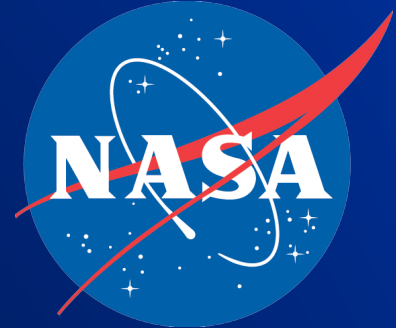


National Aeronautics and  
Space Administration



# NASA 101 Talk Series Supercomputing in Supersonics Quiet Supersonic Flight

Marian Nemec  
NASA Ames Research Center  
November 18-22, 2024



# X-1

- Broke sound barrier on Oct 14, 1947
- $M = 1.06$



Credit: USAF / NASA



Credit: NASA

X-1

Fast but loud sonic booms



Credit: NASA

X-59

Fast and quiet

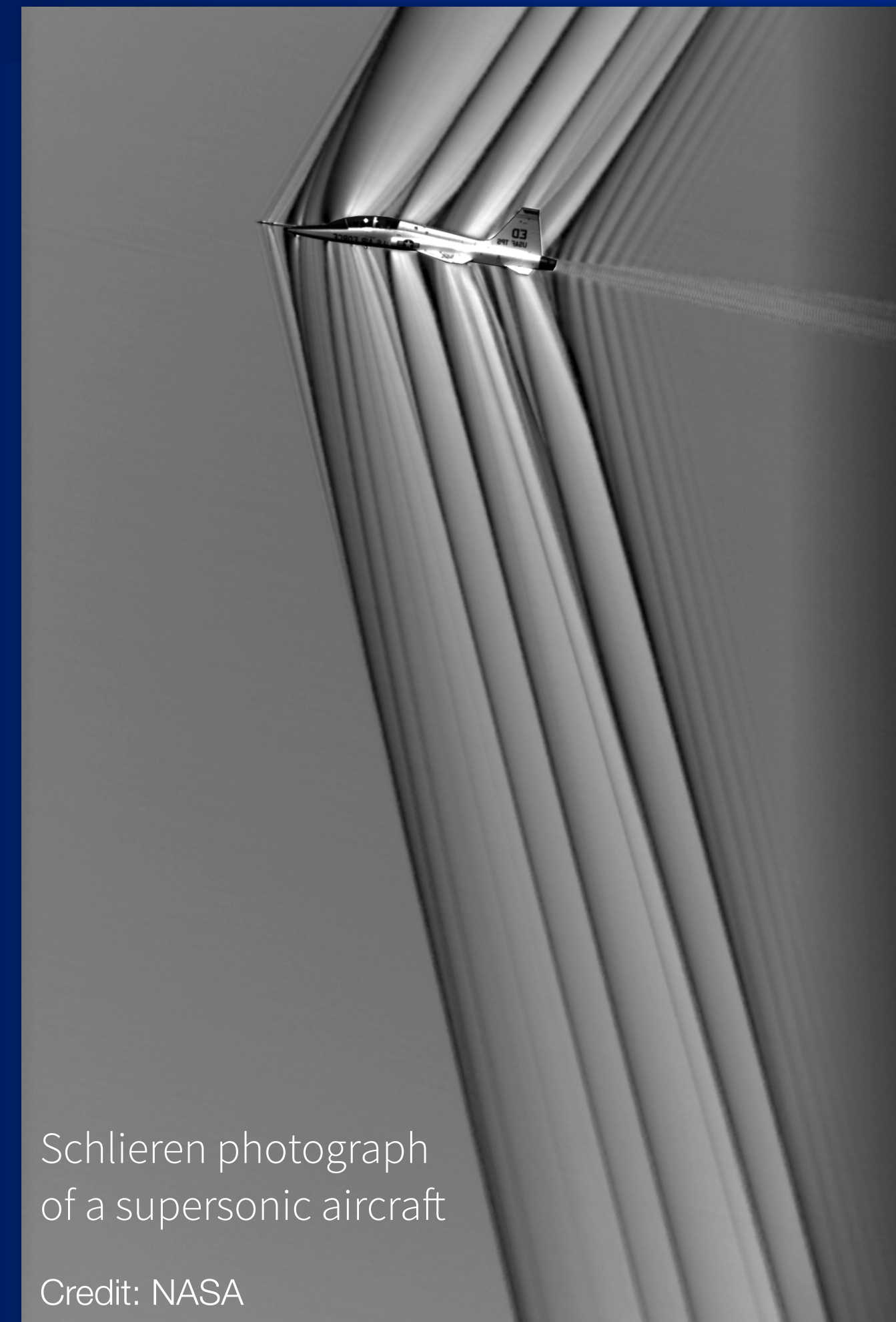
Credit: USAF



## NASA Aeronautics Strategic Thrust #2 Achieve practical, affordable commercial high-speed air transport

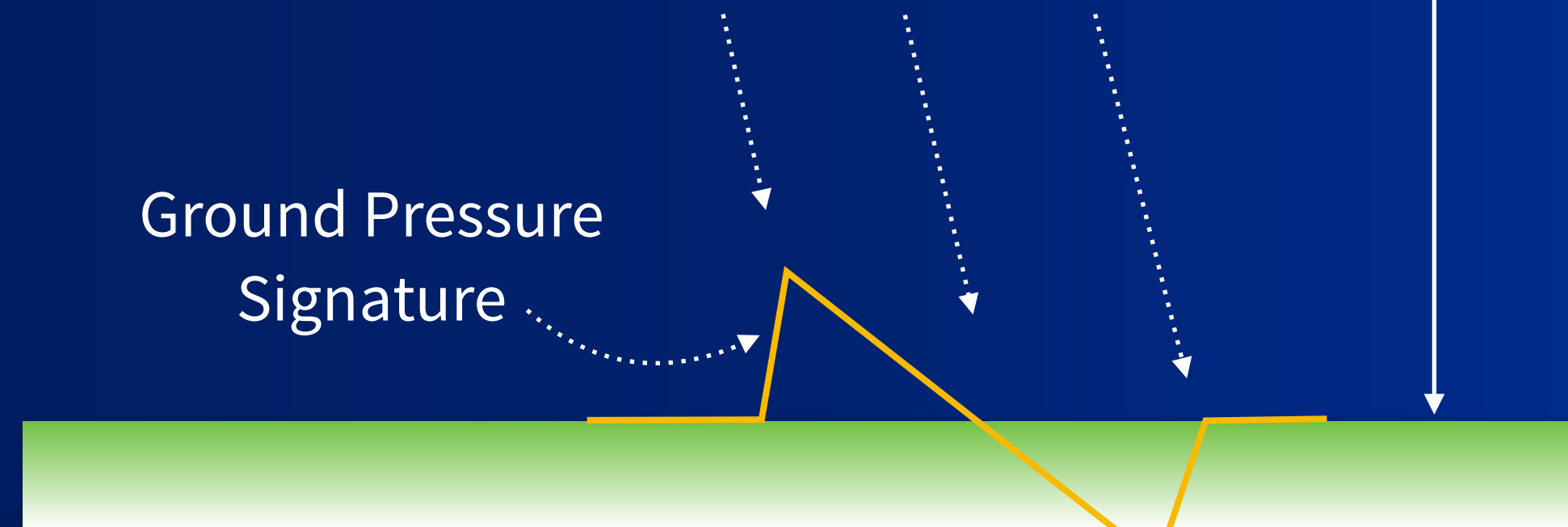
- Overcome barrier to overland supersonic flight
- Fully sustainable and cost-effective
- X-59 and Quesst mission support development of a new **en-route noise standard**
  - Cooperation with FAA and international aviation regulatory agencies

# Sonic Booms



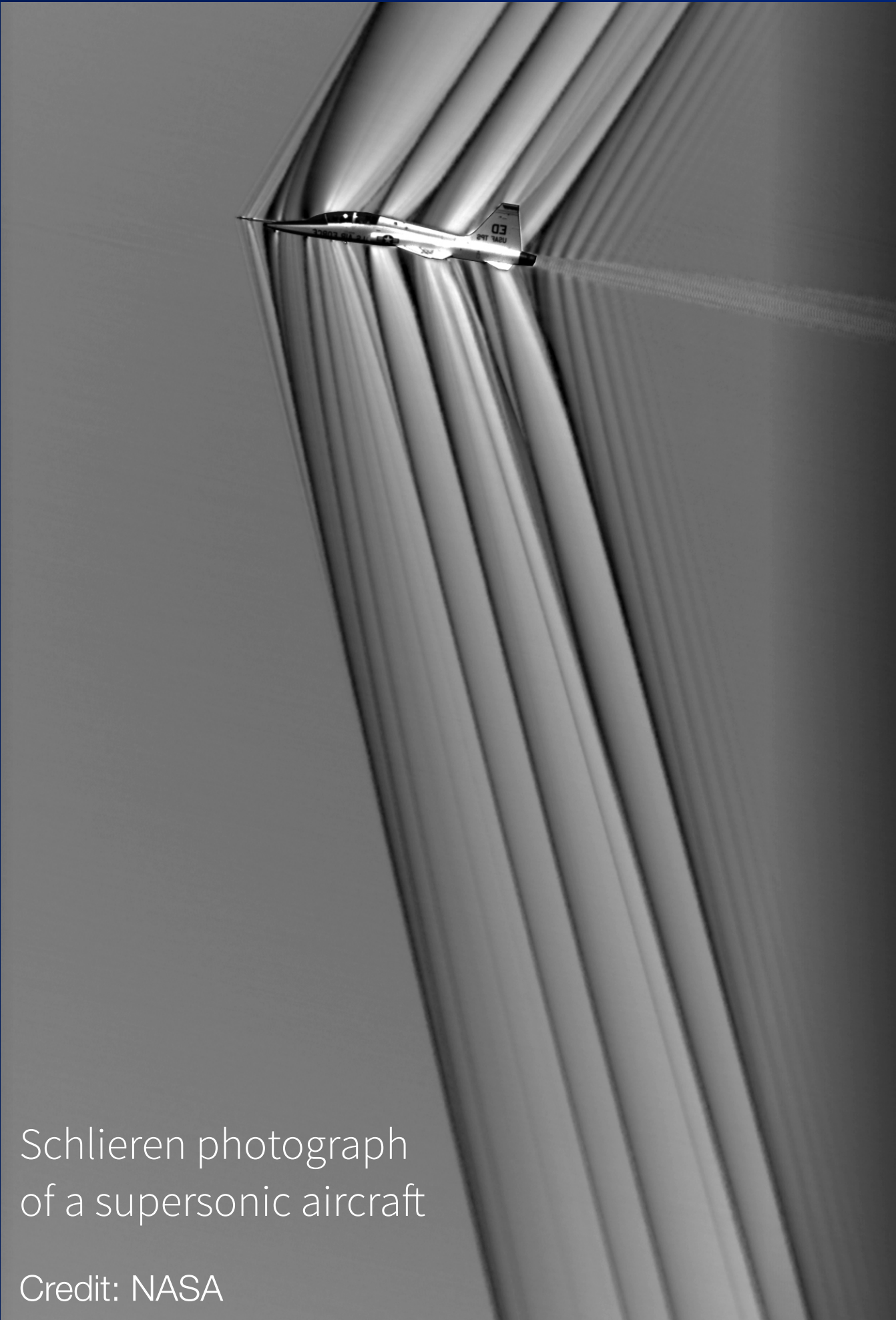
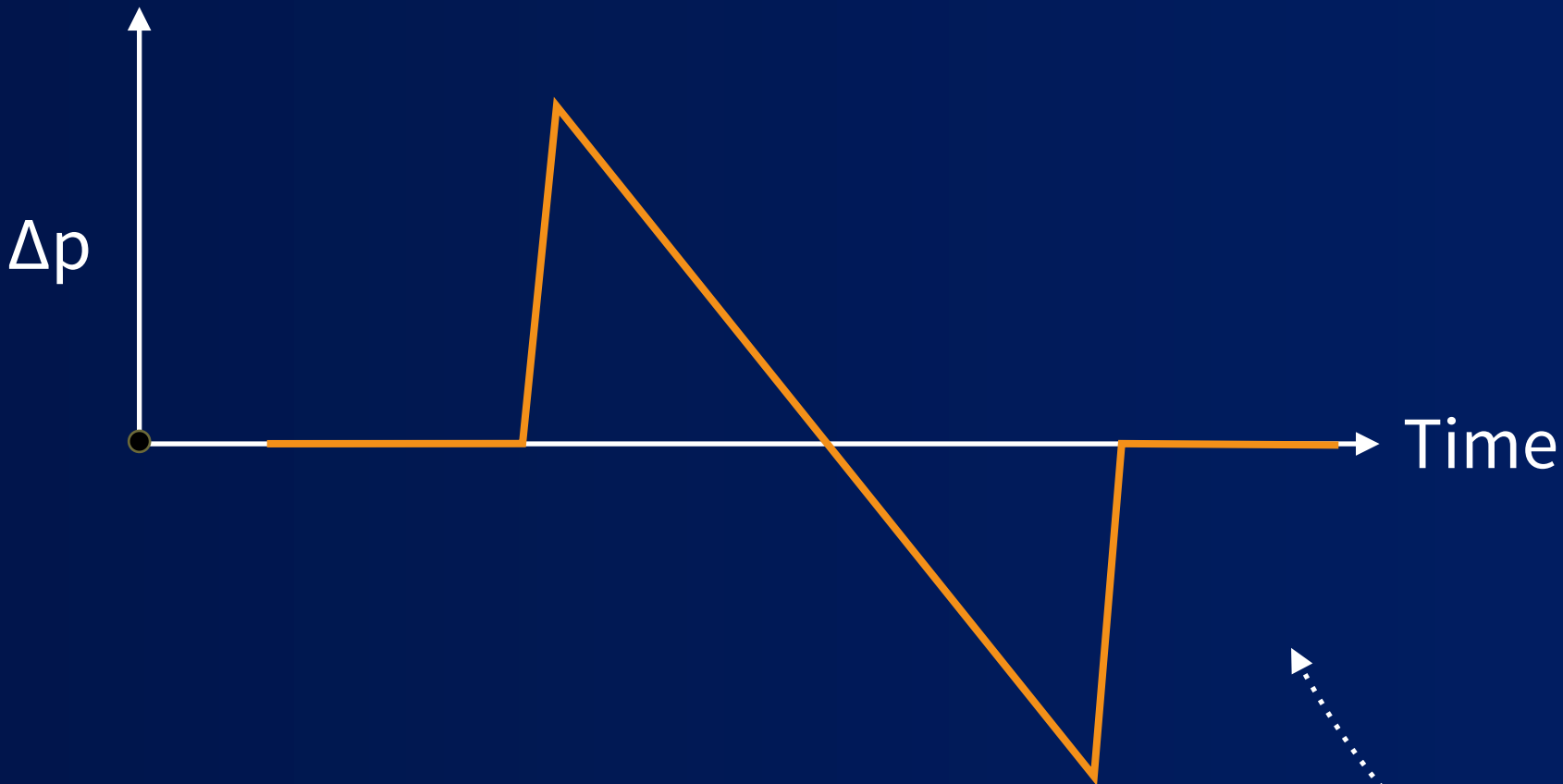
Altitude  
(~10 miles)

Ground Pressure  
Signature



# Sonic Booms

- Classical signatures are N-waves
- Sound characteristics are a function of the ground pressure signature



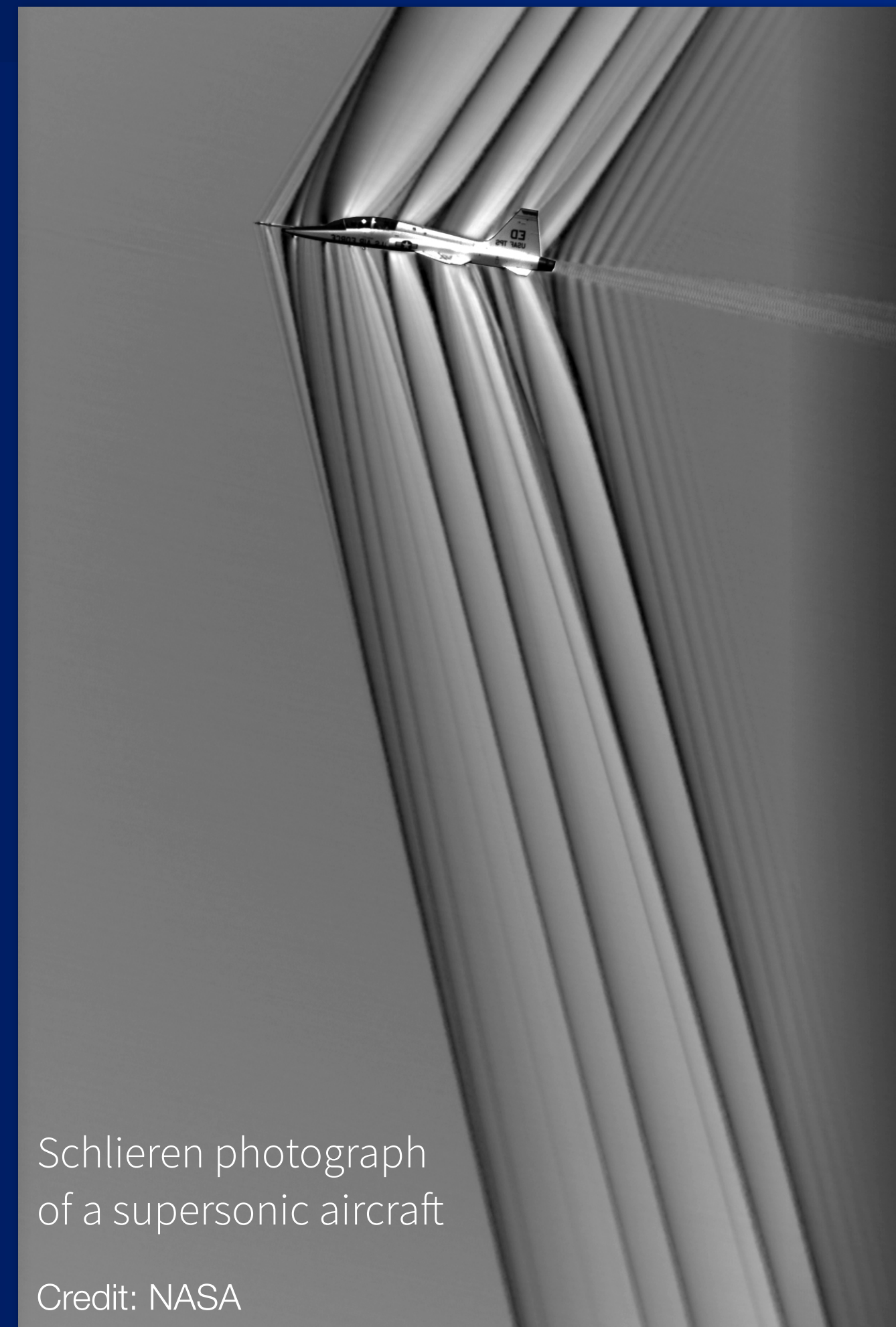
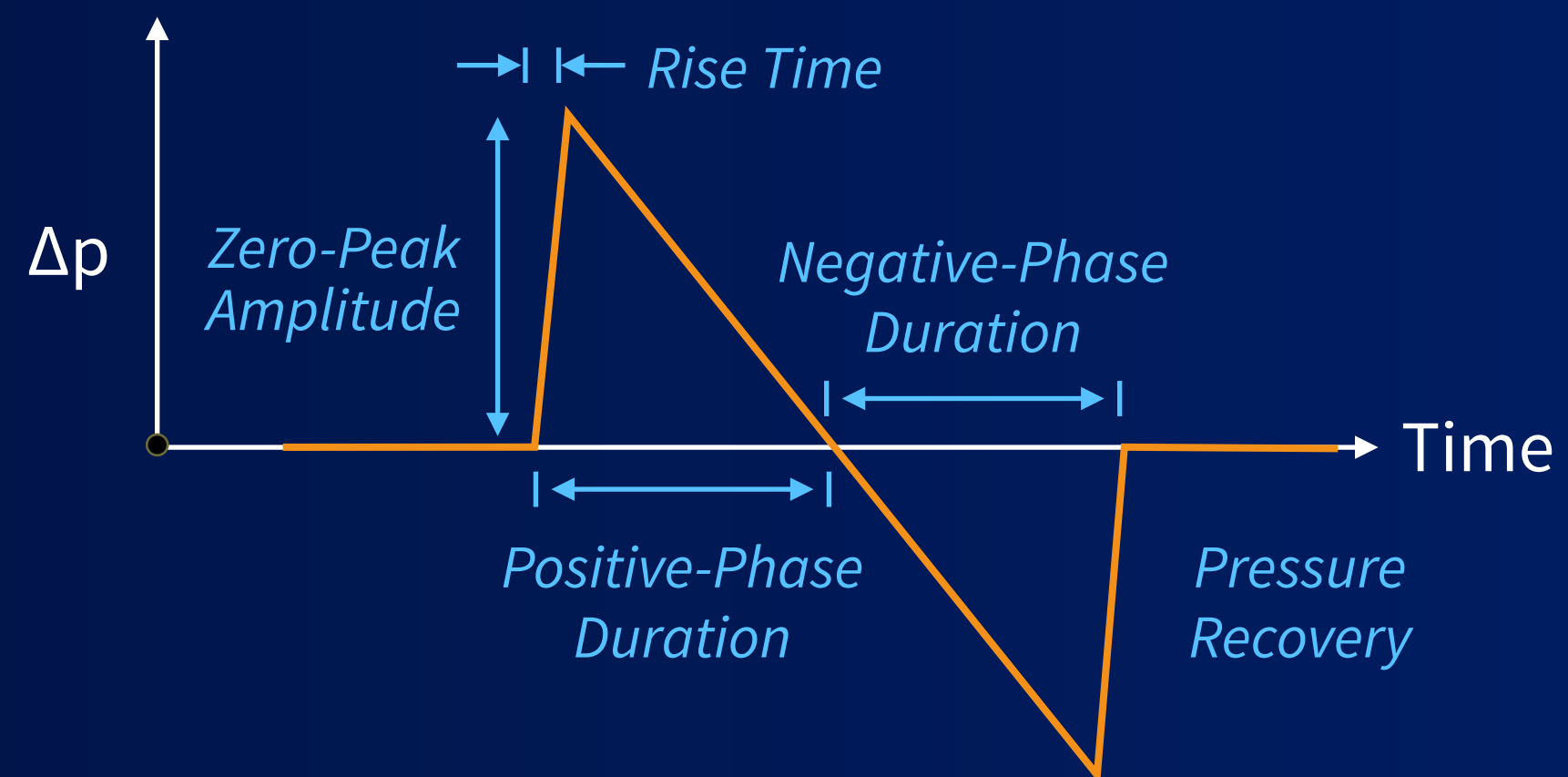
Altitude (~10 miles)

Ground Pressure Signature



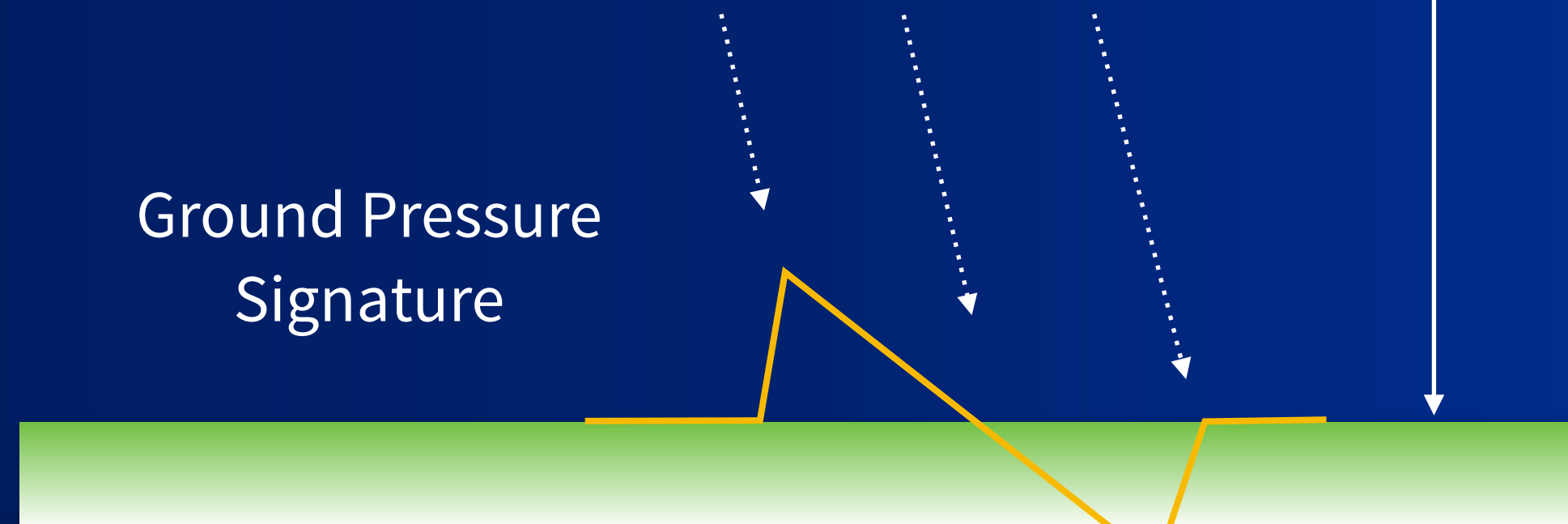
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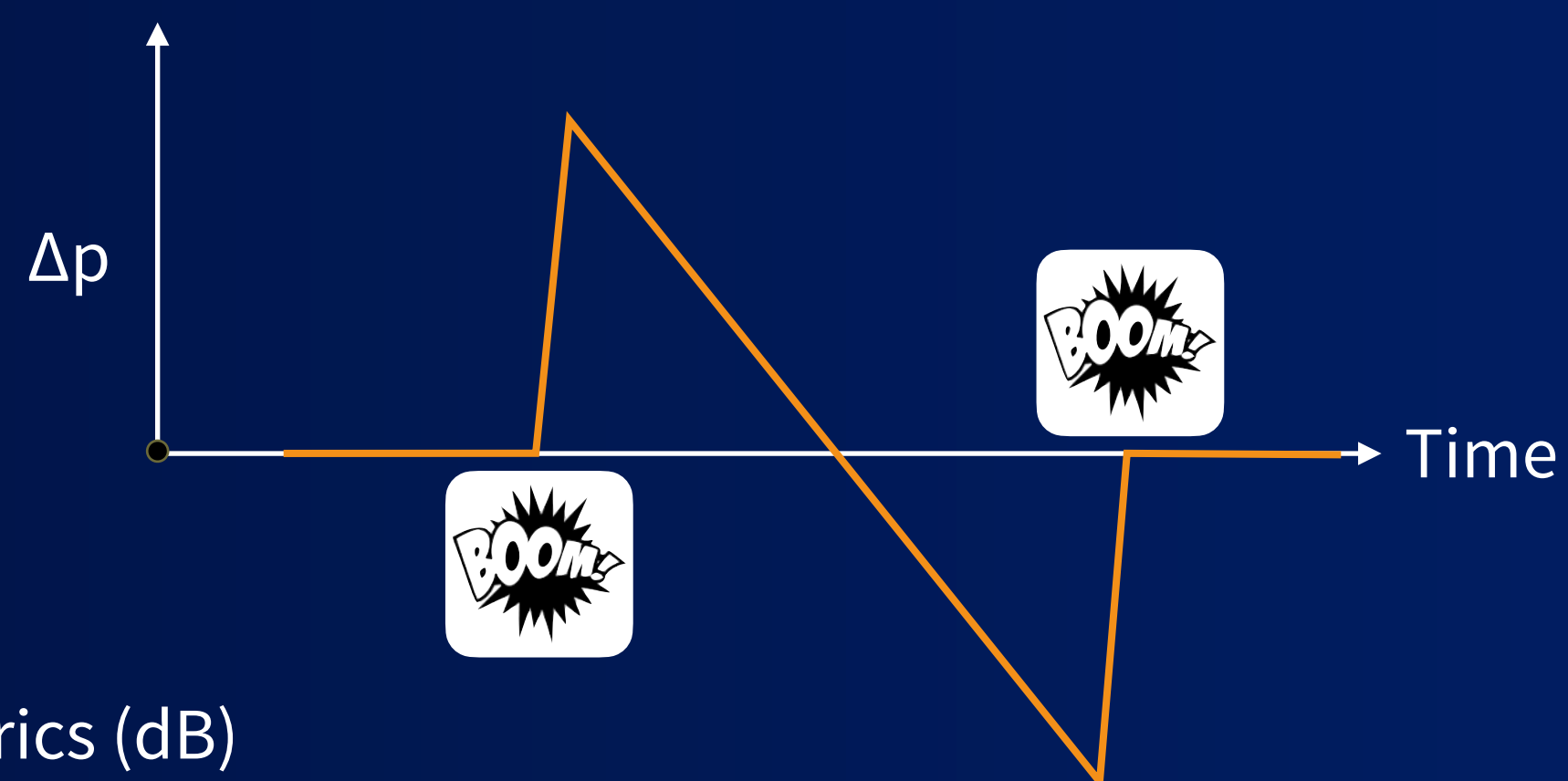
Altitude  
(~10 miles)

Ground Pressure Signature



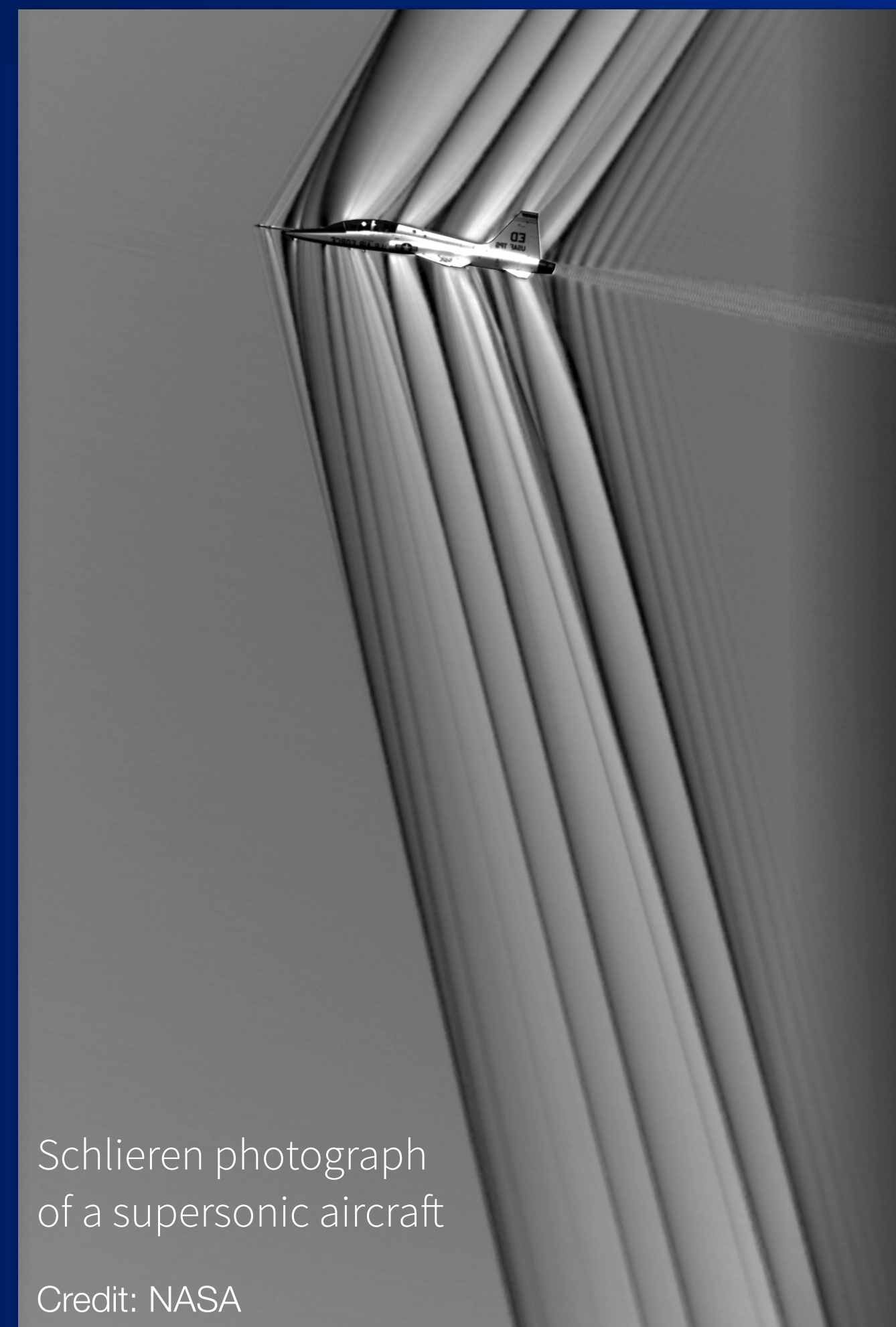
# Sonic Booms

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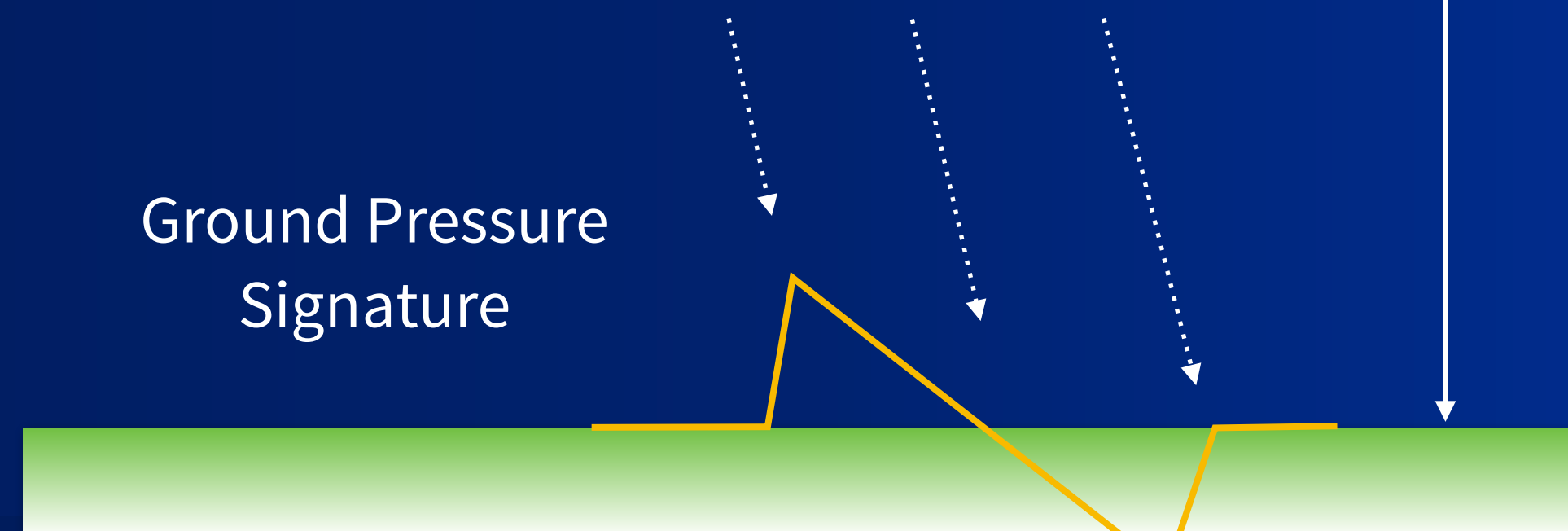
## Loudness metrics (dB)

- Perceived Level PL
- Weighted Sound Exposure Level: A/B/C/D/ESEL
- Indoor Sonic Boom Annoyance Predictor

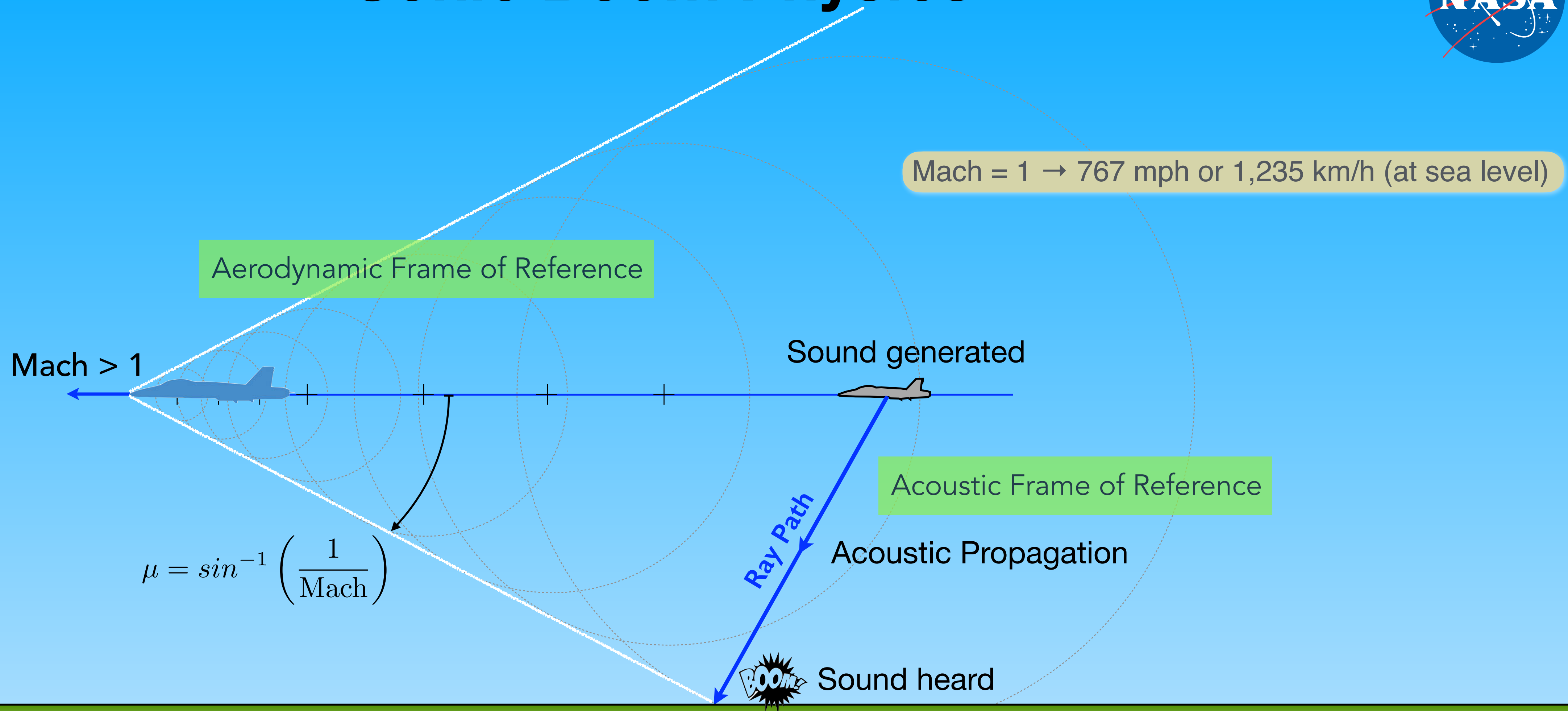


Altitude  
(~10 miles)

Ground Pressure  
Signature



# Sonic Boom Physics

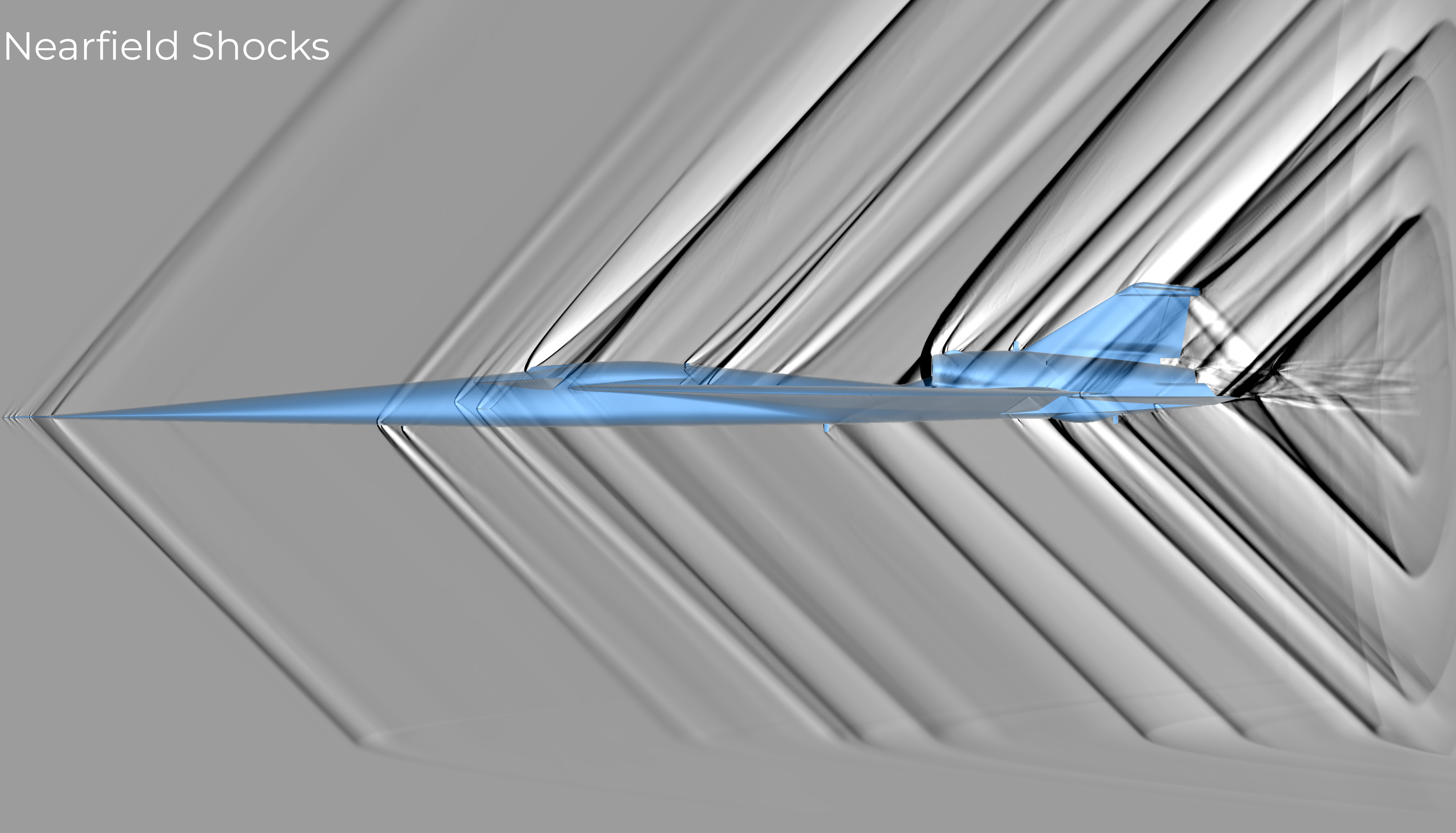


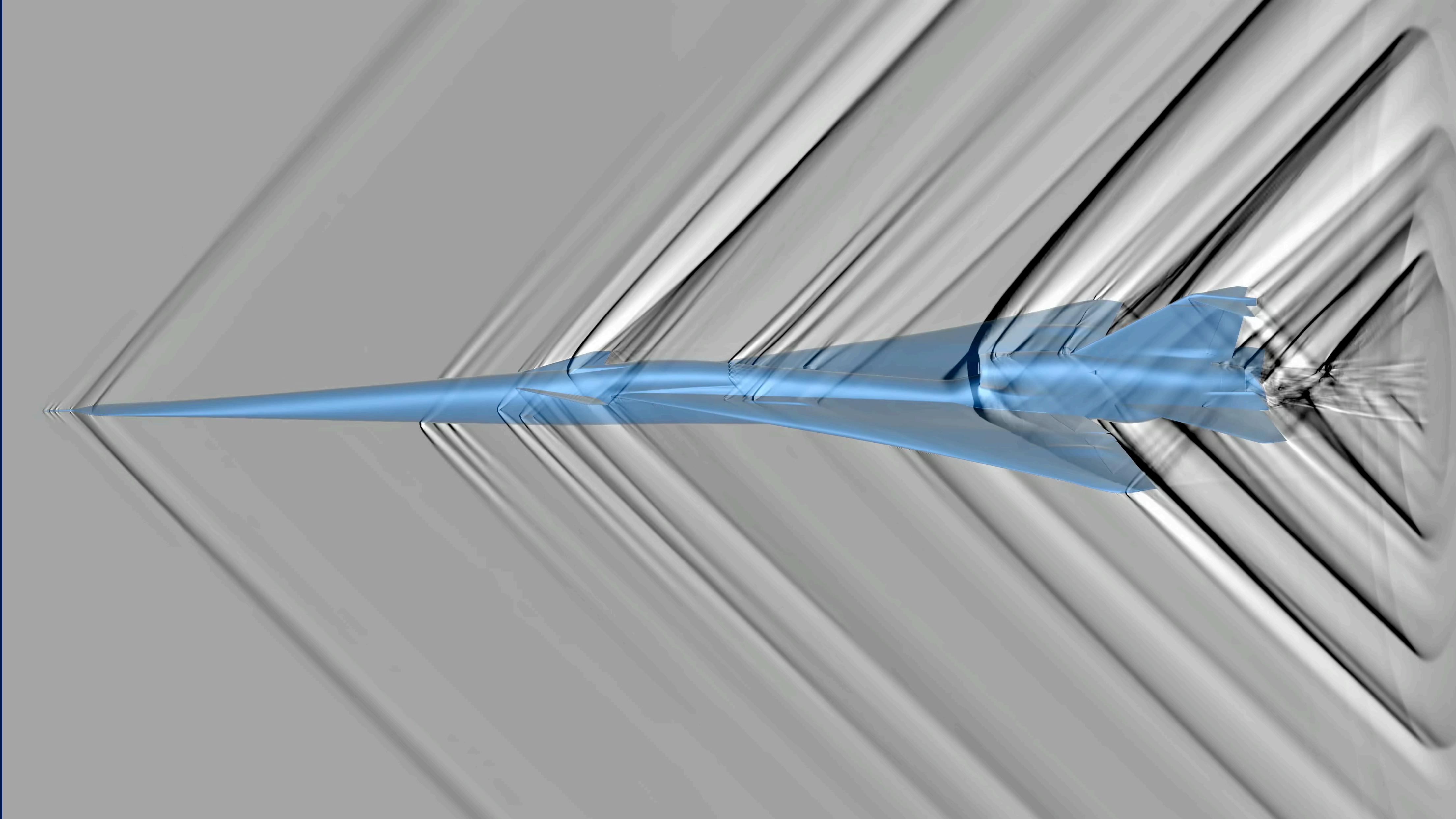
- Goals
- Simulation-based analysis must reliably predict ground noise
  - Simulation-based design must reliably determine aircraft shape to minimize ground noise



Credit: NASA

# Nearfield Shocks





SSBD

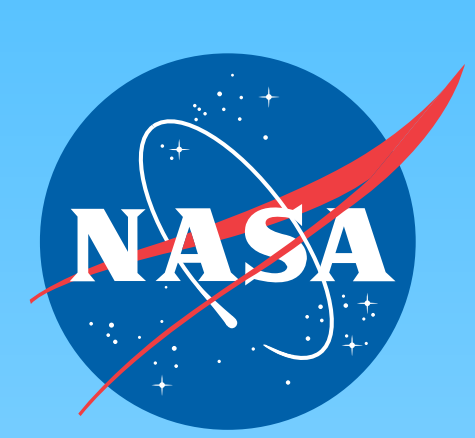


Credit: NASA

# Quiet Spike

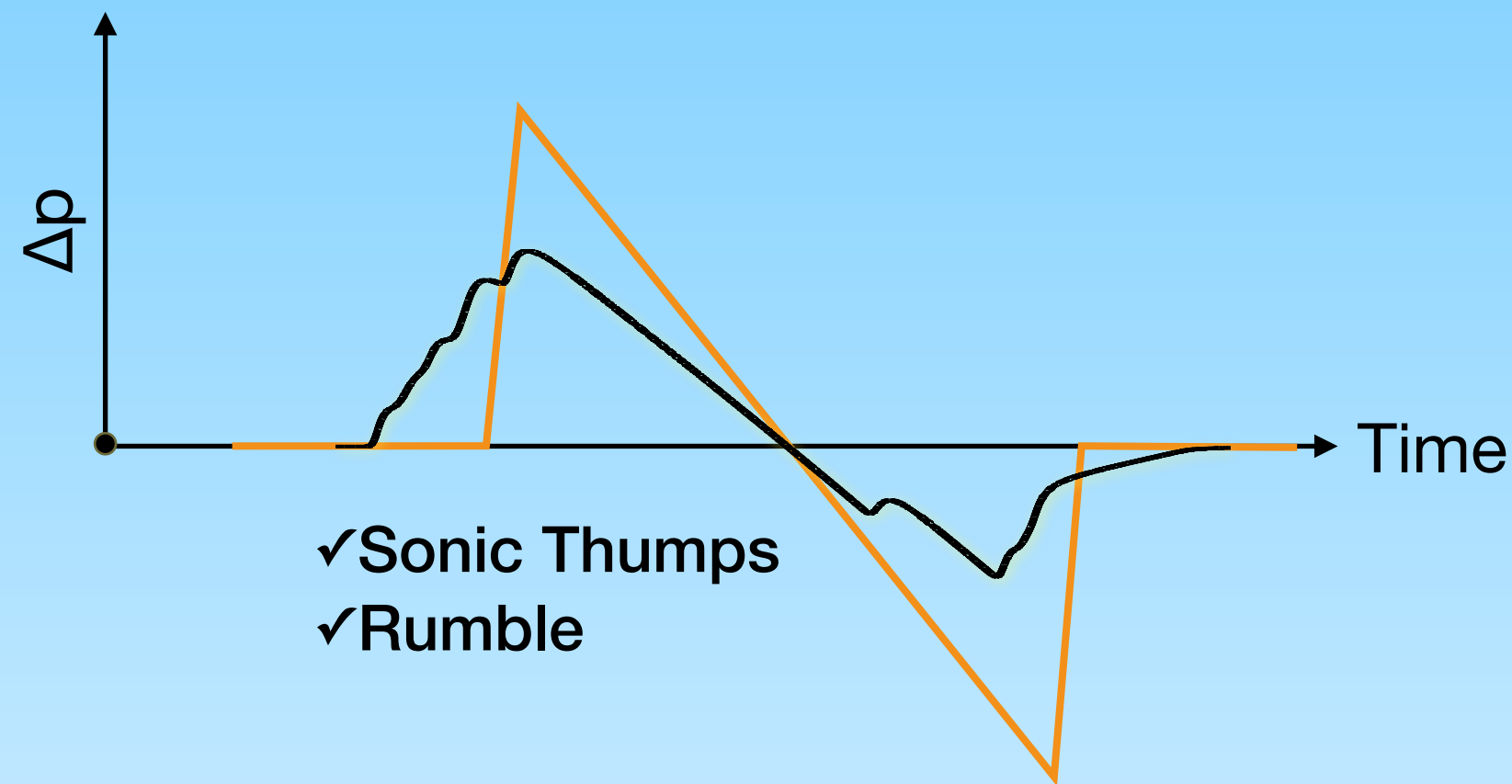


Credit: NASA Credit: NASA



# X-59: Low-Boom Design

- Aerodynamic shaping to eliminate sonic booms



- Strategy is to increase rise time, decrease amplitude, increase duration and smooth recovery
- Requires designing aircraft with signatures that do not coalesce into N-waves
- Extensive reliance on high-fidelity simulations based on Computational Fluid Dynamics
  - ▶ Shock dominated, strongly nonlinear flowfield
  - ▶ Limited “expert knowledge” in quiet supersonic flight

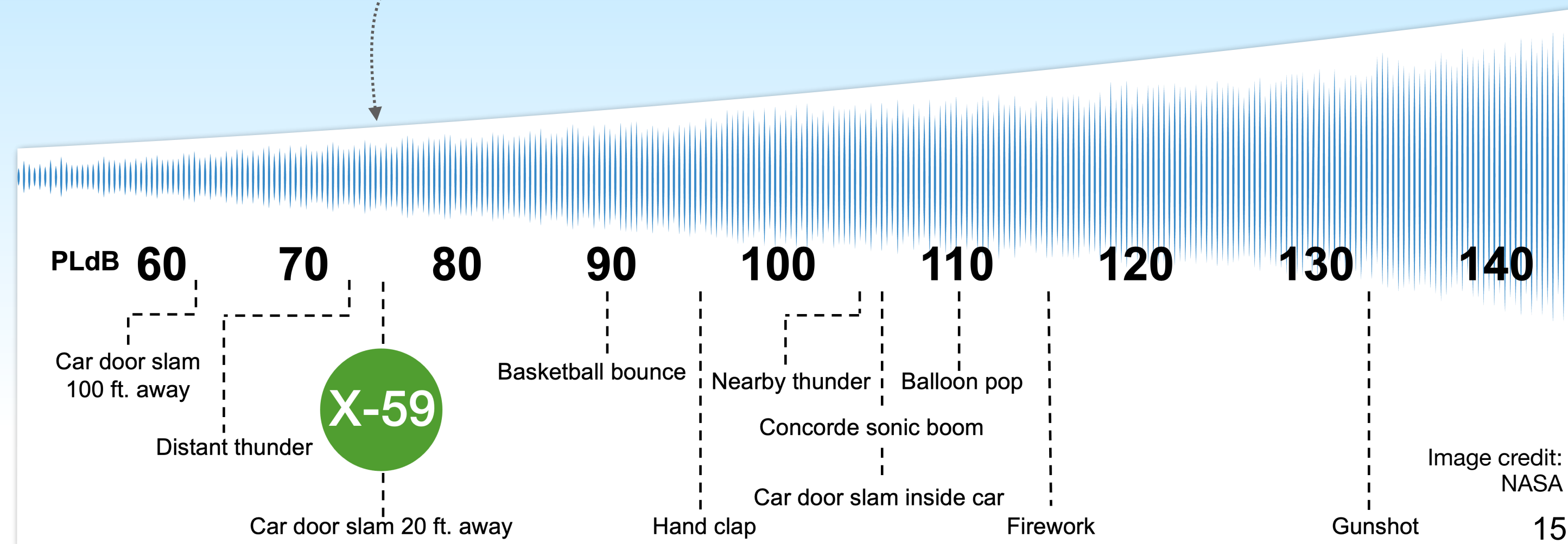
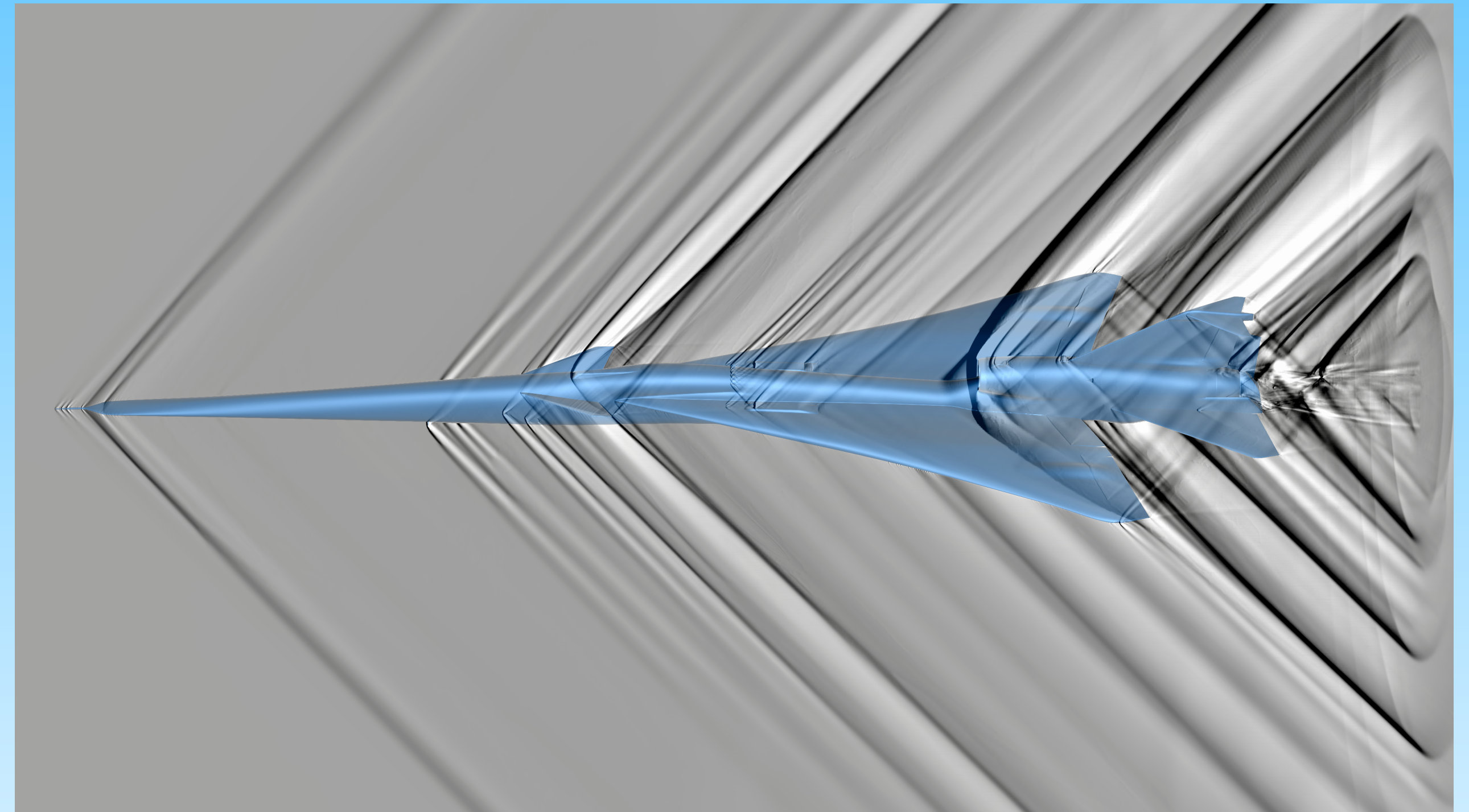
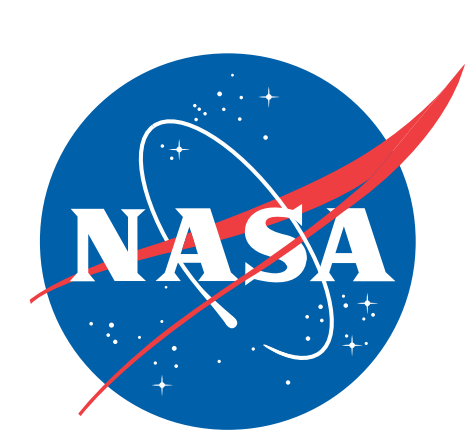
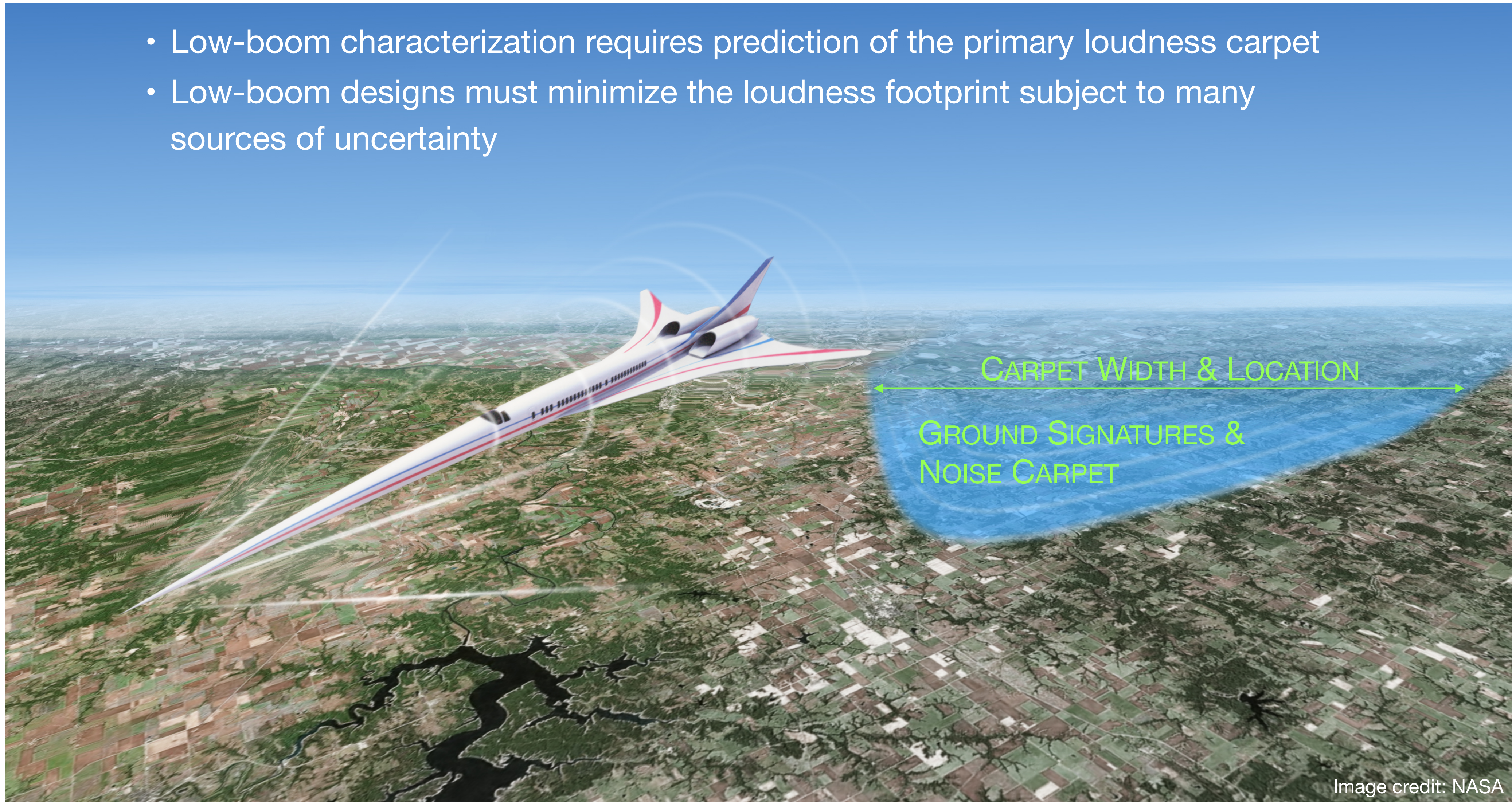


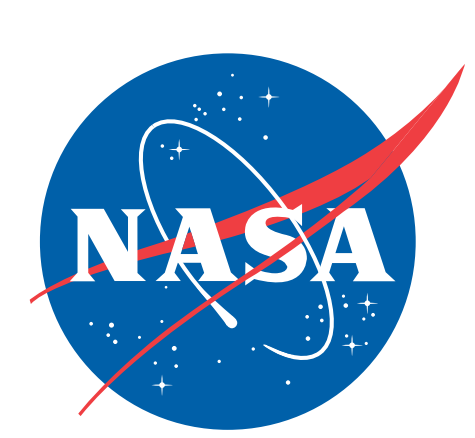
Image credit: NASA



# Predicting En Route Noise

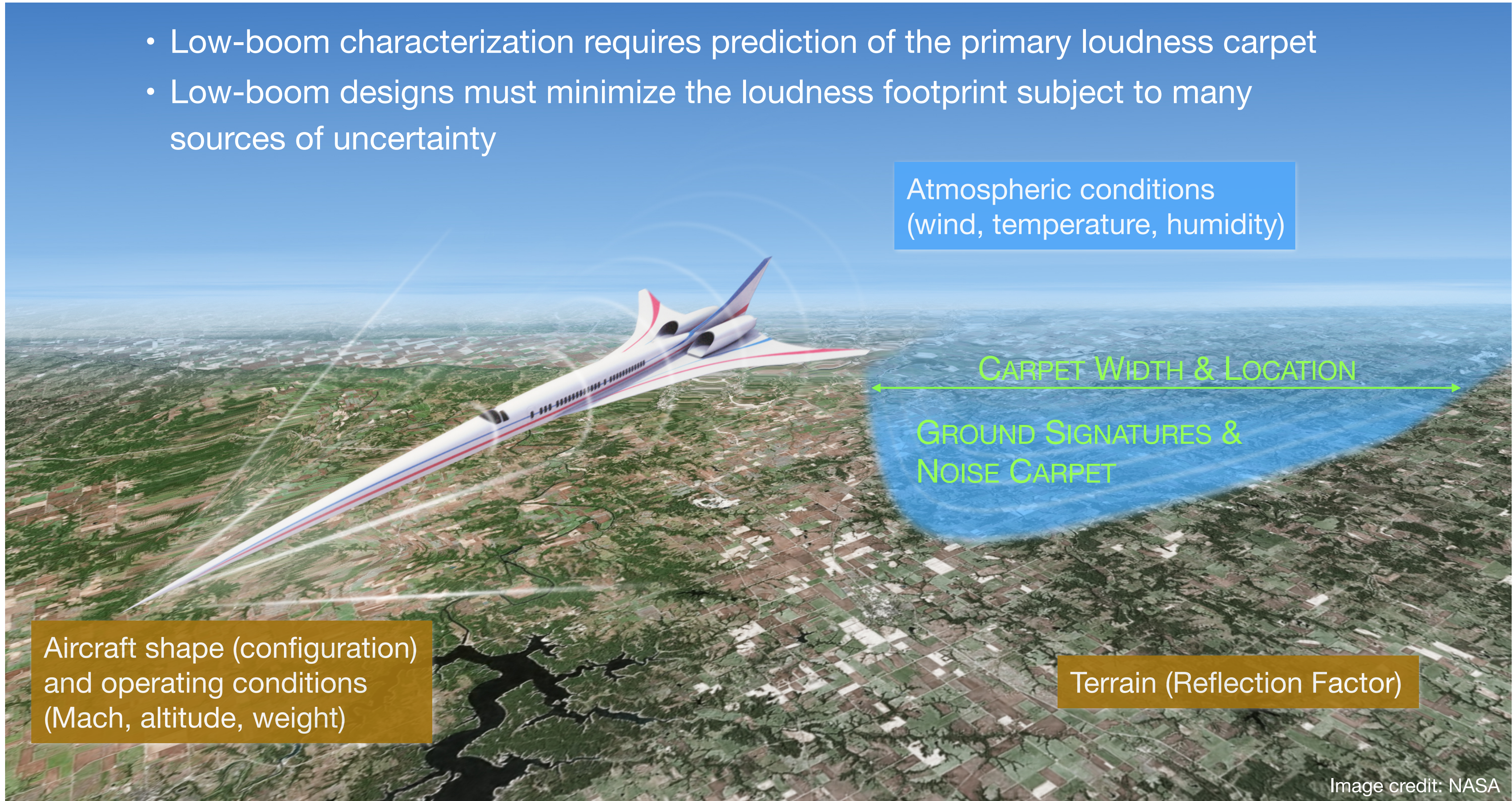
- Low-boom characterization requires prediction of the primary loudness carpet
- Low-boom designs must minimize the loudness footprint subject to many sources of uncertainty



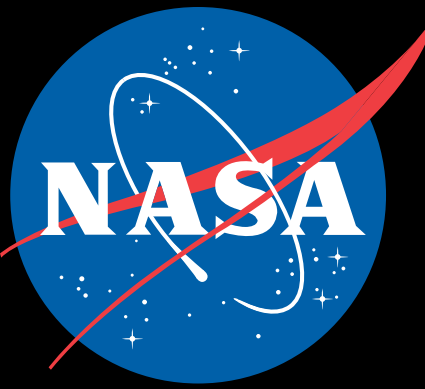


# Predicting En Route Noise

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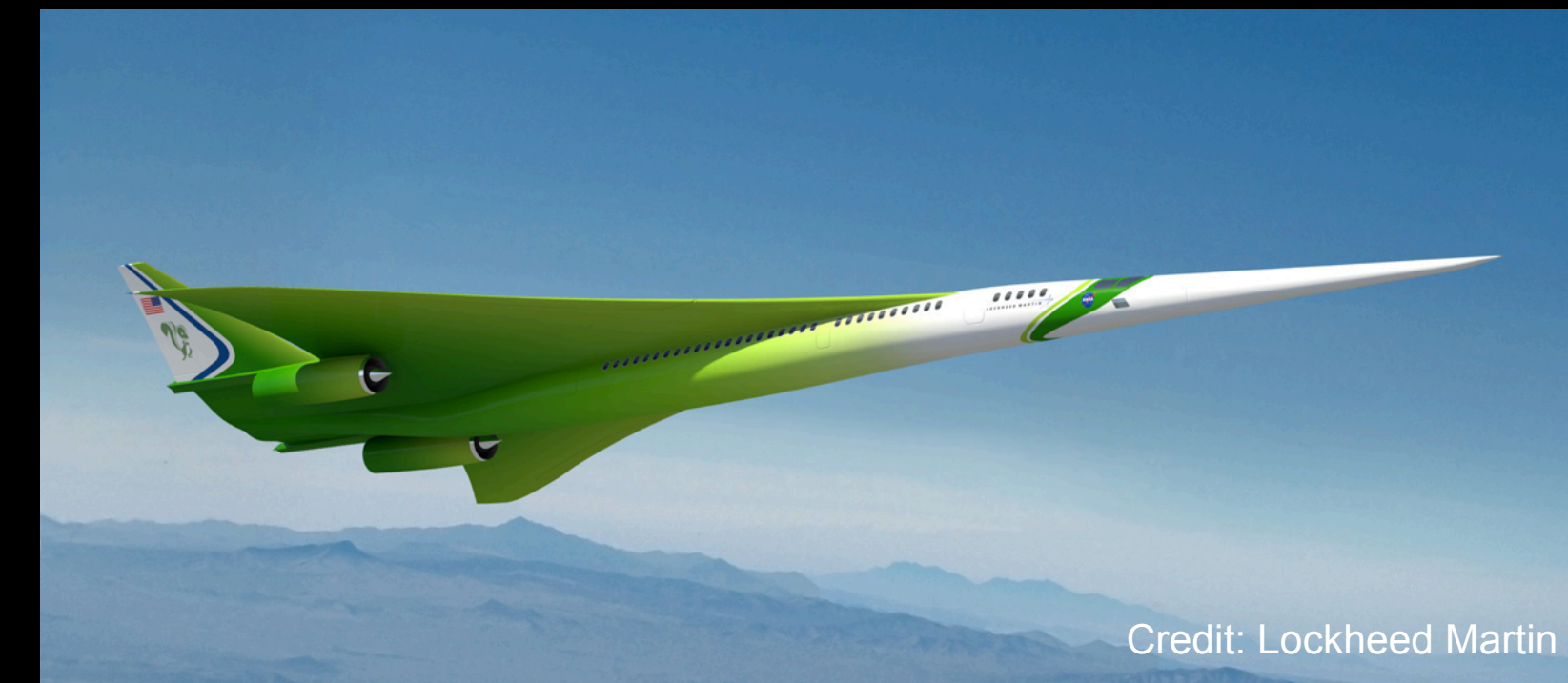


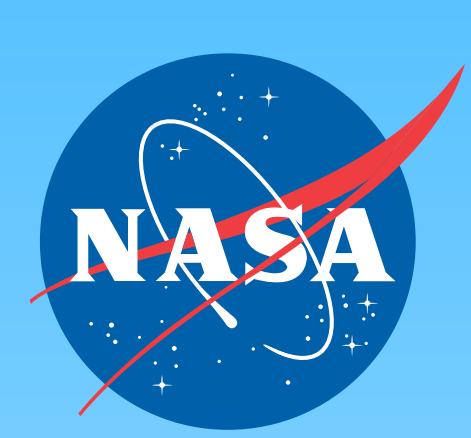
# Motivation



## Overcoming the Barrier to Overland Supersonic Flight

- Vision for Commercial Supersonic Flight is a future where fast air travel is available to a broad spectrum of the traveling public
- Biggest challenge is sonic boom
  - Civil supersonic flight operations are prohibited over many parts of the world
  - Currently, U.S. law prohibits flight in excess of Mach 1 overland
- Supersonic En-Route Noise standard is required
  - Must be accepted internationally (ICAO, FAA, EASA, TCCA)
- Additional barriers include airport noise, high-altitude emissions, efficiency, and many more



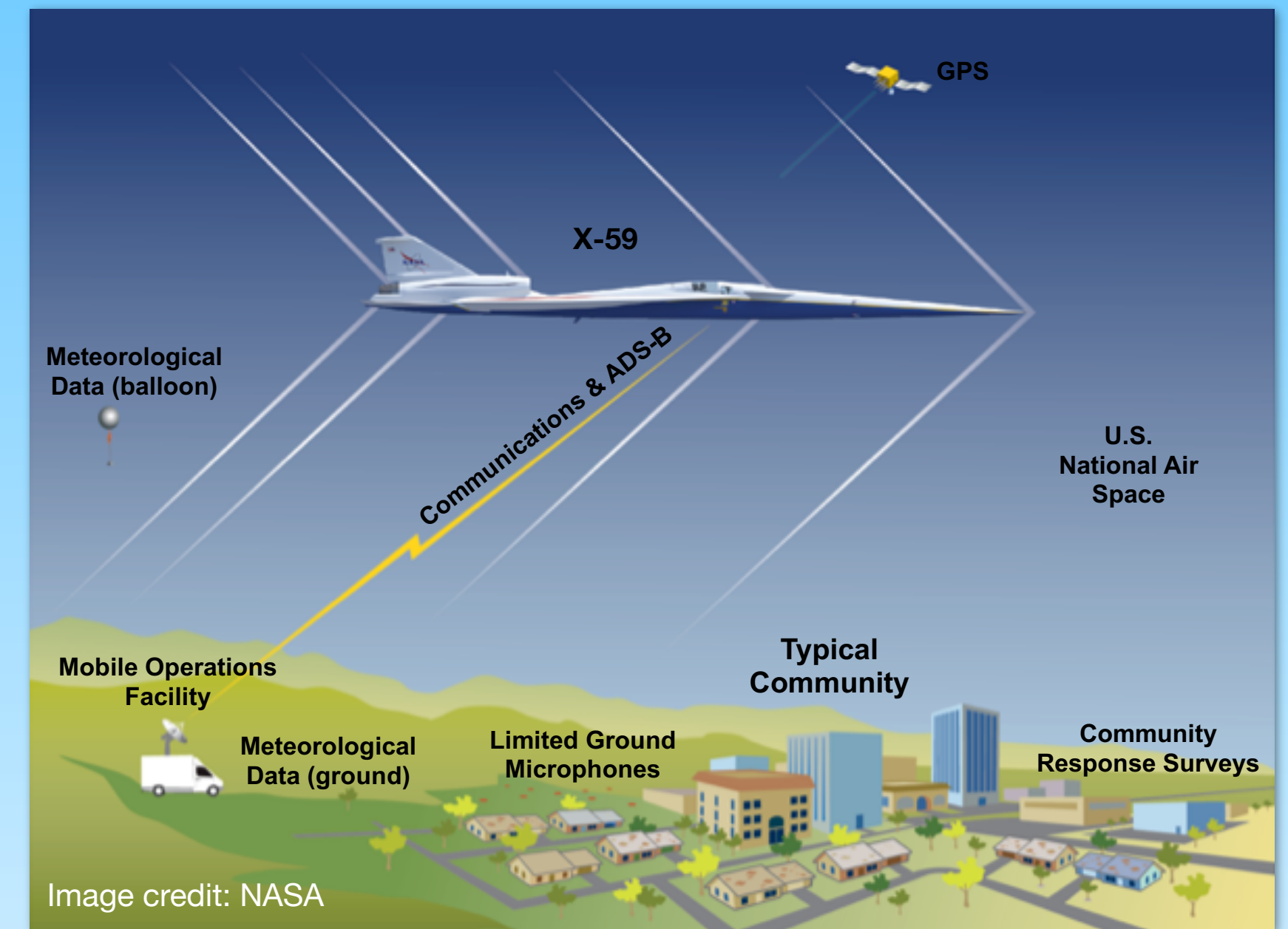


# X-59 & Quesst Mission



## Overcoming the barrier to overland supersonic flight

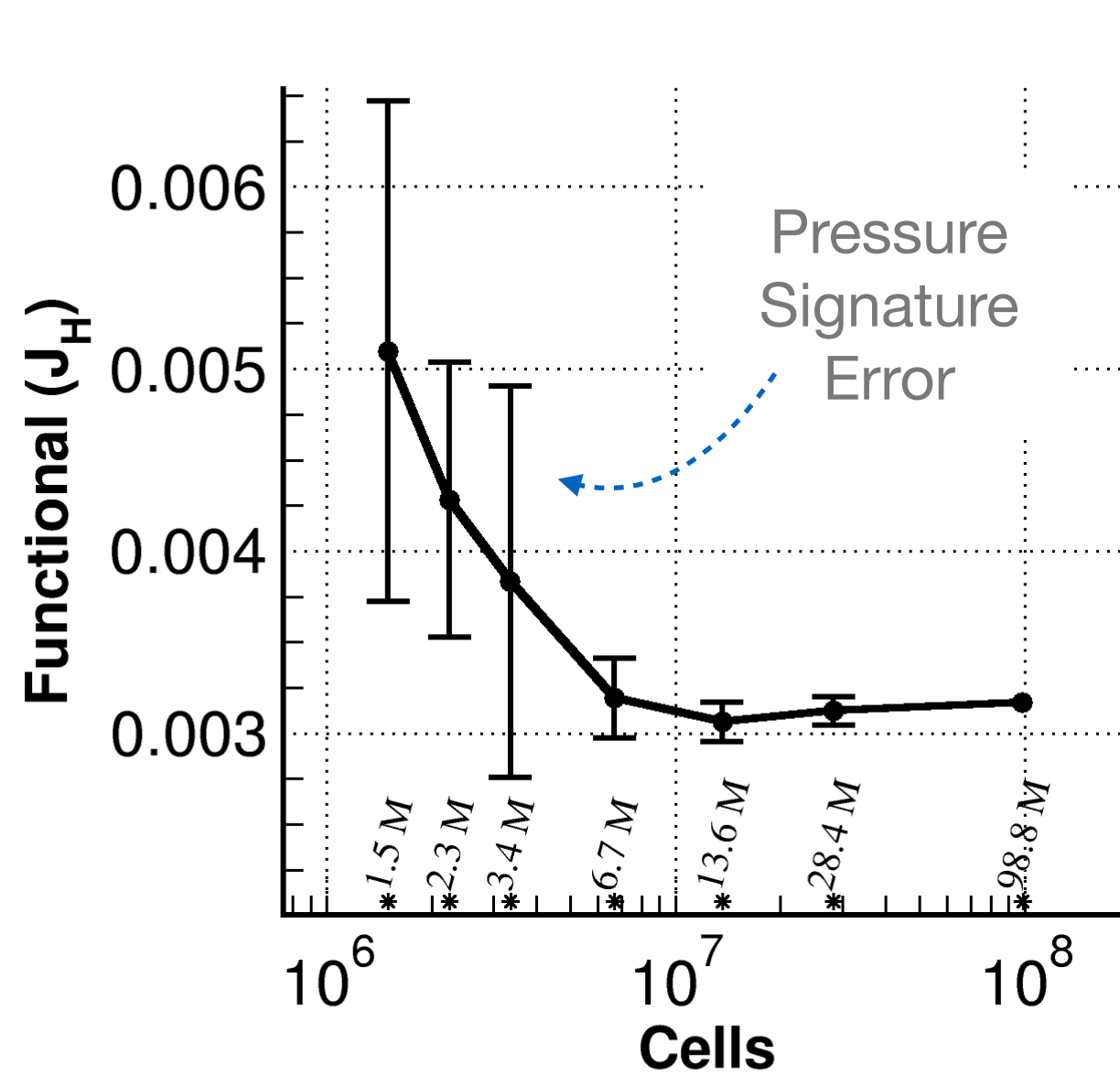
- Civil supersonic flight operations are prohibited over many parts of the world
  - Flight in excess of Mach 1 over land is prohibited in US and Canada
- NASA mission to support development of an en route noise standard
- X-59 is a supersonic-acoustic-signature-generator with characteristics representative of a commercial supersonic transport
- Goal is to perform multiple overflights of representative communities and climate across the US to collect noise response data
- Deliver community response data to ICAO
  - New standard must be accepted internationally (ICAO, FAA, EASA, TCCA)



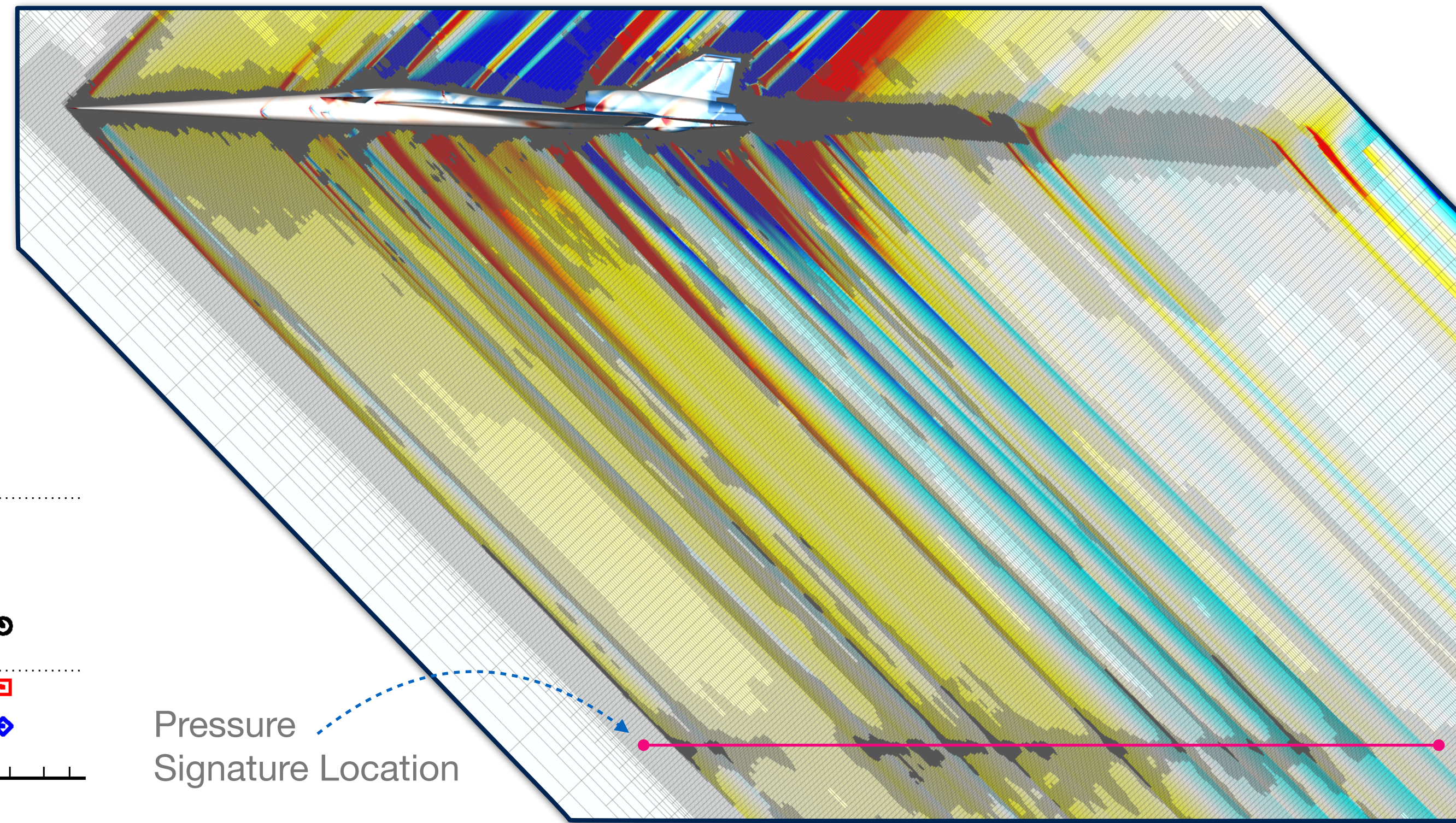
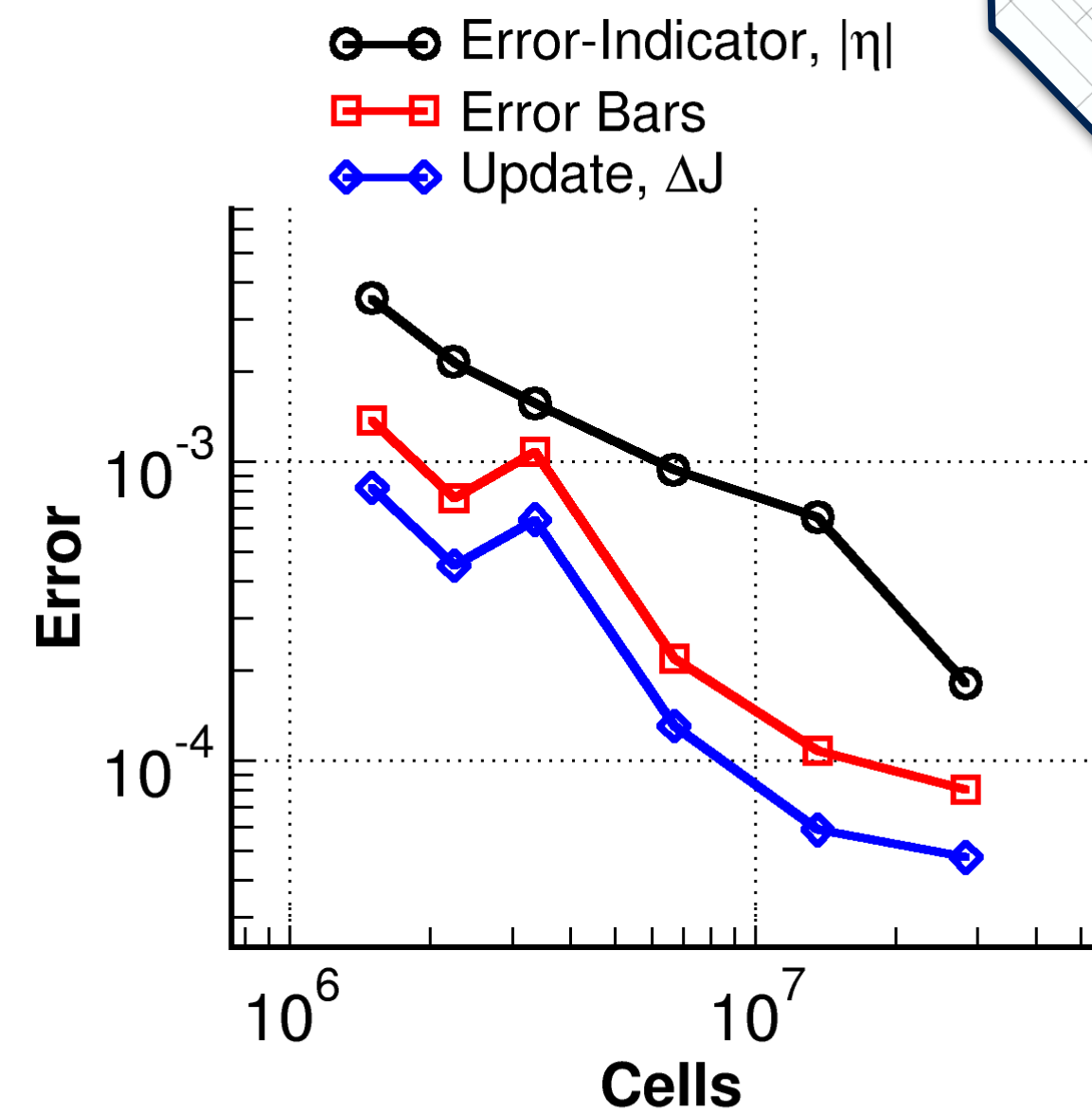
# Core Solver: Cart3D

## Error Estimation and Goal-Oriented Mesh Adaptation

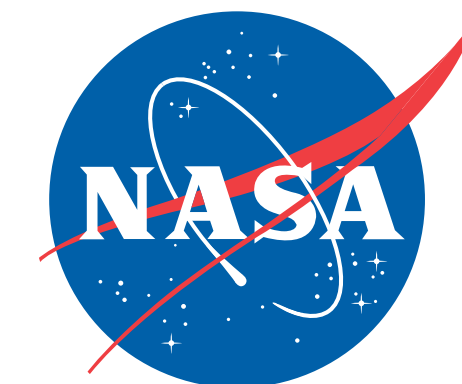
- Mesh automatically refined in locations with most impact on user selected outputs (pressure signatures, lift, drag, moments, ...)
- Method of adjoint weighted residuals
- Used for every simulation



Adaptation Convergence History



Near-body region of adapted mesh around LBFD aircraft for pressure sensor output ( $C_p$  contours)

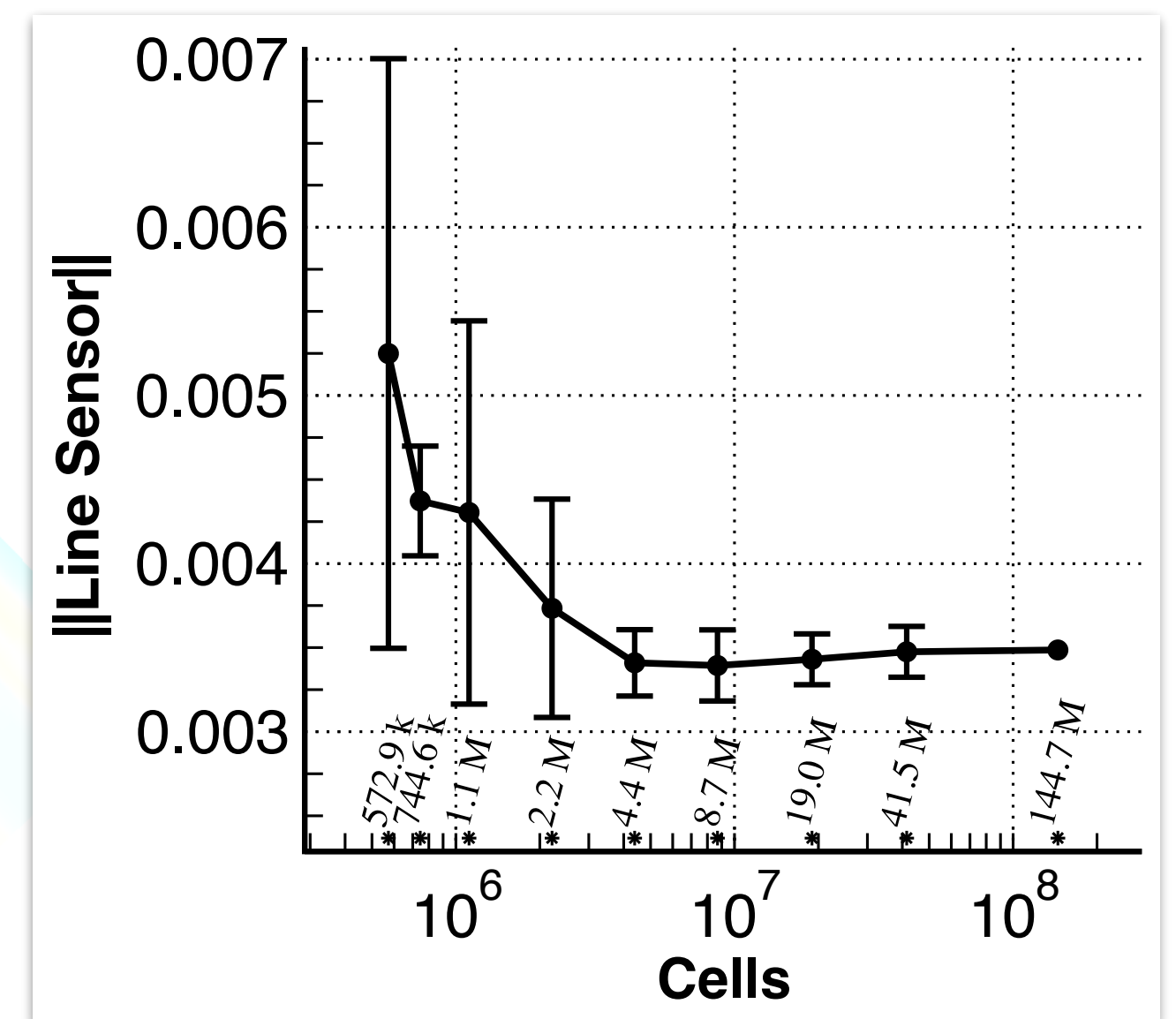
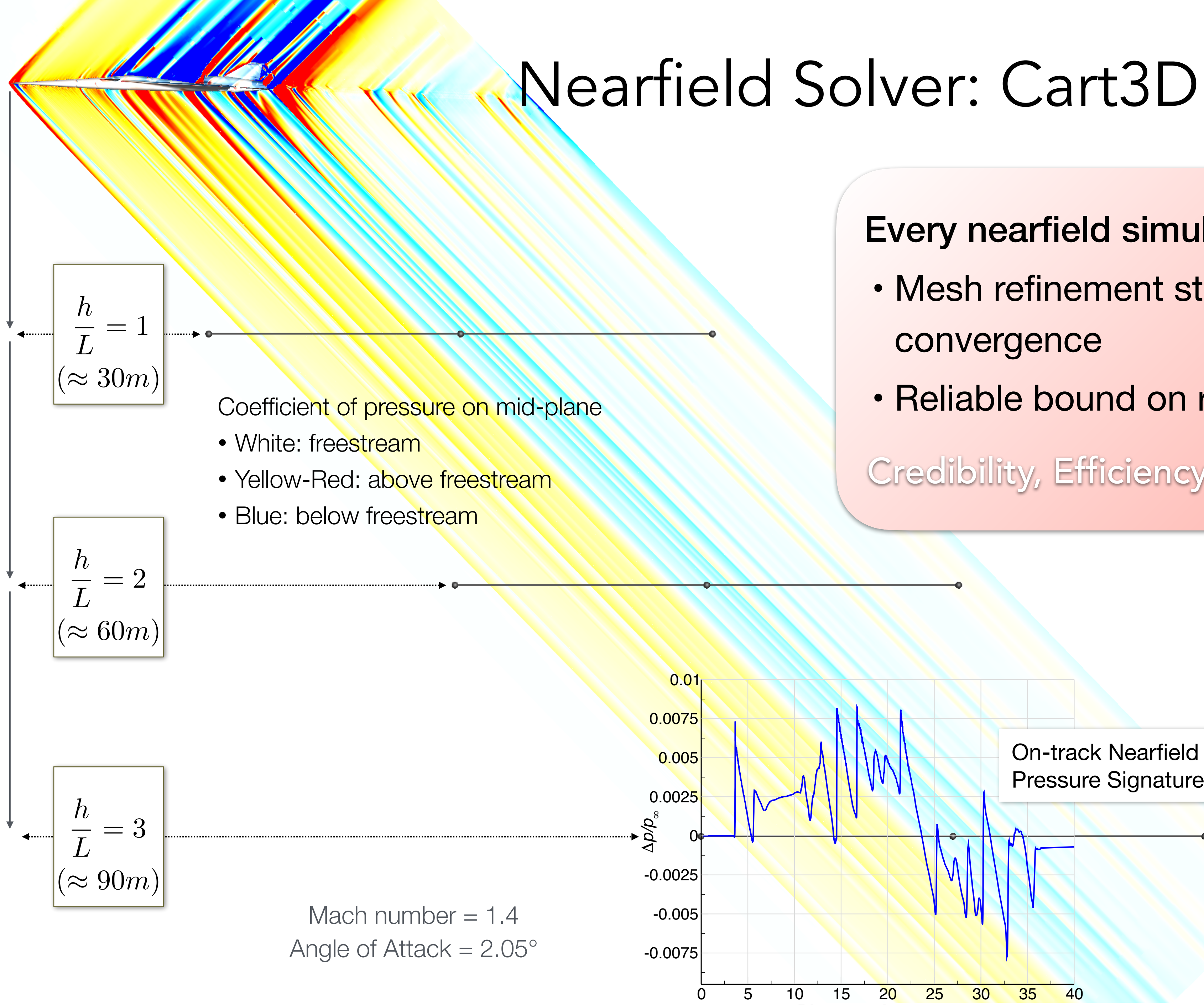


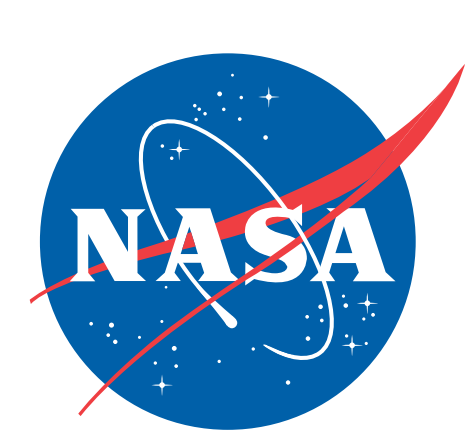
# Nearfield Solver: Cart3D

Every nearfield simulation includes

- Mesh refinement study to demonstrate mesh convergence
- Reliable bound on remaining discretization error

Credibility, Efficiency & User-Independent Results





# Farfield Solver: sBOOM

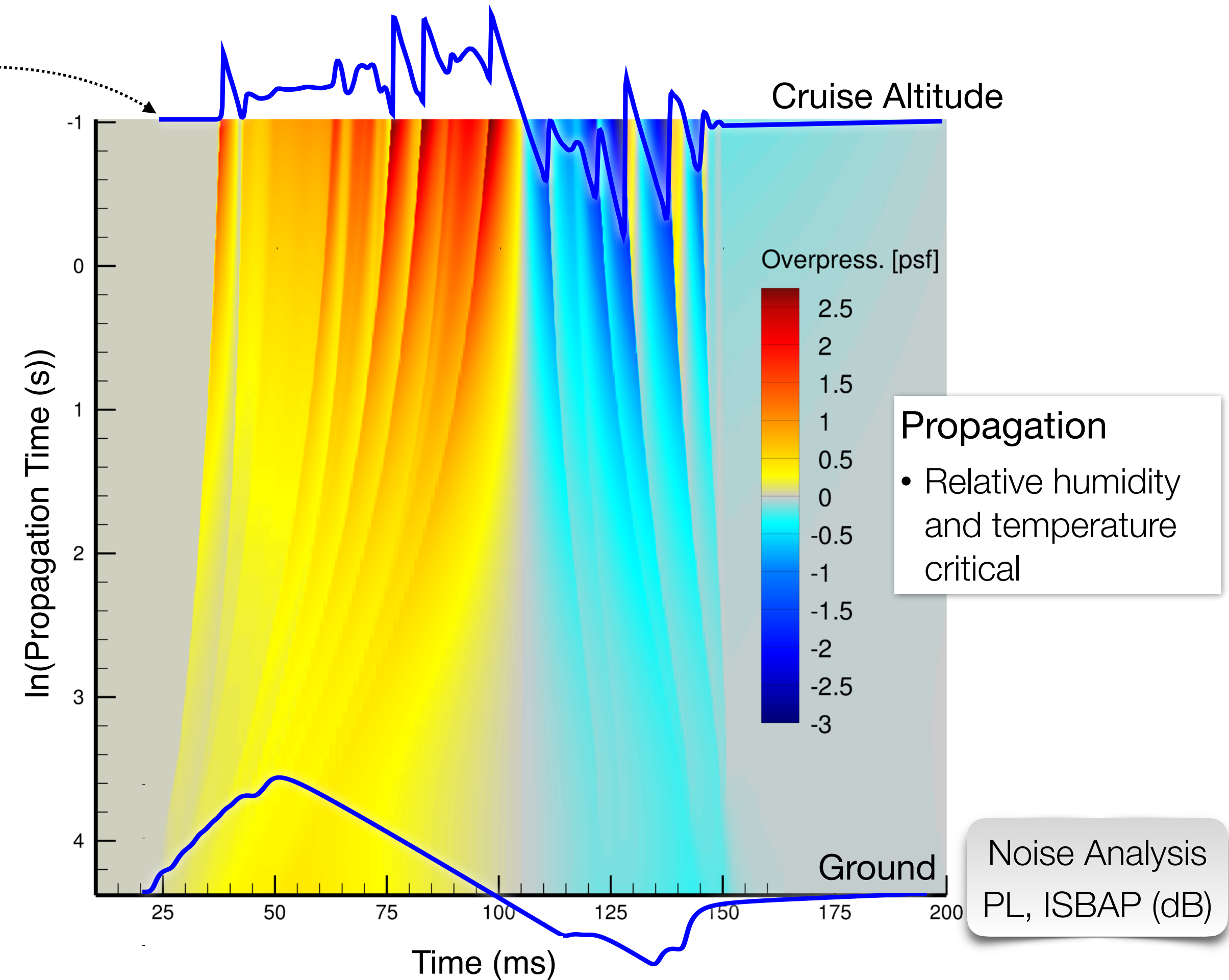
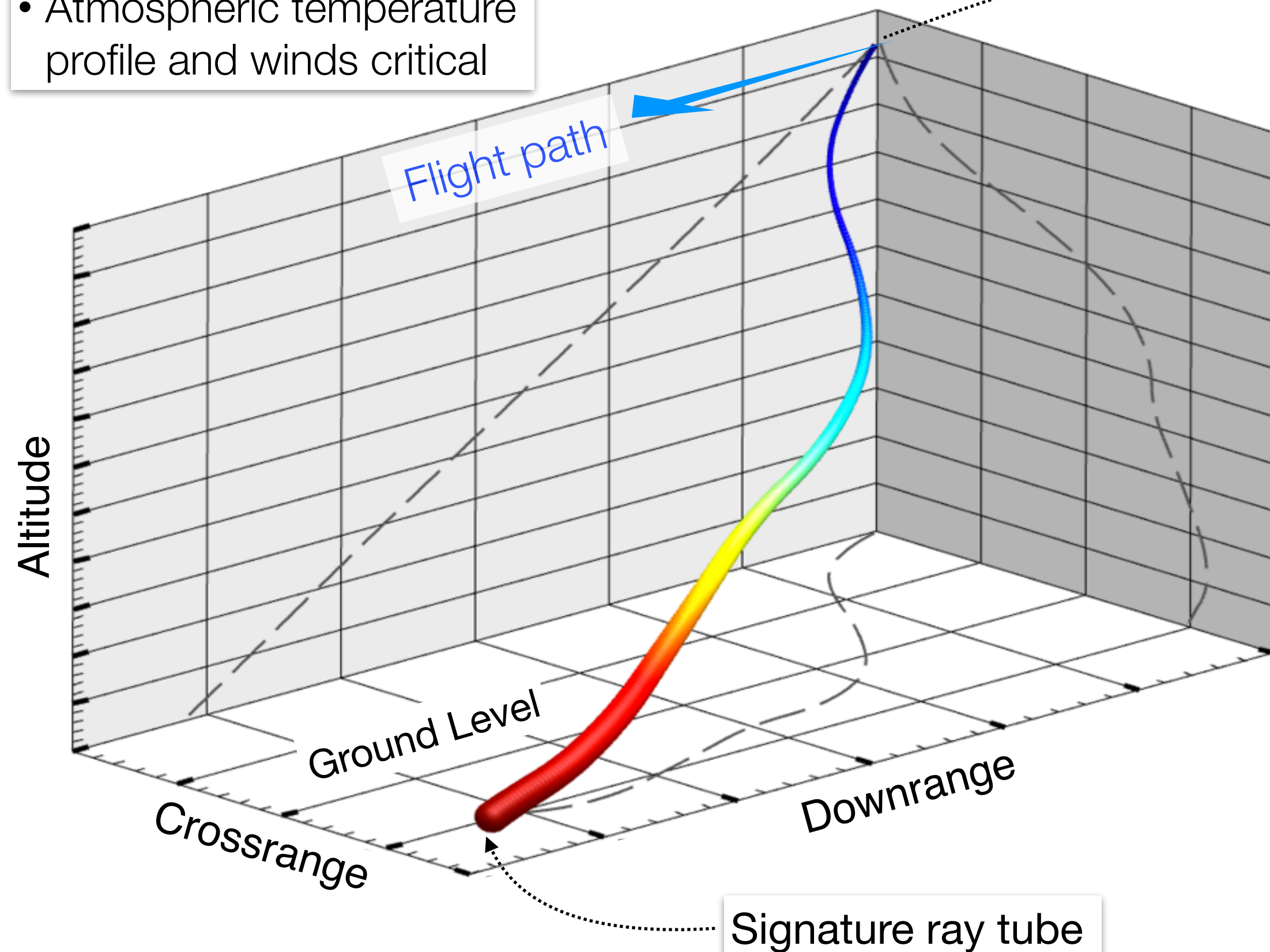
Ray tracing coupled with augmented Burgers' equation

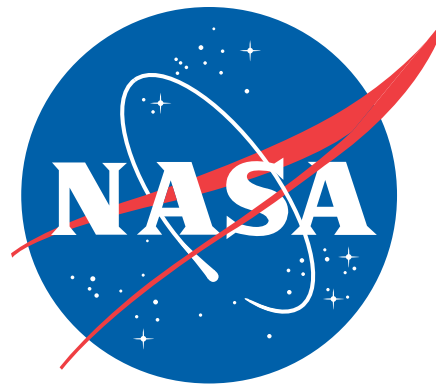
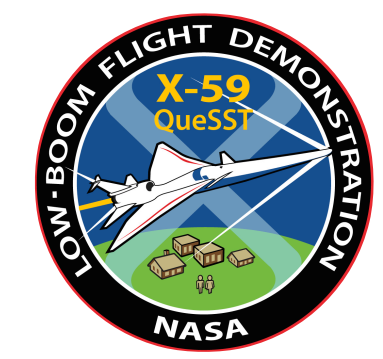
$$\mathbf{R}_F(\mathbf{Q}_N, \mathbf{Q}_F) = 0$$

- Includes nonlinearity, thermoviscous absorption and relaxation
- 2nd-order finite volumes: Godunov's flux, van Leer Limiter, RK2, uniform mesh

## Ray tracing

- Atmospheric temperature profile and winds critical

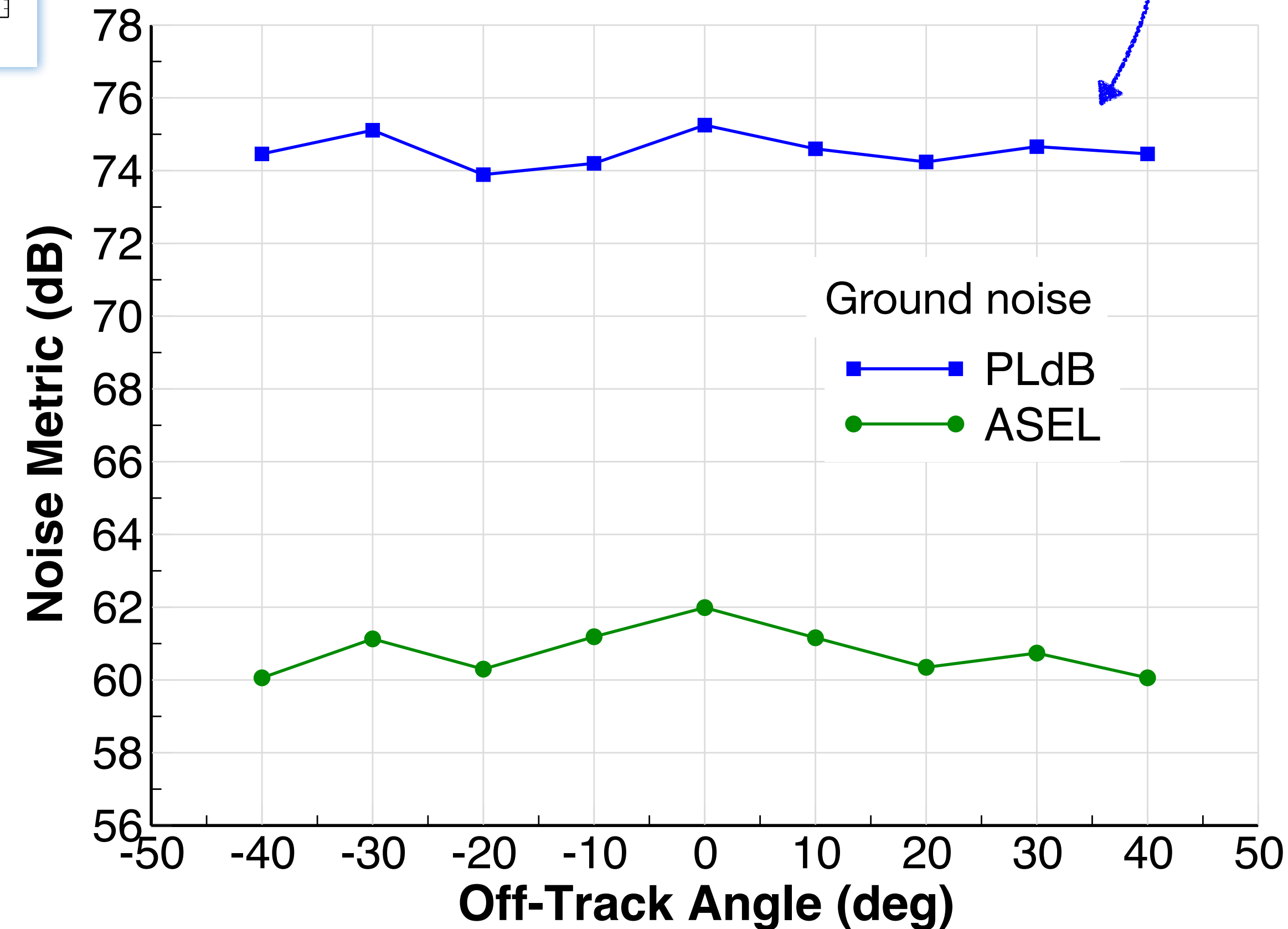
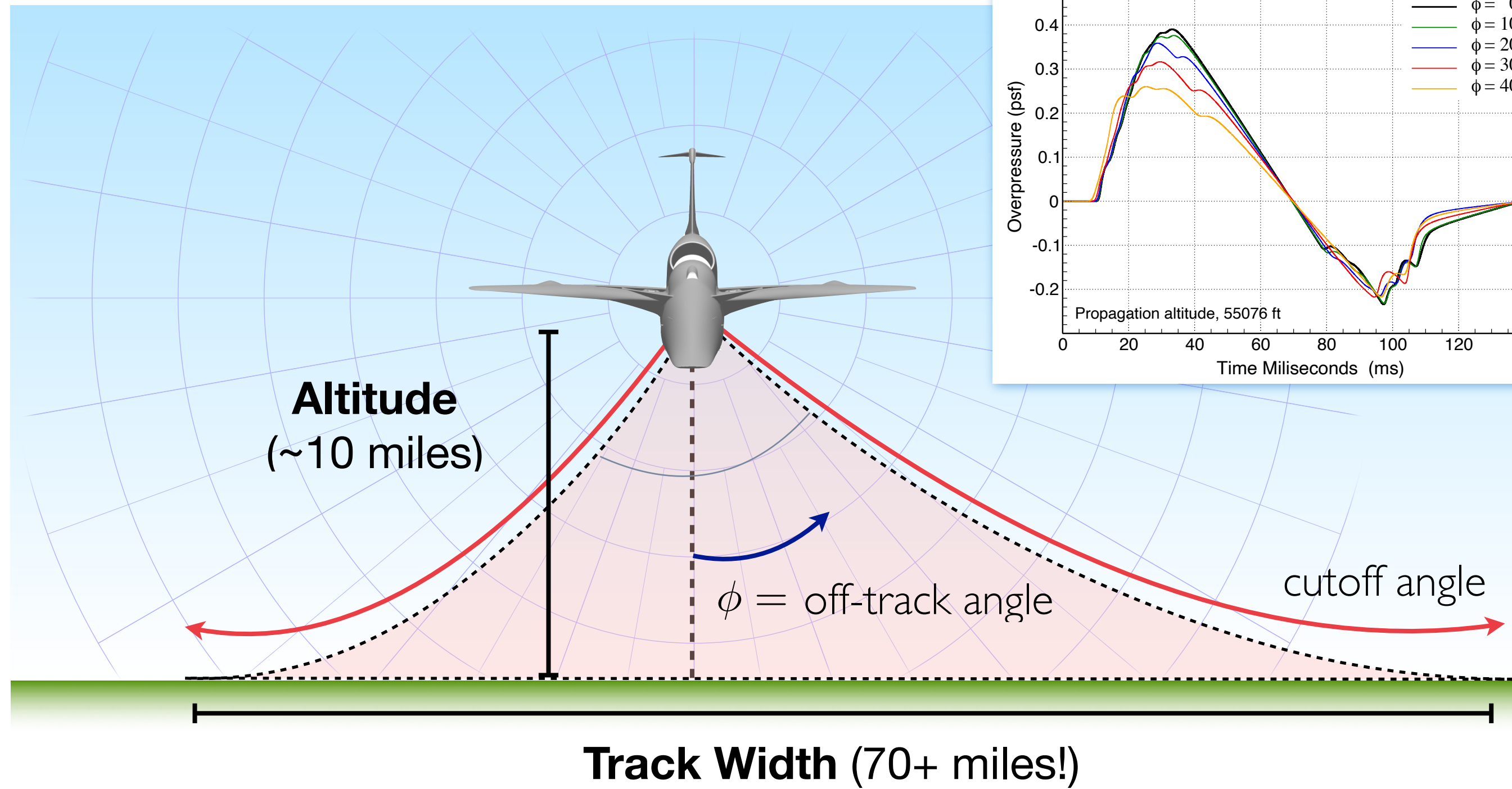
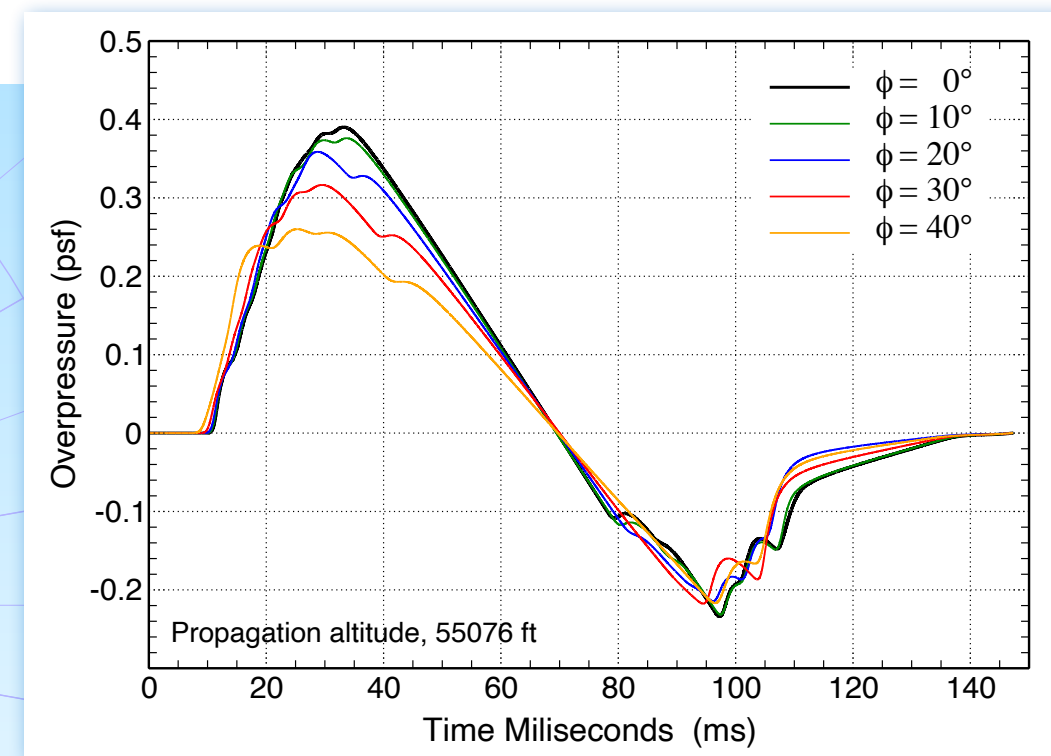




# Sonic Boom Carpet

Noise target is **75 PLdB**

- Current design is **quieter** than target over the full carpet
- Holds for most atmospheric conditions



Convert ground waveform to level of noise for each off-track angle up to cutoff

- Perceived level (PLdB) is the primary metric
- ASEL, BSEL & CSEL also used



Credit: USAF



Credit: NASA

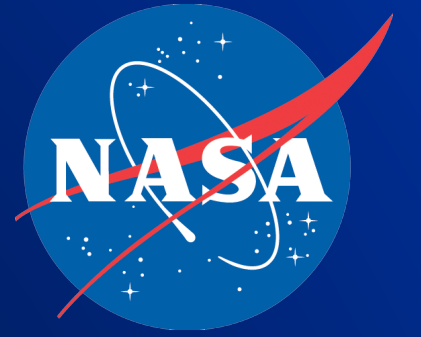




# Acknowledgements

- NASA's High-End Computing Program through the NASA Advanced Supercomputing (NAS) Division at Ames Research Center
  - SciCon in-house performance monitoring and debug tools
- NASA's ARMD Commercial Supersonic Technology Project
- NASA's Transformational Tools and Technologies Project





# Questions?

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<https://www.nasa.gov/aeronautics/supersonic-flight>

