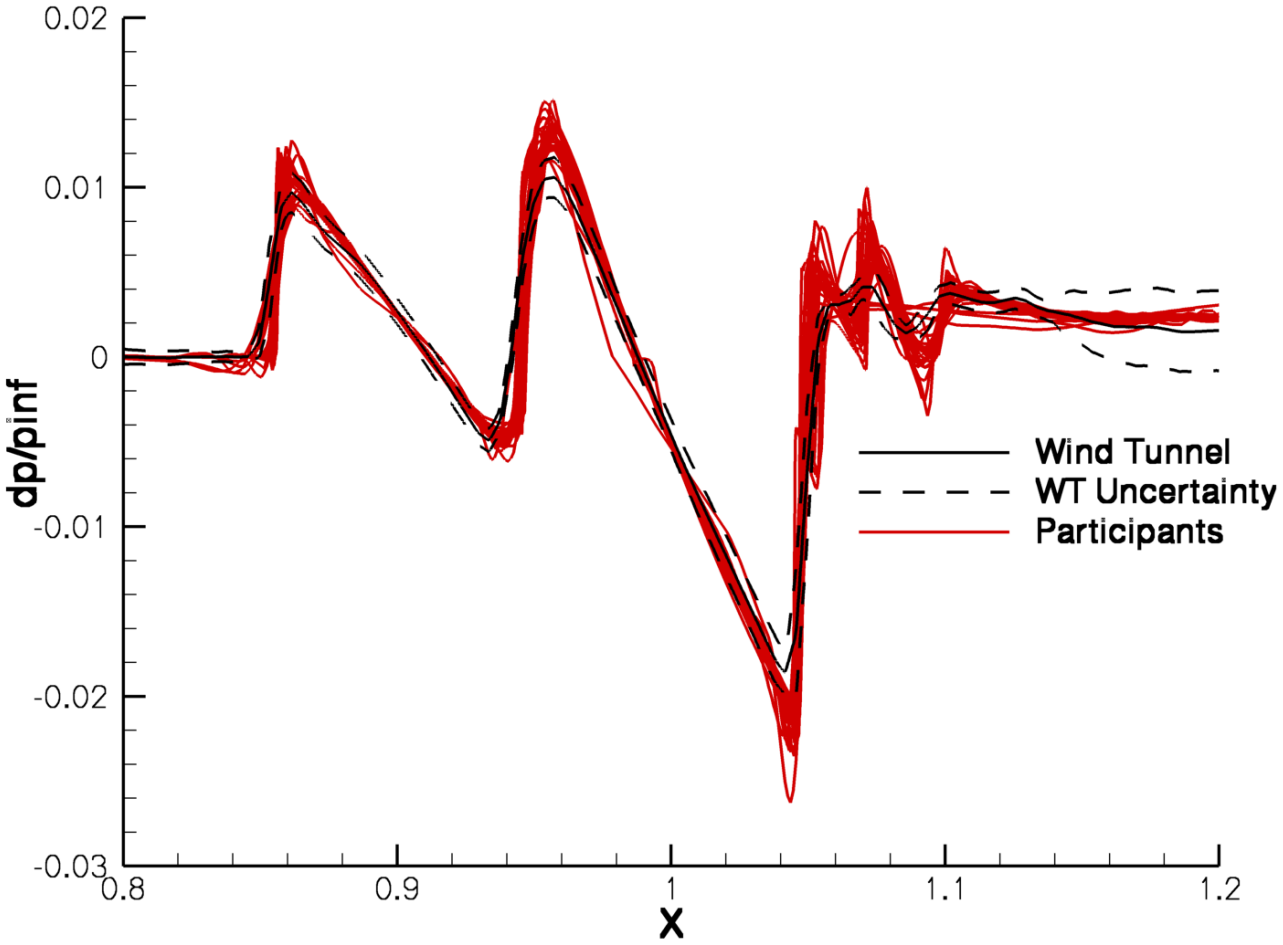


AIAA Sonic Boom Workshop Models

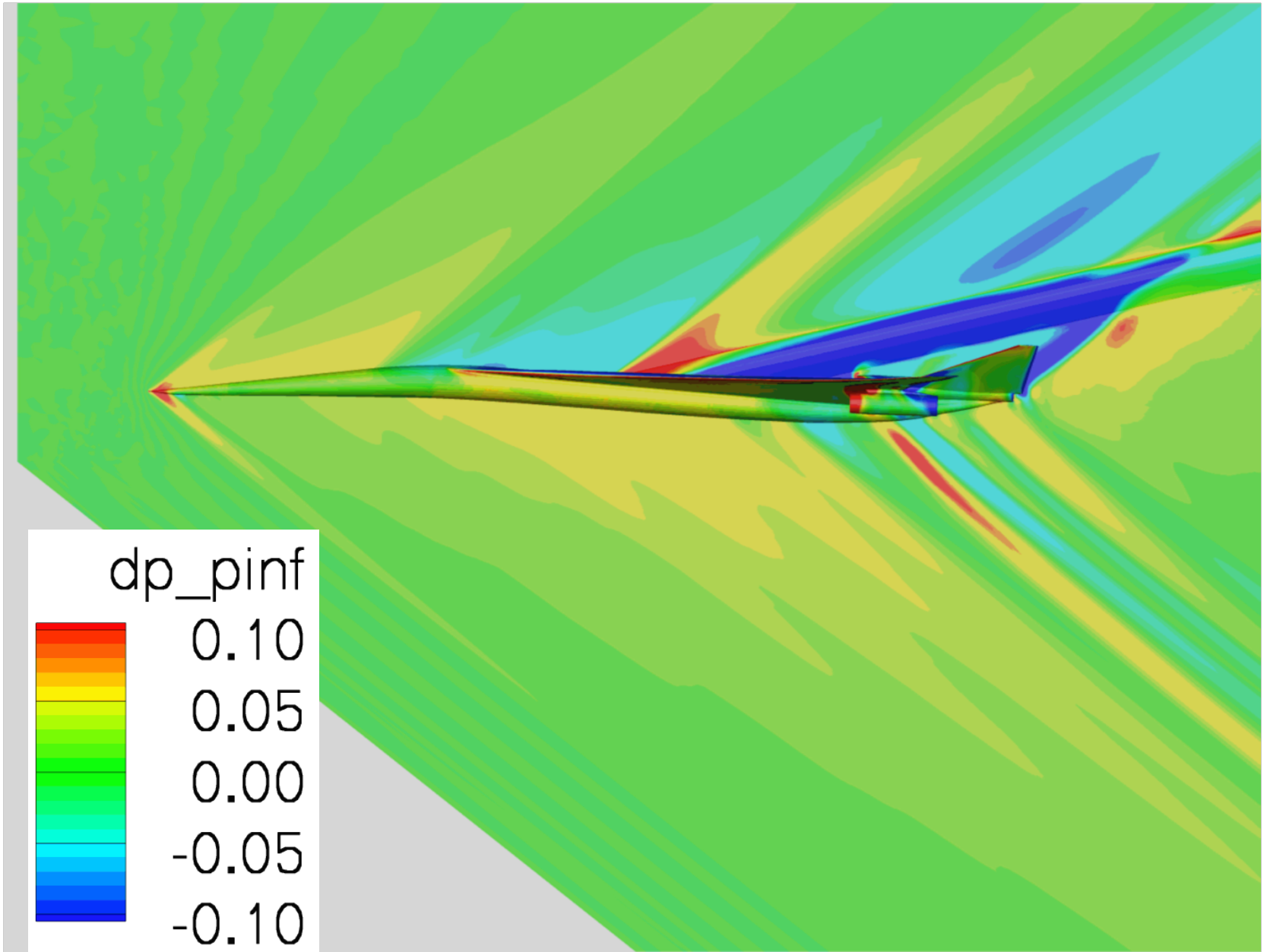
[image: Aftosmis, Nemec AIAA-2014-558]

LM1021 (Lockheed-Martin)

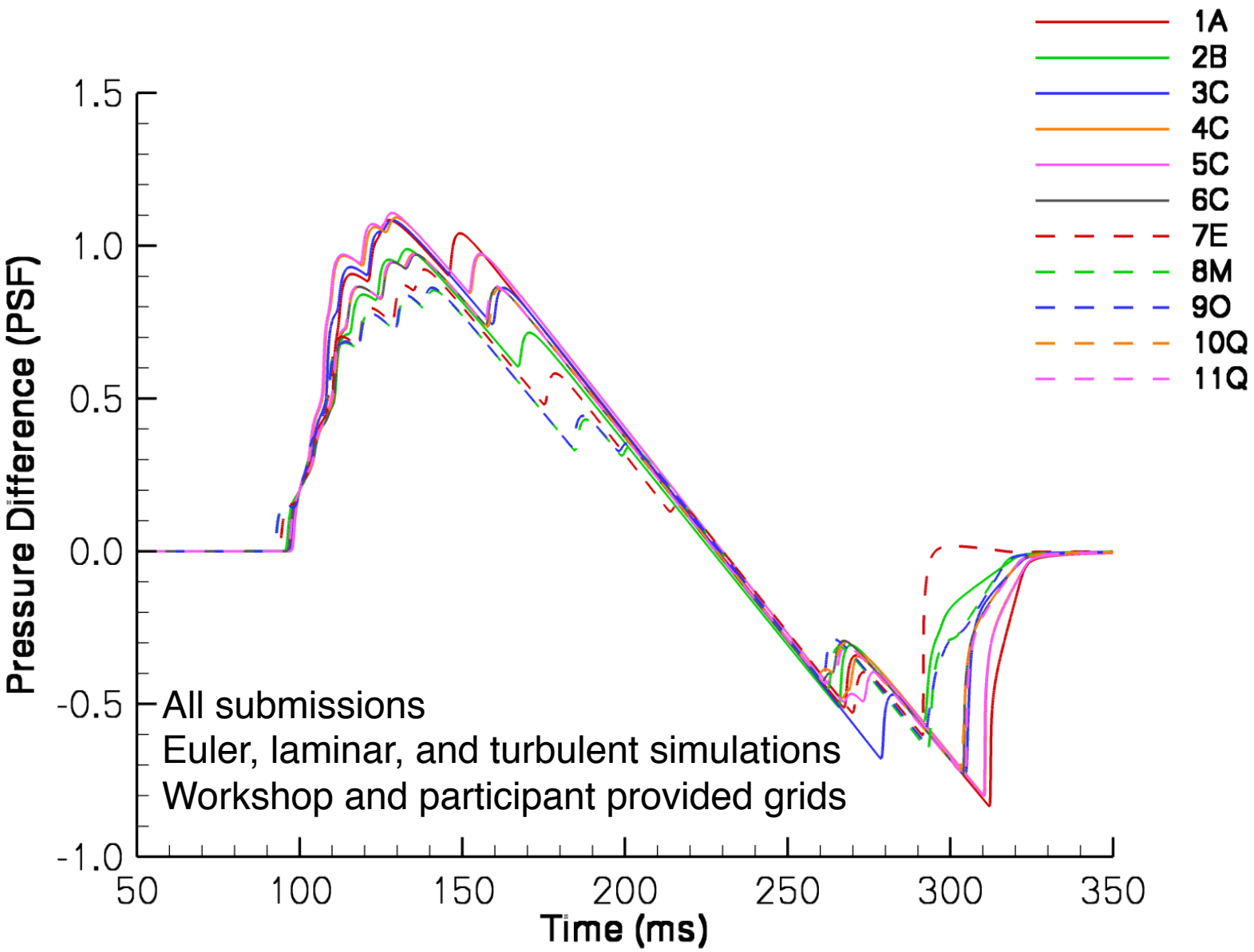
- Developed for NASA by Lockheed-Martin under contract
- Complex configuration with wing, body, tails, and nacelles examined at 2.1 degree angle of attack
- 22.4in long, 4in half span
- Mach 1.6
- Wind tunnel Reynolds number and blade sting mount increase loudness
  - Full-scale free-flight has a typical carpet of 85 PL (dB)
- 11 sets of extracted signatures (optional case)

[image: Cliff, et al.]

LM1021 Pressure on Centerline

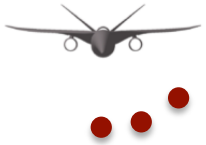


LM1021 Ground, R/(b/2)=7.9, Centerline

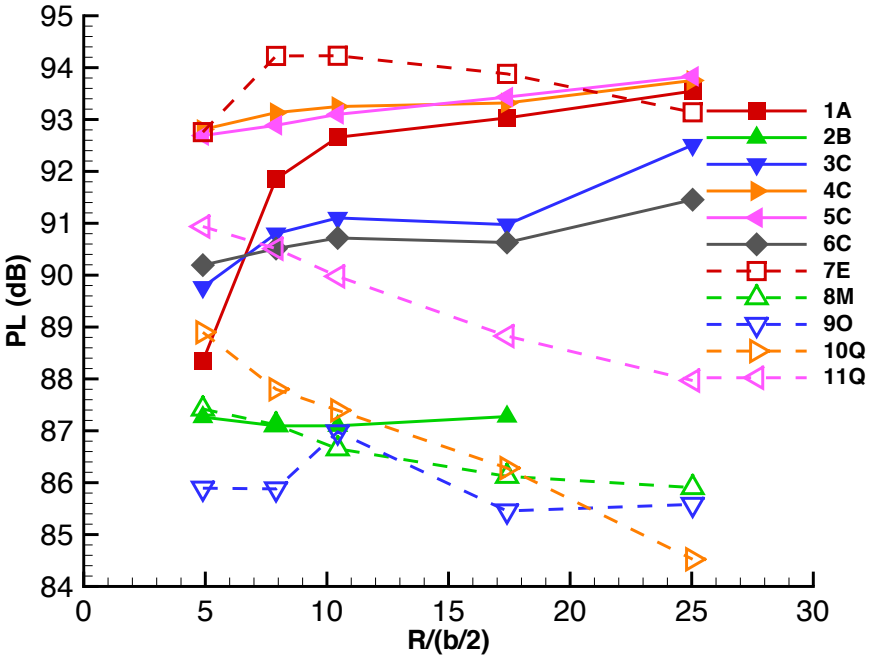


LM 1021 Background and Motivation

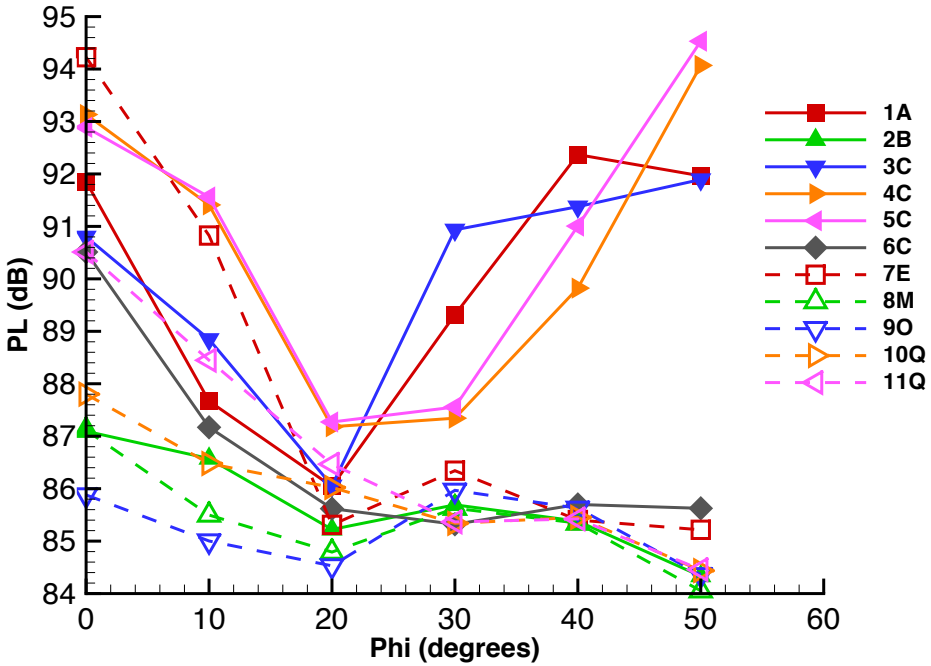
PL extracted at different H/L



PL extracted at different phi



At centerline

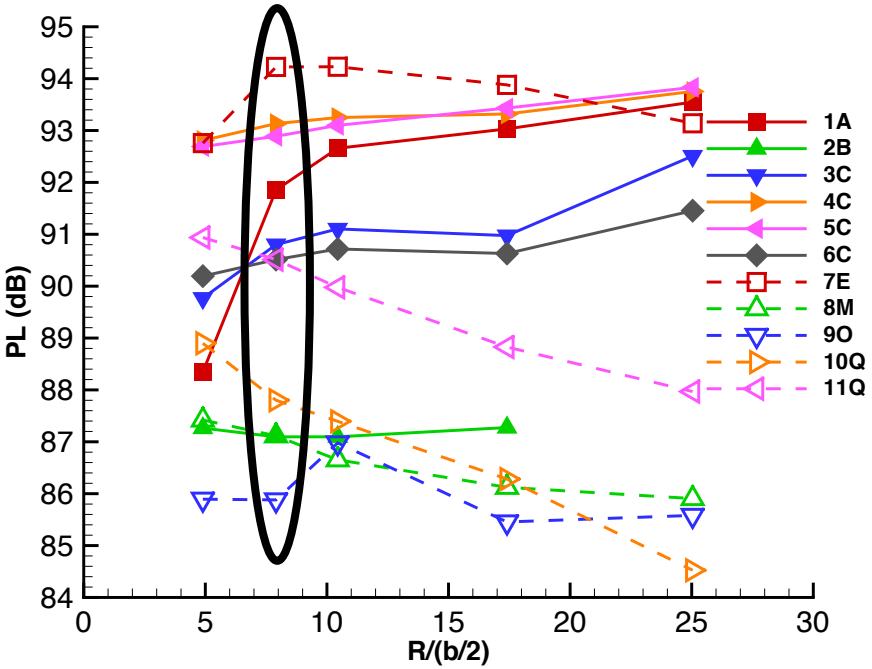


From R/(b/2)=7.9

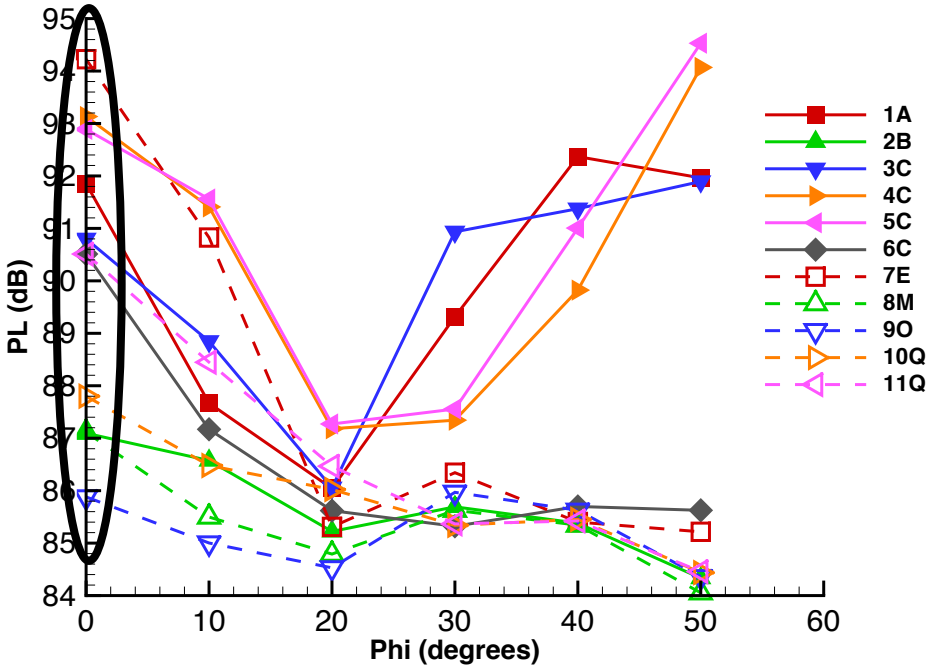
LM 1021 Background and Motivation

PL extracted at different H/L

PL extracted at different phi



At centerline

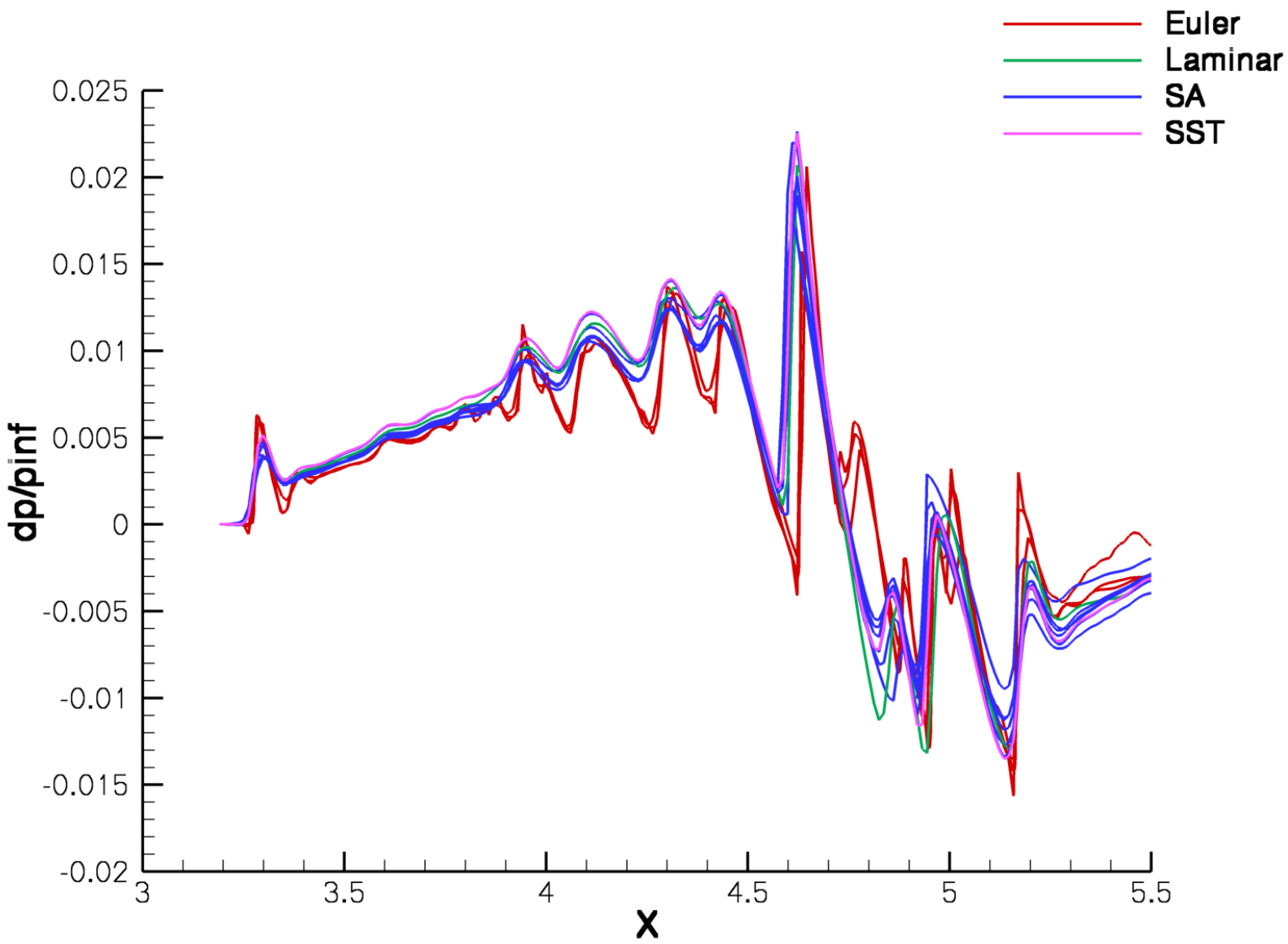


From R/(b/2)=7.9

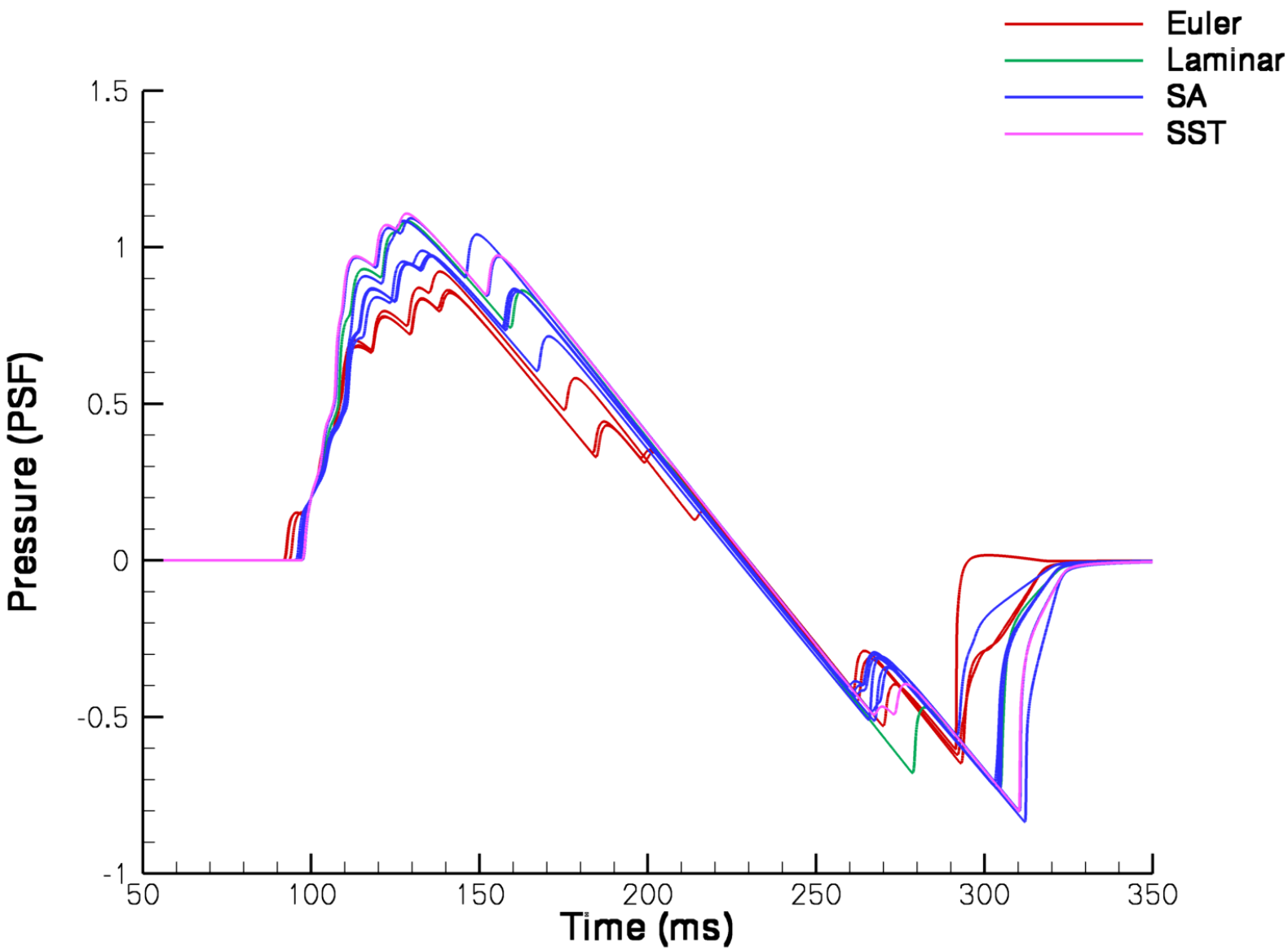
Examine Size of Variation Sources

- Physical model
- Far-field multipole correction
- Signature close-out reconstruction
- Contribution of each shock (i.e., nose and tail shocks)
- Extraction distance
- Off-track

LM1021 Signatures, R/(b/2)=7.9, Centerline

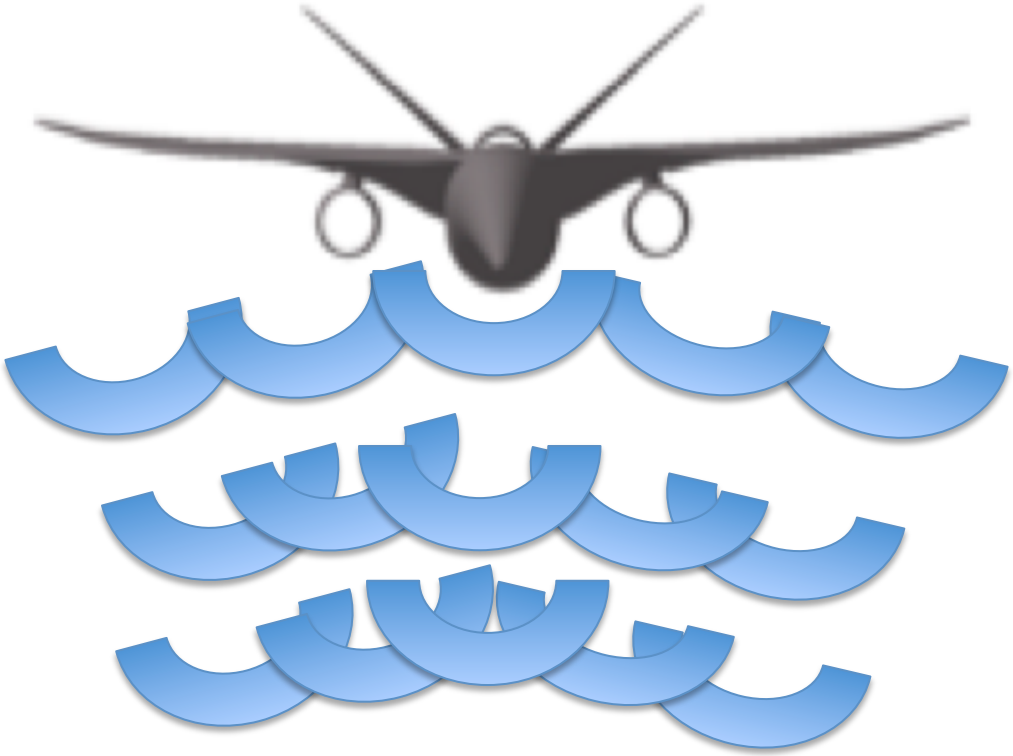


LM1021 Ground, R/(b/2)=7.9, Centerline



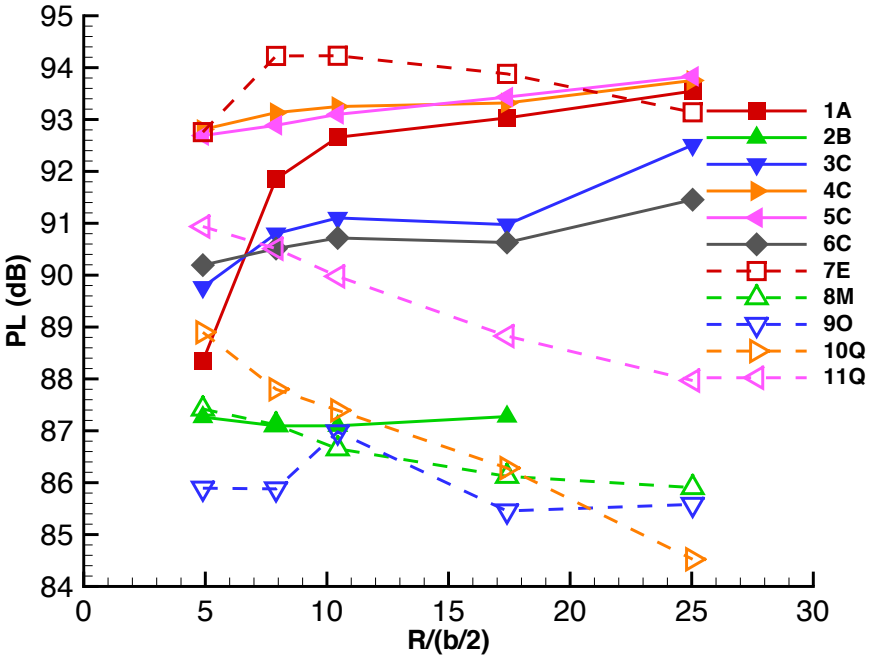
Multipole Far-Field Correction

- Page and Plotkin AIAA-91-3275
- Corrects for diffraction of acoustic sources in span wise direction
  - Mitigate sampling near-field pressure too close to the configuration
  - Correction is configuration dependent and decreases to zero with distance

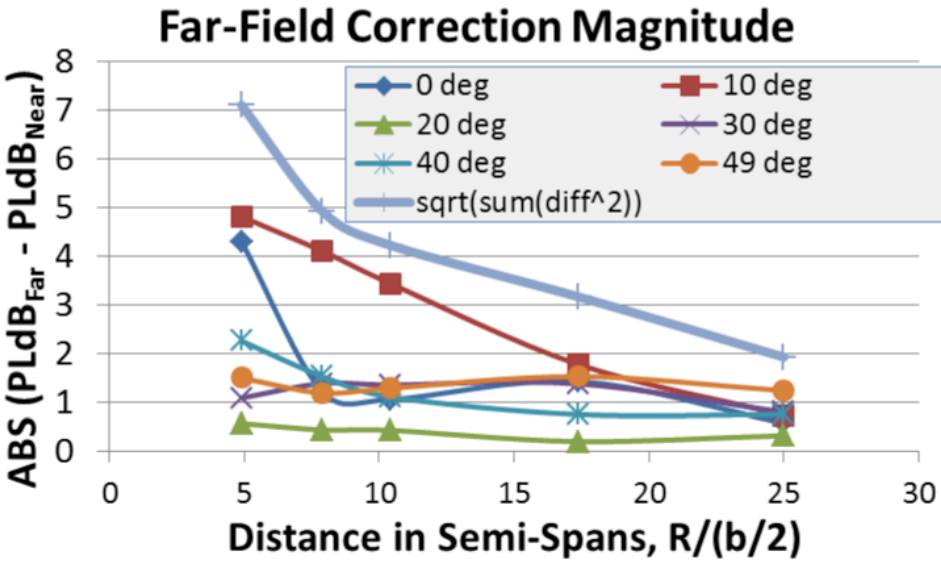


LM 1021 Far-Field (Multi-Pole) correction

PL extracted at different H/L



Multi-pole correction

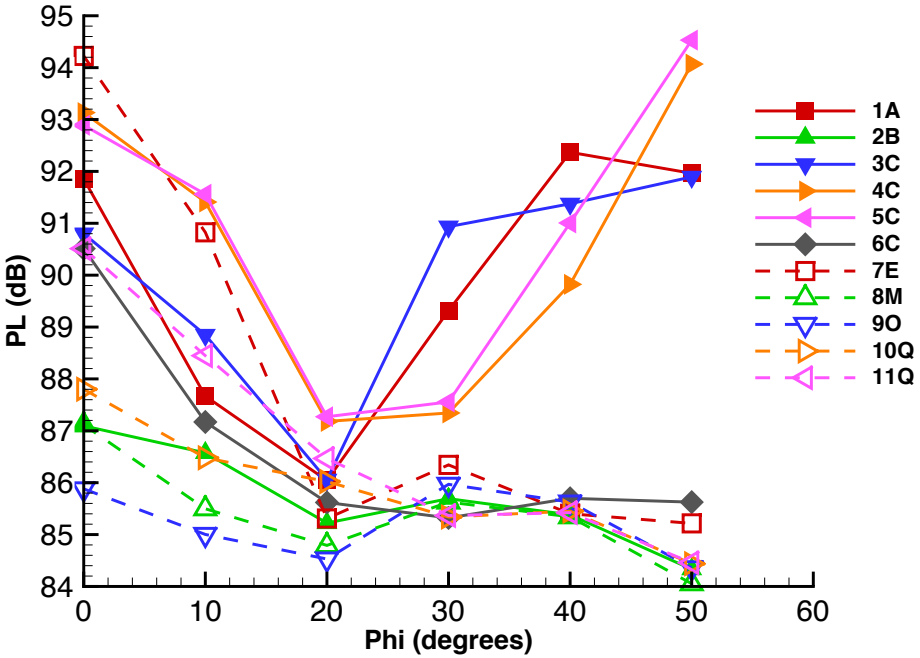


At centerline

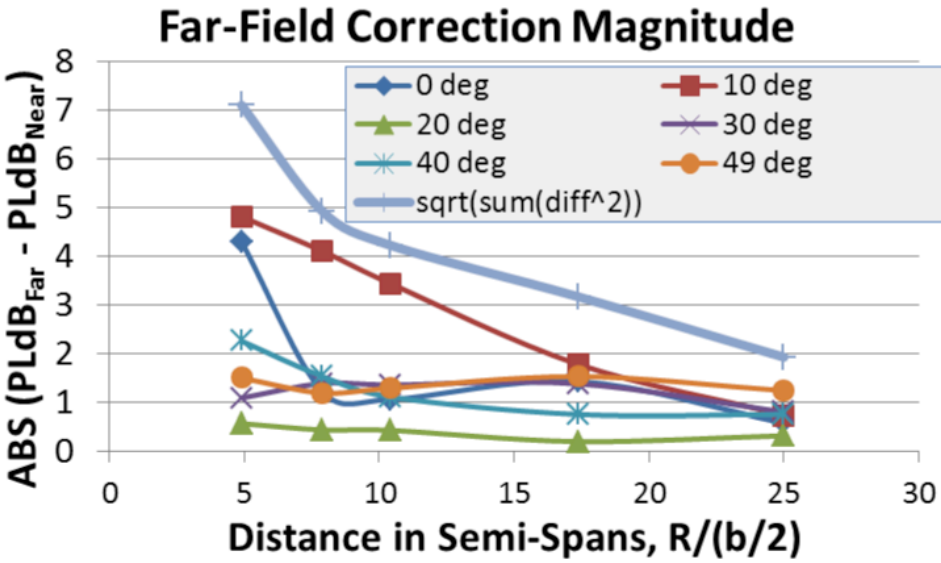
[AIAA-2014-2006]

LM 1021 Far-Field (Multi-Pole) correction

PL extracted at different phi



Multi-pole correction

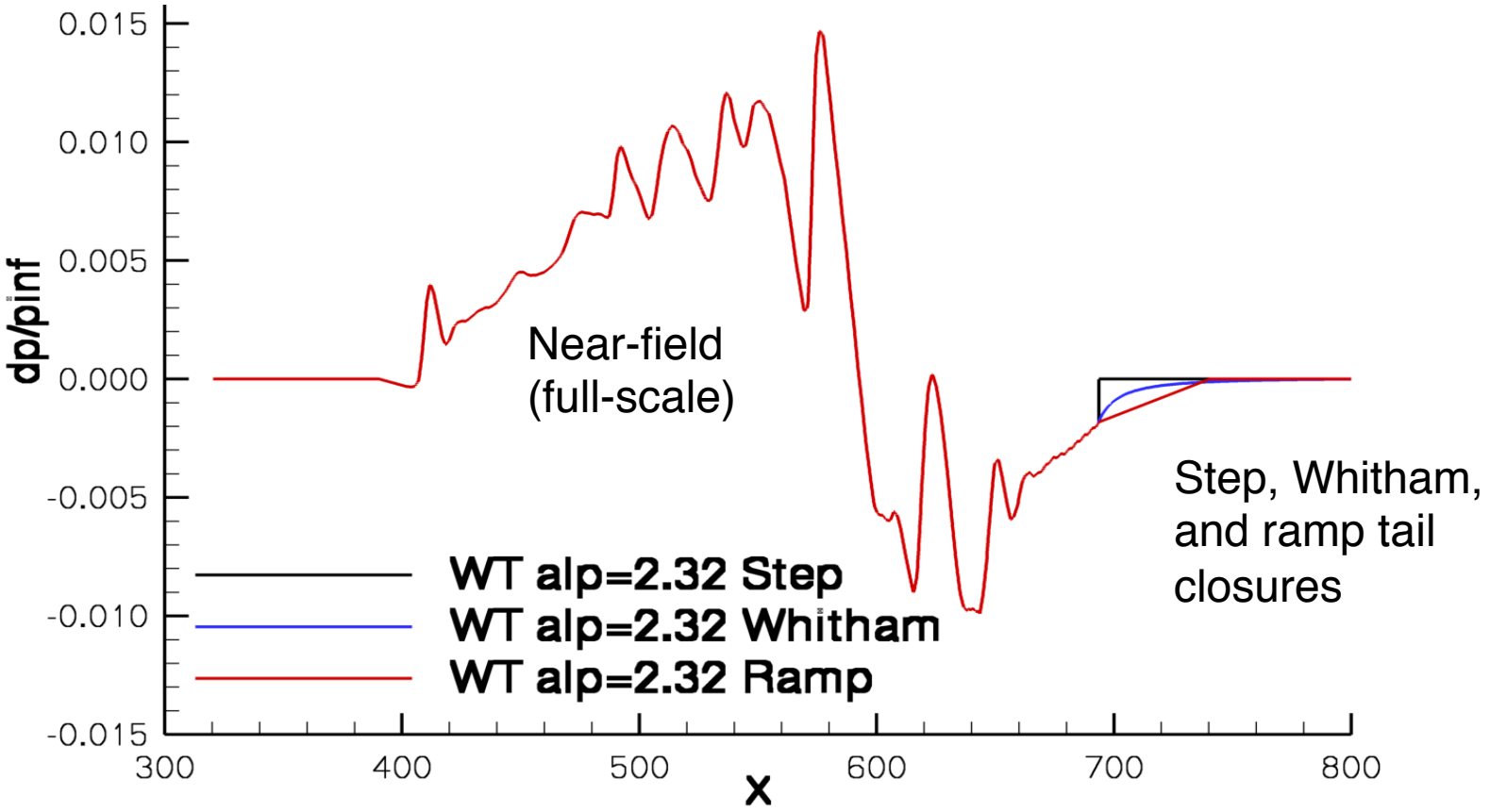


From R/(b/2)=7.9

[AIAA-2014-2006]

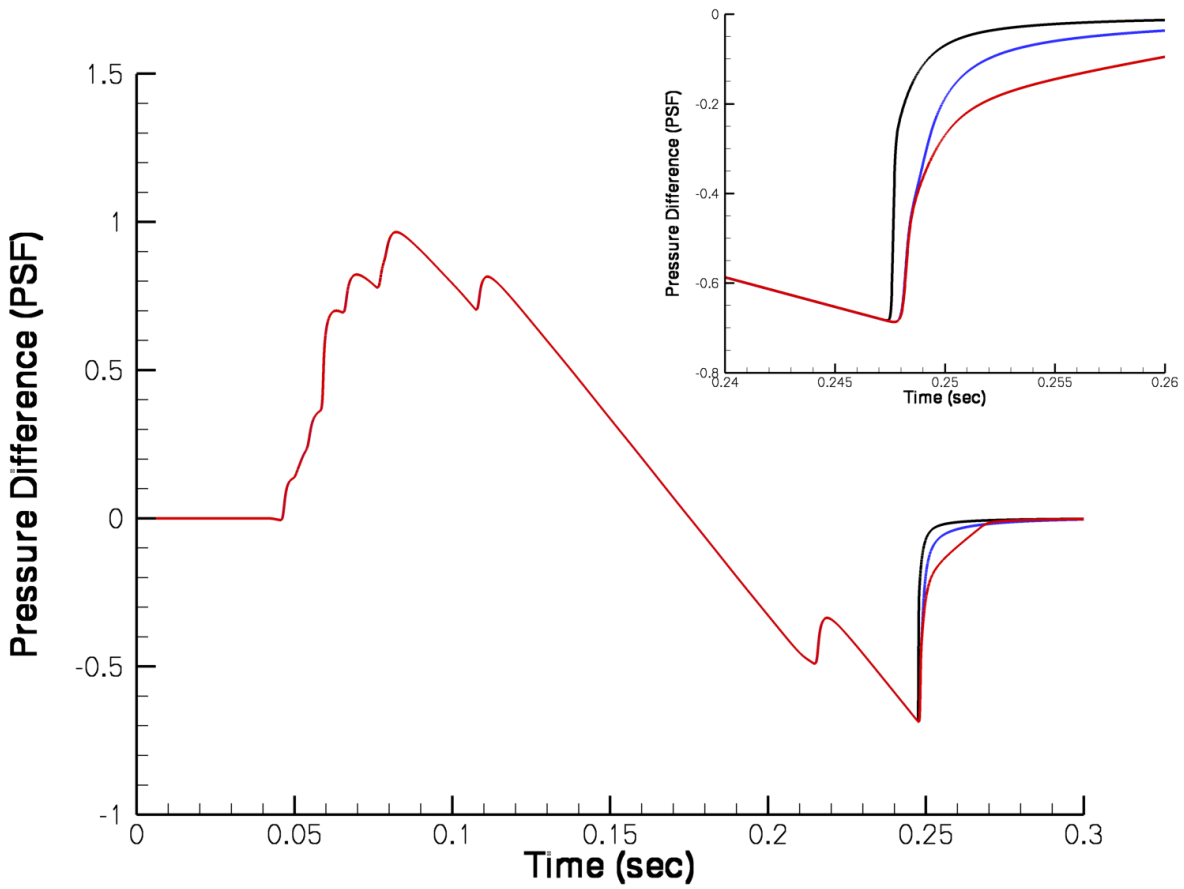
Tail closure

- LM1021 wind tunnel model aft signature must be recreated to remove the mounting sting from the measurements and simulation



Tail closure

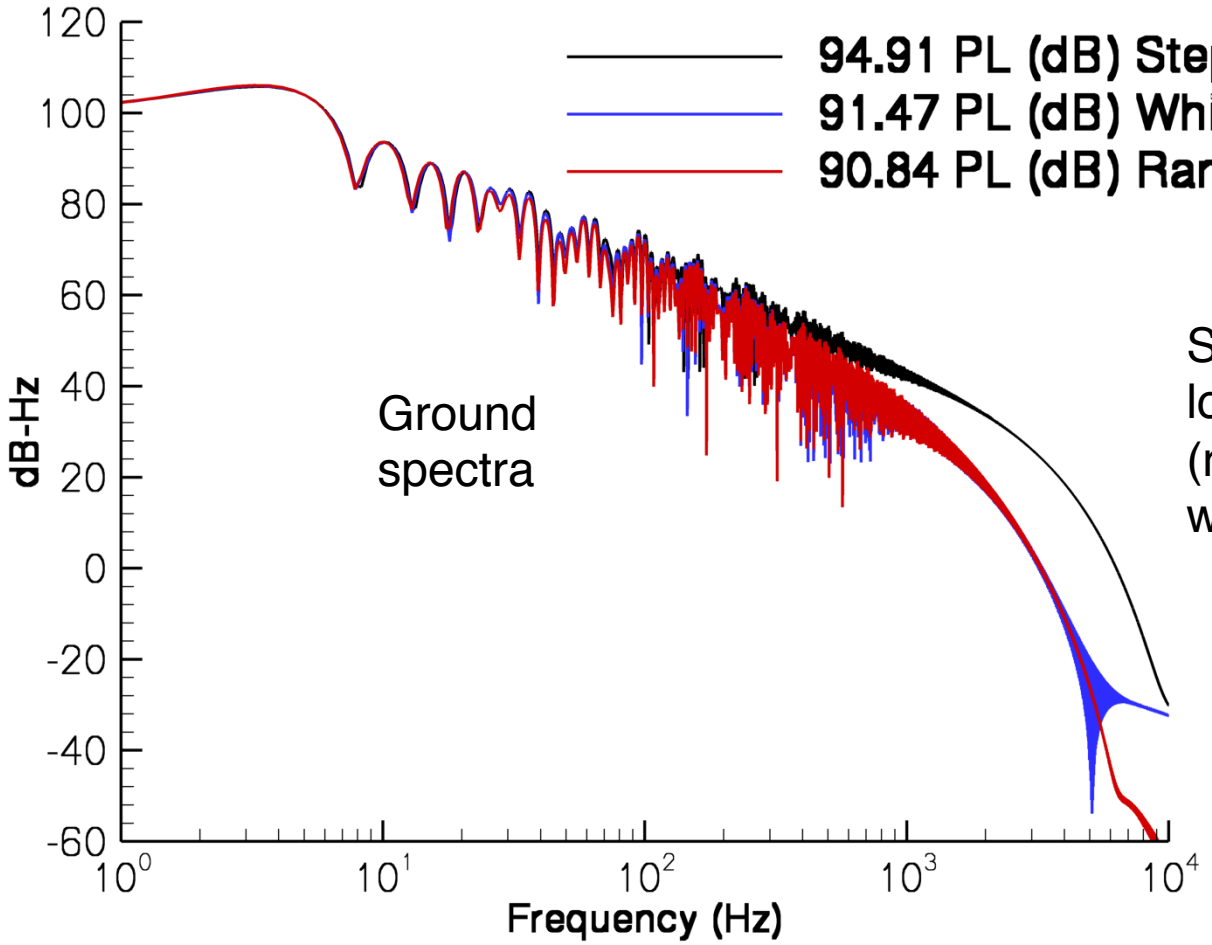
- The steepness of the aft shock of this model is sensitive to the aft signature reconstruction method



Step, Whitham, and ramp tail closures

Tail closure

- Higher frequencies are impacted by tail shock steepness

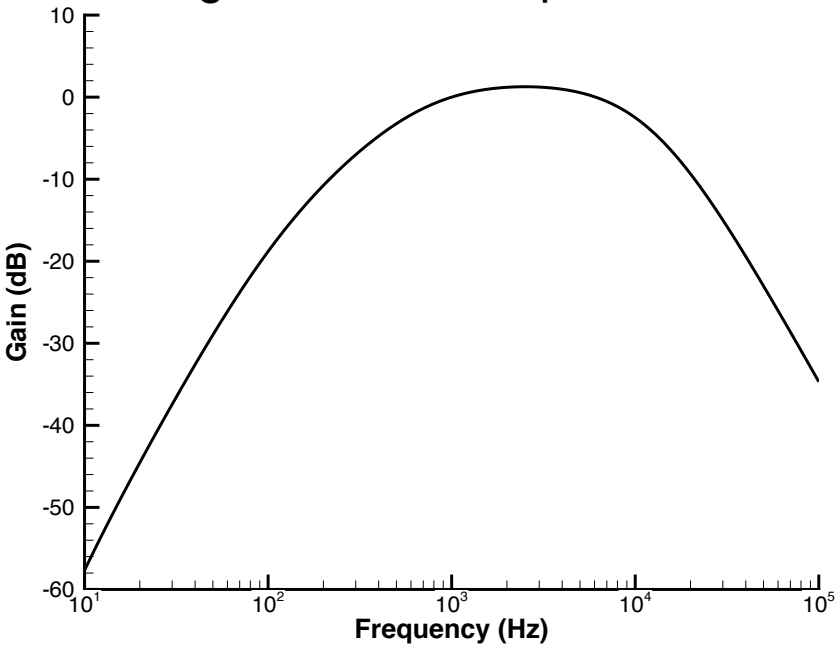


Step closure 4 PL (dB) louder than ramp (ramp was used at workshop)

Background on Noise Measures

- Humans perceive noises to be louder if they are 600 Hz to 10,000 Hz
- Measures have been evaluated in experiments (PL best loudness correlation)
- ASEL is a good surrogate for PL and is a continuous weighting

A-Weighted Sound Exposure Level



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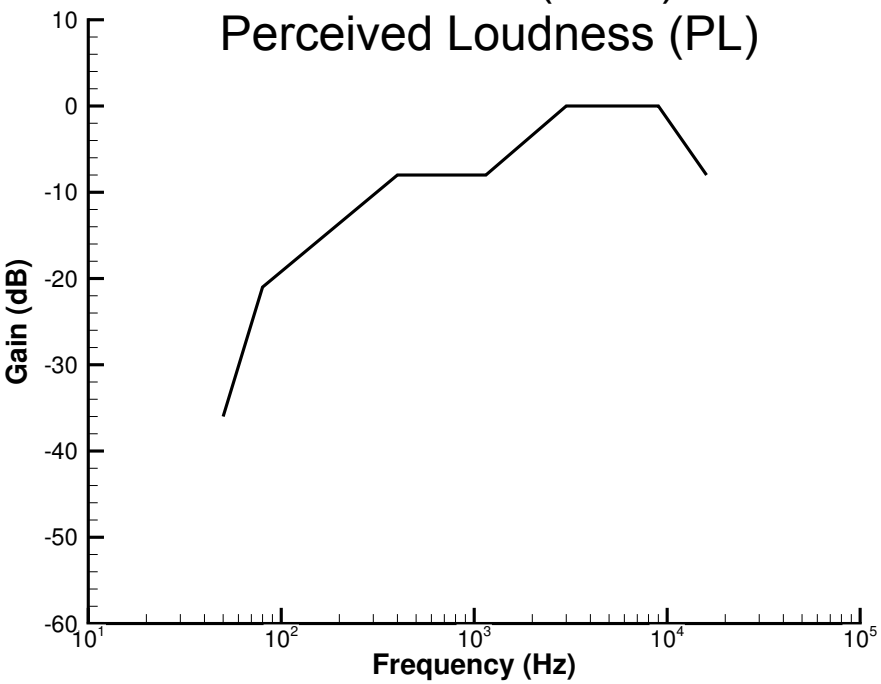
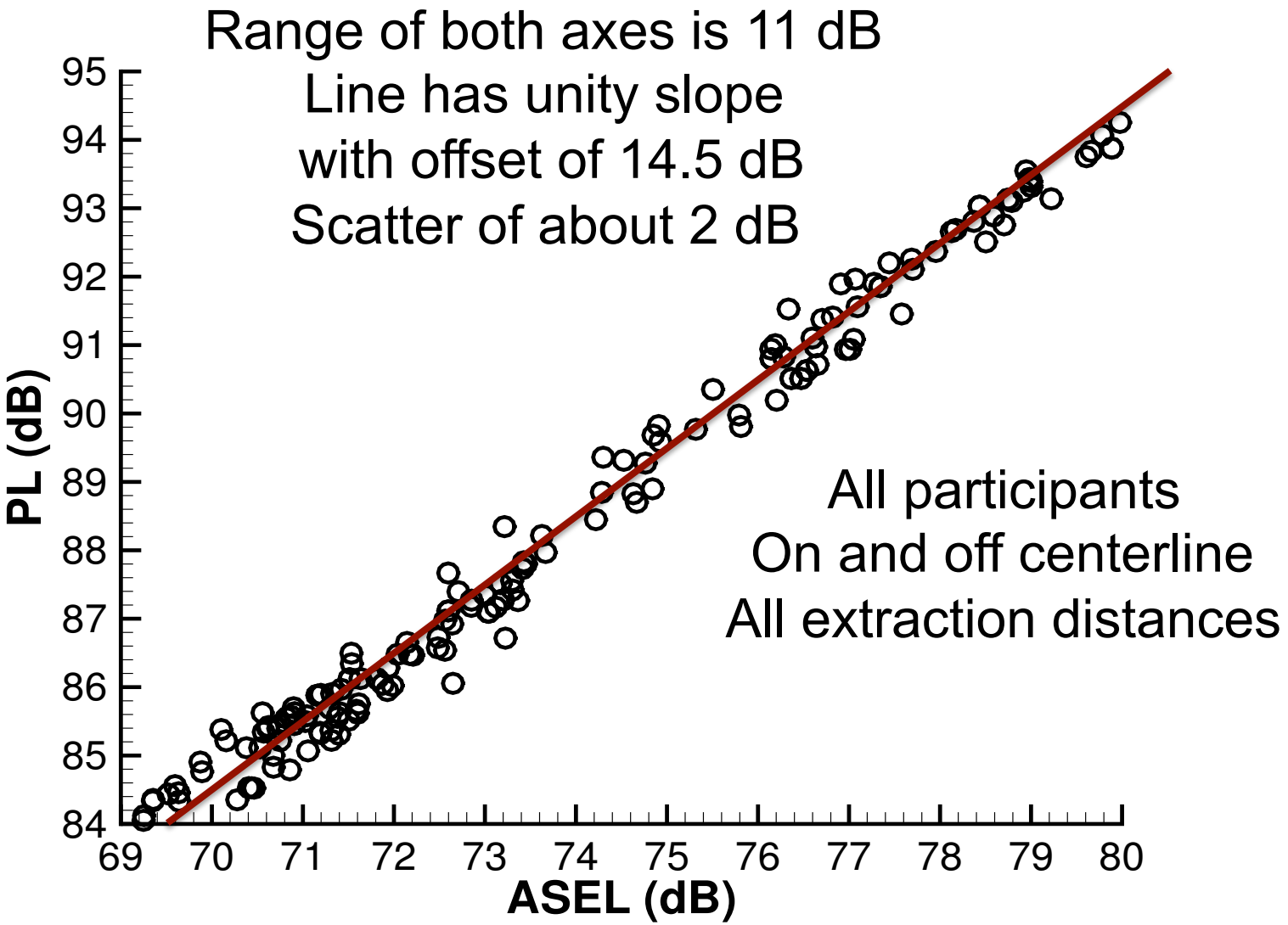
Perceived Loudness (PL)



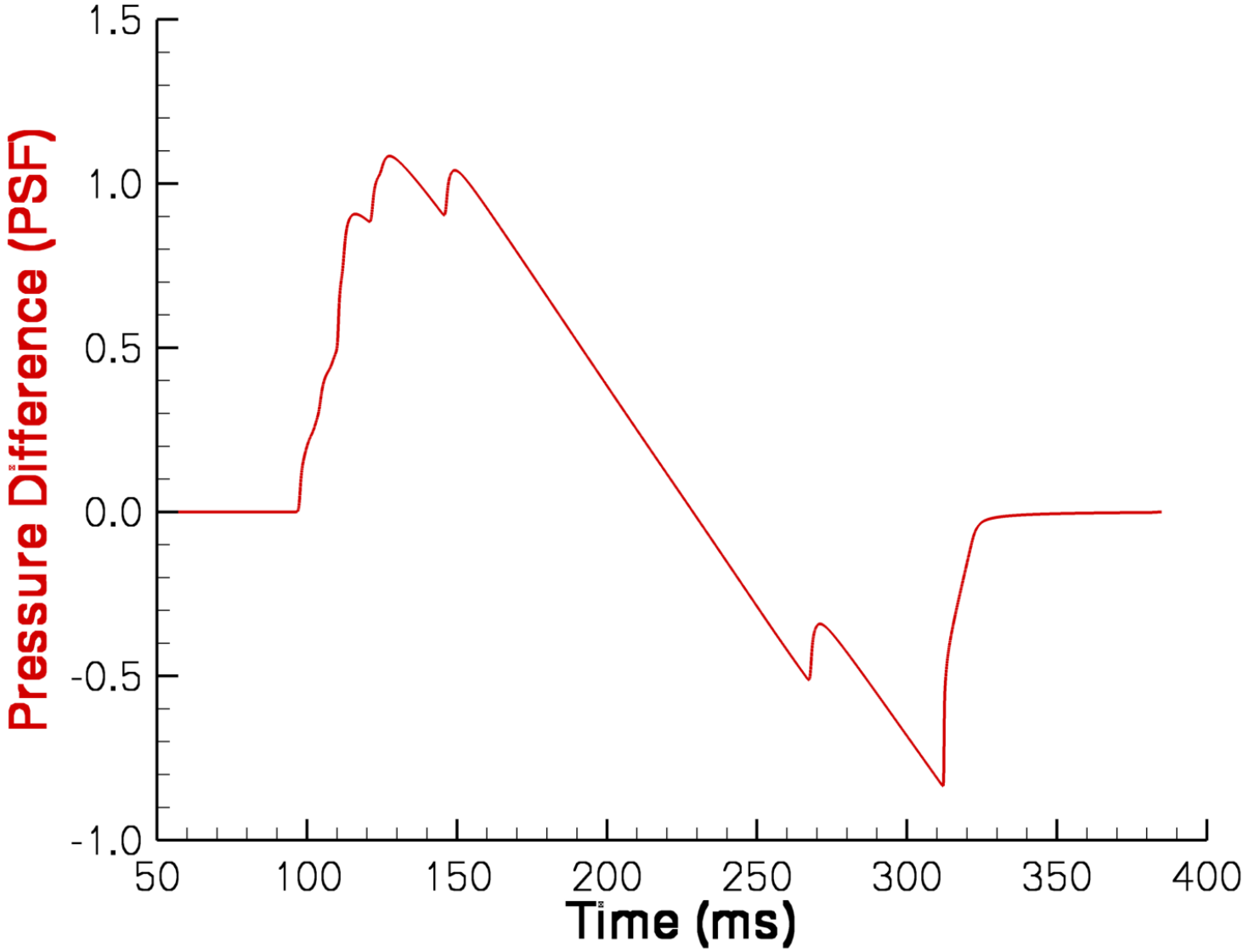
A-Weighted Sound Exposure Level (ASEL) and PL



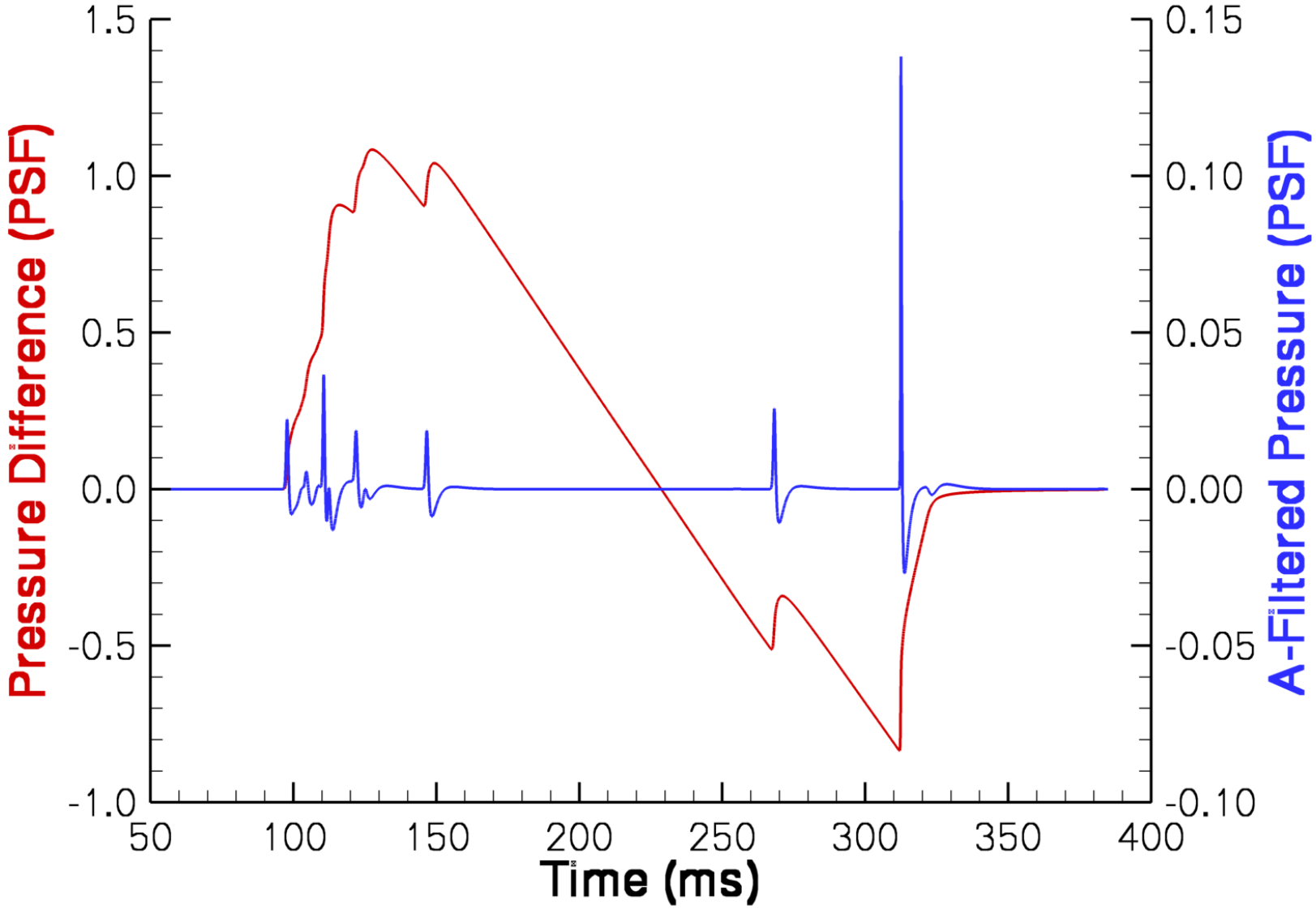
Time Domain A-Weighted Filter

- Continuous weighting of ASEL enables time domain filtering
- Integrated to yield ASEL as a function of position
  - See the contribution of each ground signature feature to the total

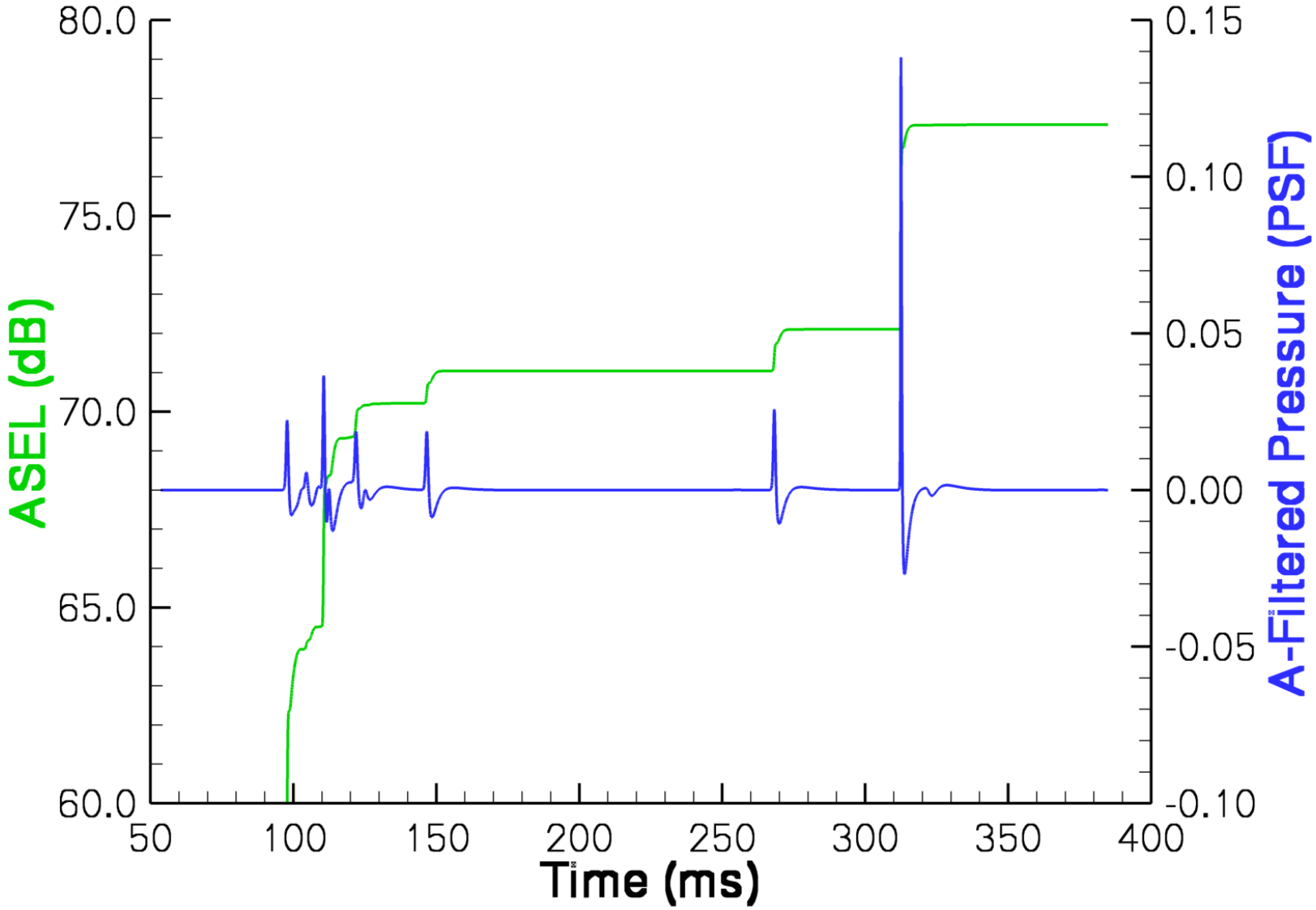
LM1021 Ground Signature



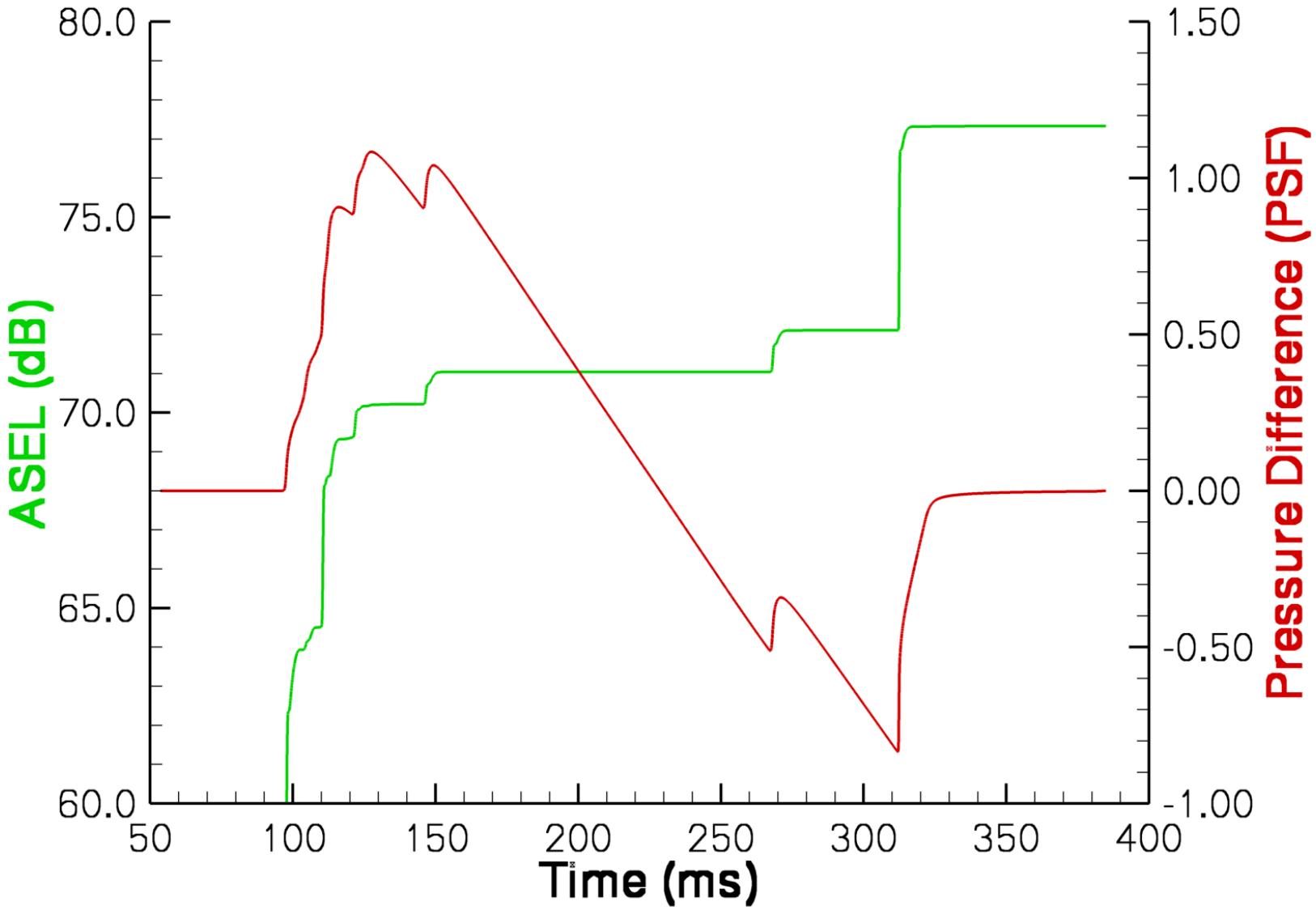
LM1021 A-Filtered Pressure and Ground Signature



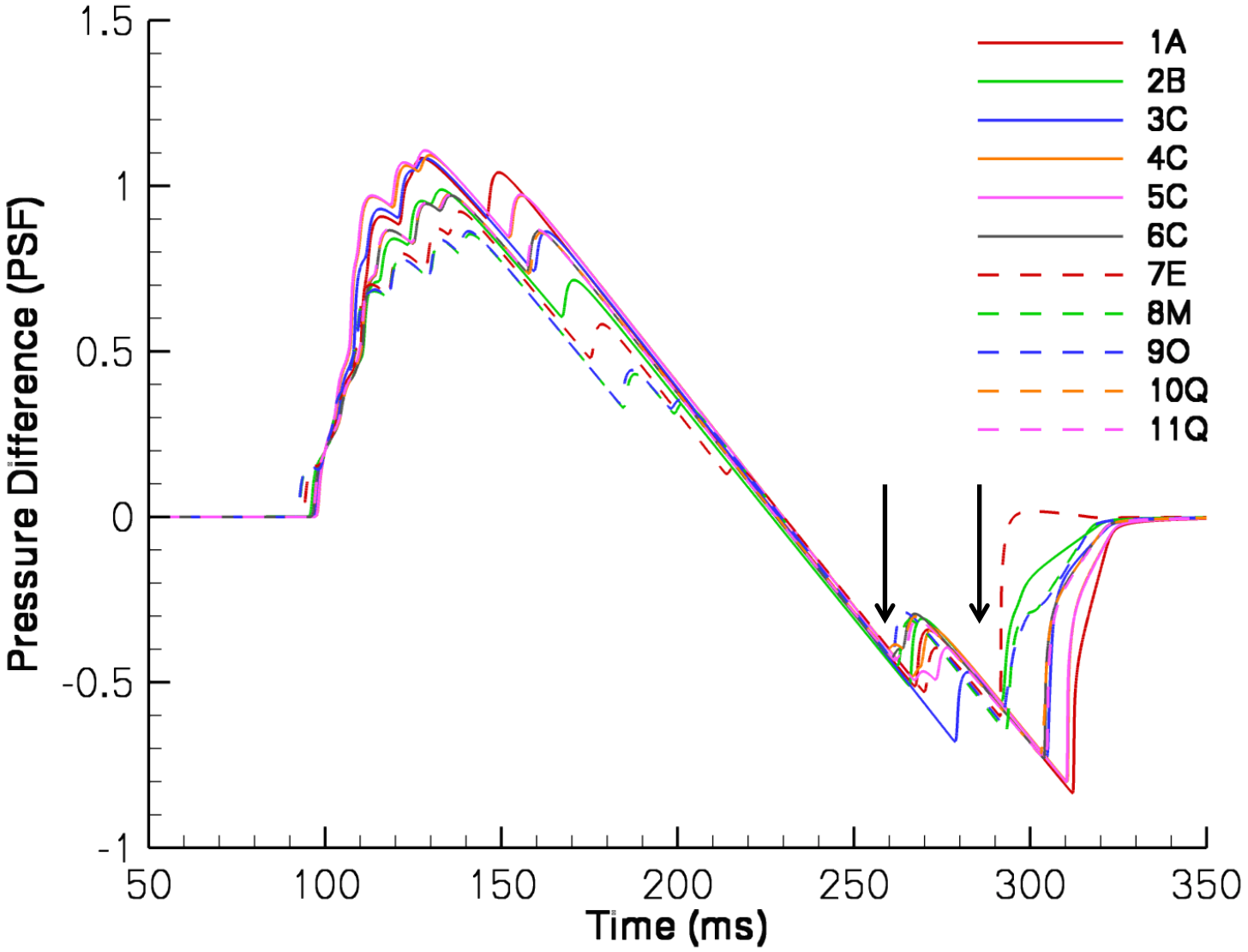
LM1021 ASEL and A-Filtered Pressure



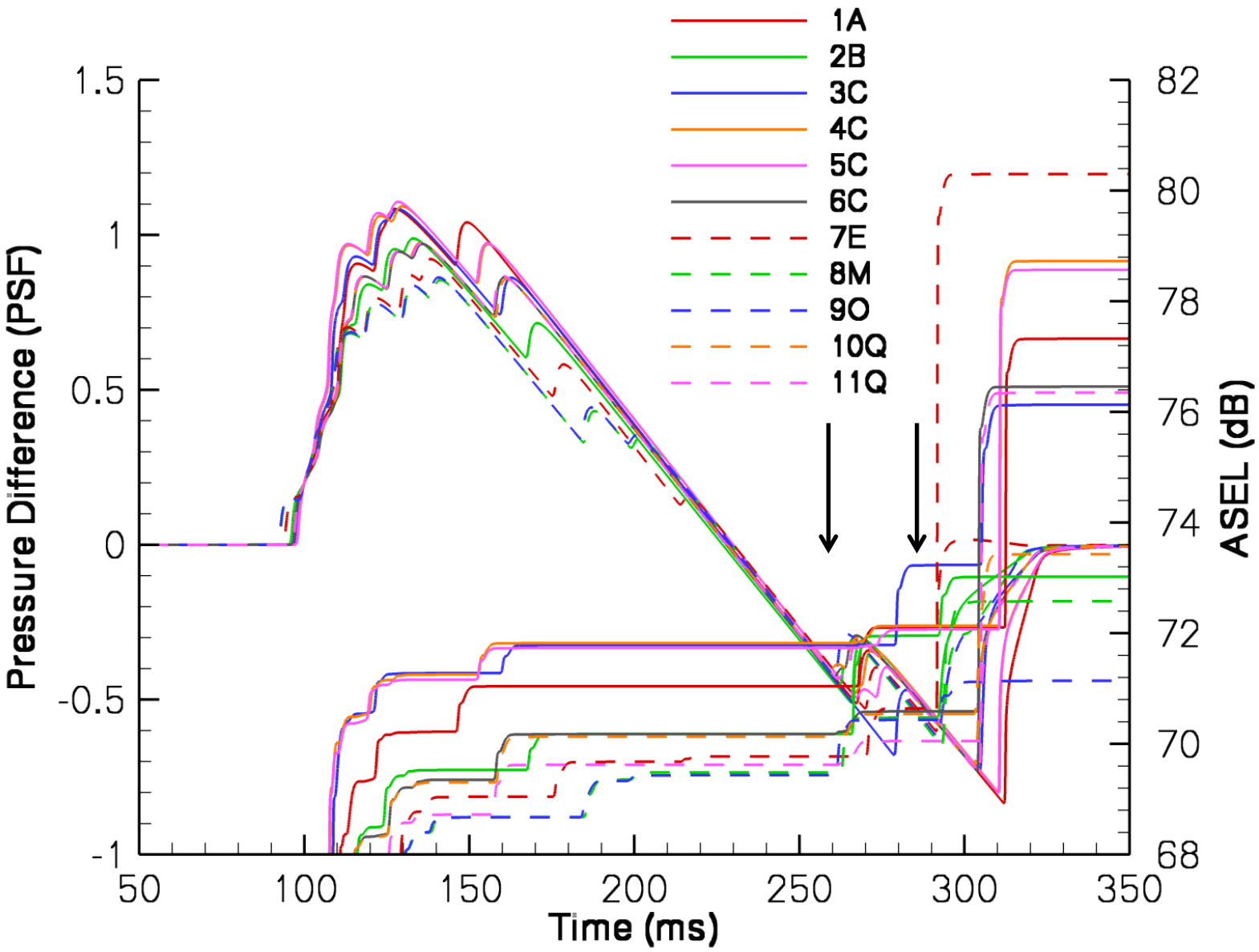
LM1021 Ground and ASEL



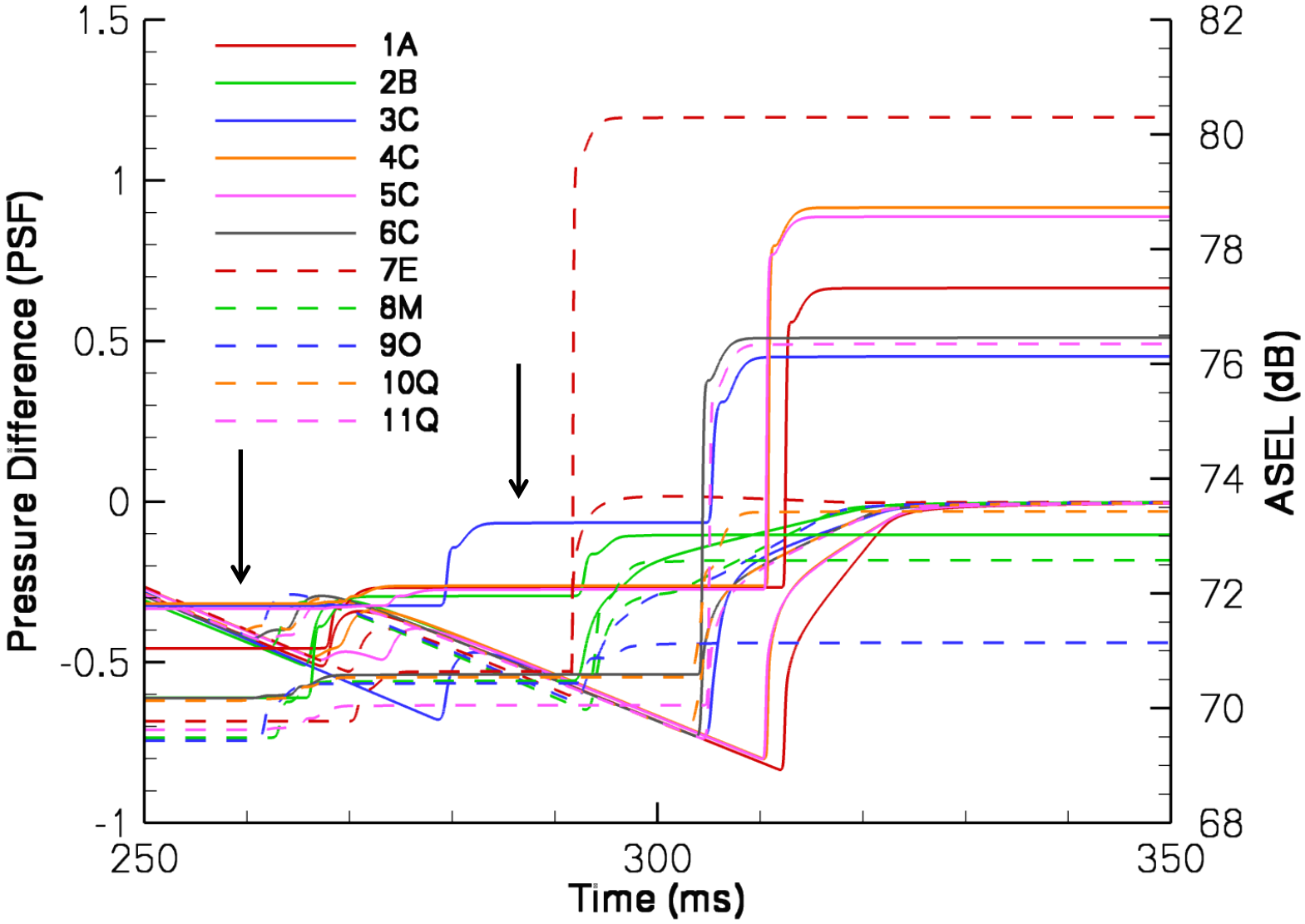
LM1021 Ground Signature



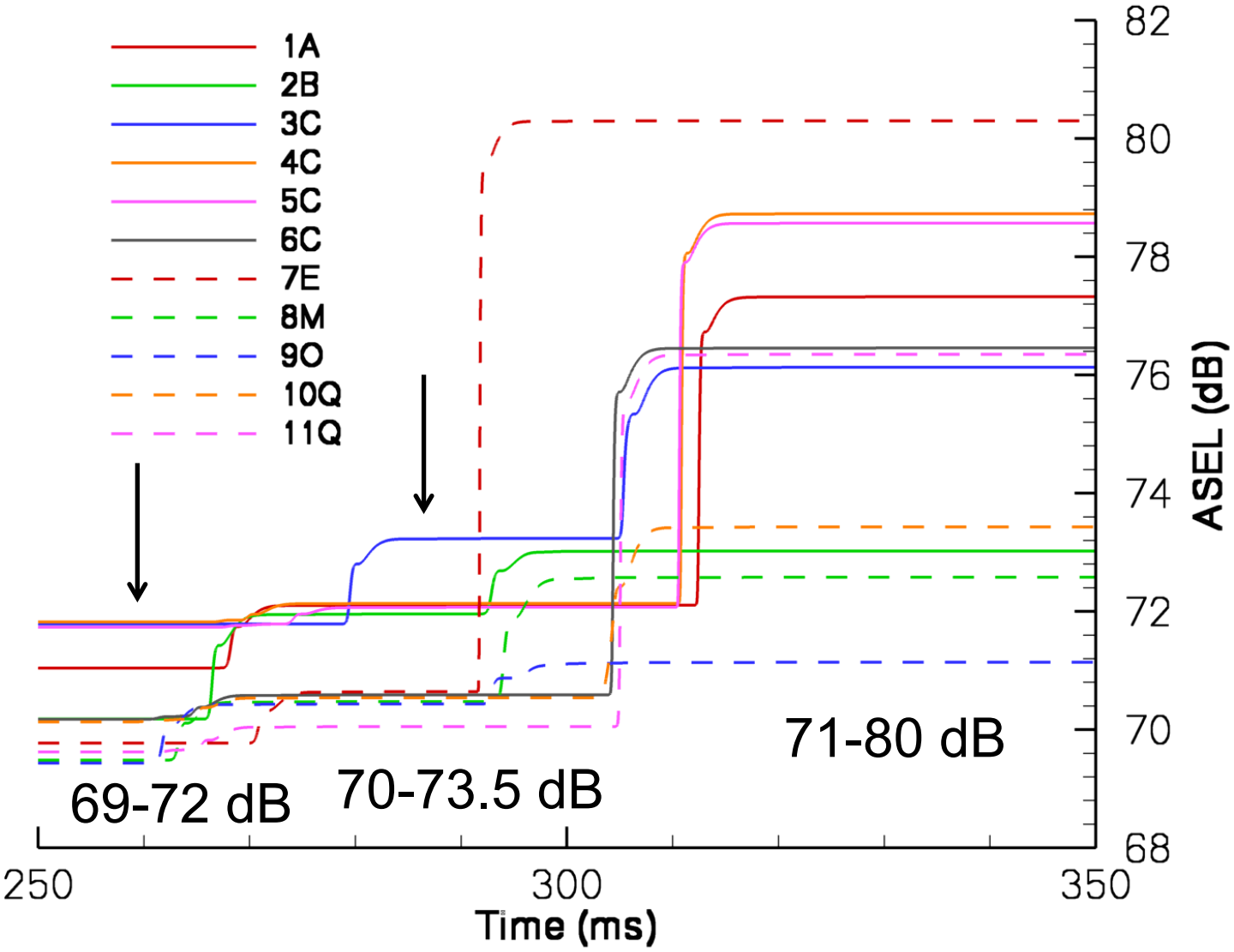
LM1021 Ground Signature and ASEL



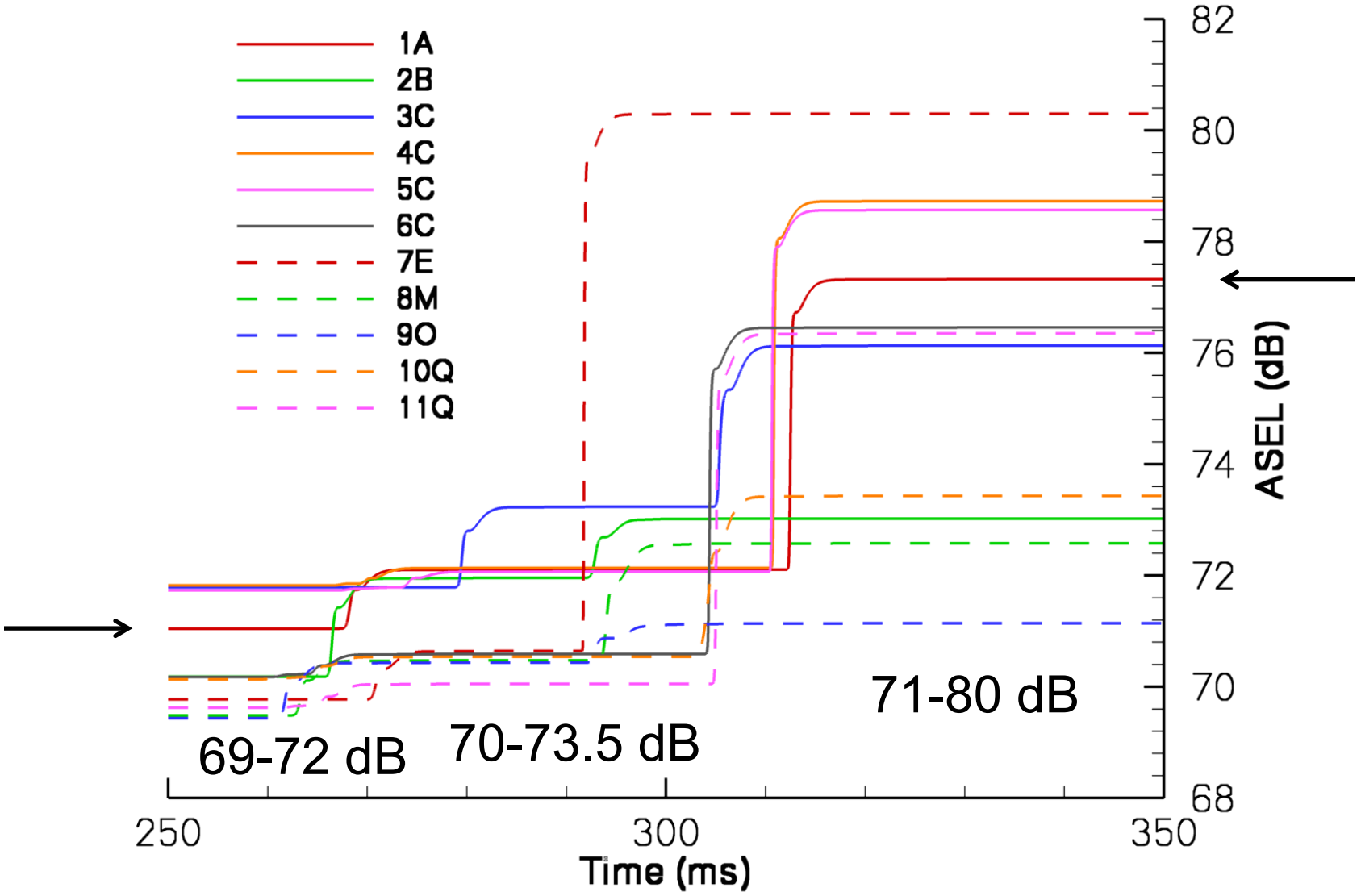
LM1021 Ground Signature and ASEL



LM1021 Ground Signature and ASEL

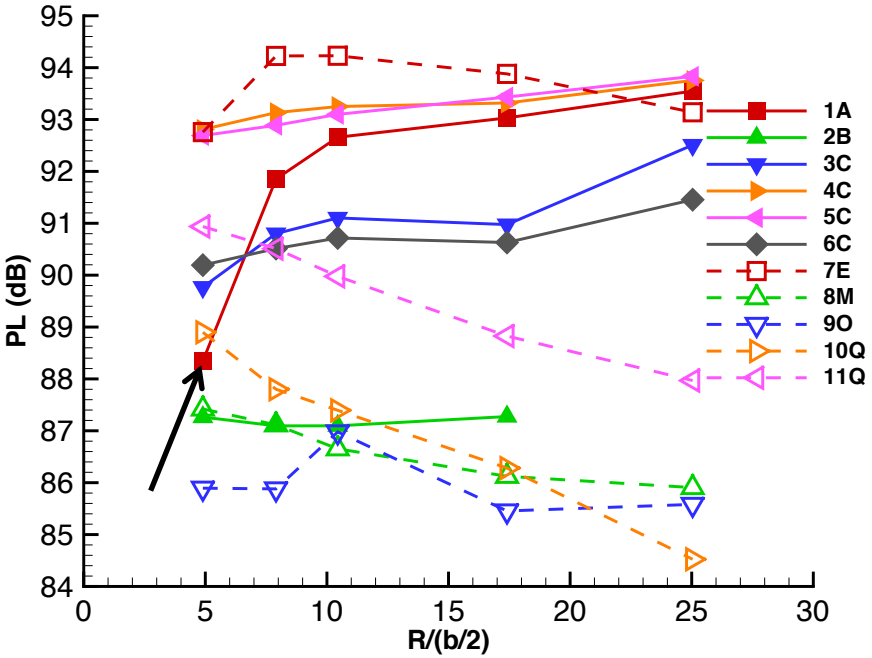


LM1021 Ground Signature and ASEL

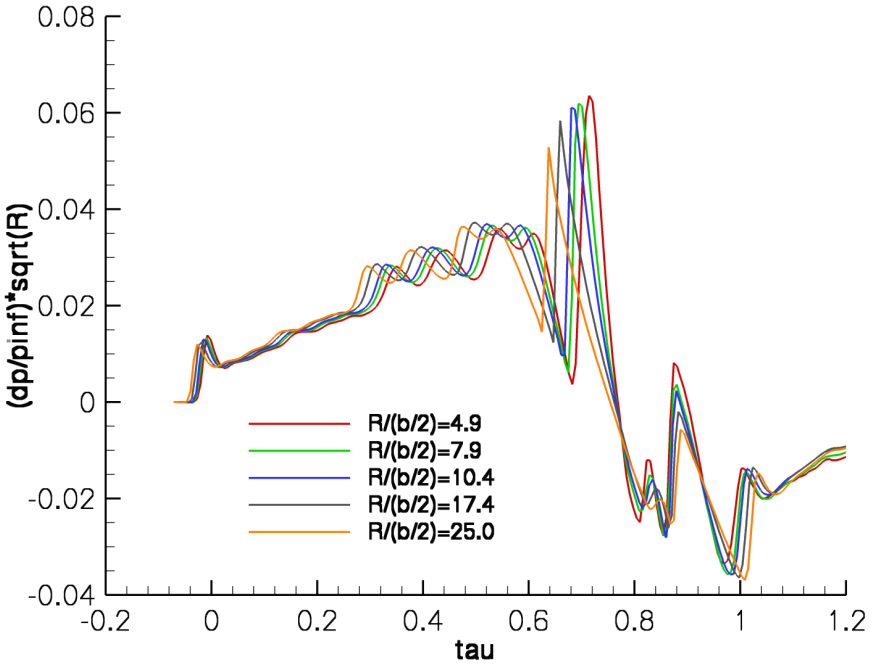


LM 1021 Background and Motion

PL extracted at different H/L



Near-field extracted at diff. H/L

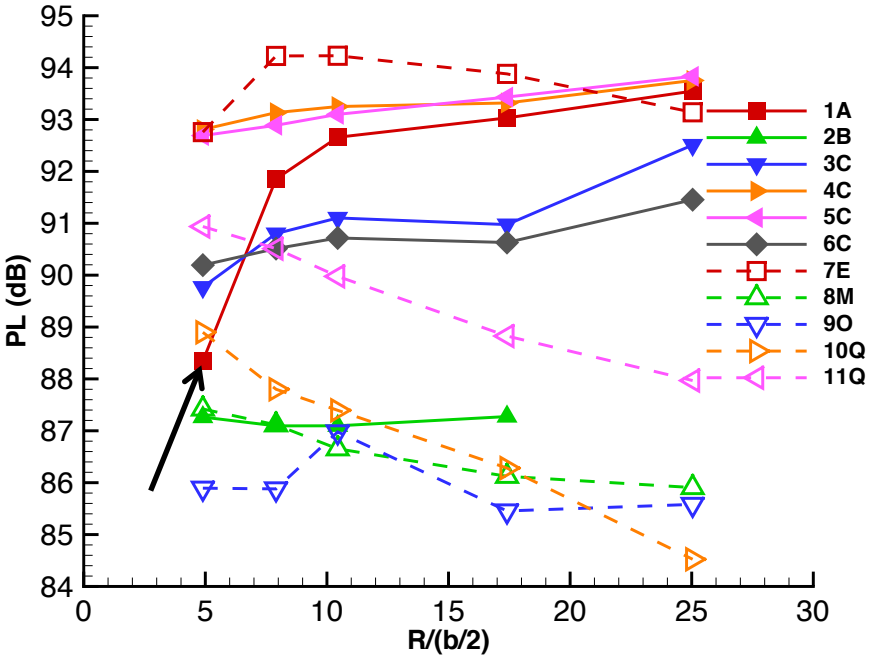


At centerline

At centerline

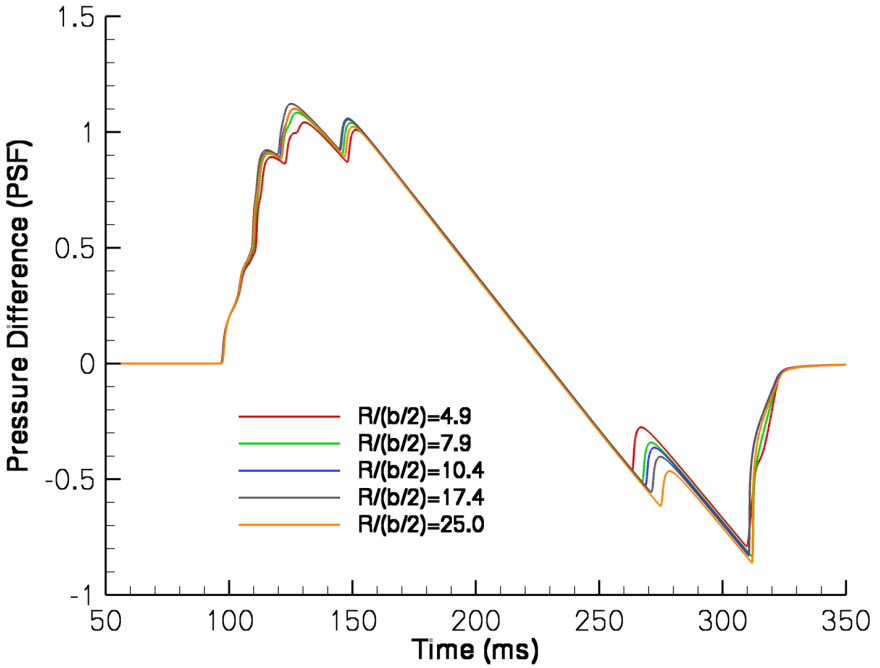
LM 1021 Background and Motion

PL extracted at different H/L



At centerline

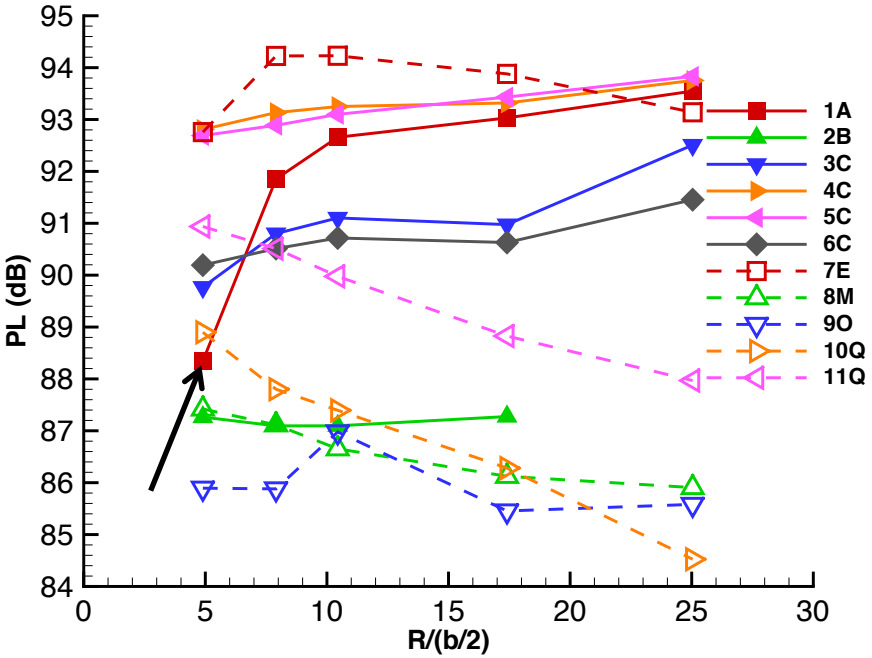
Ground extracted at diff. H/L



At centerline

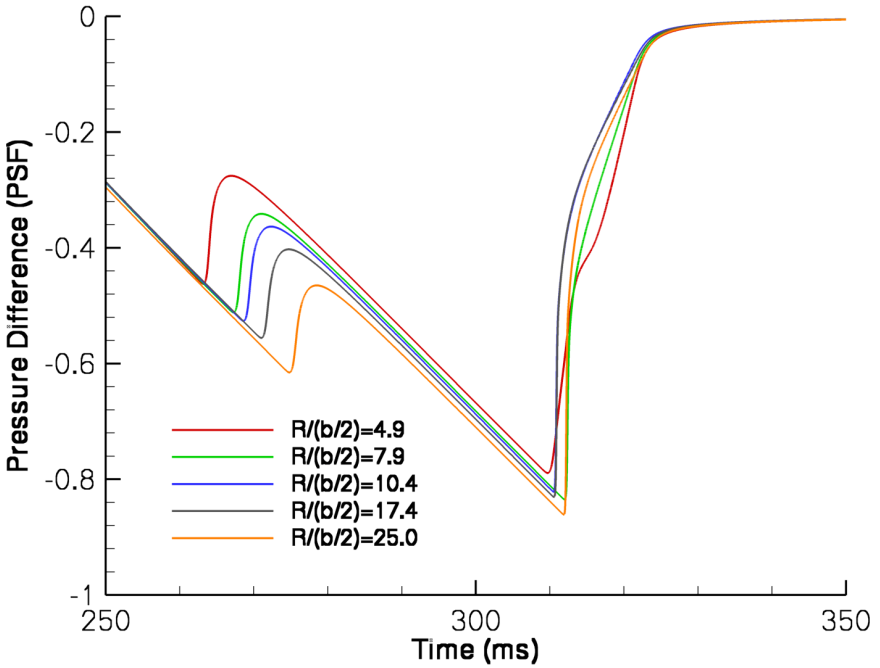
LM 1021 Background and Motivation

PL extracted at different H/L



At centerline

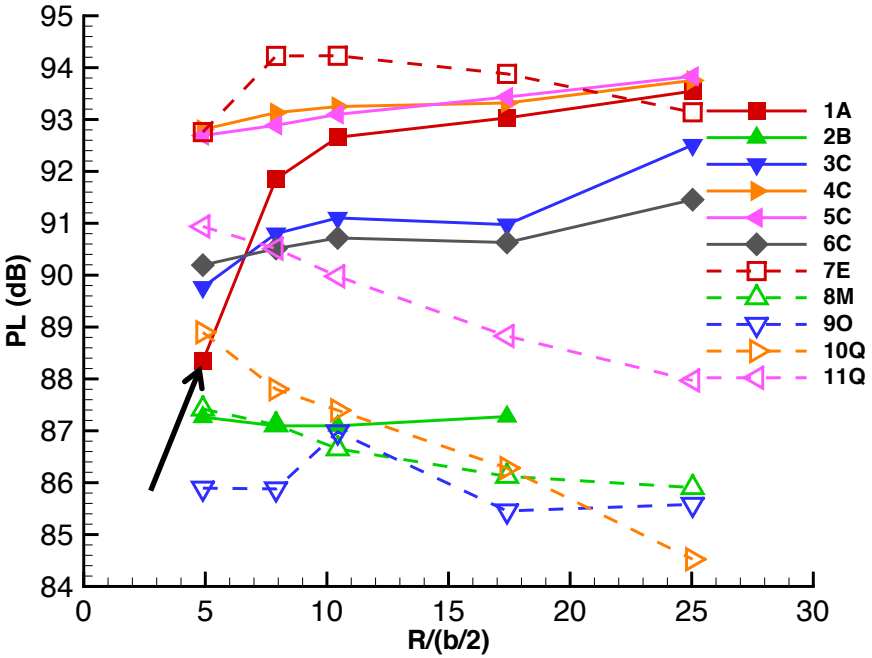
Ground extracted at diff. H/L



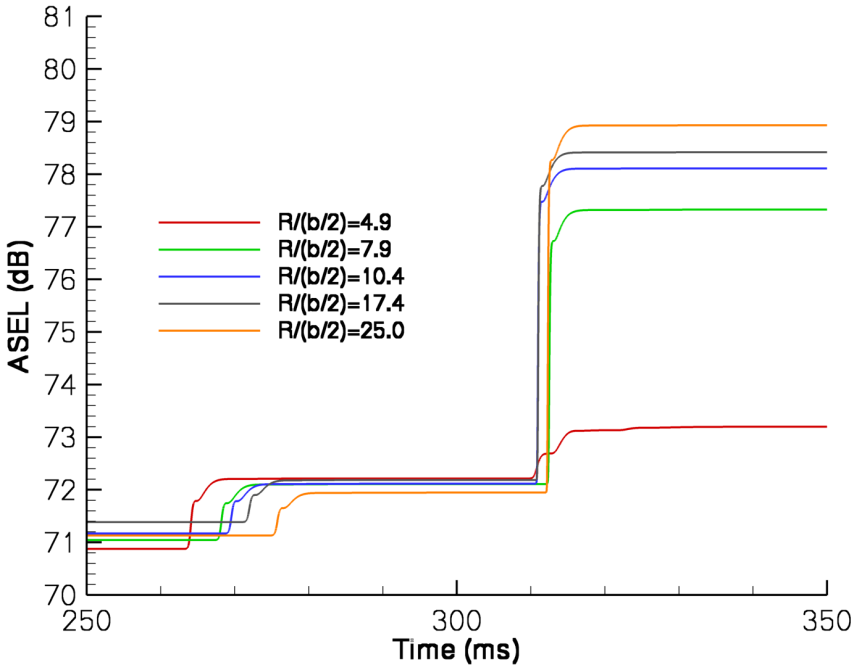
At centerline

LM 1021 Background and Motion

PL extracted at different H/L



ASEL extracted at diff. H/L

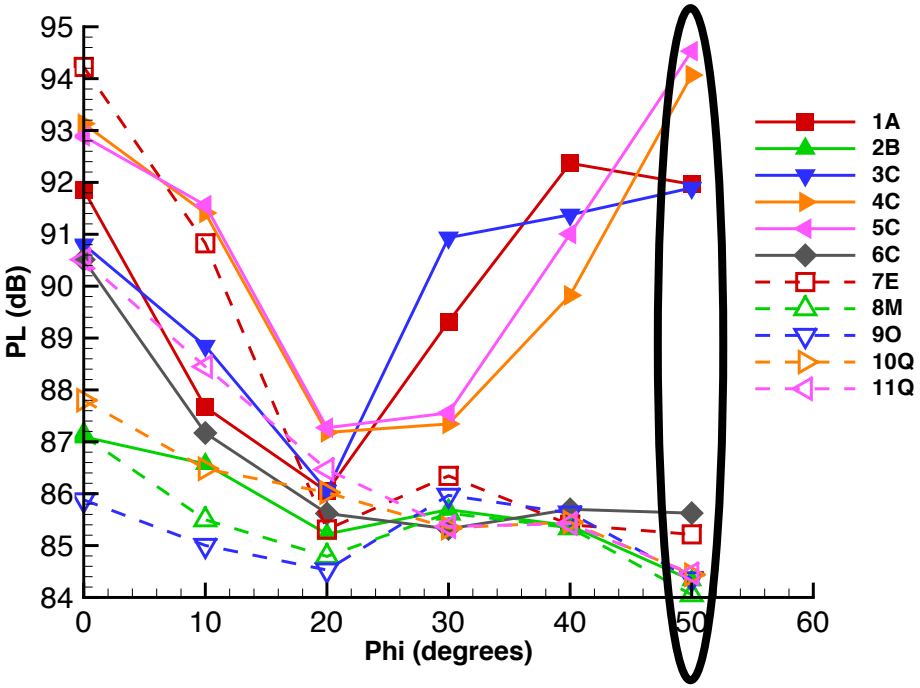


At centerline

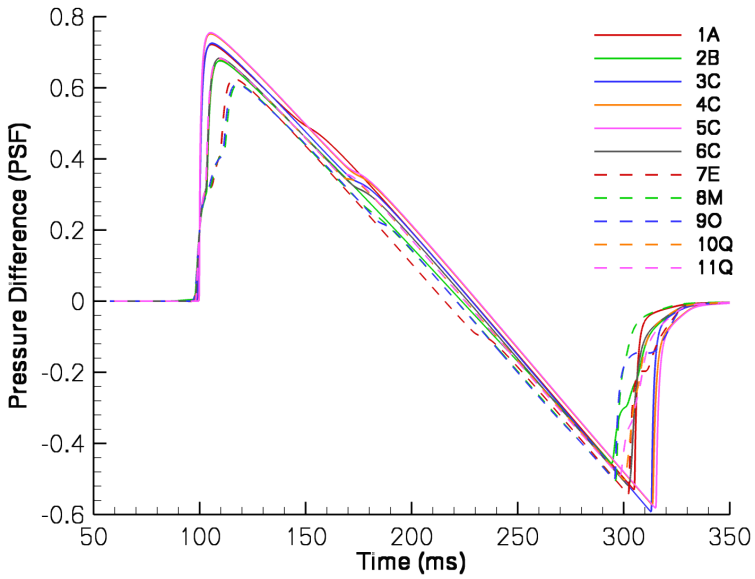
At centerline

LM 1021 Phi = 50 Degrees

PL extracted at different H/L

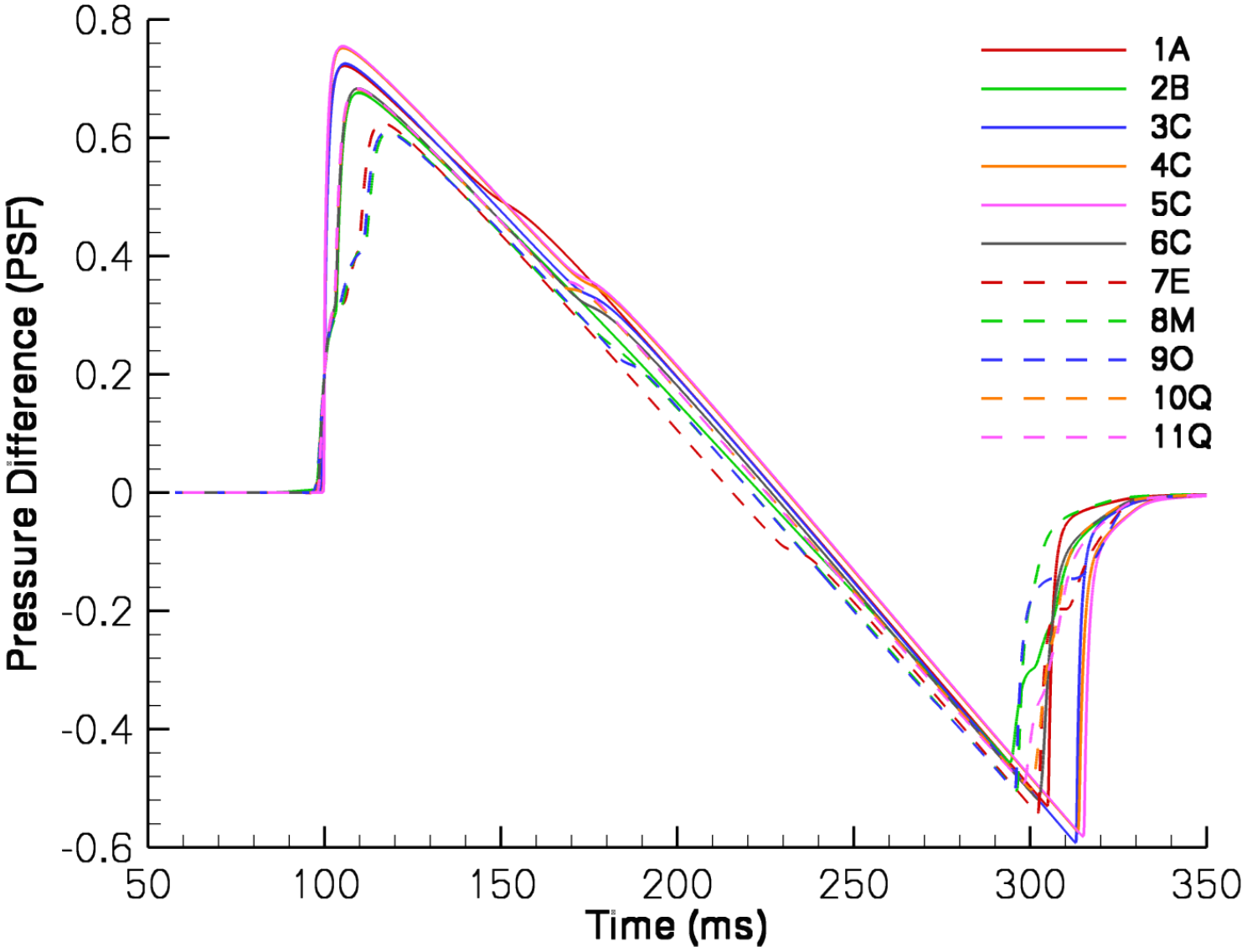


Ground signature

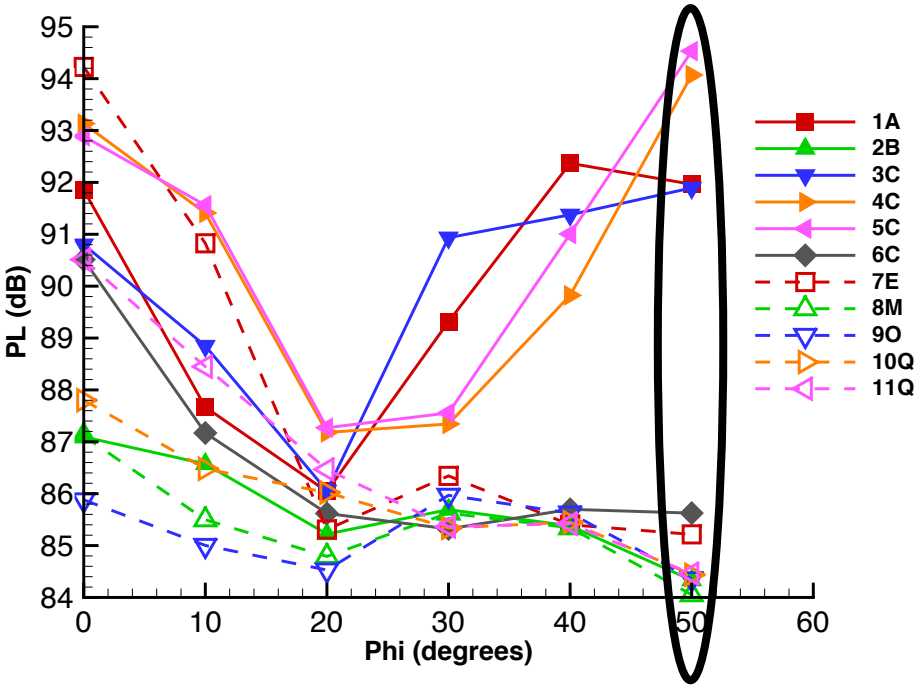


H/L=25, phi=50 degrees

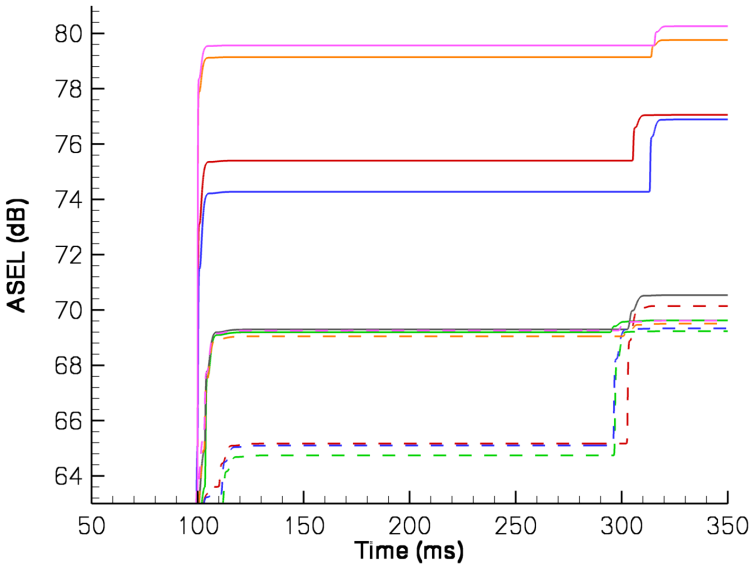
LM 1021 Phi = 50 Degrees Ground



LM 1021 Phi = 50 Degrees

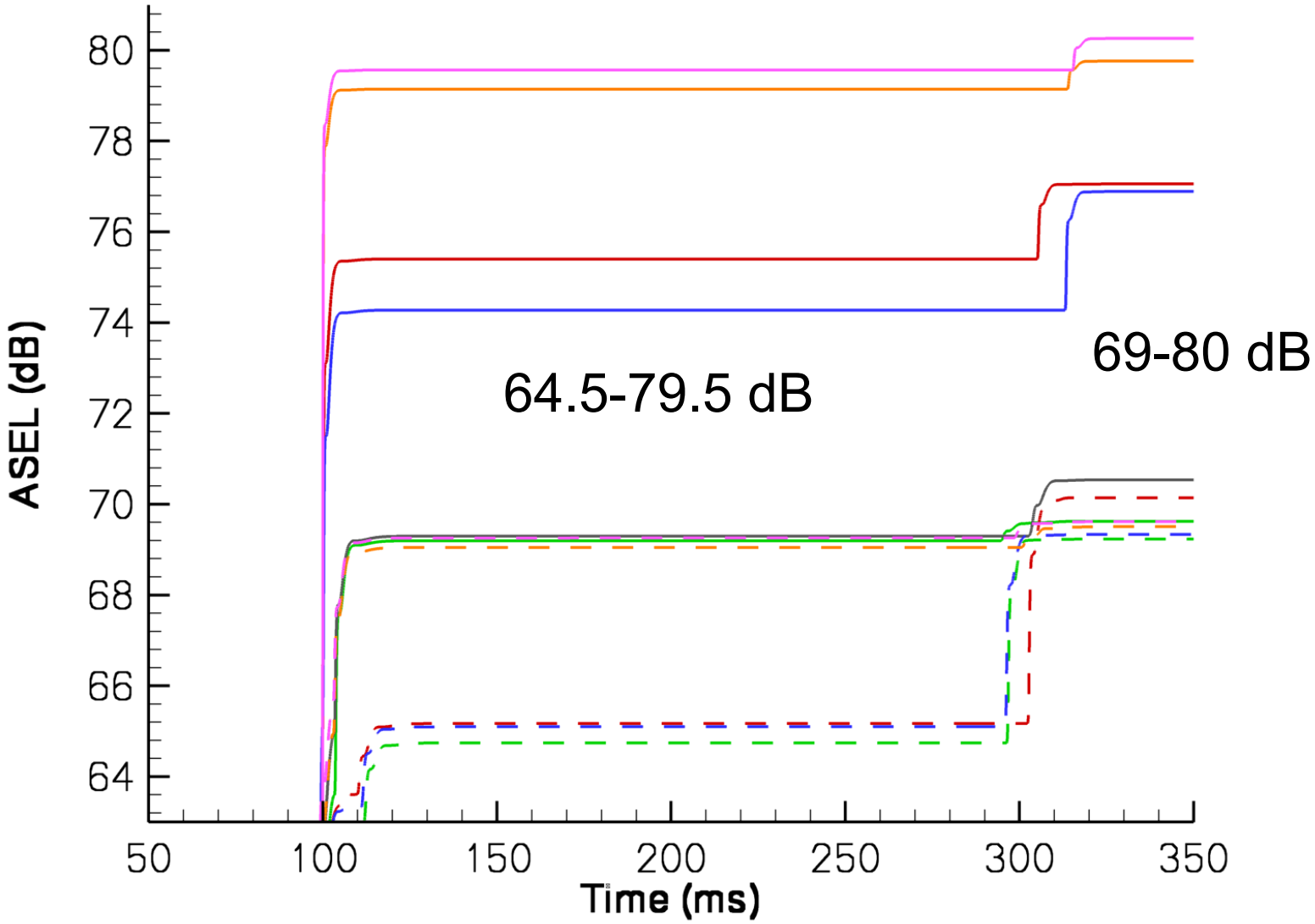


ASEL



H/L=25, phi=50 degrees

LM 1021 Phi = 50 Degrees ASEL



Conclusions

- Successful first workshop with international participation that includes government agencies, industry, and academia
- The simpler required configurations each had 60+ submissions
- The optional full-configuration case had 11 submissions
- SEEB-ALR: 91.8 PL (dB) median, 0.3 dB standard deviation
- Delta Wing Body on centerline: 95.5 PL (dB) median, 0.2 dB standard deviation
- LM1021 wind tunnel configuration: large 85 PL (dB) to 95 PL (dB) variation and small sample size (no statistics)
- Exclusion of coarser grids in the uniform grid refinement study had a negligible effect on median and limits for SEEB-ALR and Delta Wing Body

Conclusions

- LM1021 signature was more sensitive to inviscid and viscous simulations than simpler configurations (tail shock) but did not produce clear trends in Perceived Level (PL)
- Multiple sources of variation for LM1021 PL and ASEL
  - Centerline ground noise measures are dominated by the tail shock
  - Both bow and tail shocks contribute to the 50 degree off-track ground noise measures
- A-weighted Sound Exposure Level (ASEL) is a useful surrogate for Perceived Level (PL)
- ASEL is continuous and can be applied in both the frequency and time domains

Recommendations

- Design for reduced PL and ASEL sensitivity to small localized signature changes
- Identify the sensitive portions of the signal (and model) to target for adequate grid refinement
- A uniform grid refinement study may have provided insight into the LM1021 PL sensitivity
- Minimize the variation introduced during reconstruction of aft pressure signature for models with sting or extend aft boundary for free-flight models
- Apply far-field (multipole) correction into participant evaluations in a more consistent manner to quantify the impact of extraction distance
- Use A-weighted filter and ASEL with PL for compiling statistics

Participate

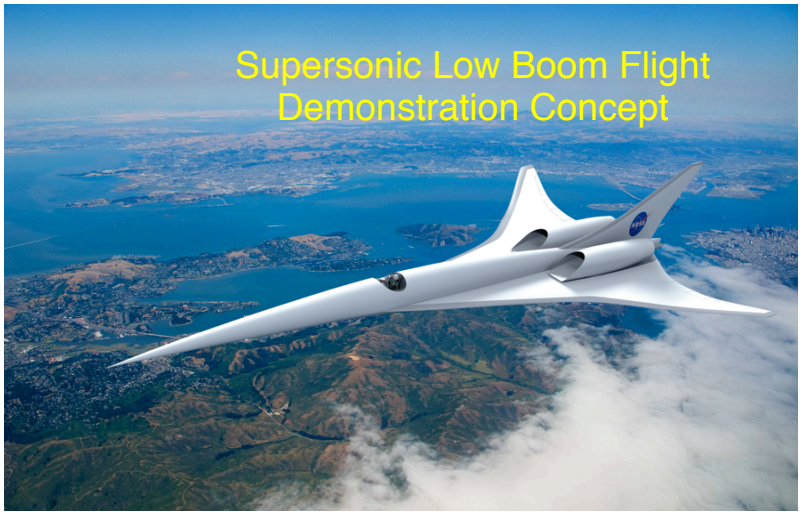
- Visit http://lbpw.larc.nasa.gov for
  - Presentations and references
  - Geometry, grids, submitted data, and derived data are available: **independent analysis encouraged!**
  - Sign up for the low-traffic announcement e-mail list
- See you for the next workshop
  - AIAA SciTech 2017, 7-8 January 2017, Grapevine, Texas, USA
  - Lower PL configurations from 90s to 70s
  - Expand participation to include propagation and noise metric experts
  - Include propulsion effects for optional case
  - Provide uniformly refined grids for all cases

Flight Demonstration Concept Formulation & Planning

Recent Technical progress has created an opportunity for a new effort to overcome the sonic boom barrier

Requirements

- Demonstrate that noise from sonic booms can be reduced to a level acceptable to the population residing under future supersonic flight paths.
- Create a community response database that supports an International effort to develop a noise based rule for supersonic overflight



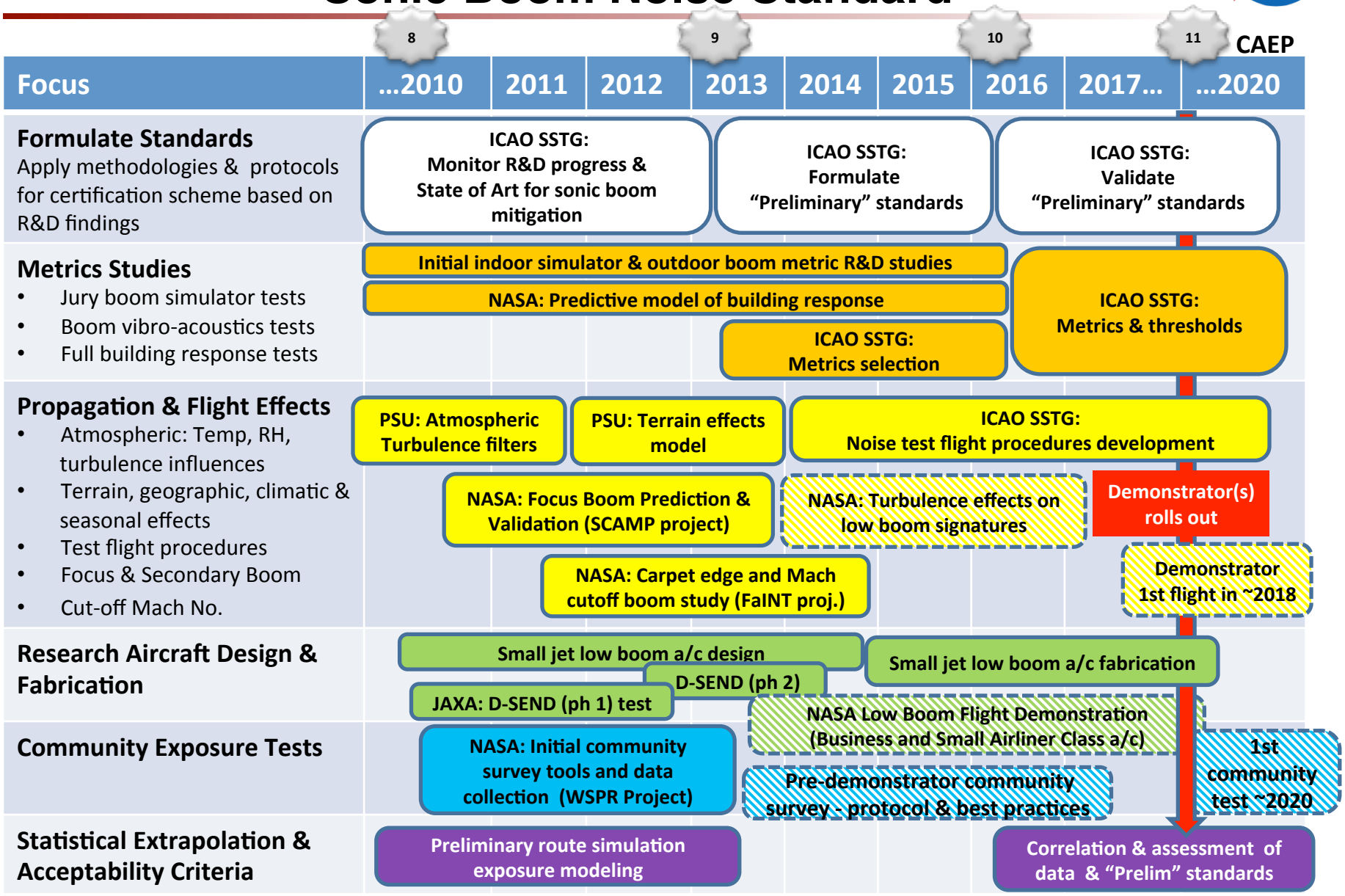
Approach

- Build on recent NASA progress to prepare for a future flight demonstration
- Partner with regulatory agencies and communities to create a roadmap for community response study and rule development
- Revitalize the excitement of manned X-Planes using a focused and cost-effective approach to design and operate a low boom research aircraft
- Flight demonstration project is under consideration as a new project

Acknowledgements

- Peter Coen provided the project and potential demonstrator overview
- Fellow organizers and participants of the First AIAA Sonic Boom Prediction Workshop
- Mathias Wintzer, Michael Aftosmis and Susan Cliff, NASA Ames, for contributing diagrams of the models and analysis process
- Sriram Rallabhandi, National Institute of Aerospace, and Joe Salamone, formerly Gulfstream Aerospace, provided the suggestion of A-weighted filter for time domain analysis

ICAO/FAA Notional Roadmap for Sonic Boom Noise Standard



May 2013 version

Typical Mission Boom Carpet