Nearfield Summary and Statistical Analysis of the Second AIAA Sonic Boom Prediction Workshop

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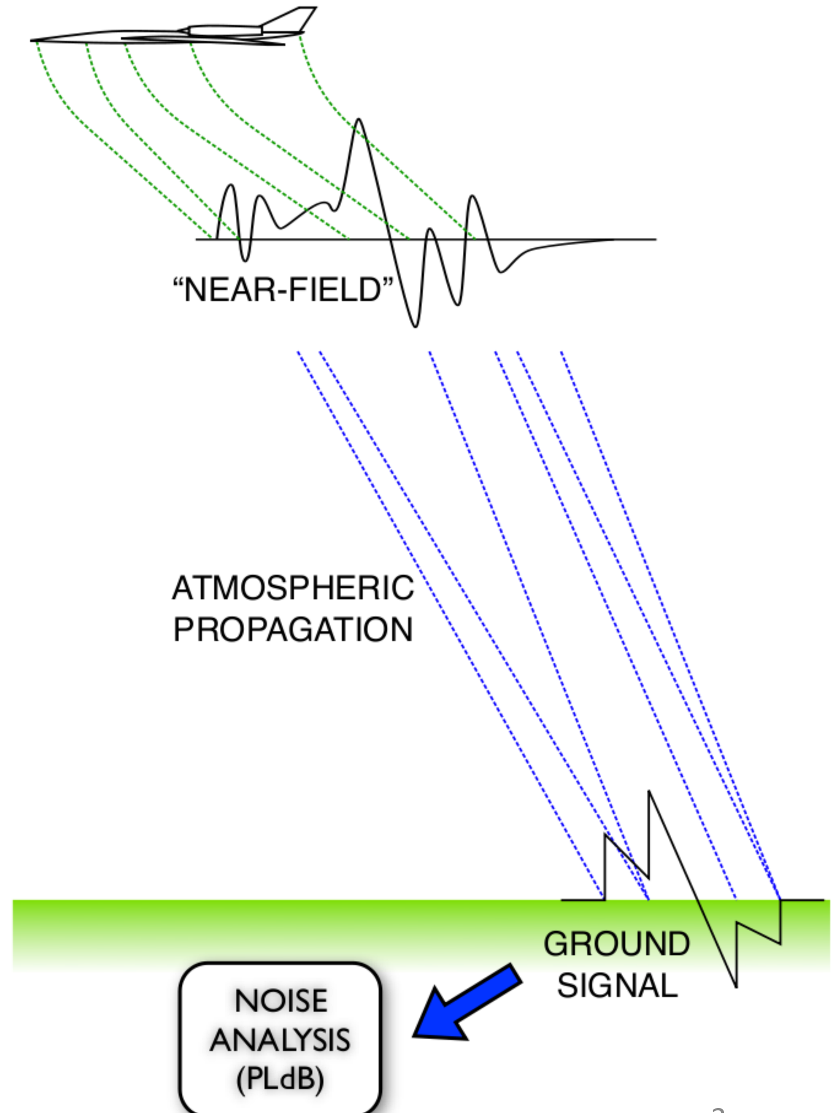
Motivation

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

Motivation

- Nearfield CFD is part of sonic boom prediction
- Impartially compare signatures by uniform investigation of
  - Propagation and Loudness measures
  - Grid refinement
  - Statistics

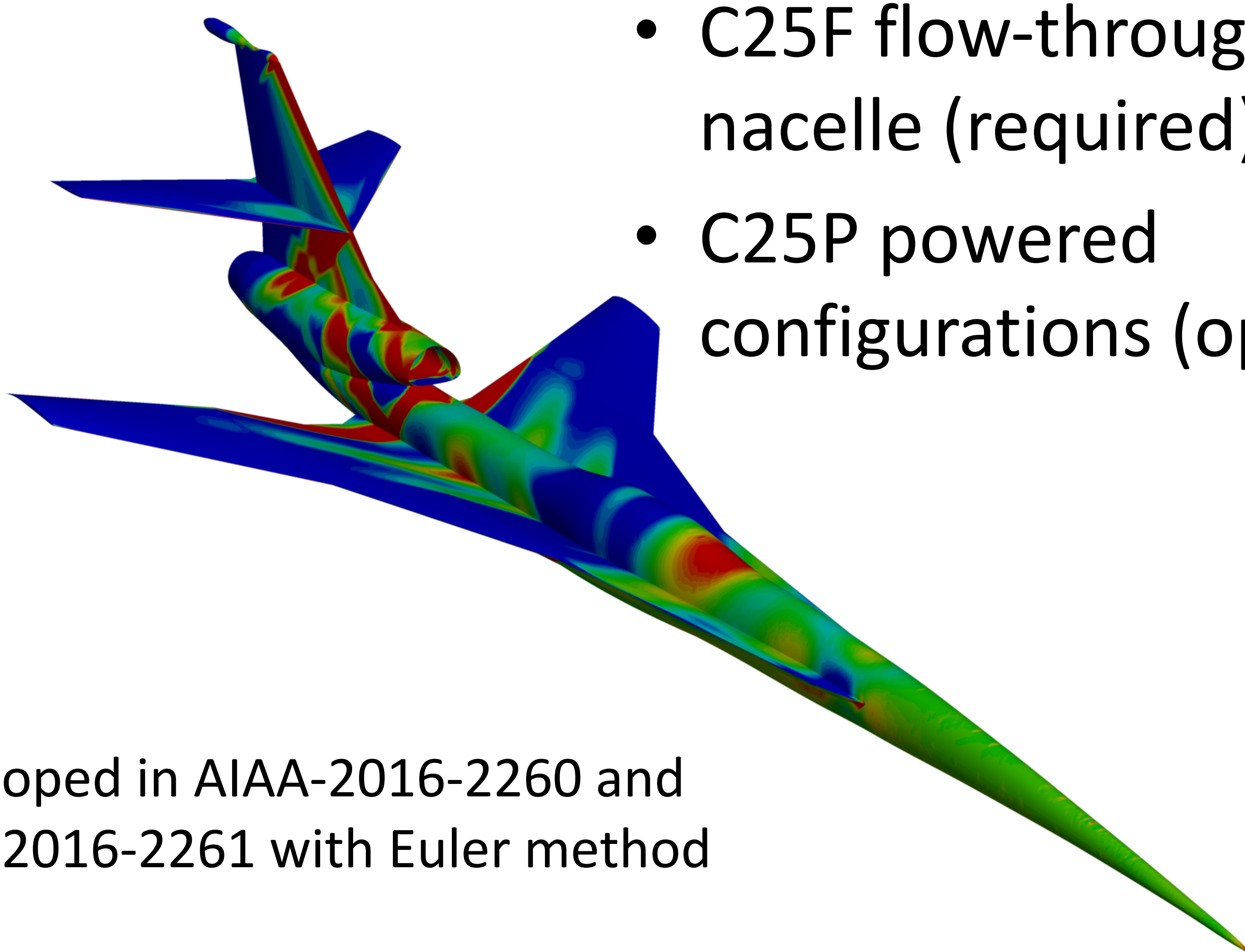


Models and Cases

- Designed to produce similar signatures with a range of simulation complexity
- Mach 1.6
- Euler and Reynolds-averaged Navier-Stokes (RANS) at flight unit Reynolds number of 5.7 million per meter requested
- US Standard atmosphere at 15,760 meter altitude
- Propulsion boundary conditions provided

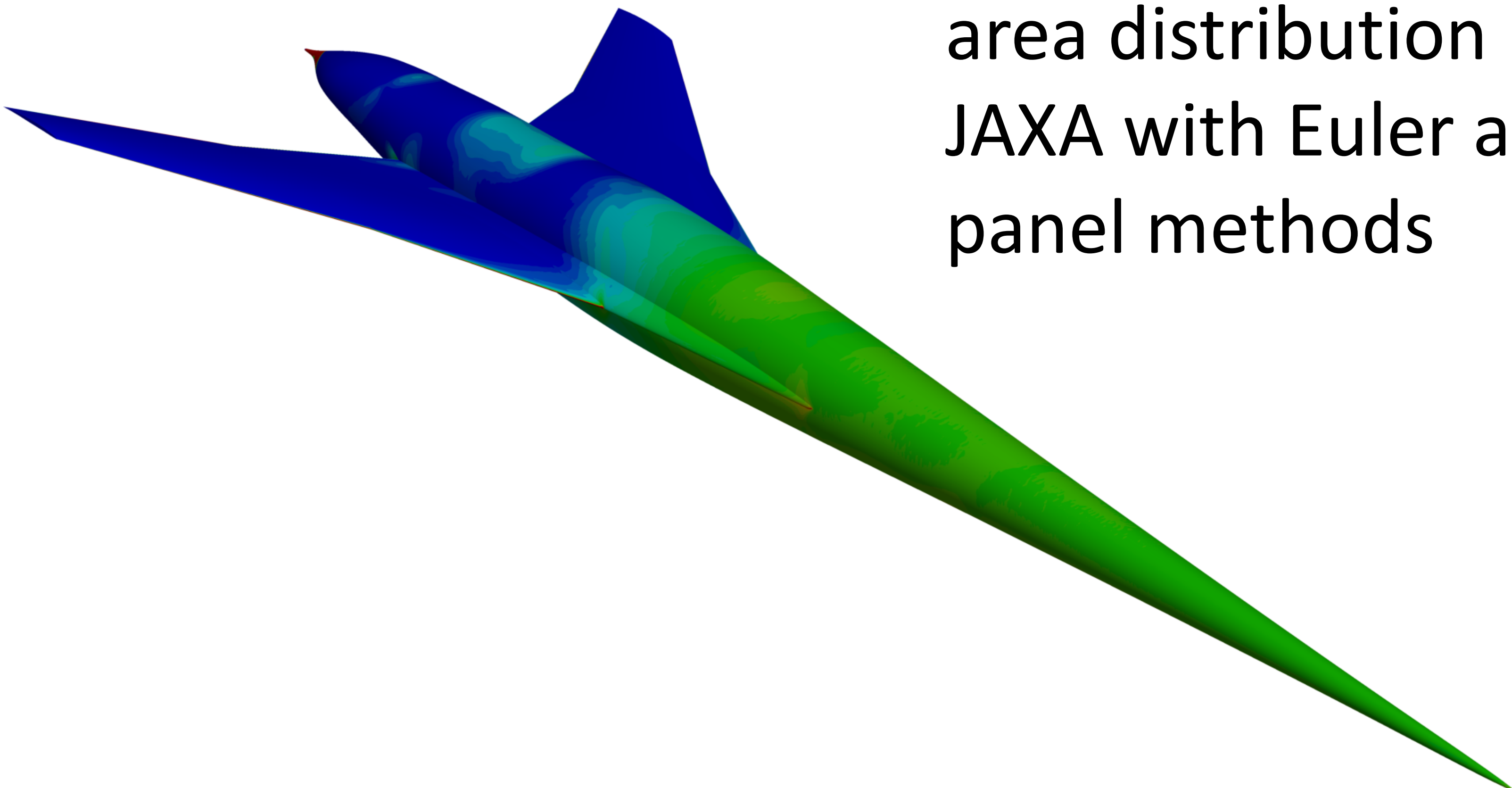
C25F (shown) and C25P

- C25F flow-through nacelle (required)
- C25P powered configurations (optional)



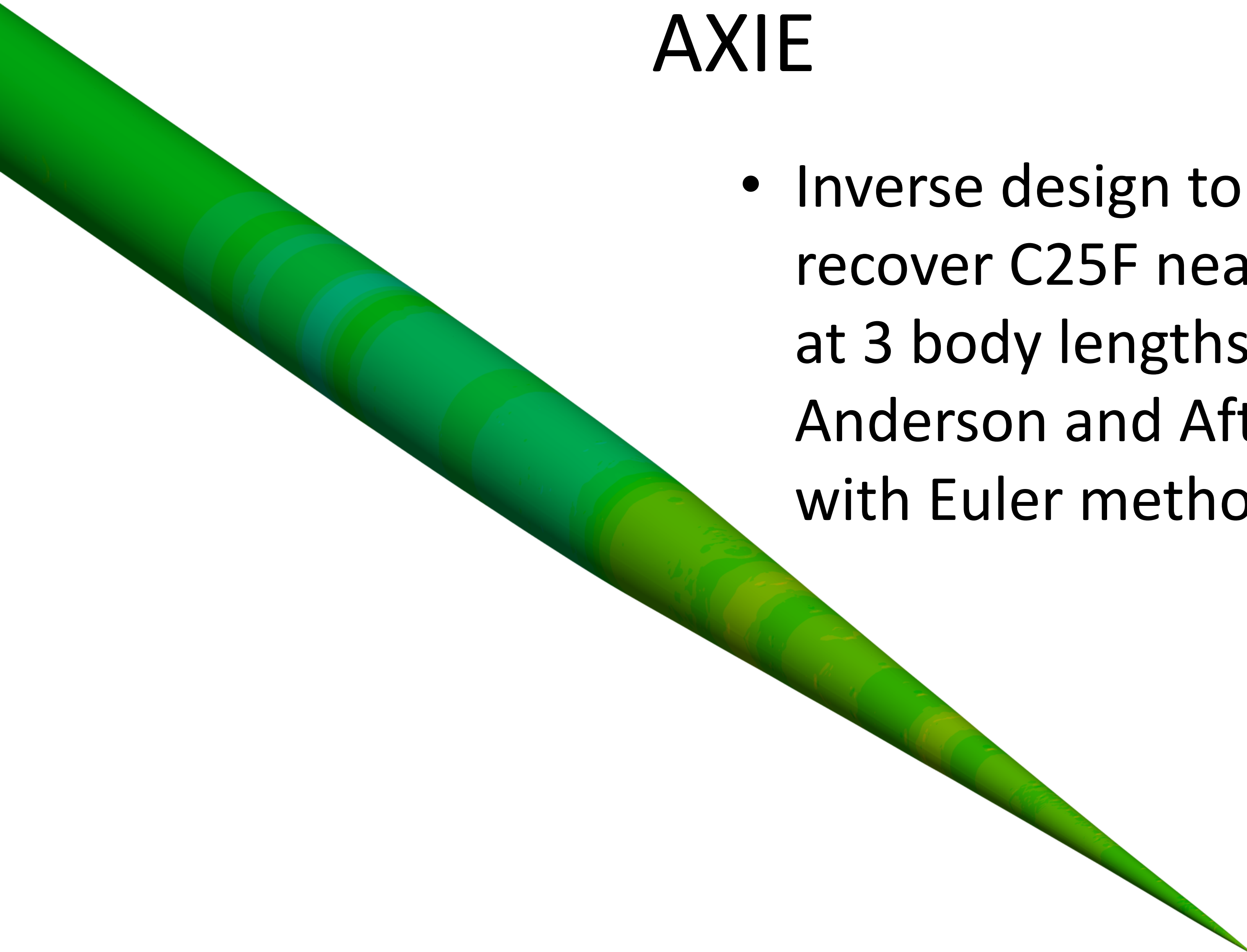
Developed in AIAA-2016-2260 and AIAA-2016-2261 with Euler method

JWB



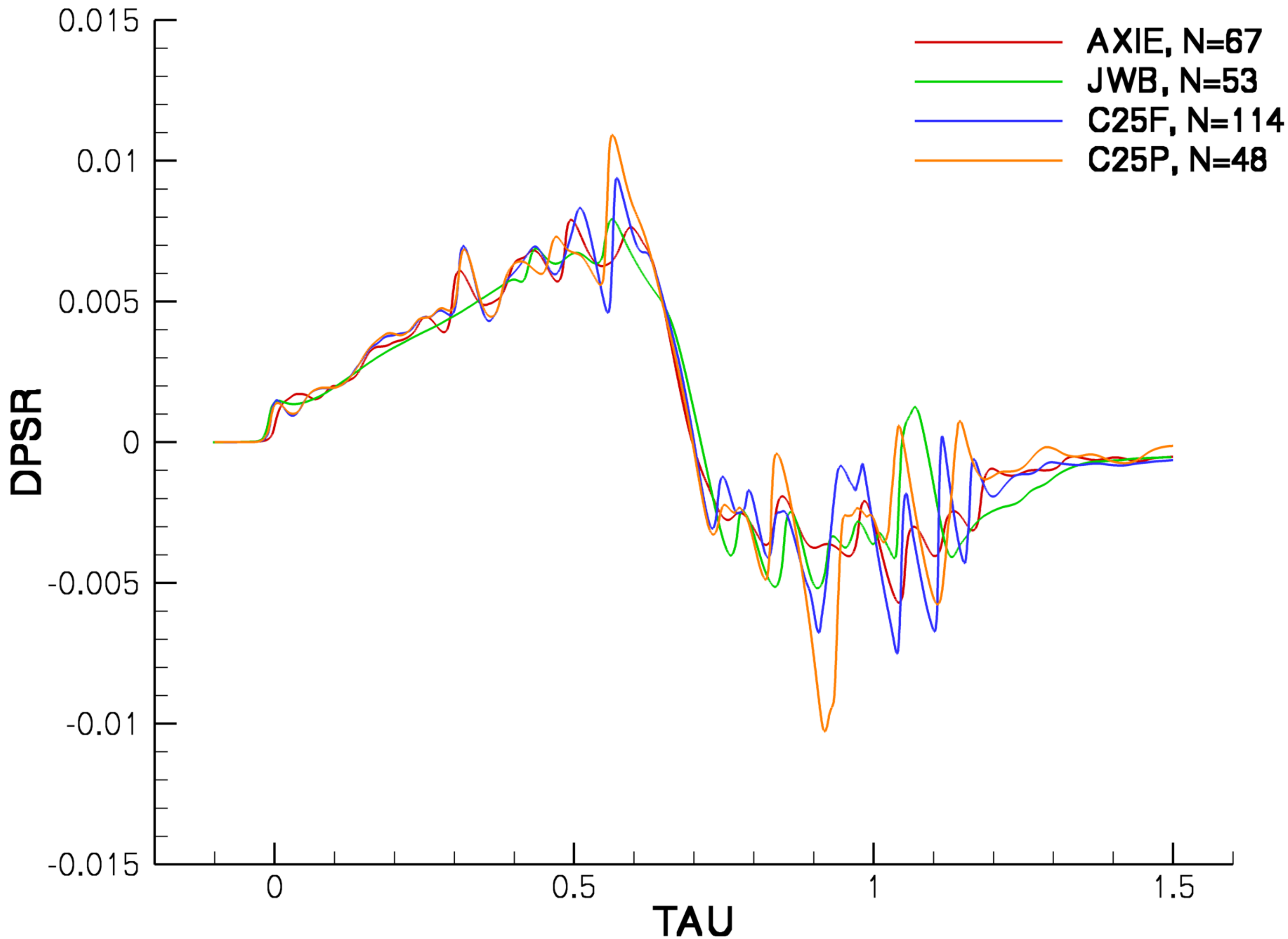
- Inverse design to recover C25F equivalent area distribution by JAXA with Euler and panel methods

AXIE

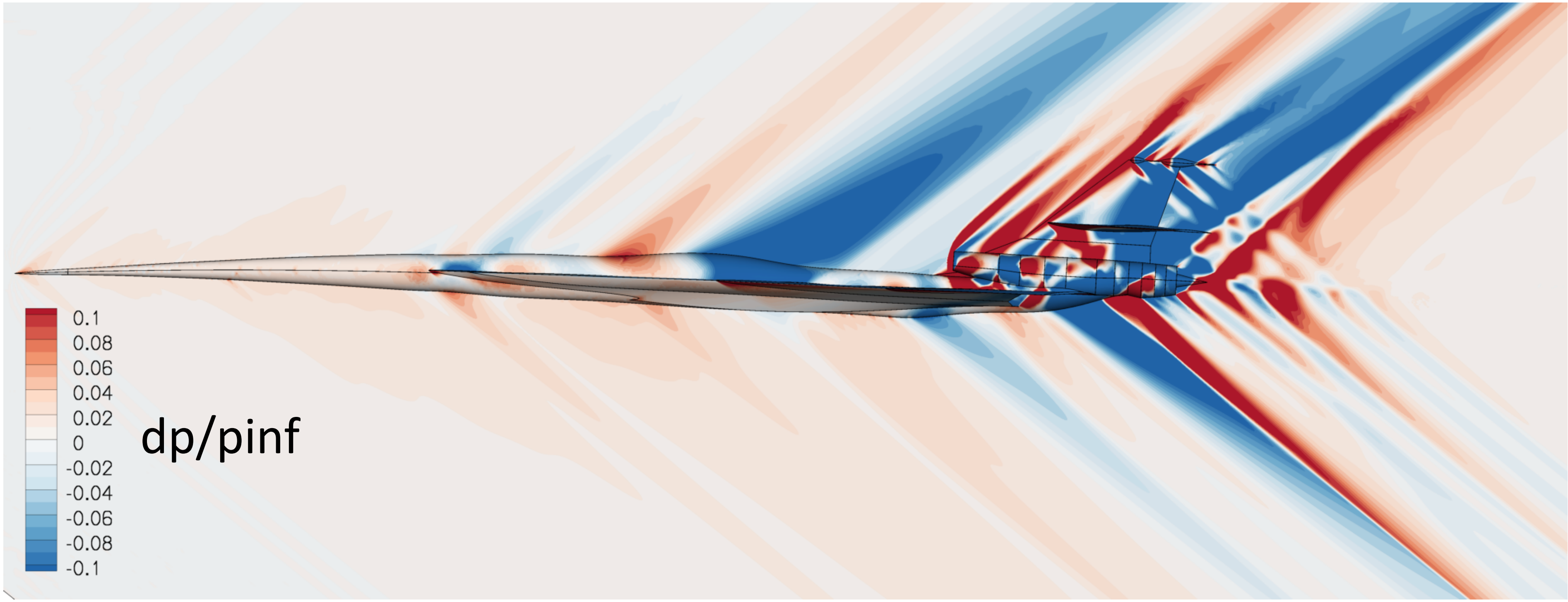


- Inverse design to recover C25F nearfield at 3 body lengths by Anderson and Aftosmis with Euler method

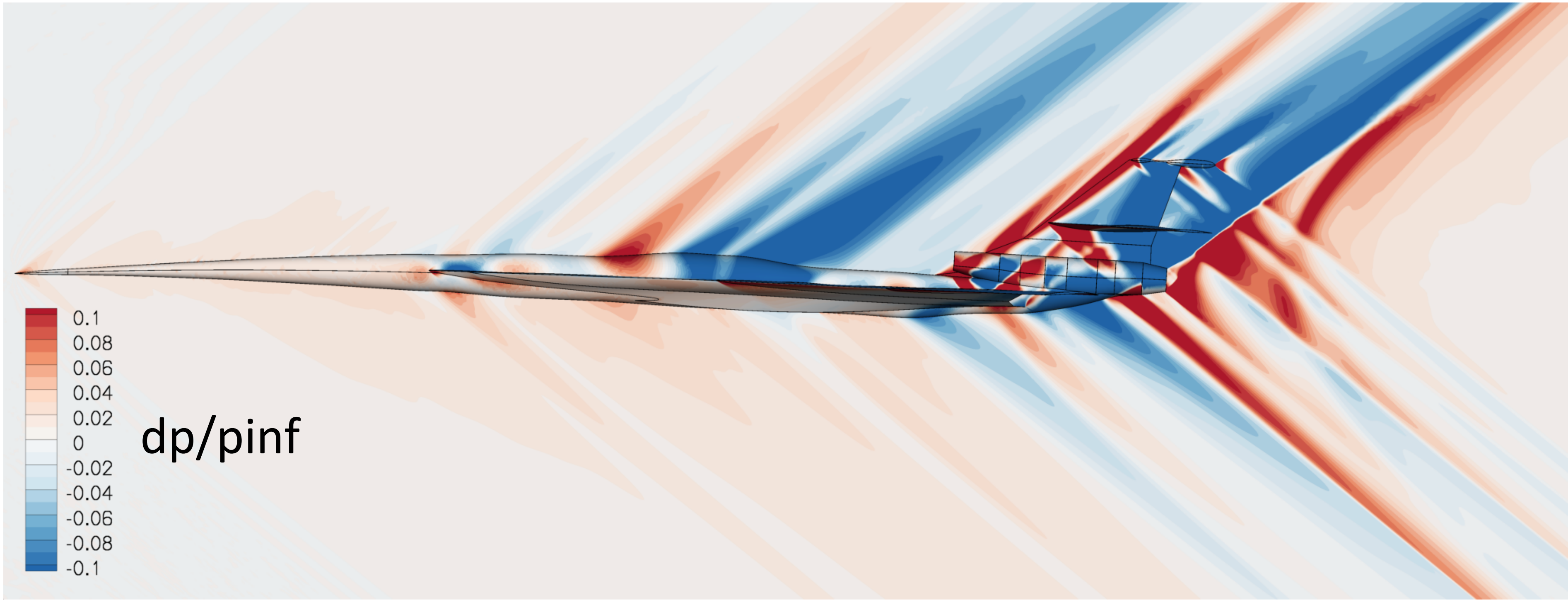
Nearfield Ensemble Mean R=3, PHI=0°



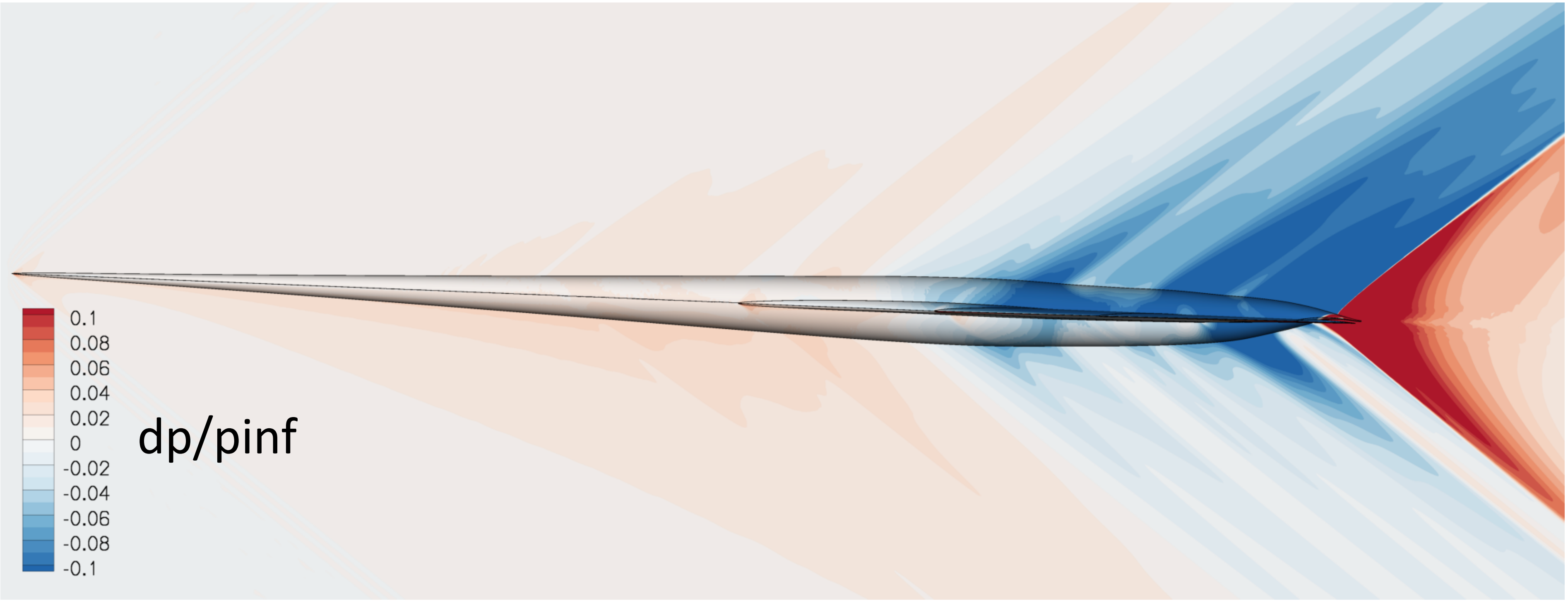
C25P Pressure Disturbance



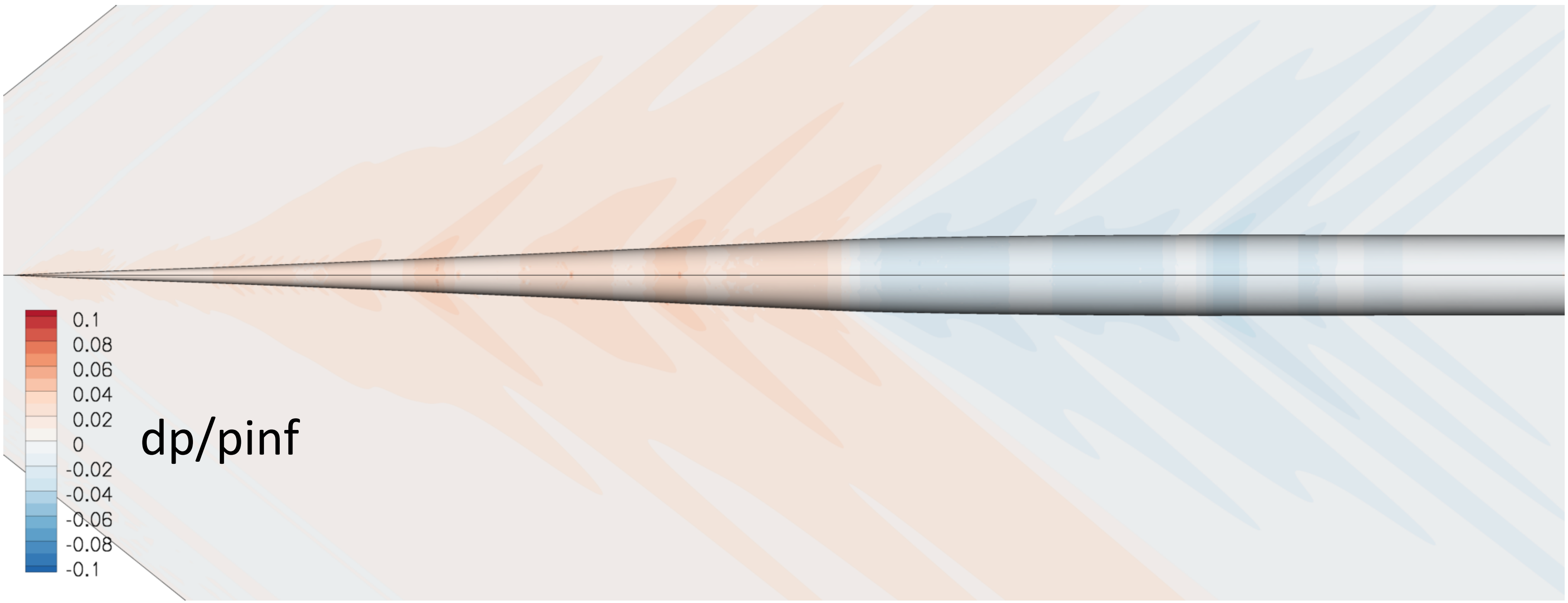
C25F Pressure Disturbance



JWB Pressure Disturbance



AXIE Pressure Disturbance



AXIE, C25F, and C25P Provided Grids

- Mixed element and tetrahedra only families of core grids with semistructured Mach-aligned collar grids (same as SBPW1, see AIAA-2014-115)
  - 0.6 to 56 million node Euler AXIE (5)
  - 3-104 million node Euler C25F (6)
  - 5-138 million node viscous C25F (6)
  - 3-52 million node Euler C25P (5)
  - 5-70 million node viscous C25P (5)

JWB Provided Grids

- HeldenMesh generated surface and tetrahedral volume grids with anisotropic Mach-aligned spacing function in a single grid topology
  - 6, 11, and 18 million node Euler JWB (3)

Participant Grids

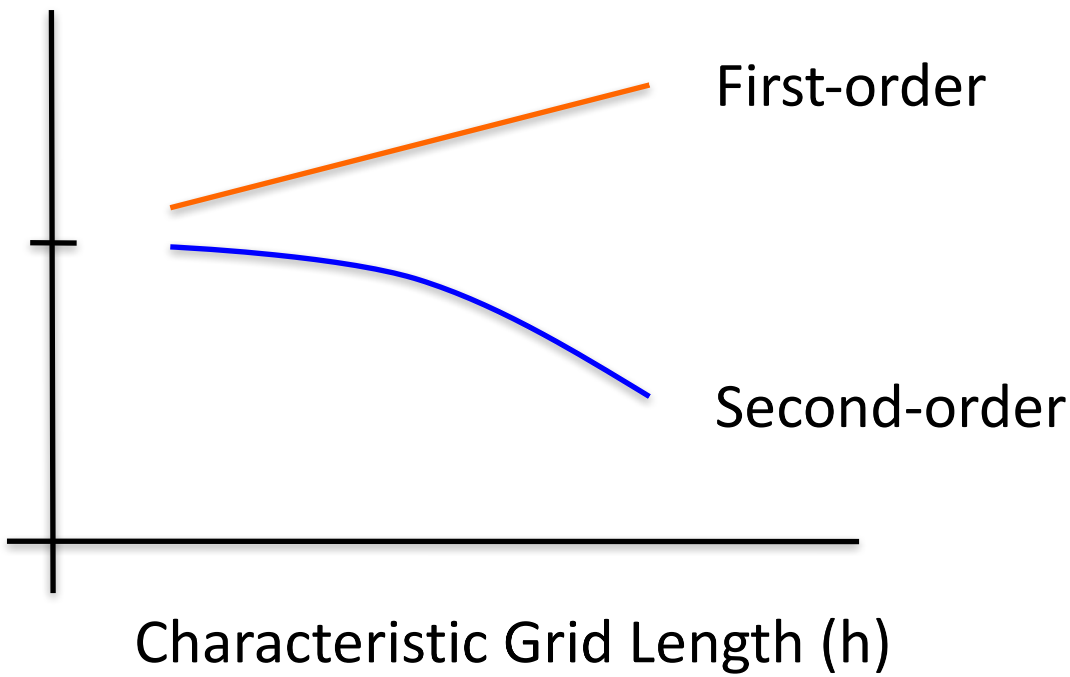
- Participants also provided grids based on their best practices
  - Grids received before the workshop were available as optional grids
- A series of three grids was requested from participants with adaptive methods
  - Final grid and two coarser intermediates

Loudness and Annoyance

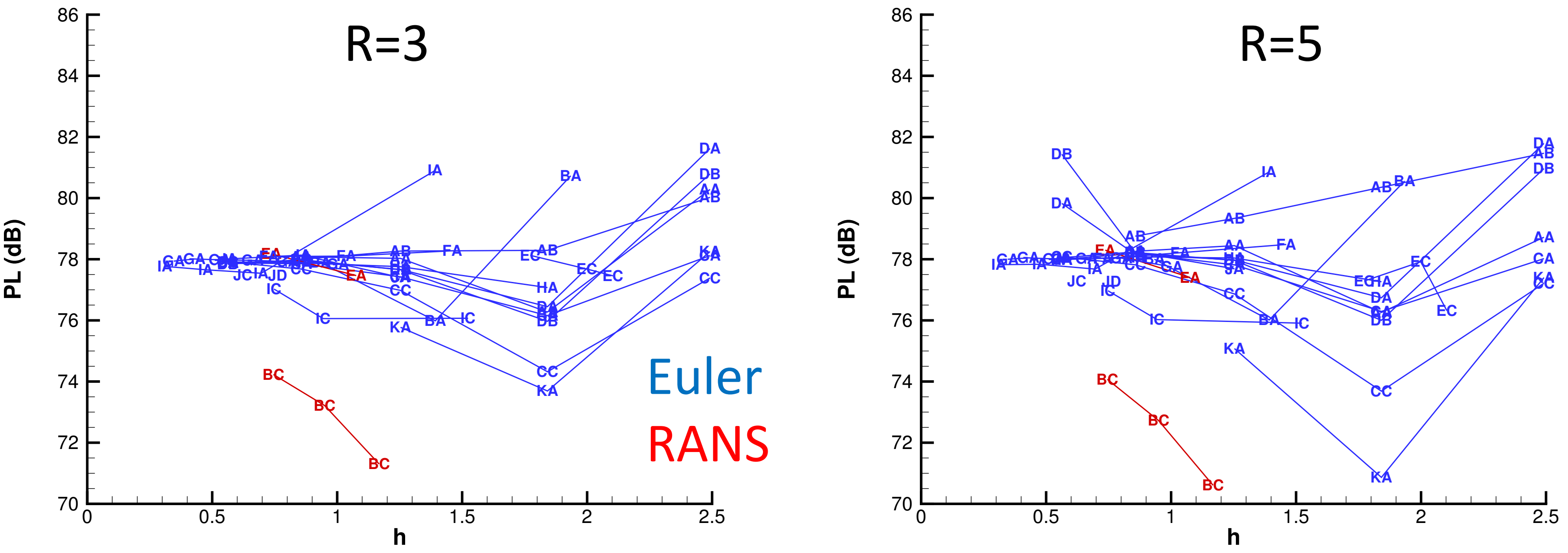
- Subjective metrics
- These human experiences are correlated to noise descriptors through experiments
  - Leatherwood et al. JASA 2002
  - Stevens Mark VII Perceived Level (PL)

Expected Grid Convergence

- Consistent methods should approach a value as the grid is refined to “zero” h (inverse cube root of CFD control volumes, propagation fixed)

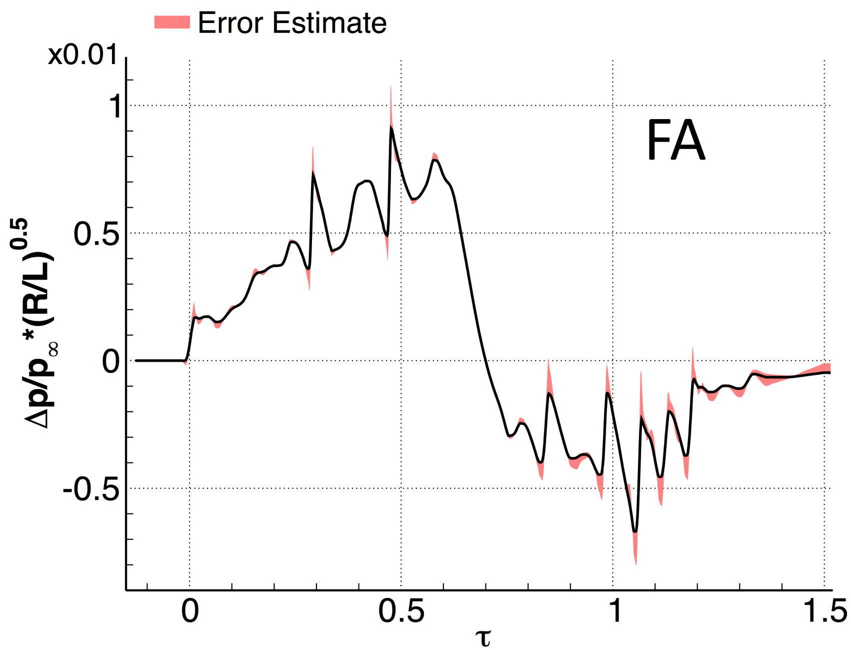


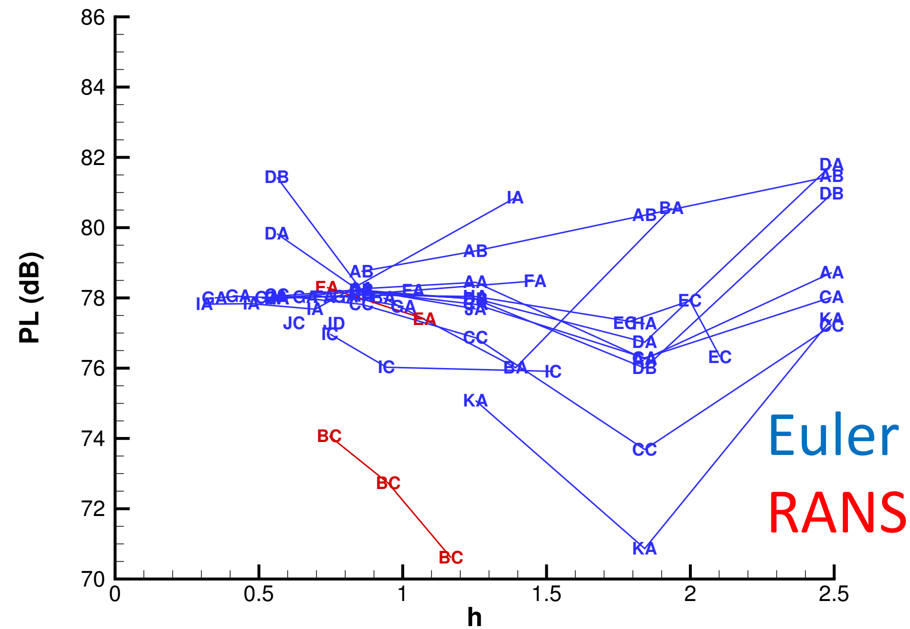
AXIE PL Grid Convergence



- Participant D reported that the collar grid construction was not optimal for their solver
- Participant C reported iterative convergence difficulties in the collar grid, but not at the extraction location

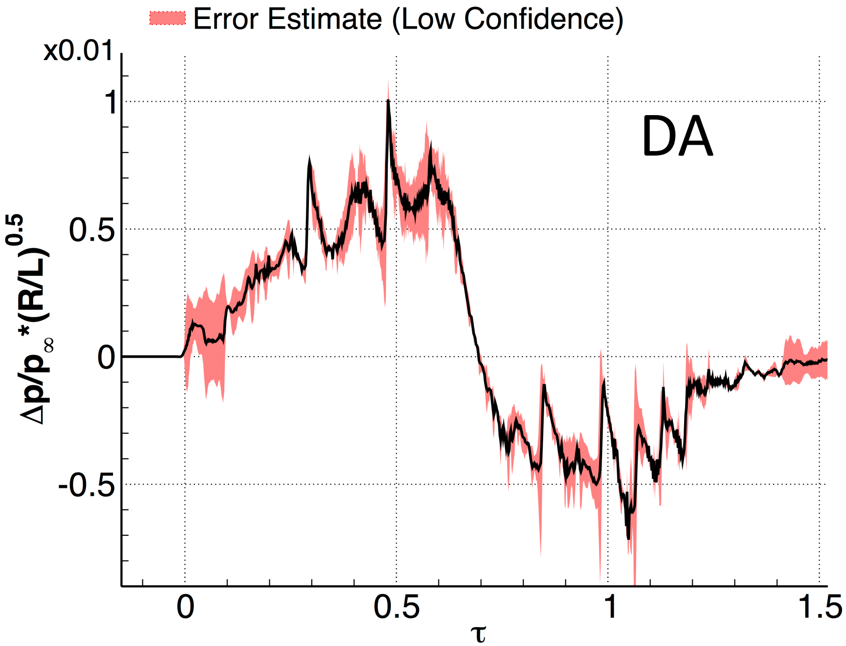
AXIE Grid Convergence, R=5

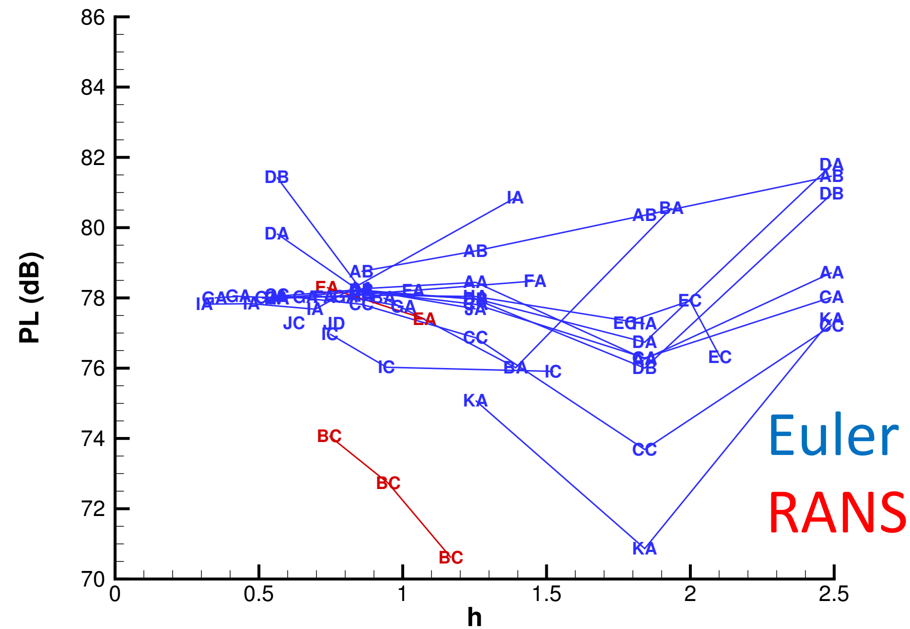




- A norm of the signature is treated like the PL scalar and the signature is pointwise extrapolated (Richardson, Roache) from three grids to infinitely refined grid (h=0)
- The red area is the extrapolation, largest at shocks

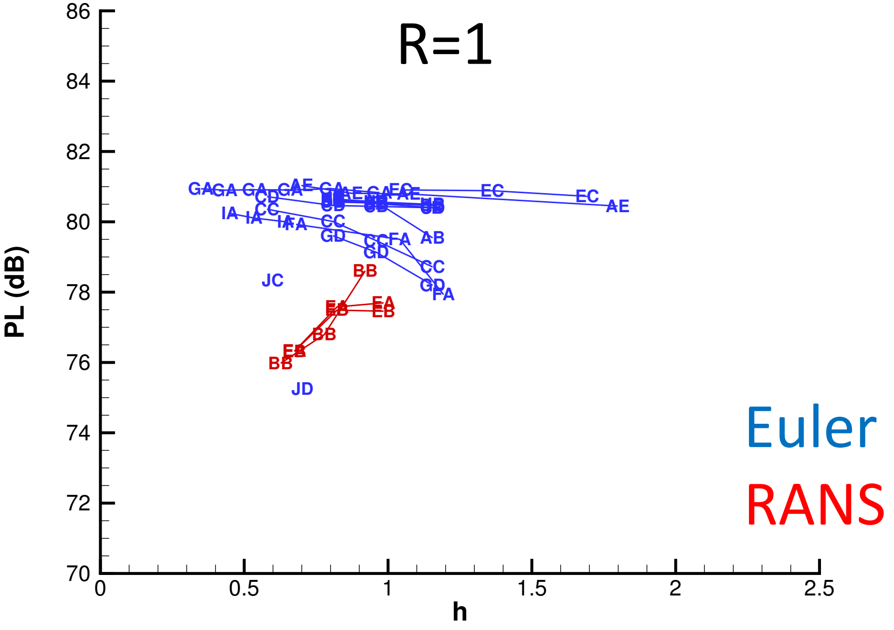
AXIE Grid Convergence, R=5

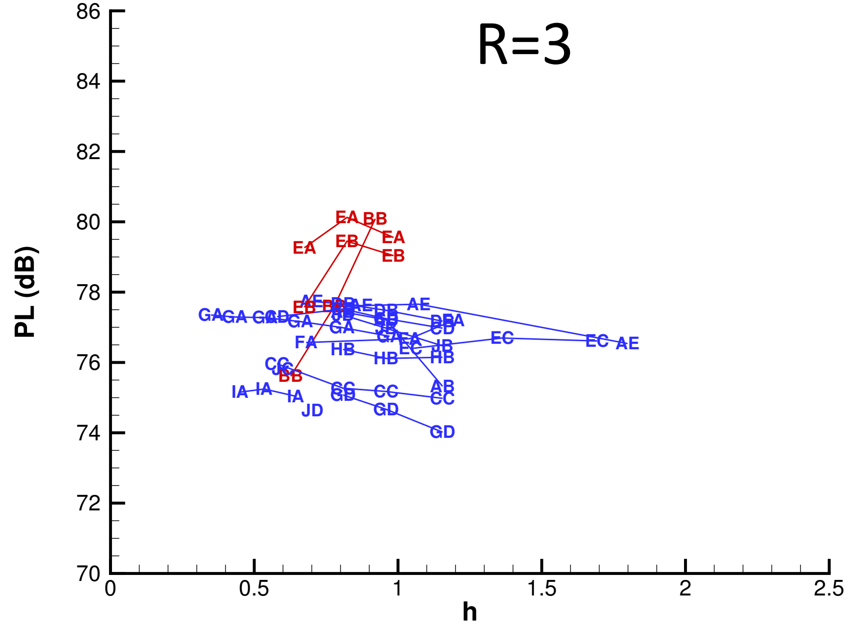




- A norm of the signature is treated like the PL scalar and the signature is pointwise extrapolated (Richardson, Roache) from three grids to infinitely refined grid (h=0)
- The red area is the extrapolation, confirming divergence

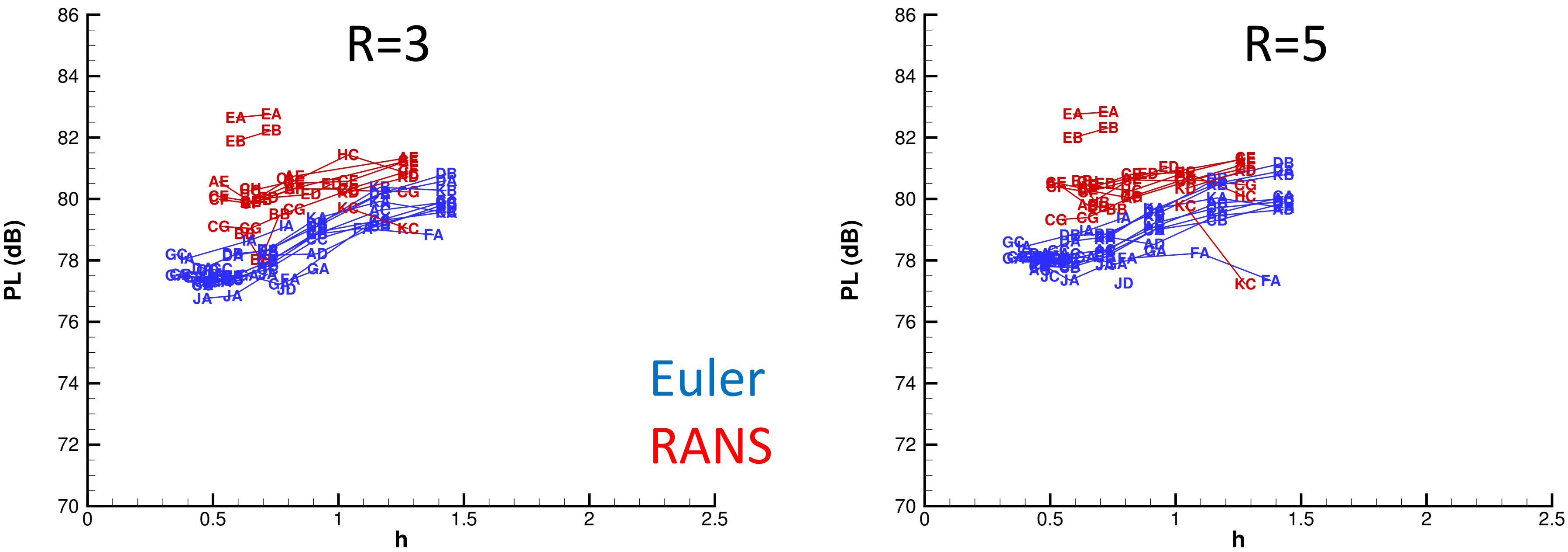
JWB PL Grid Convergence, PHI=10°





- JWB has the strongest expansion and extraction distance sensitivity
- JWB grid construction different from other models
- JWB showed the greatest reconstruction limiter sensitivity

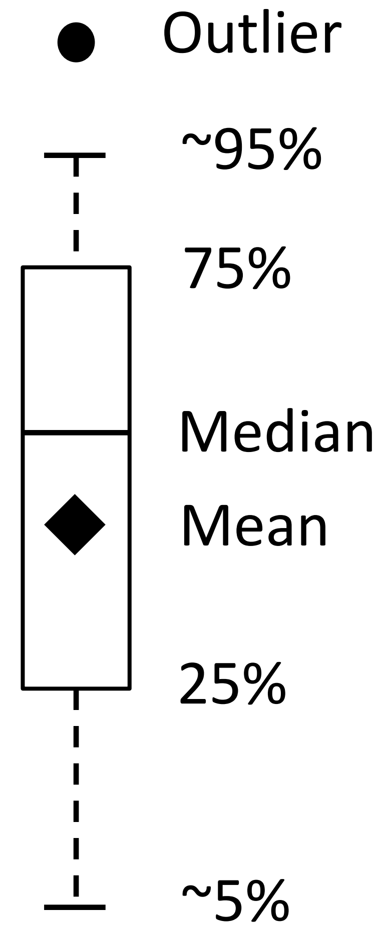
C25F PL Grid Convergence, PHI=0°



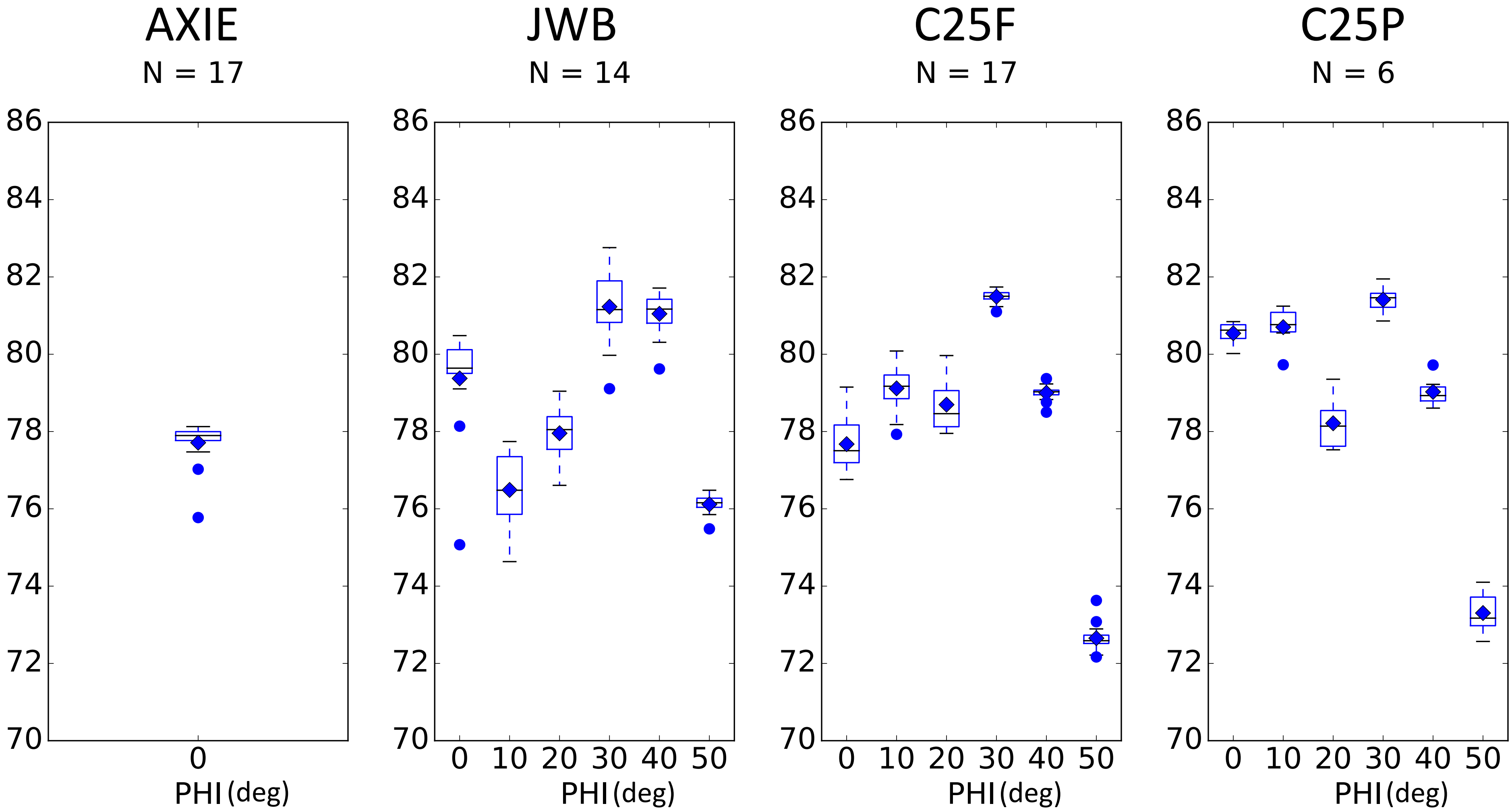
- Trend change for the finer meshes (new physics)
- RANS has more fine grid variation than Euler (smaller grids)
- C25P has similar trends (when updates after the workshop included)

Statistical Method

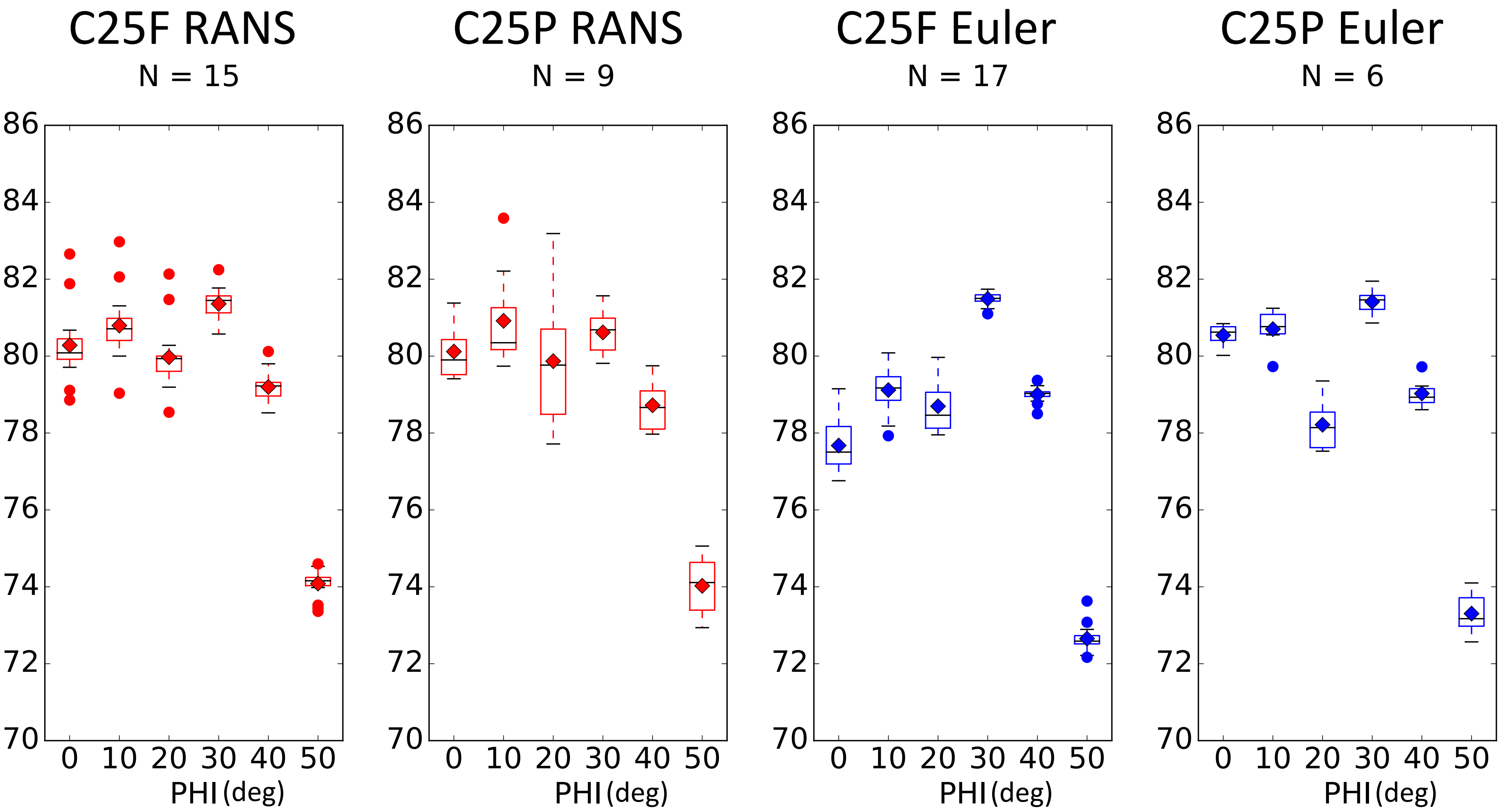
- Goal is to identify "different" results, not "correct" or "wrong"
- Box (half of submissions) and whisker plots (95% coverage for normal distribution)
- Used by Drag Prediction Workshop (AIAA-2017-1209)



PL Euler from R=3



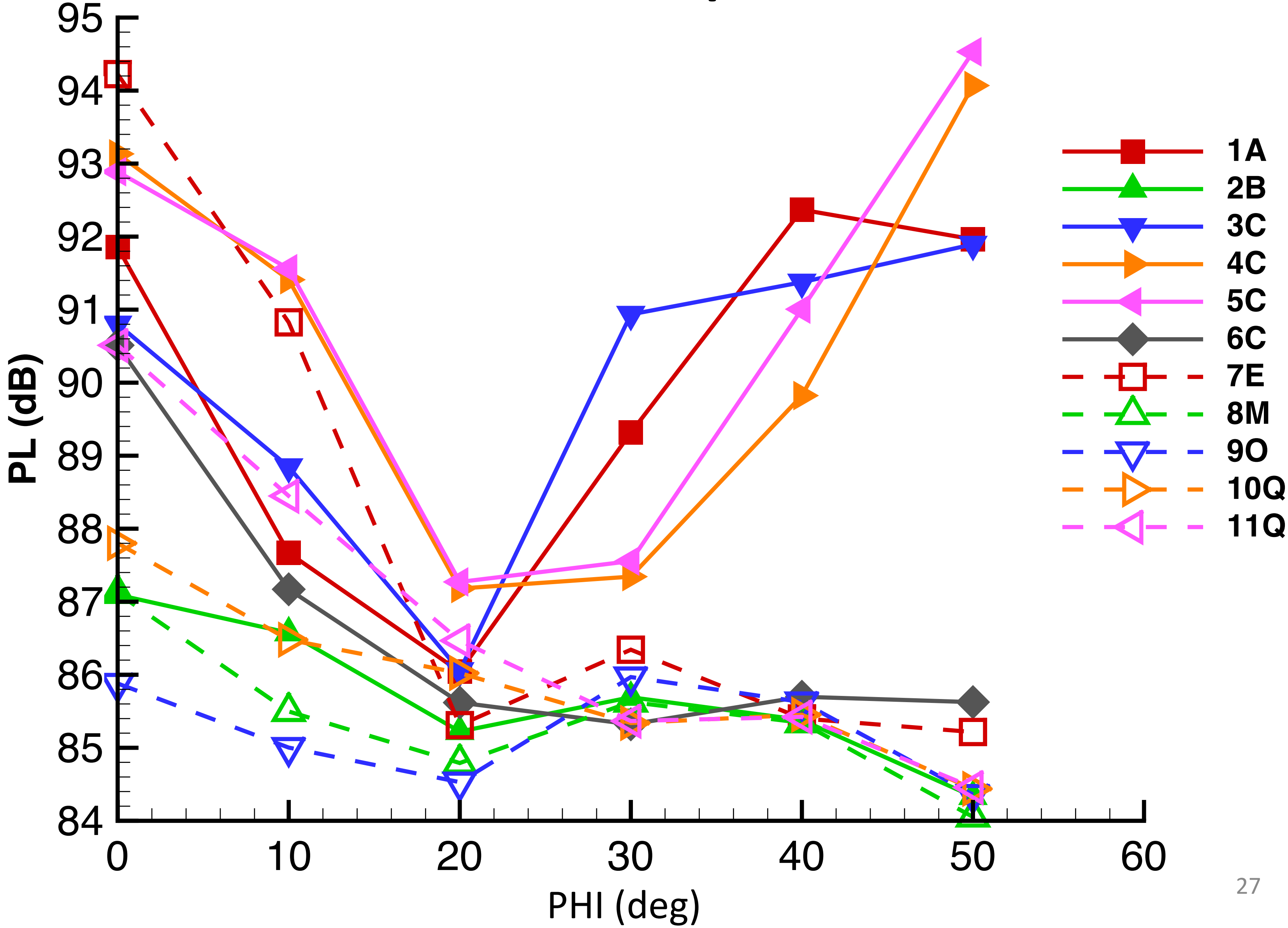
C25F and C25P from R=3



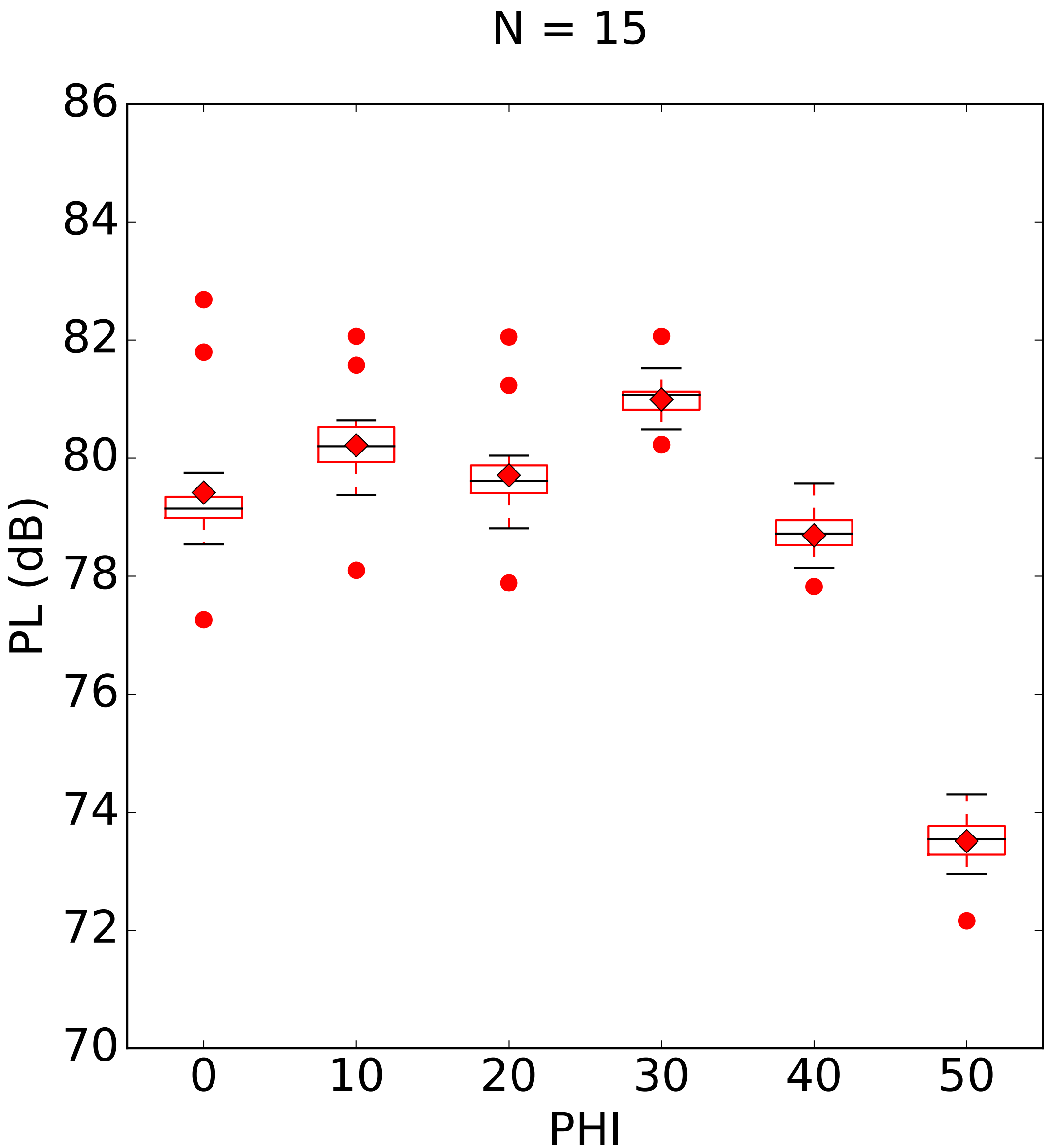
Progress Since SBPW1

- Much quieter mean PL (dB)
  - SBPW1: 91.8 axisymmetric, 95.5 wing body
  - SBPW2: 77.7 axisymmetric, 79.4 wing body
- Standard deviation is difficult to compare, PL (dB) is logarithmic
  - SBPW1: 0.3 axisymmetric, 0.2 wing body
  - SBPW2: 0.6 axisymmetric, 1.4 wing body
- More complex and more submissions
  - Statistics for required full configuration
  - Optional propulsion boundary condition case

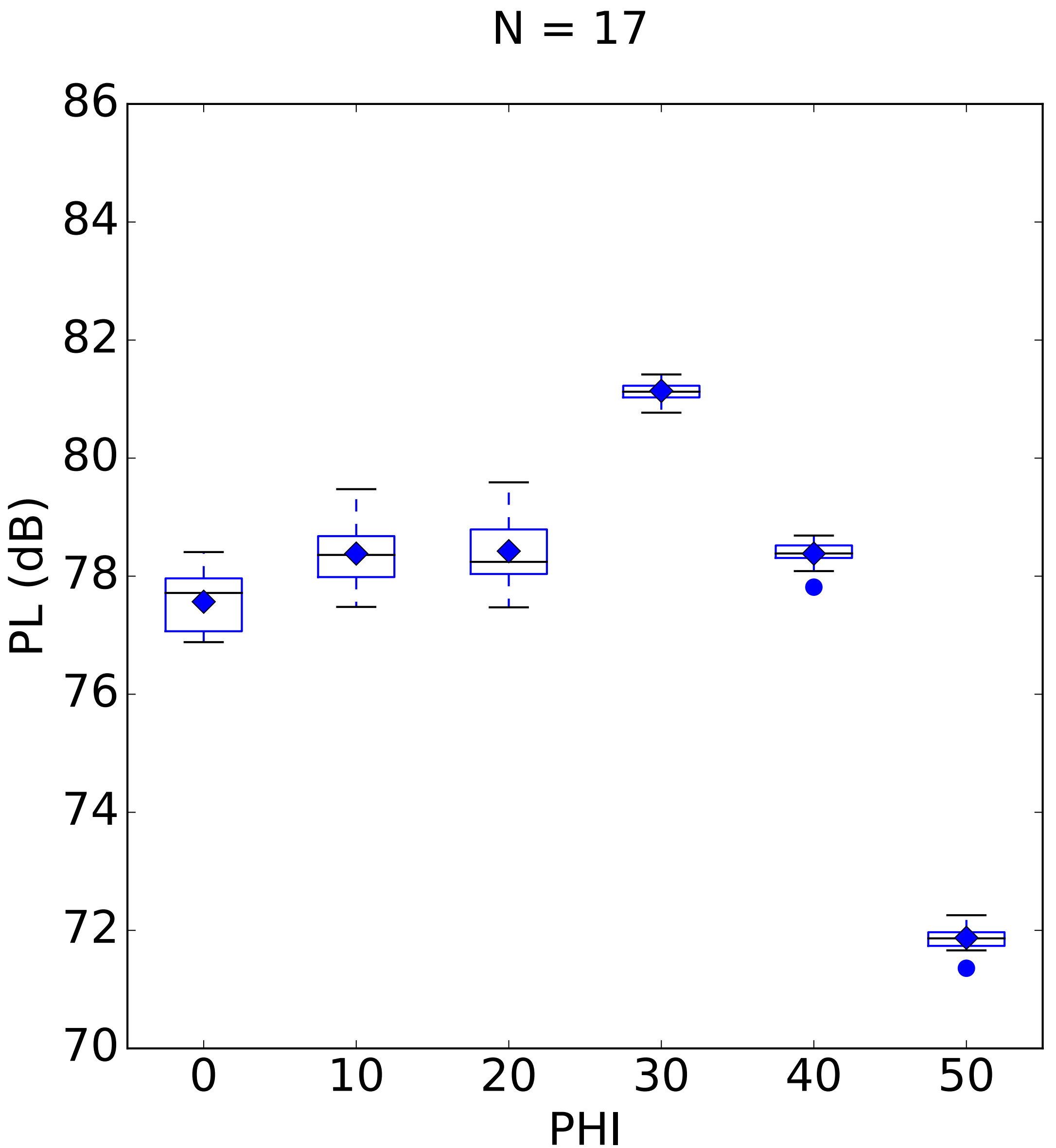
LM1021 PL Carpet, R=1.4



C25F RANS PL Carpet, R=1



C25F Euler PL Carpet, R=1



Conclusions

- PL trends with grid refinement were shown for the AXIE, JWB, and C25F
  - AXIE convergence the best with outliers at R=5
  - AXIE observations at R=5 confirmed with examination of nearfield signature convergence
  - JWB had a larger variation than the more complex C25F

Conclusions

- PL statistics visualized with box and whisker plots
  - Euler and RANS analyzed separately when sufficient samples available
  - The size of the box (middle 50%) was largest for the JWB Euler
  - RANS has larger box than Euler for C25F and C25P

Conclusions

- Progress made since the first workshop identified
  - Simple cases much quieter
  - JWB had a larger standard deviation, but PL logrithmic
  - Statistics available for complex C25F and C25P

In the Paper

- Grid convergence of nearfield submissions
  - Confirms and explains the trends shown in PL
- Pointwise mean and standard deviation of nearfield submissions
  - Euler and RANS nearfield differ by more than one standard deviation in many important locations
- Lift and iterative convergence
  - Euler and RANS lift approach different values with grid convergence

In the Paper

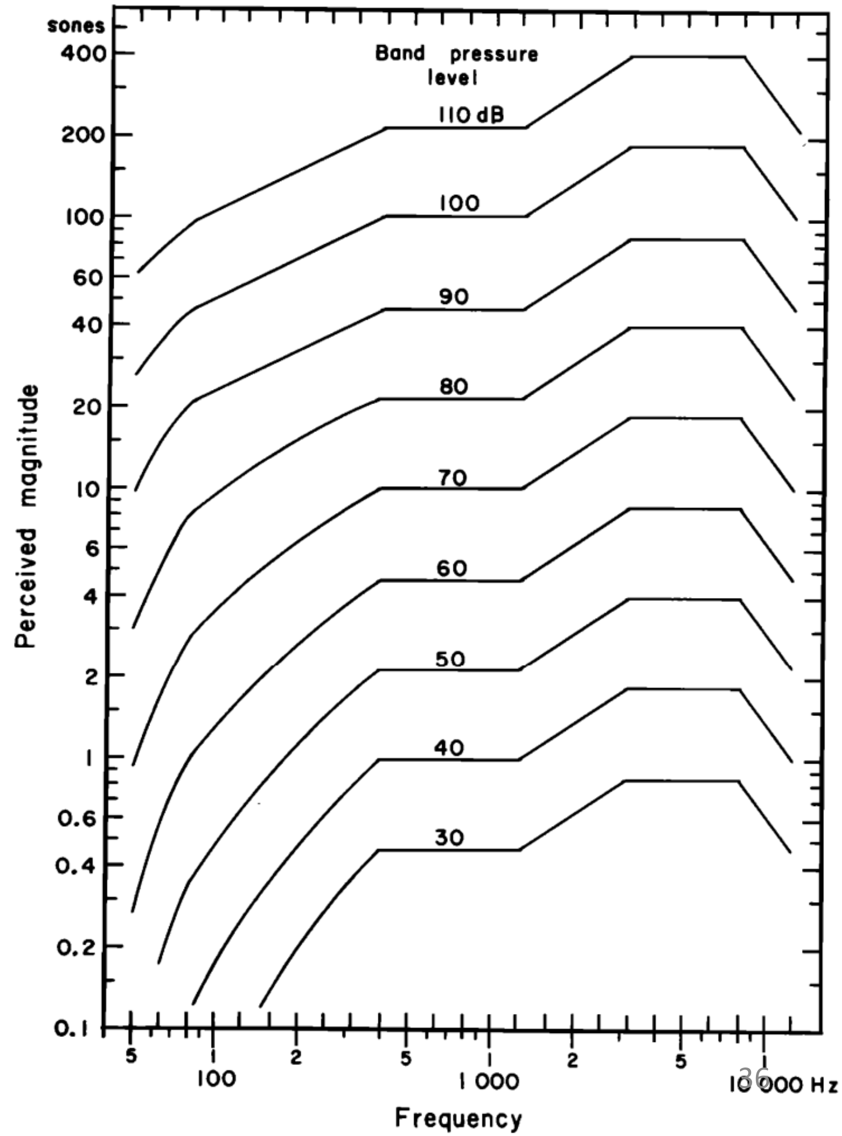
- Details of required grid families
- Summaries of participant presentations
- Discussion, recommendations, and next steps toward SBPW3
  - Quieter SBPW2 cases exposed issues not seen in SBPW1
  - Quieter configurations, ideally at or below 75 PL (dB)
  - Additional research needed to reduce sensitivity to convection scheme
  - Establishing benchmark (archived submissions)

Acknowledgments

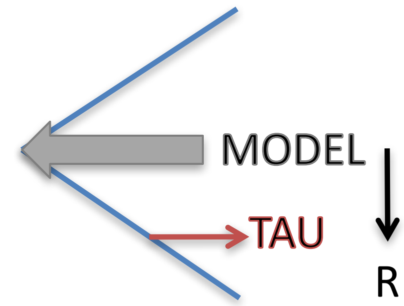
- All participants
- Mathias Wintzer, Irian Odaz, James Fenbert, and Sriram Rallabhandi for C25F and C25P designs
- George Anderson and Michael Aftosmis for AXIE design
- Atsushi Ueno, Masashi Kanamori, and Yoshikazu Makino for JWB geometry
- Andrew Clemens for JWB grids
- Marie Denisen, Adrein Loseille, Alaa Elmiligui, and Mike Aftosmis for grid evaluation and feedback
- Scott Brynildsen, Bill Jones, and Sriram Rallabhandi for geometry preparation
- Joe Derlaga for statistical tools
- NASA Commercial Supersonic Technology Project of the Fundamental Aerodynamics Program.

Perceived Level (PL)

- Signature sound pressure level 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



Nearfield Plotting



- Tau is distance from freestream Mach cone originating at tip of nose
- Delta pressure divided by freestream pressure is scaled by the square root of radius in body lengths
  - Signatures at different radii readily comparable and "aging" effect observed