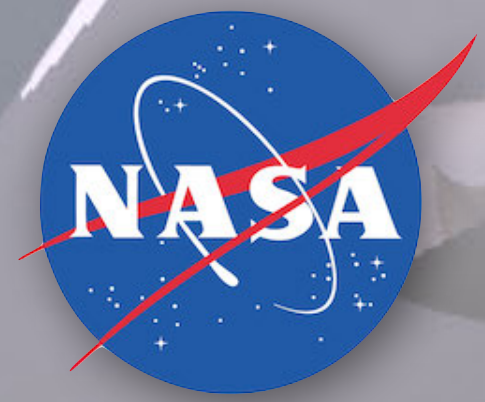
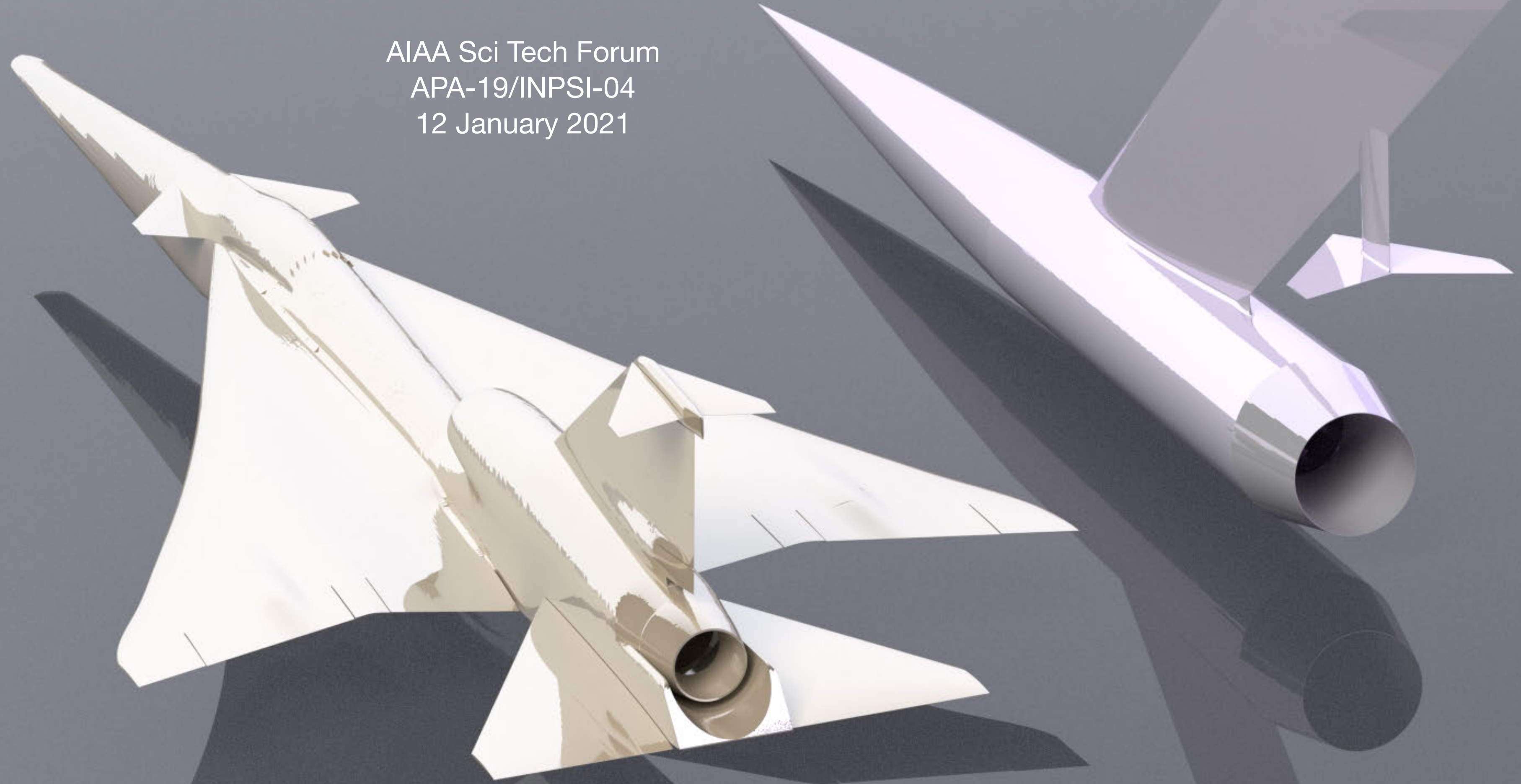


Cartesian Mesh Simulations for the Third AIAA Sonic Boom Prediction Workshop



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Wade M. Spurlock

Science and Technology Corp.
Computational Aerosciences Branch
Moffett Field, CA 94035
wade.m.spurlock@nasa.gov

Michael J. Aftosmis

Computational Aerosciences Branch
NASA Ames Research Center
Moffett Field, CA 94035
michael.aftosmis@nasa.gov

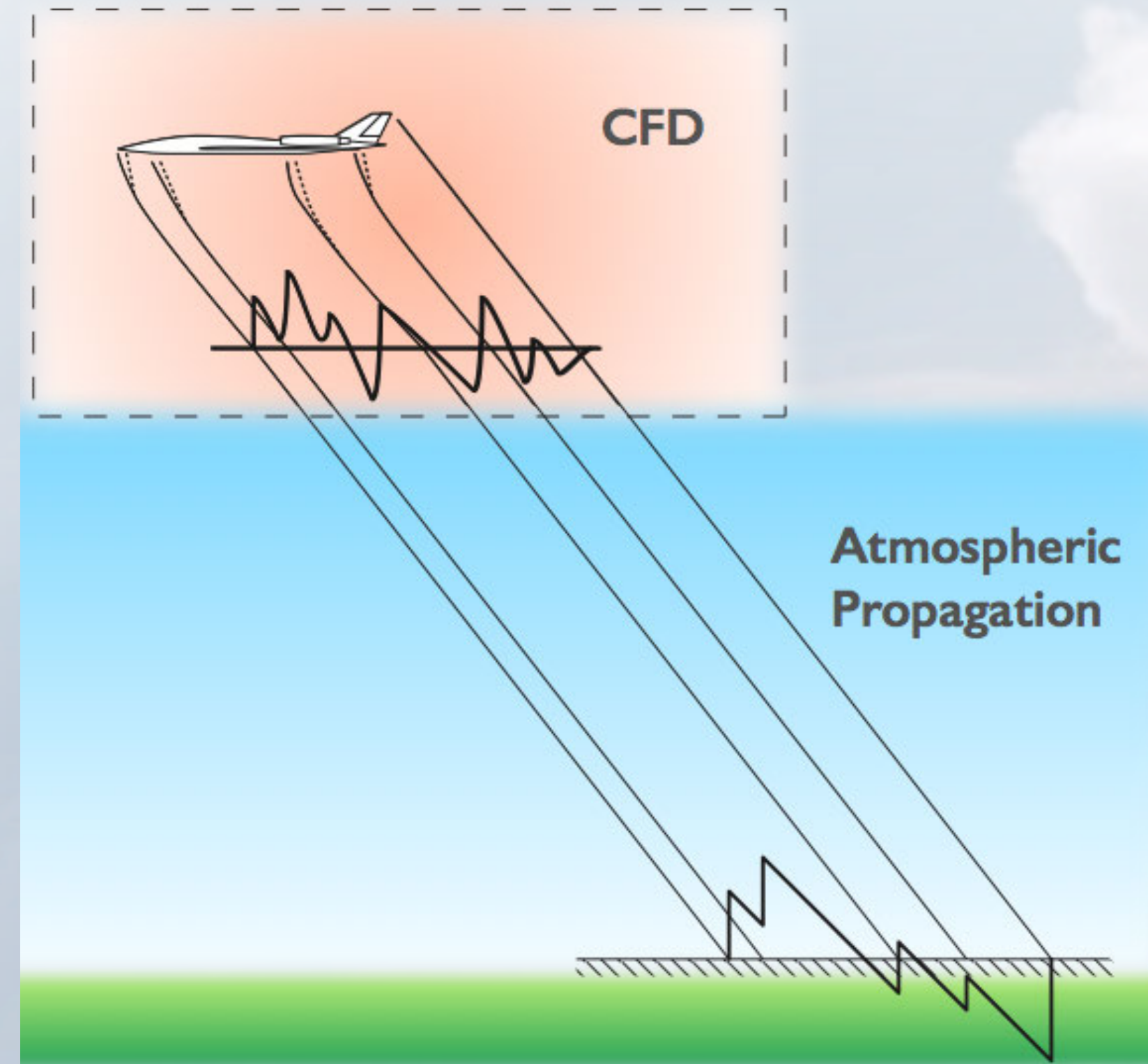
Marian Nemec

Computational Aerosciences Branch
NASA Ames Research Center
Moffett Field, CA 94035
marian.nemec@nasa.gov

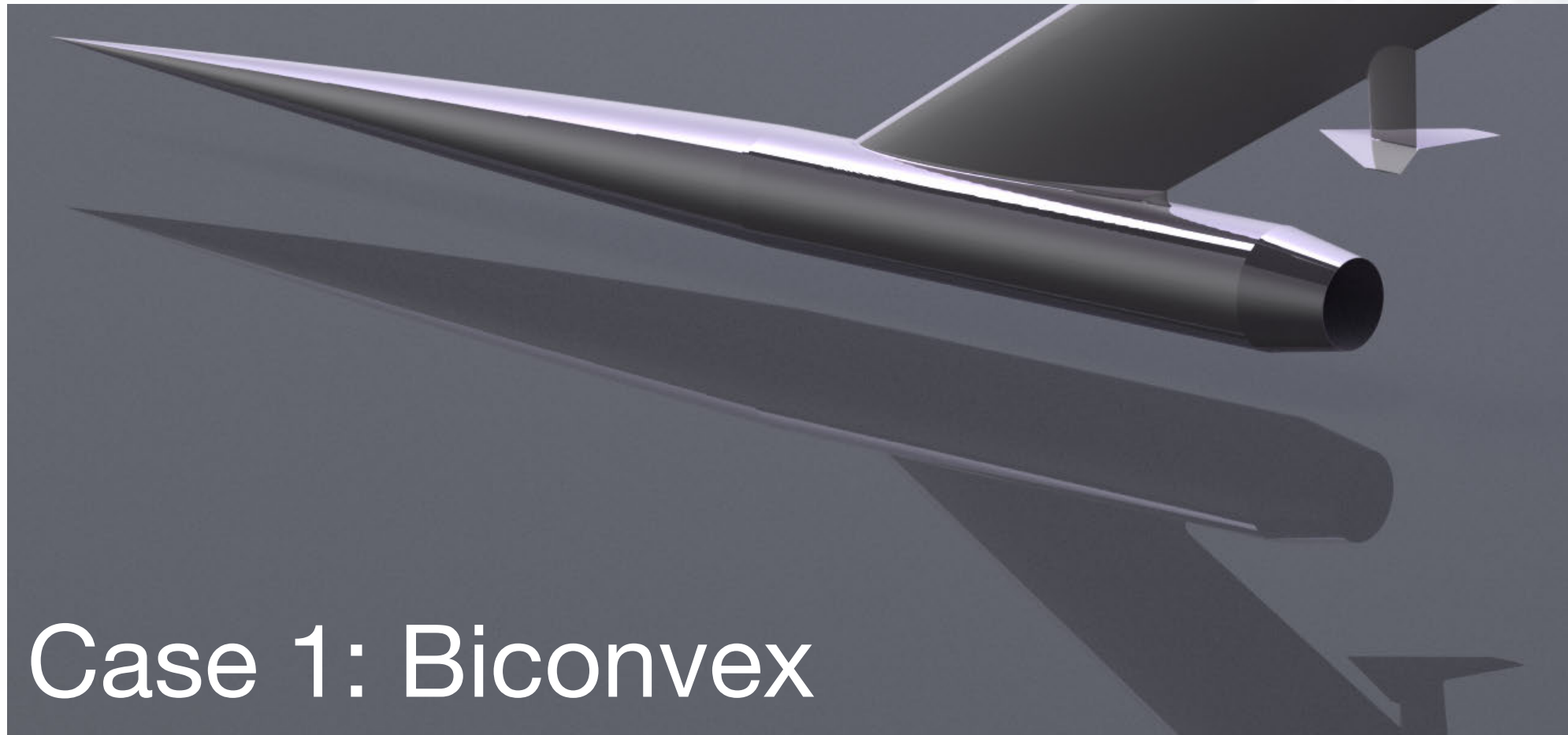
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Outline

- Nearfield CFD
 - Cases: Biconvex and C608
 - Flow solver & methodology
 - Results
 - Computational resources
- Farfield Propagation
 - Cases: C25P and C609
 - Mesh convergence studies
 - Results: Case 2 C609
- Takeaways

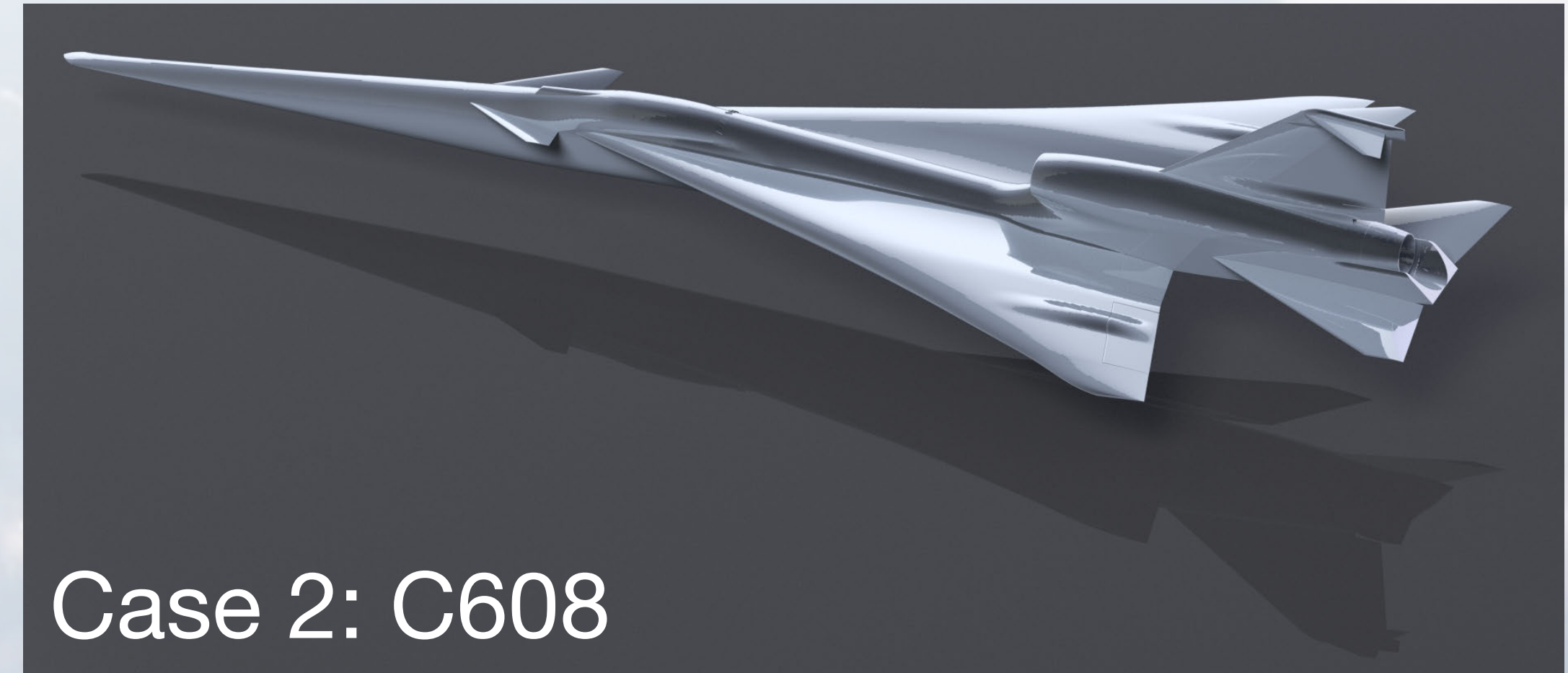


Nearfield CFD Cases



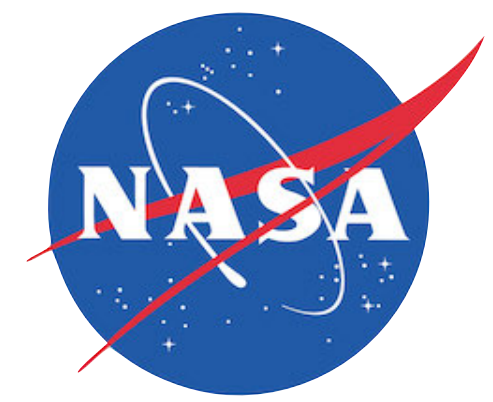
Wind tunnel model setup to examine shock/plume interaction

- Freestream $M_\infty = 1.6$
- Pressure signal at radial location $R = 15$ in (0.38 m)
- Model is approximately 22 in (0.56 m) long



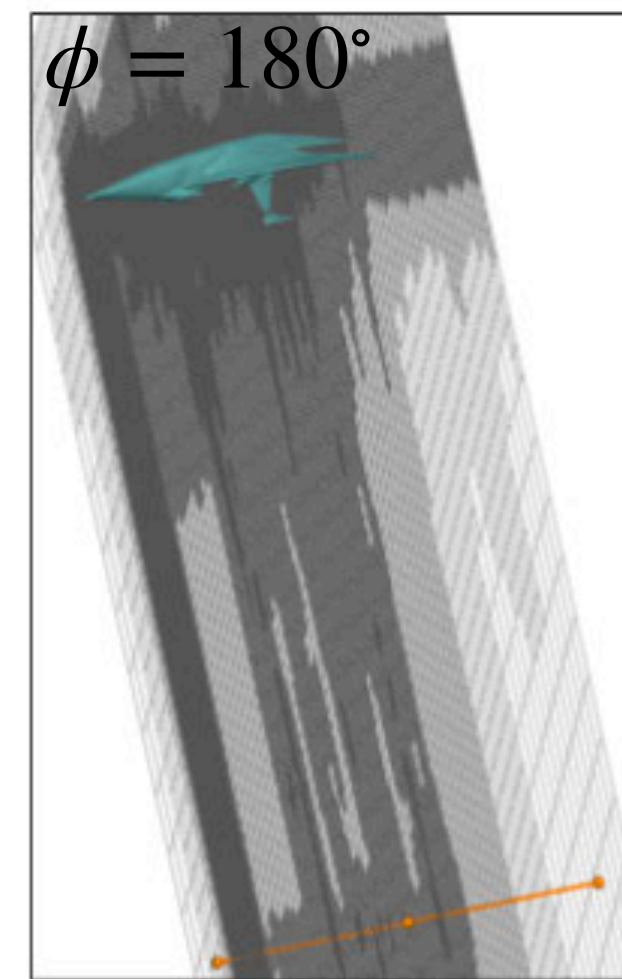
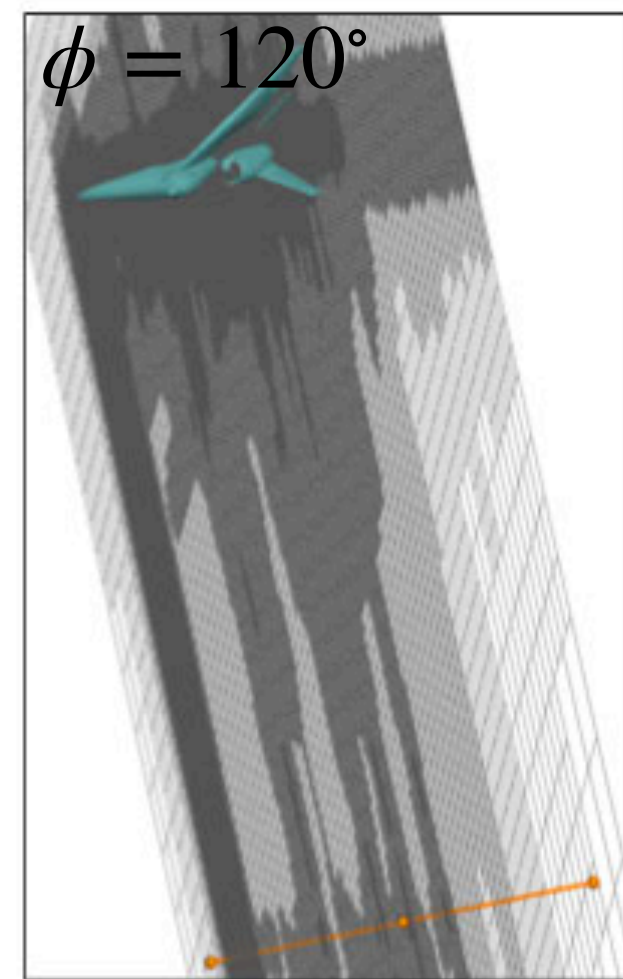
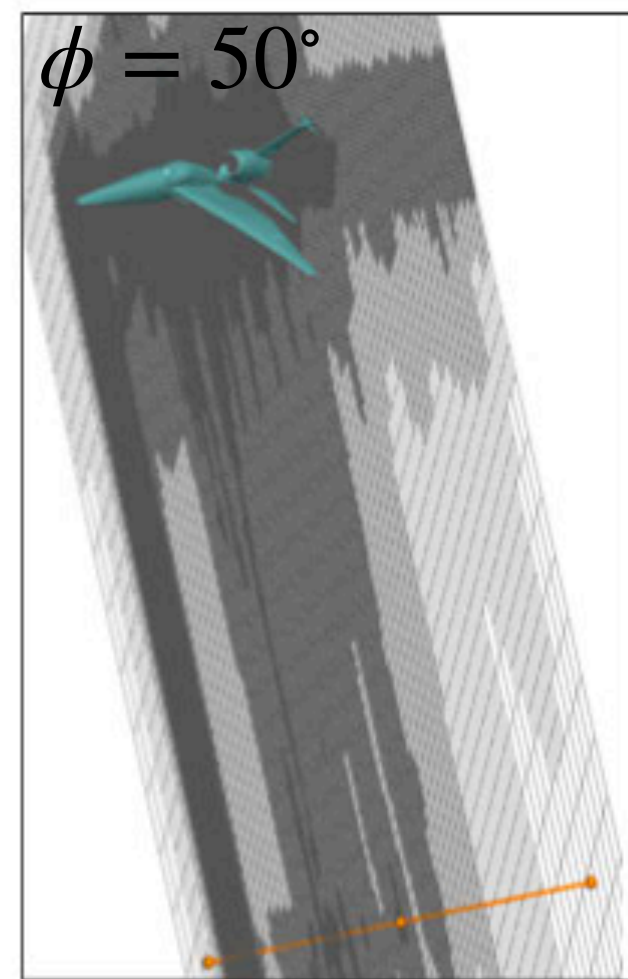
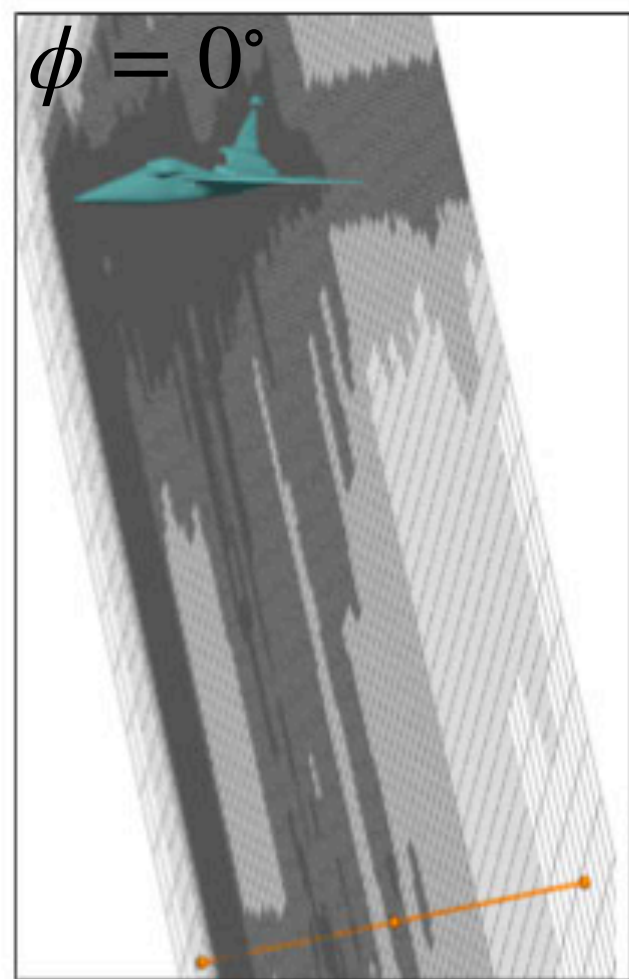
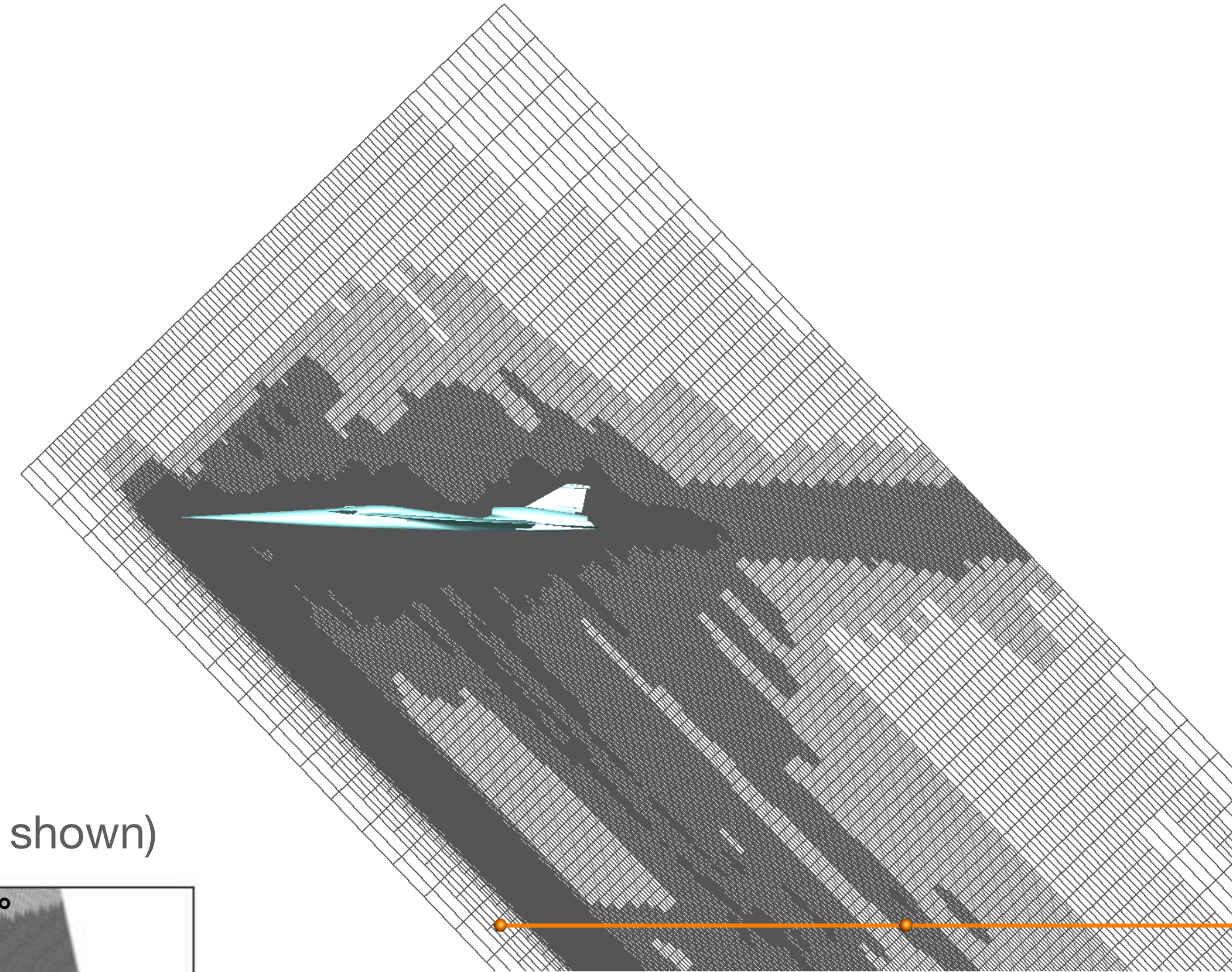
Design iteration from NASA Low Boom Flight Demonstrator (LBFD) project

- Freestream $M_\infty = 1.4$
- Geometry is approximately 90 ft (27.4 m) long
- Pressure signal at radial location $R/L = 3.0$
- Multiple inflow/outflow boundary conditions

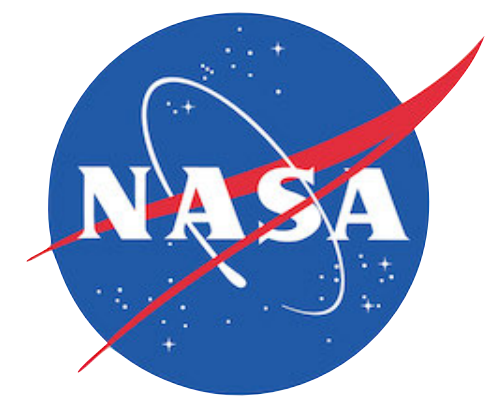


Cart3D Software Package

- Cart3D v1.5.5.3
 - Inviscid flow solver, multigrid acceleration
 - Domain decomposition, highly scalable
 - Multilevel Cartesian mesh with embedded cut-cell boundaries
 - Adjoint-based mesh adaptation, several different output functionals
- Previous development and boom prediction workshops
 - Mach-aligned mesh rotation (right)
 - Rotate the model geometry to align azimuth ϕ (bottom)
 - Separate simulation for each azimuth ϕ , can be run simultaneously
 - Tested different cell aspect ratios in propagation and spanwise directions (4:1 shown)

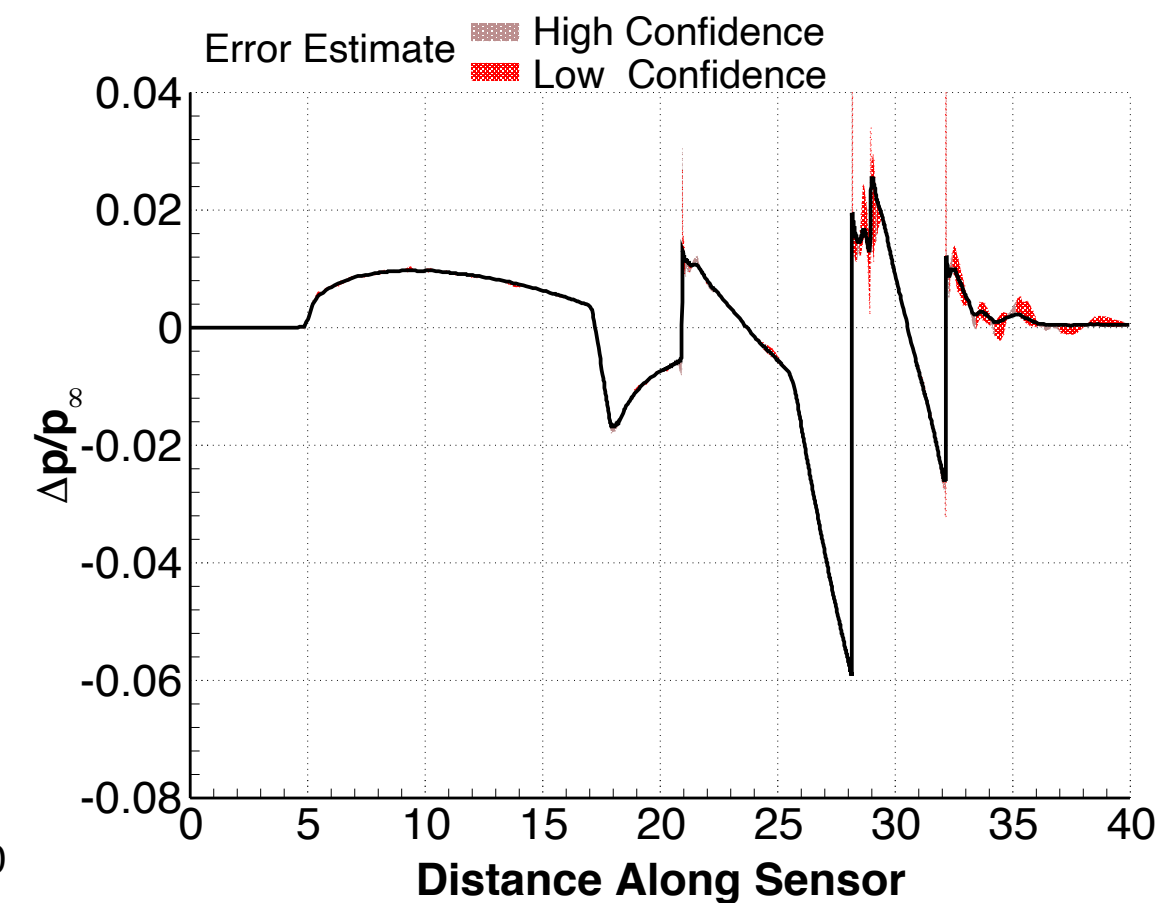
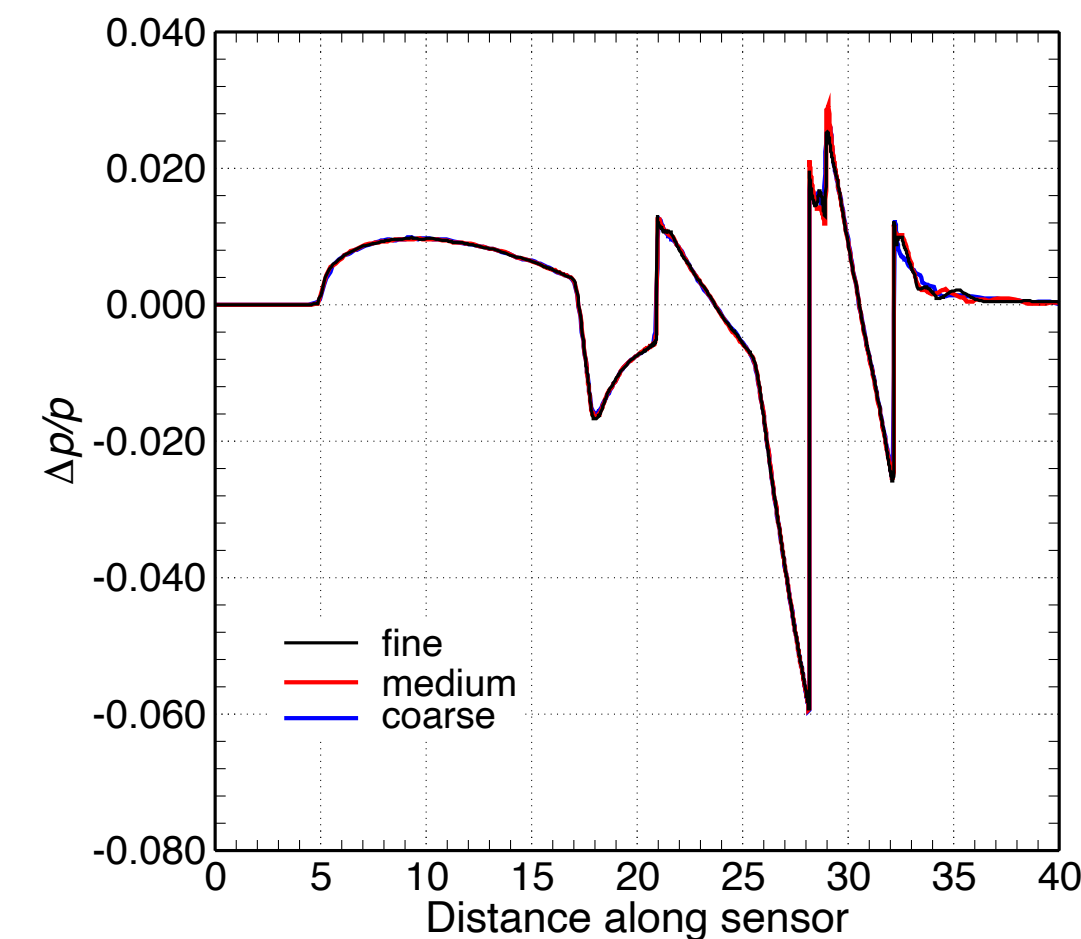
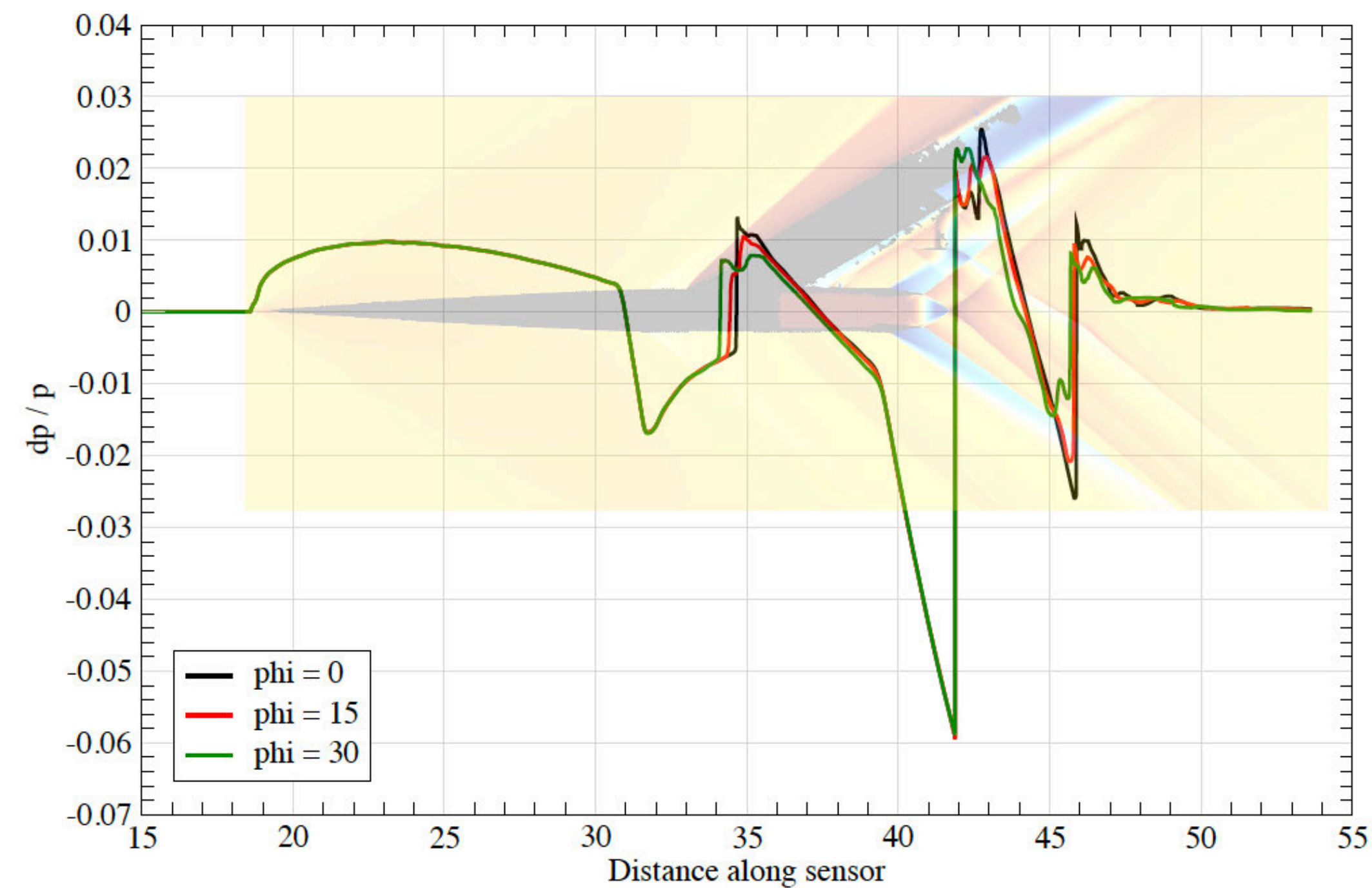
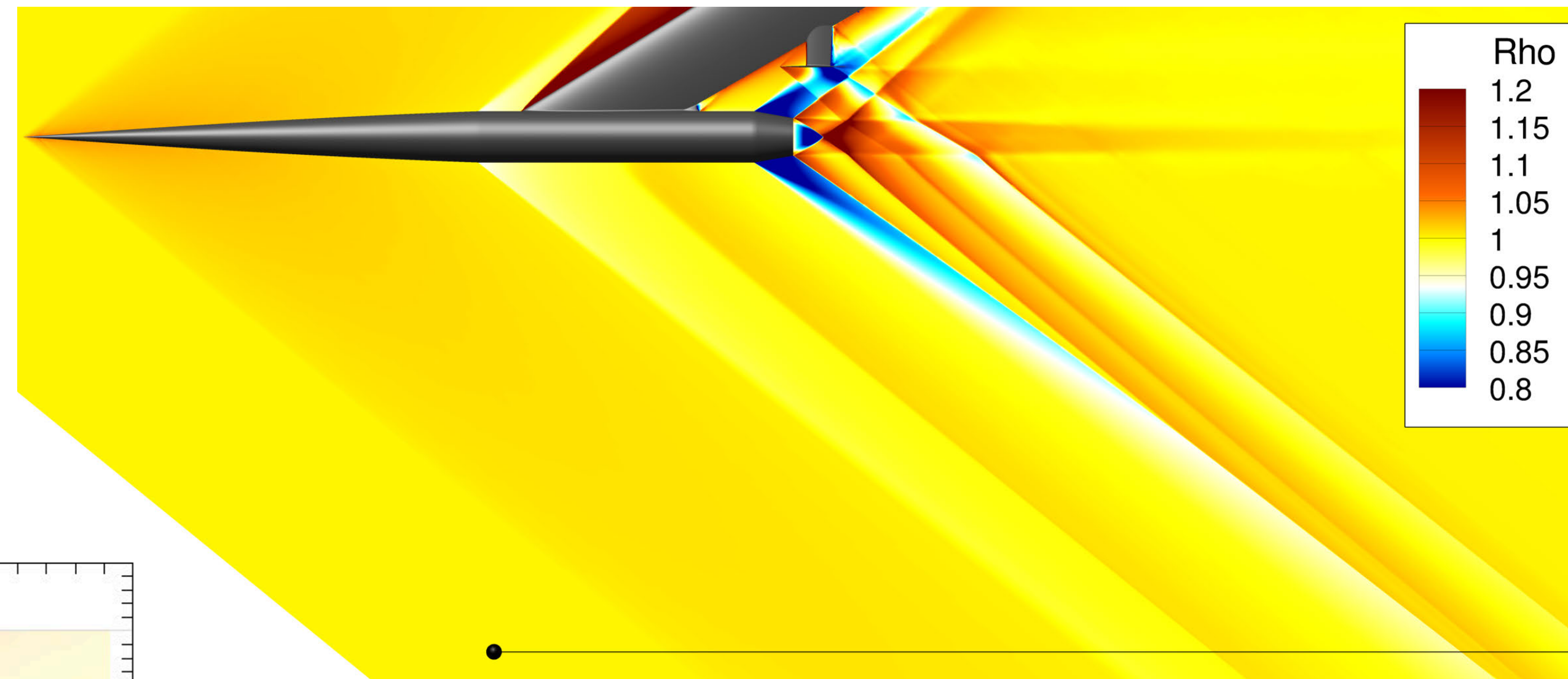


Cart3D



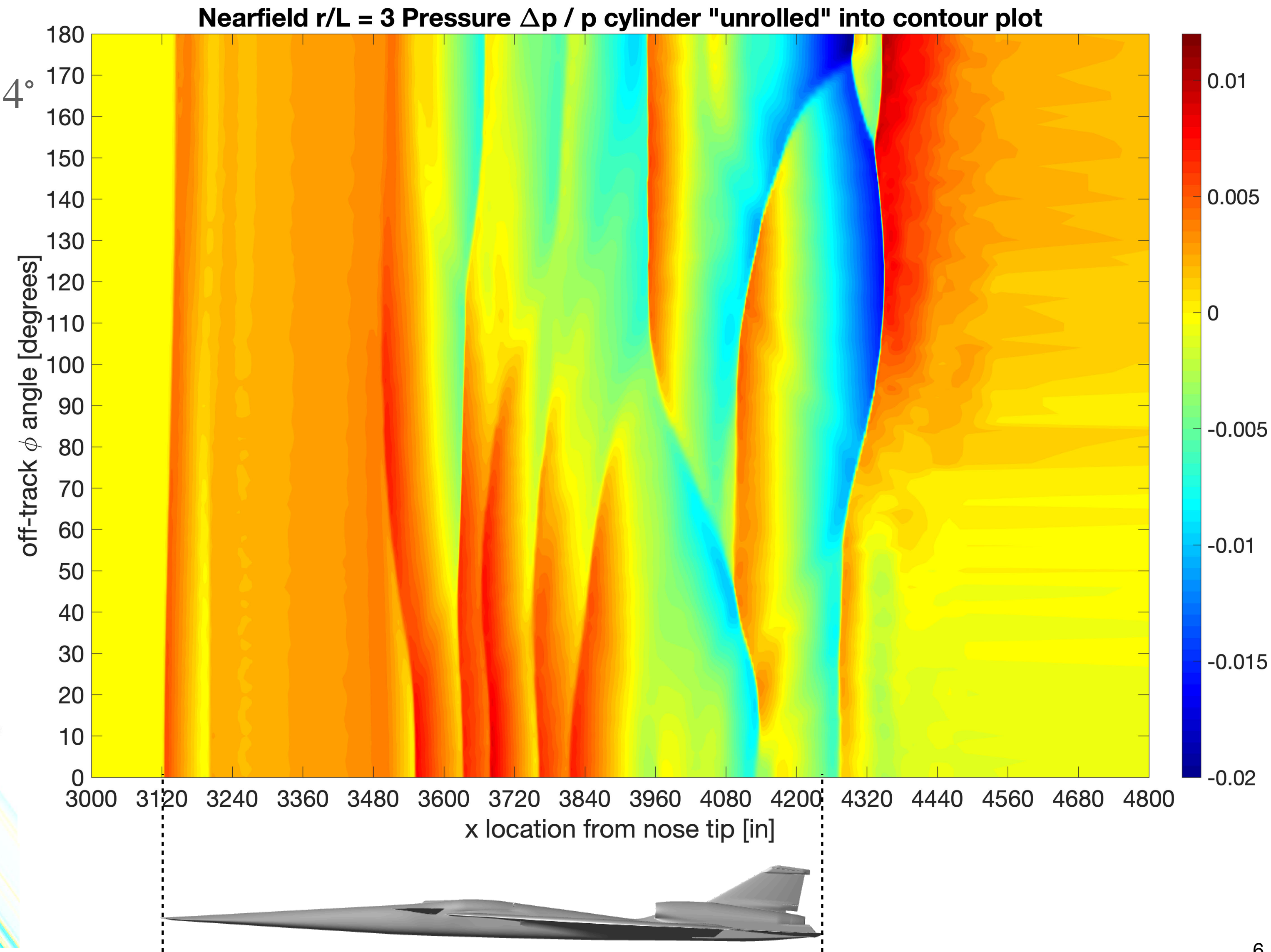
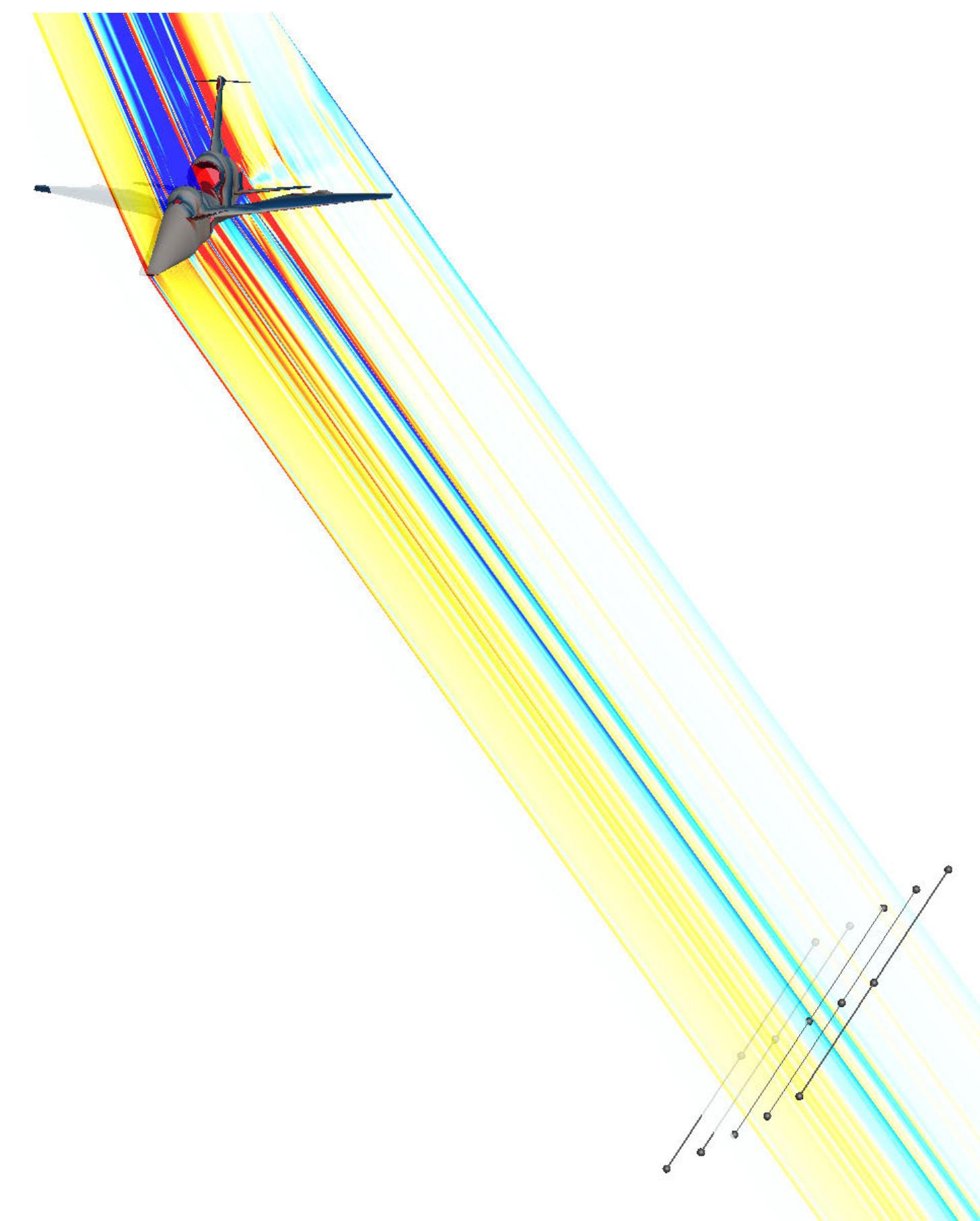
Results: Case 1 Biconvex

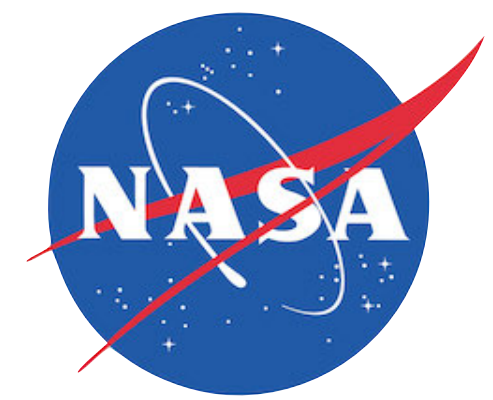
- Iterative & mesh convergence (in paper)
- Flowfield (right - density contours)
- Pressure signals (bottom left)
- Richardson-based error estimate (bottom right)



Results: Case 2 C608

- Split-and-align every $\phi = 10^\circ$
- Additional line sensors at $\pm 2^\circ$ & $\pm 4^\circ$
- Unroll half-cylinder in $x\phi$ -plane



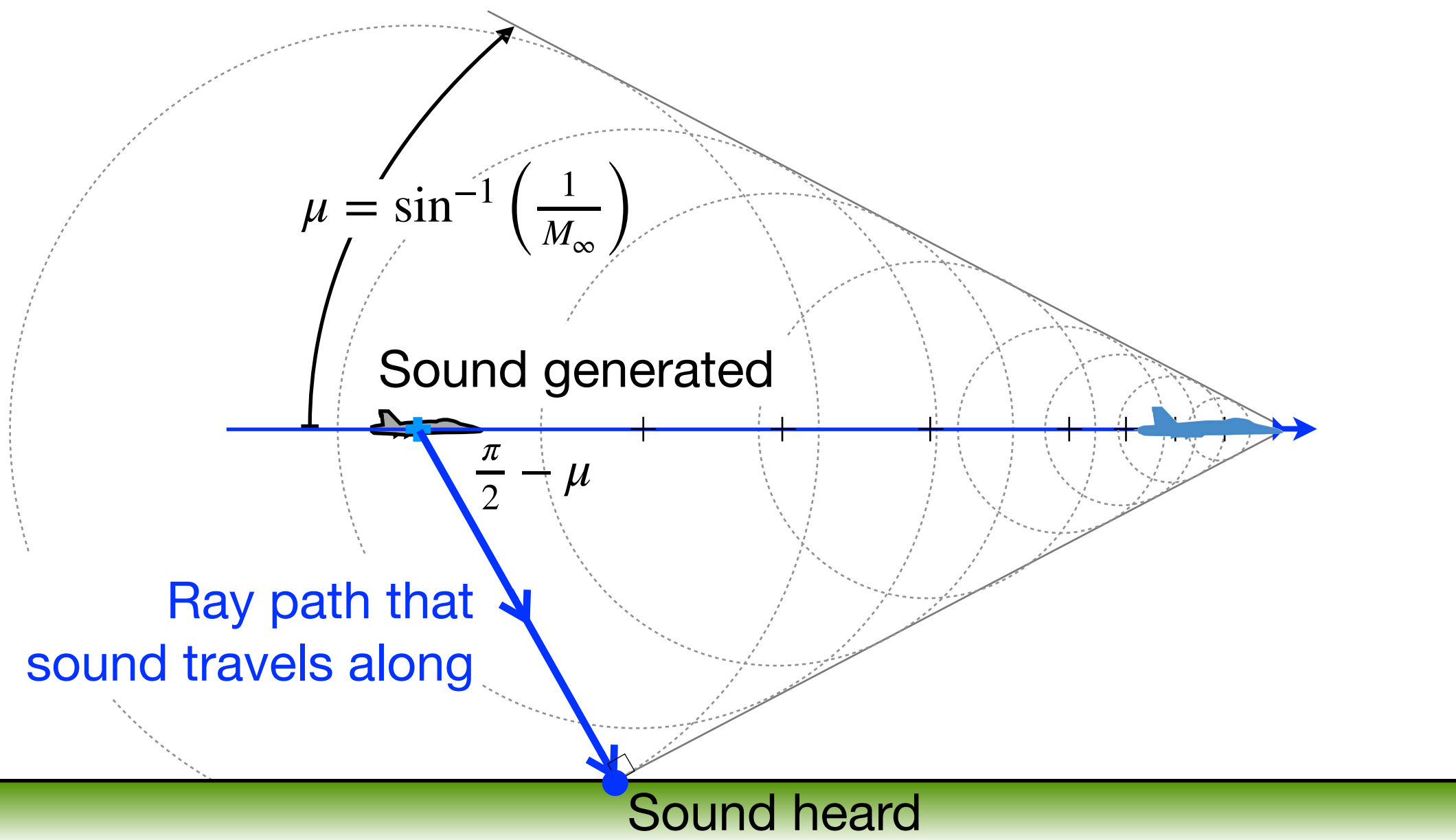


Nearfield CFD Computational Costs

	Biconvex	C608
Initial grid size	330 k	1.6 M
Coarse, medium, fine adapt cycles	5, 6, 7	3, 4, 5
Coarse grid size	4.5 M	7.1 M
Medium grid size	8.8 M	14.2 M
Fine grid size	19.9 M	29.6 M
Adaptive meshing wall time	32 min	53 min
Fine grid flow solution wall time	40 min	60 min
Independent off-track angle runs	3	19
Total computational time	144 cpu-hr	1431 cpu-hr
Total wall-clock time	72 min	113 min

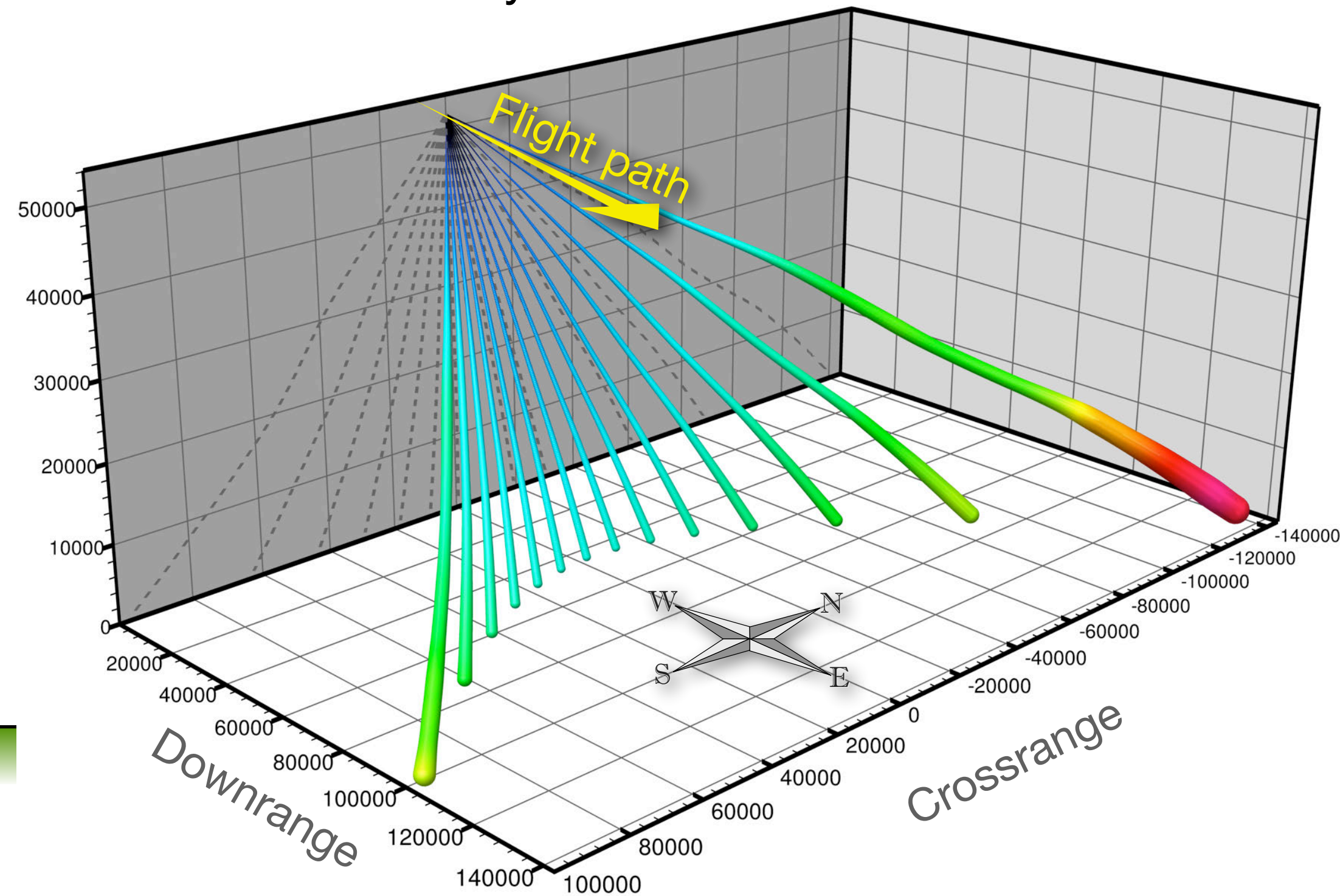
Farfield Propagation

2-D Schematic

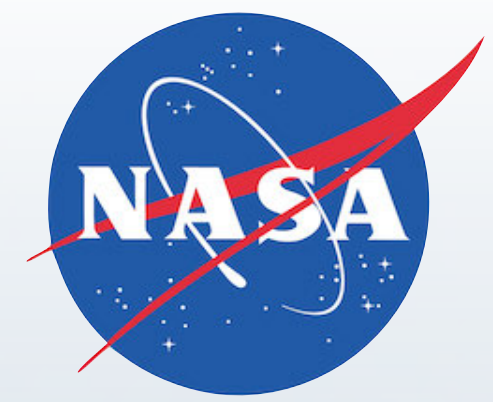


- Quasi-1D Burgers' equation along the ray path
- Ray path and speed of sound determine time required for signal propagation
- Solved using NASA's advanced Sonic Boom propagation tool sBOOM

3-D Ray Paths



- Determines the ground intercept of sound emanating from given trajectory point & azimuth
- Acoustic rays that reach the ground form a boom carpet under the flight path



Farfield Propagation Cases

Case 1: C25P

- NASA C25 Powered Concept
- Freestream $M_\infty = 1.6$, altitude $h = 52$ k ft

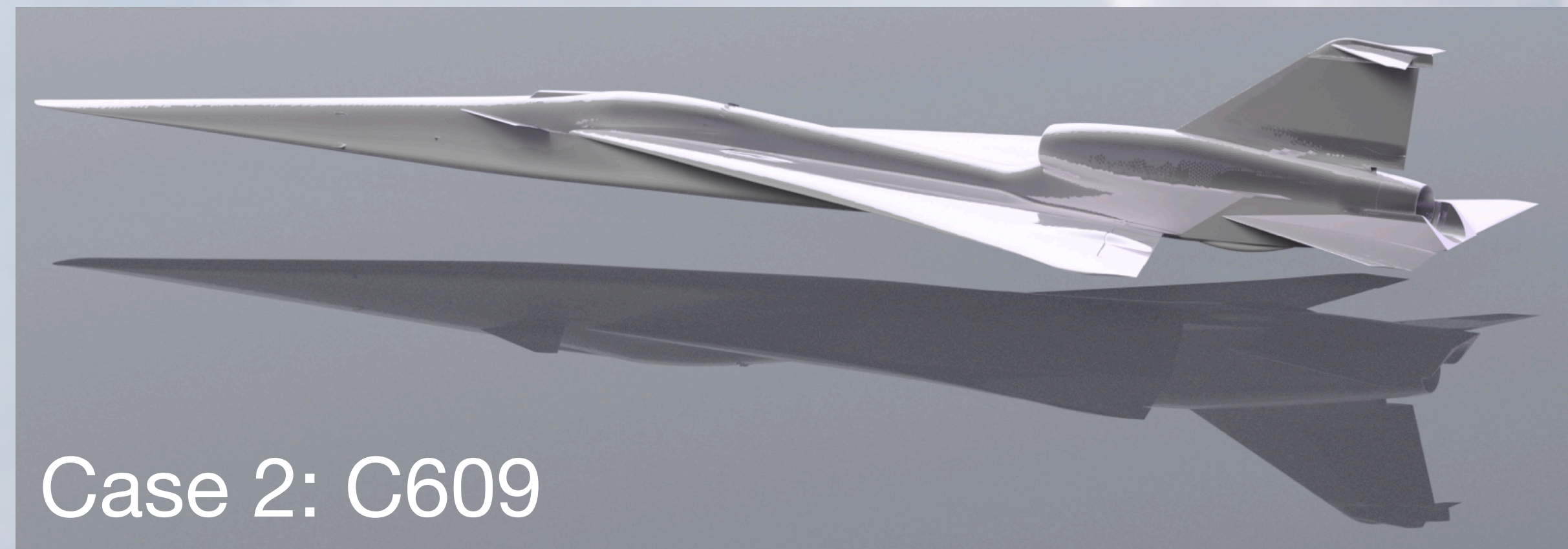
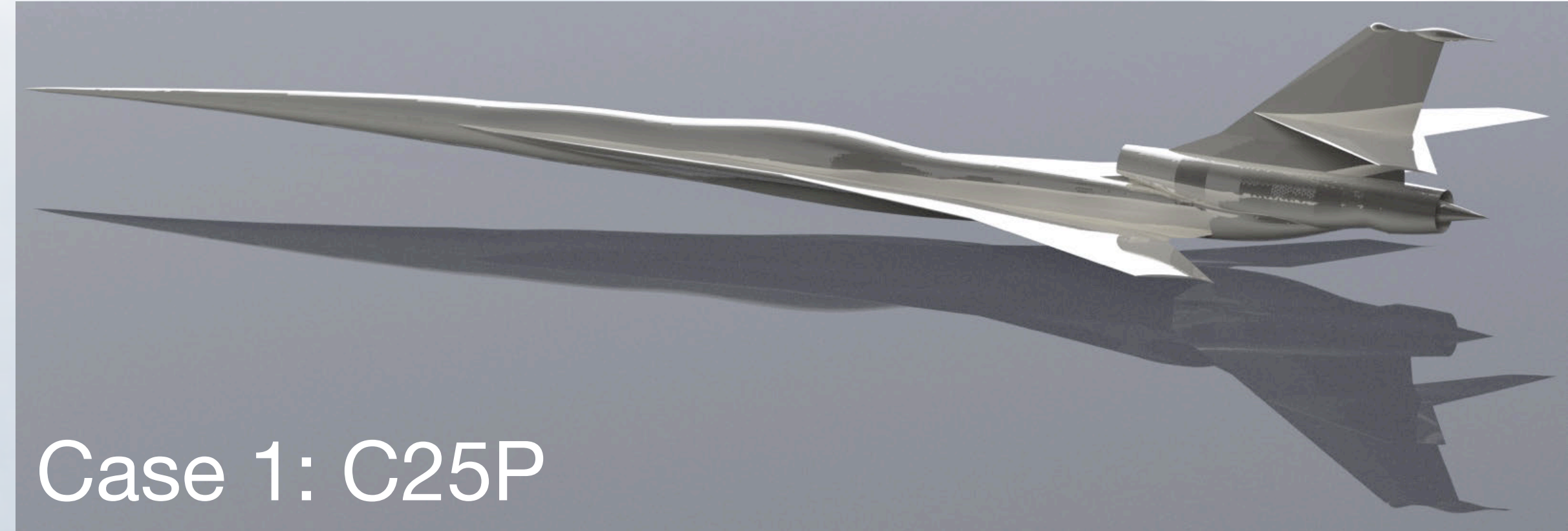
Case 2: C609

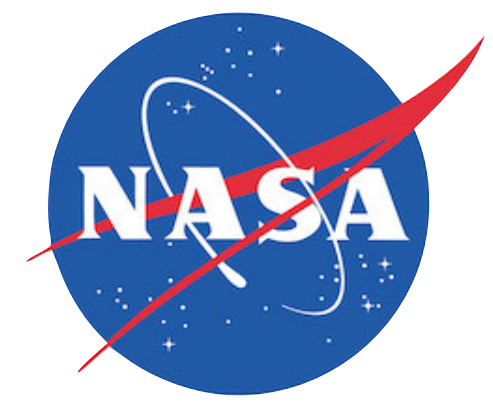
- Design iteration from NASA Low Boom Flight Demonstrator (LBFD) project
- Freestream $M_\infty = 1.4$, altitude $h = 54$ k ft

Each is propagated through a standard atmosphere and a required atmosphere

In paper:

- Nearfield signals
- Ground signals
- Ground noise profiles
- Ray paths
- Boom carpets

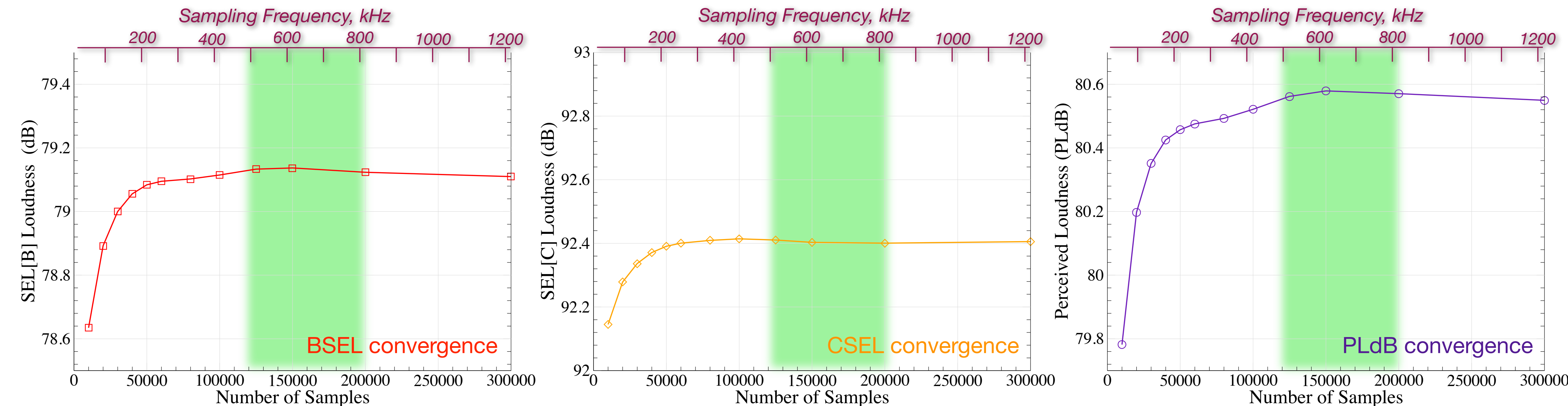




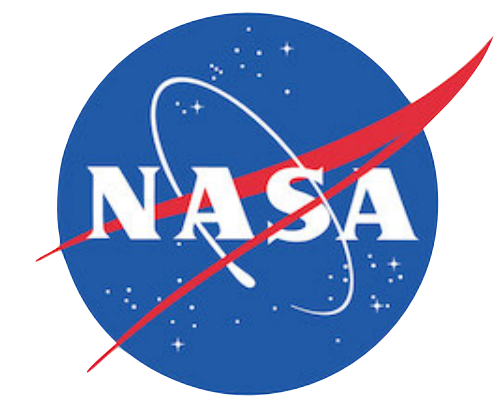
Mesh Convergence

- Need to make sure loudness metrics are sufficiently mesh converged
 - Mesh convergence of propagation is case dependent (on signal, azimuth, and atmosphere)
 - Atmospheric variability generally ~2-5 dB — tried to keep propagation error under ± 0.2 dB

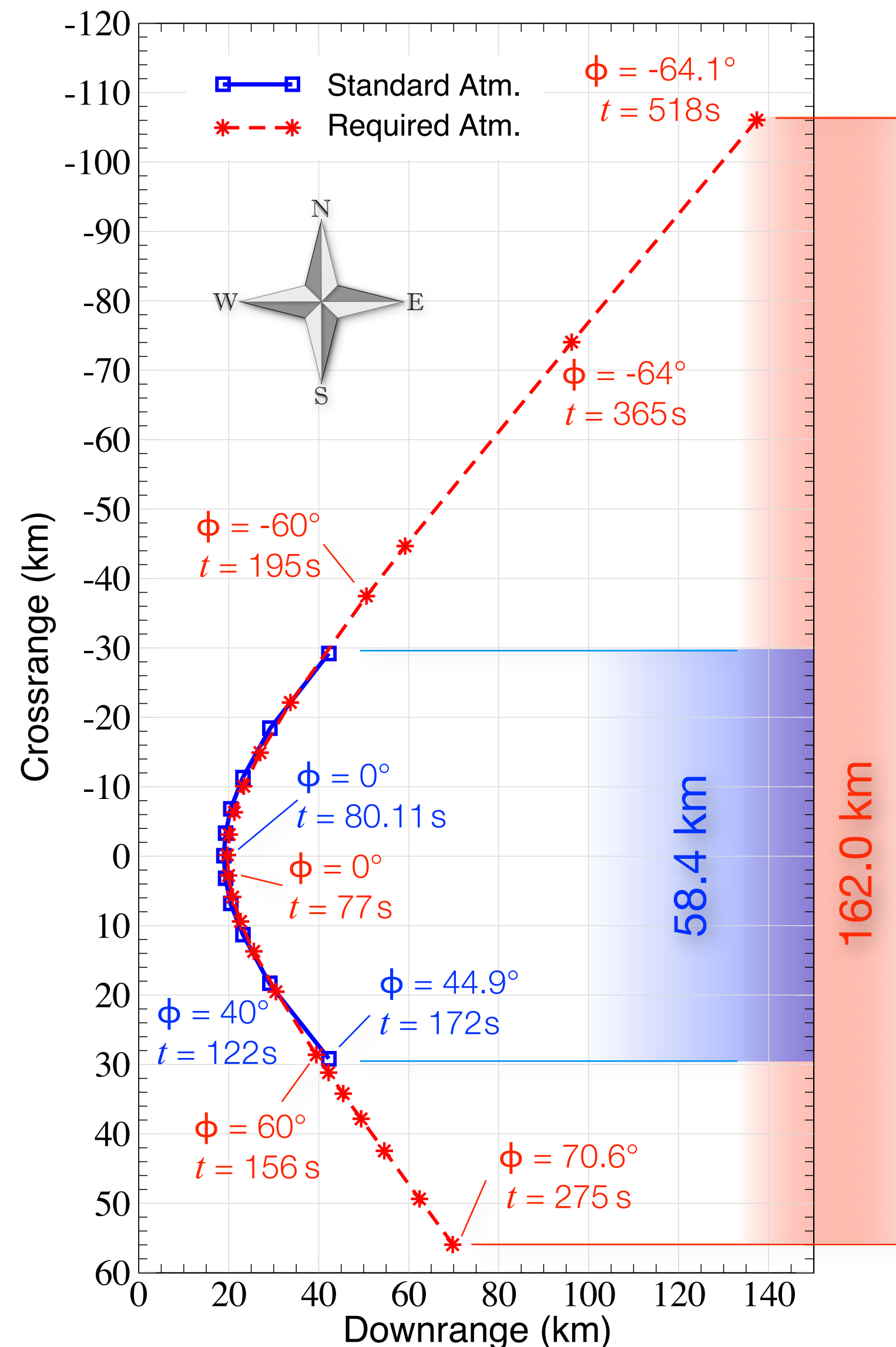
Convergence of BSEL, CSEL & PLdB noise metrics with sampling frequency (Case 1, C25P at $\phi = 0^\circ$)



- Used 500 kHz sampling frequency at $|\phi| \leq 30^\circ$ and 800 kHz at $|\phi| > 30^\circ$
- NASA's Loudness Code for Asymmetric Sonic Booms, LCASB, used for ASEL, CSEL, and PLdB
- Used digital BSEL filter in sBOOM, NASA's advanced Sonic Boom propagation tool

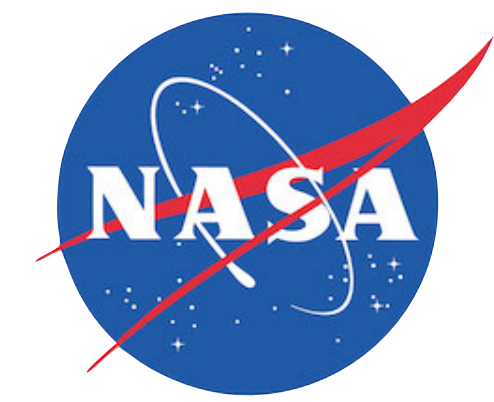


Case 2: C609 Ground Carpet



Project raytube ground intercepts on aircraft ground track

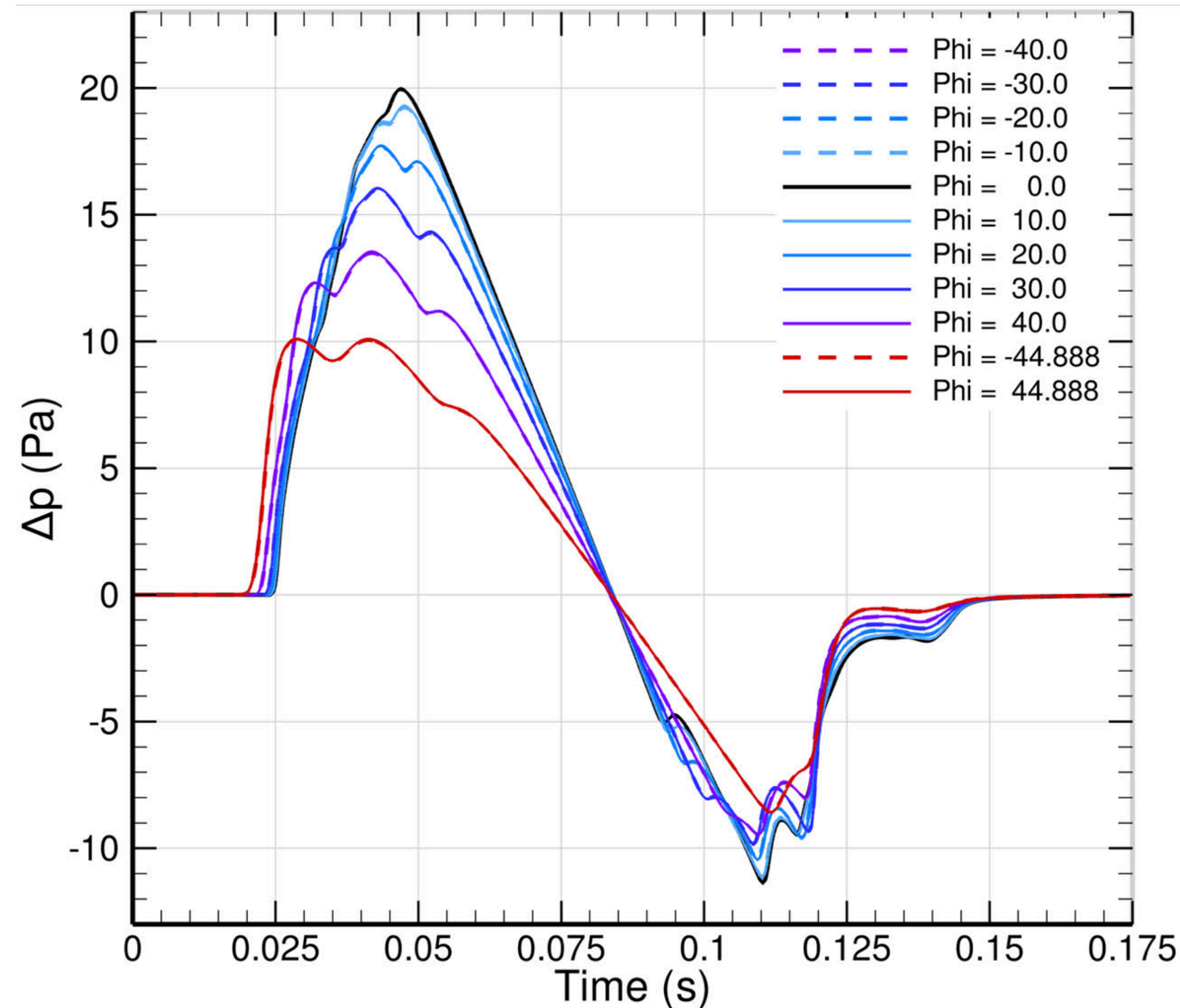
- **Standard atm.** is ~58 km wide, cutoff $\phi = [\pm 44.9^\circ]$
- **Required atm.** is ~162 km wide, cutoff $\phi = [-64.1^\circ, 70.6^\circ]$
- Long propagation distances and times near carpet edge
 - Raytube for $\phi = -64.1^\circ$ cutoff takes over 8.5 mins in Reqd. atm.
 - Mesh convergence near signal cutoff is not nearly as good as at low azimuth angles



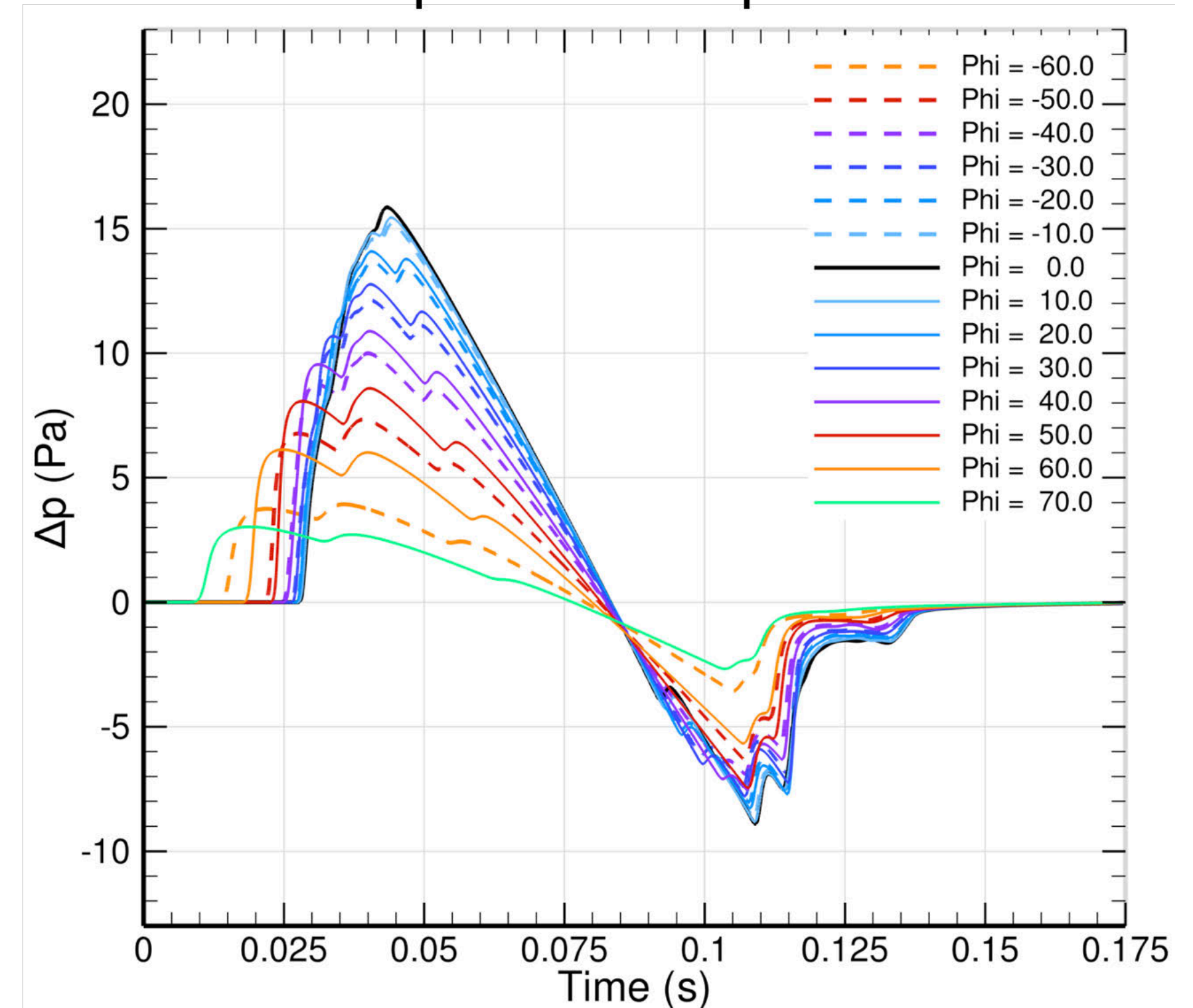
Case 2: C609 Ground Signals

Propagation altitude = 16460m, ground elevation = 110m

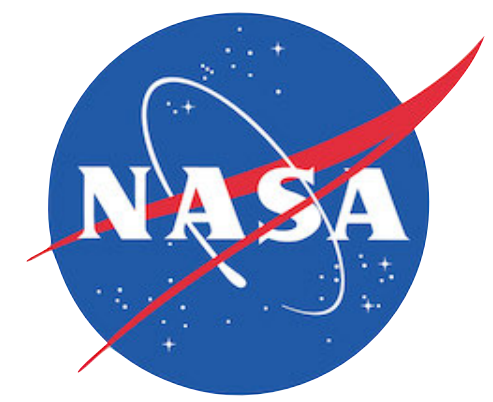
Standard Atmosphere



Required Atmosphere

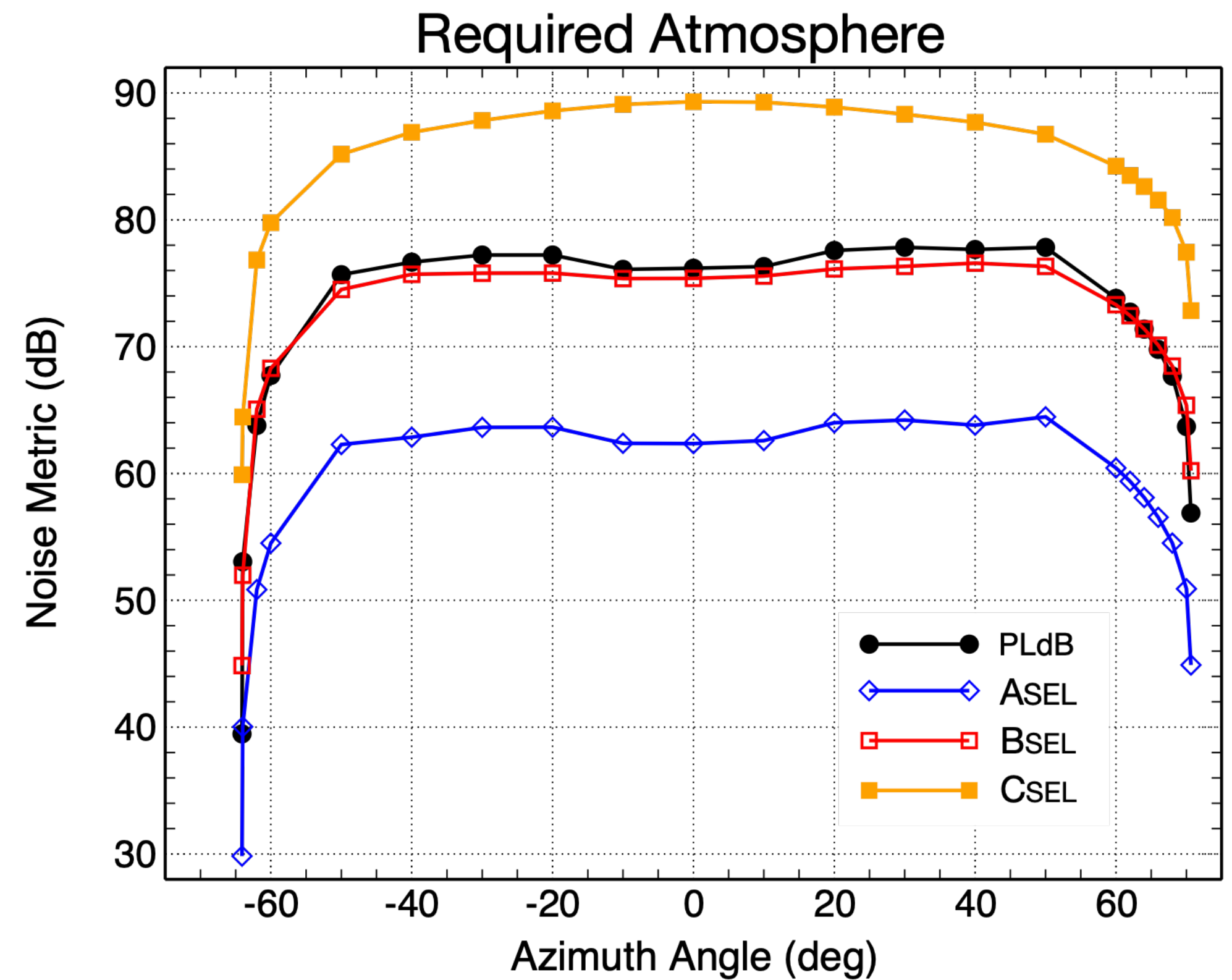
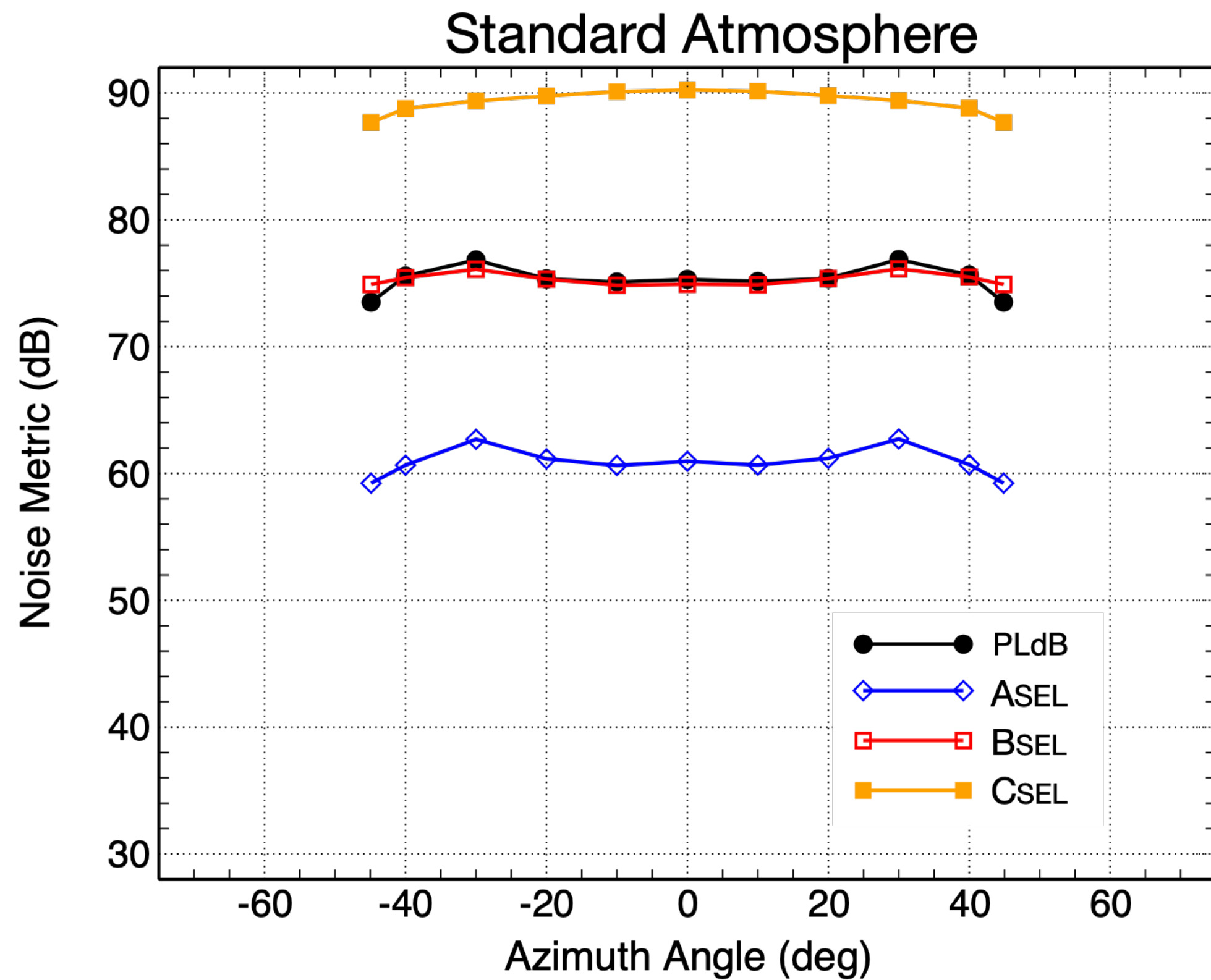


- Required Atm. introduces asymmetry, with much wider cutoffs on both sides
- Ground signal amplitudes in real atmosphere significantly reduced

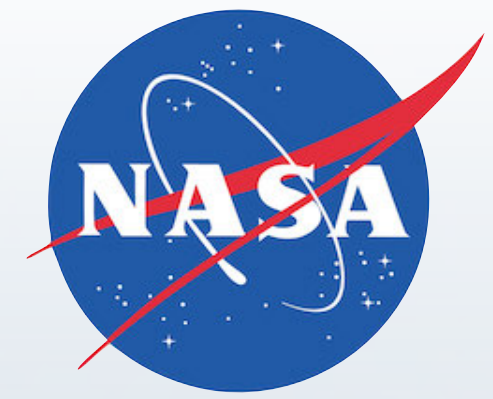


Case 2: C609 Ground Noise

Ground noise metrics across the carpet as a function of azimuth

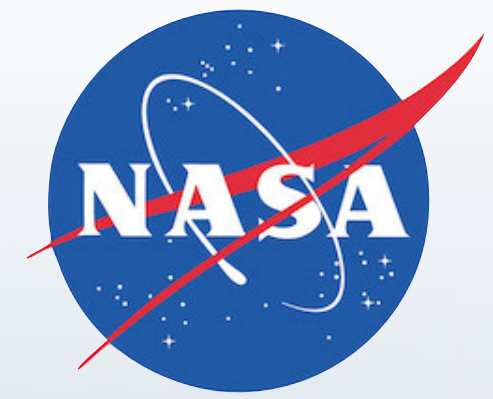


- Azimuthal range of carpet with Required Atm. is much wider than Standard Atm.
- Despite wind & reduced ground amplitude, Real Atm. and Std. Atm. have similar loudness
- Noise profiles are very flat, but Required Atm. carpet edge drops significantly



Takeaways & Discussion in Paper

- Nearfield CFD
 - Techniques focus on accuracy and efficiency in Cartesian mesh simulations.
 - Iterative & mesh convergence, Richardson-based error estimate establish confidence in results.
 - Complex geometry increases computational cost — more features to resolve and must take pressure signal farther from body.
 - Low-boom aircraft have complex flow features and may have large-amplitude signals over-the-top.
 - Cart3D package is accurate and computationally inexpensive.
- Farfield Propagation
 - Applied sBOOM v2.82 & LCASB to all propagation cases.
 - Mesh convergence of propagation depends on input signal, azimuth, and atmosphere.
 - Mesh convergence studies across the carpet to ensure accuracy of ground signals and loudness metrics. Error in noise metrics can be 2-4x higher near signal cutoff.
 - Real atmosphere is *usually* quieter than Standard atmosphere, but not always - e.g., Case 2.
 - Boom carpet in real atm. can be nearly 3x wider than standard day. Crosswinds generally increase track width and can result in large cutoff azimuths with long propagation times of 5-8 minutes.



Acknowledgments

- Thanks to James Jensen (NASA ARC) for surface triangulation of workshop C608 geometry
- SBPW3 organizers for their effort in organizing and coordinating the workshop, particularly Melissa Carter, Sriram Rallabhandi, and Mike Park (NASA LaRC)
- ARMD Commercial Supersonic Technology Project for support of this work and advancing the state of the art in boom prediction over the last decade
- NASA Advanced Supercomputing Division for providing computing resources
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