NASA's Quesst Sonic Boom Prediction Developments

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Image Credit: Lockheed Martin/Michael Jackson

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Outline

- Introduction
  - Quesst Mission: Acoustic Validation
- Prediction and Validation of Tools
  - Propagation Modeling Improvements
    - sBOOM: Modeling and Efficiency Improvements
    - PCBoom: Enhanced Turbulence Filters
  - Uncertainty Quantification
  - Design Optimization Tool Improvements
  - CLEOPATRA
  - Computational Dry Runs & CFD Improvements for Sonic Boom Prediction
- Closing Remarks

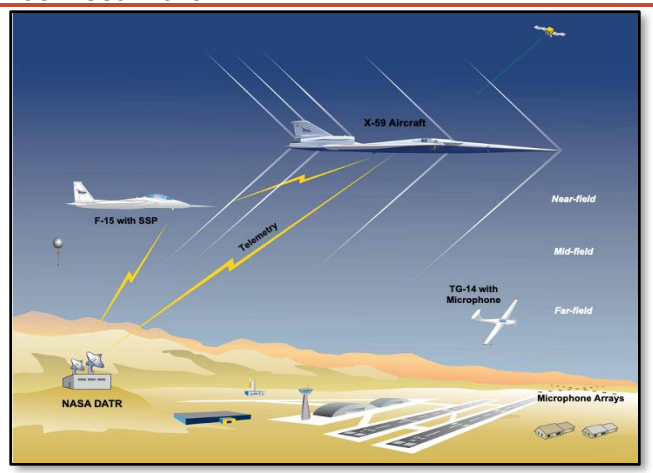
Overall Quesst Timeline

Credit: Lockheed Martin

First Flight 2025

Phase 1 – X-59 Aircraft Development
Aircraft design, fabrication, ground test checkout and envelope expansion

Systematic Approach Leading to Community Testing



2026

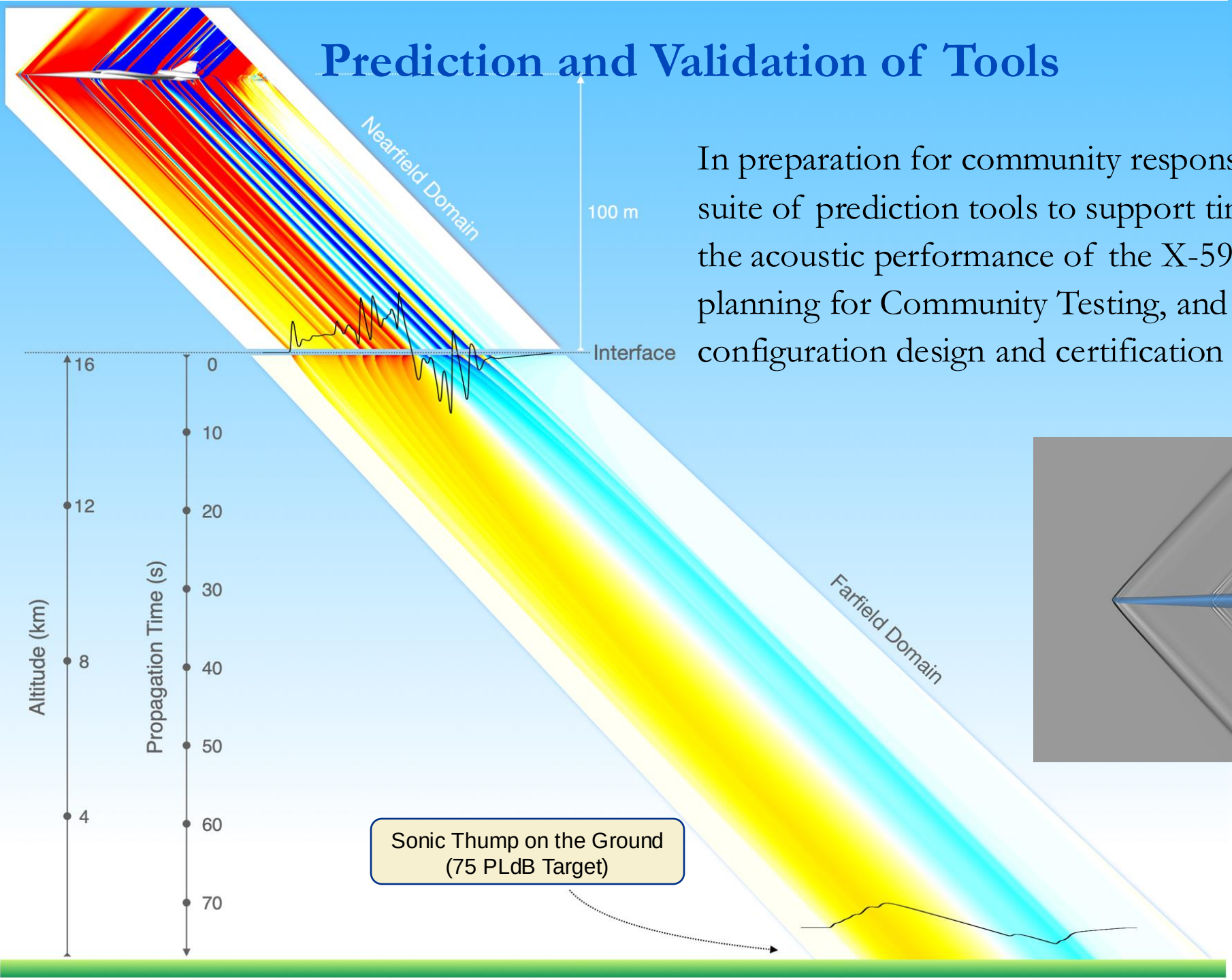
Phase 2 – Acoustic Validation
Detailed ground and flight measurements
Validation of sonic boom signature and prediction tools

2027

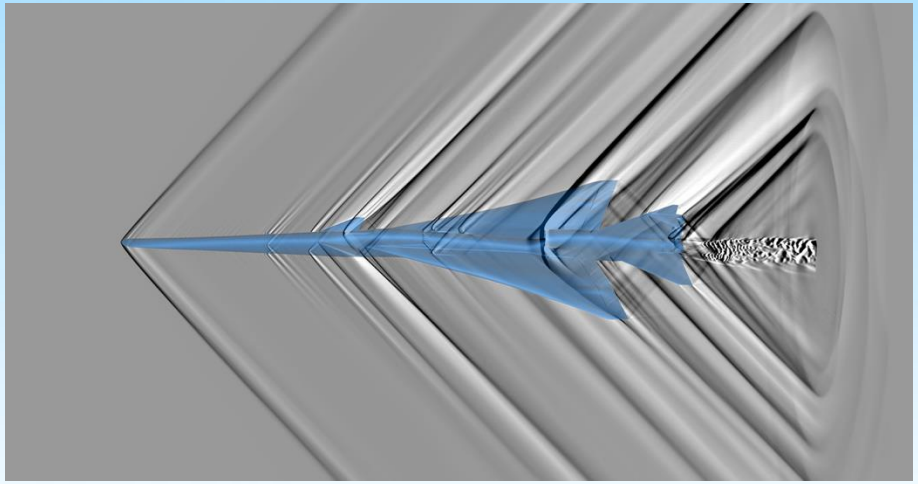
Credit: Lockheed Martin

Phase 3 – Community Response
Community response overflights, ground measurements, and surveys over representative communities across the U.S.

Prediction and Validation of Tools



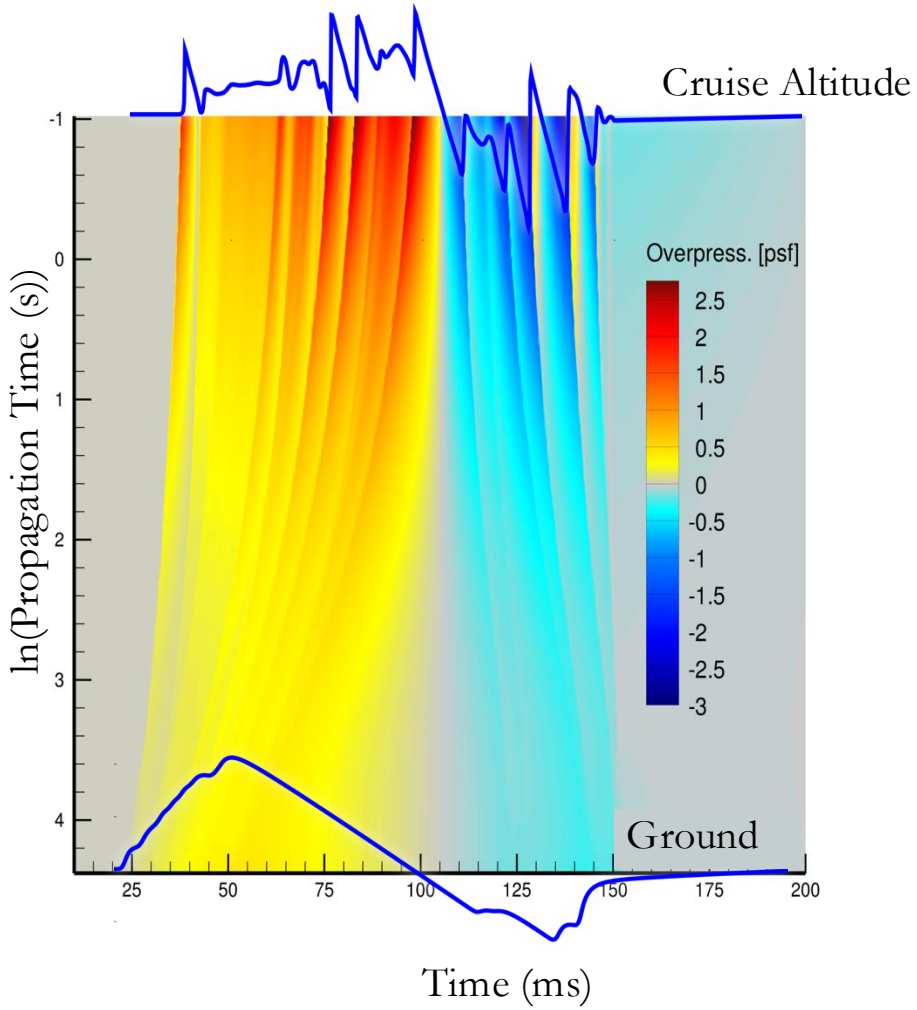
In preparation for community response testing, NASA is creating a suite of prediction tools to support timely and accurate validation of the acoustic performance of the X-59 aircraft, rapid pre-flight exposure planning for Community Testing, and provide a foundation for future configuration design and certification analysis of supersonic aircraft.



Propagation Modeling Improvements

sBOOM Solver

- Latest version v2.9.1



- Farfield propagation of CFD nearfield pressures
  - Simulation of 1-D Augmented Burgers' Equation with appropriate losses modeled
  - Ability to handle general atmosphere with arbitrary winds

- Mesh converged sonic boom predictions that minimize discretization errors in farfield simulations
- Loudness predicted <0.01 decibels for realistically complex practical examples (X-59) when analyzed at modest sampling frequencies
- Enhancements to allow coupled near-field and far-field simulations as well as reliable and robust aerodynamic shape optimization of low-boom aircraft

AIAA Paper 2023-3727, "**Recent Enhancements to Modeling Sonic Boom Propagation using Augmented Burgers' Equation**"

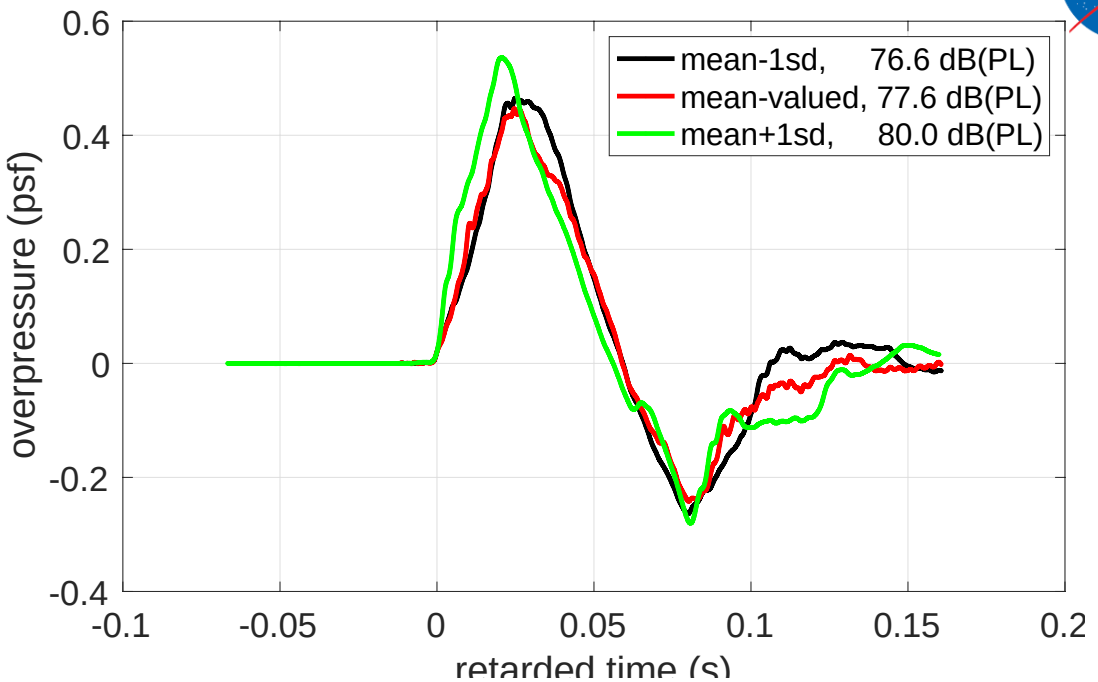
Propagation Modeling Improvements

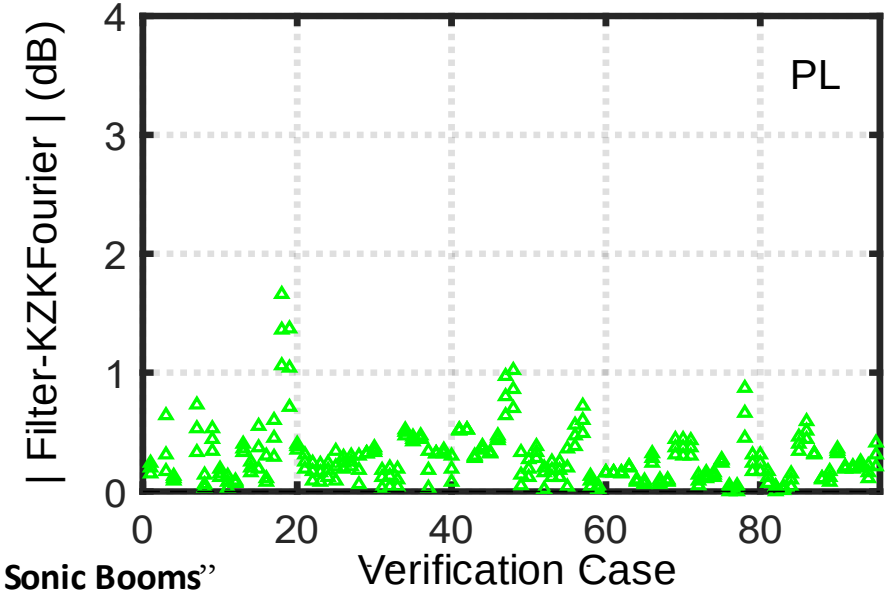
PCBoom Solver

- Latest version: v7.4.1

- Fully integrated KZK formulation based turbulence filters with enhanced Burgers solver
  - Enhanced turbulence filters yield mean and standard deviation prediction in the presence of atmospheric turbulence in the planetary boundary layer

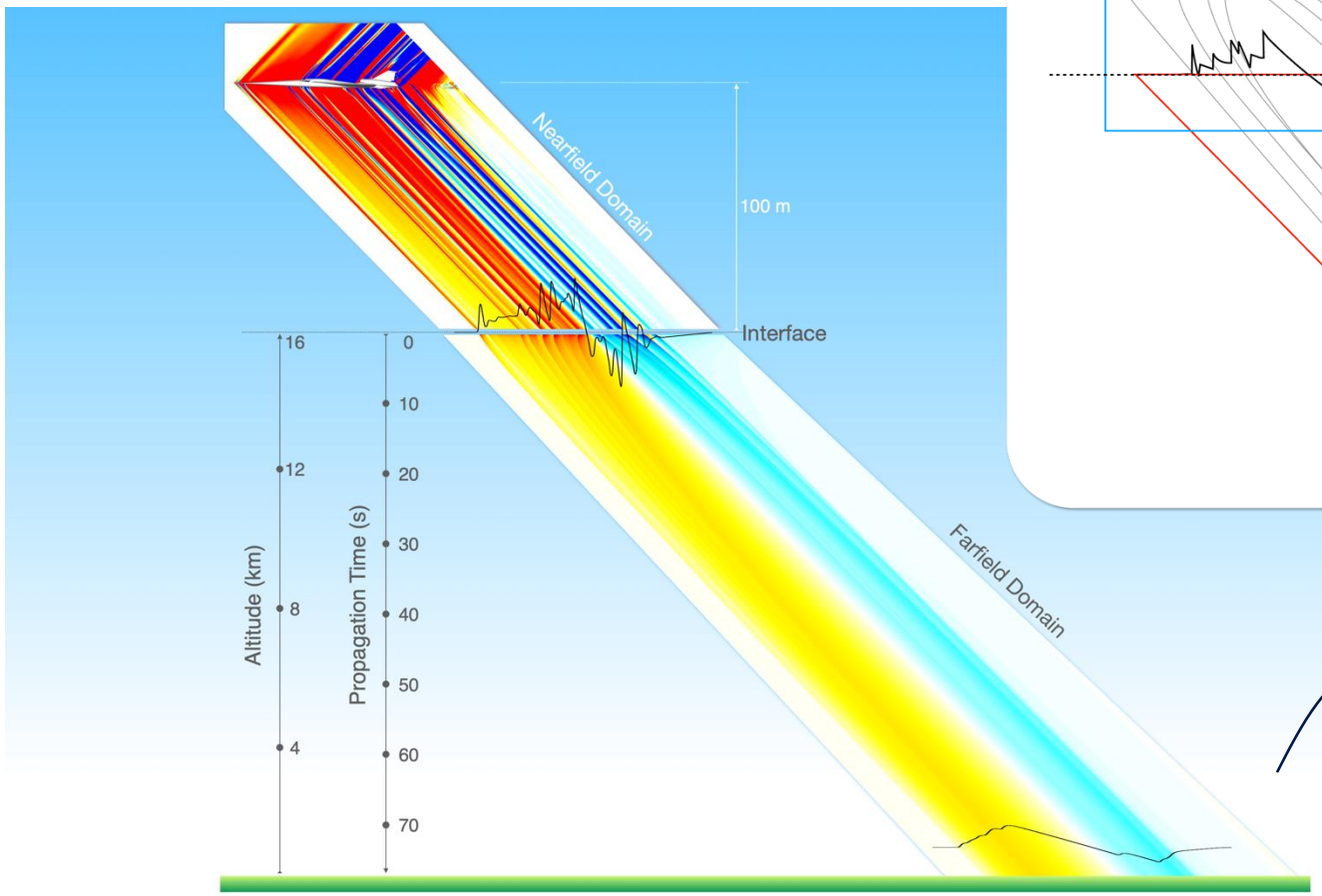
- KZK filters updated for X-59 waveforms
  - Developed enhanced shaped boom filters to cover range of turbulence parameters expected for Quesst Phase 3 testing
- Enhanced filter outputs shown to reliably estimate actual KZKFourier implementation to < 1dB



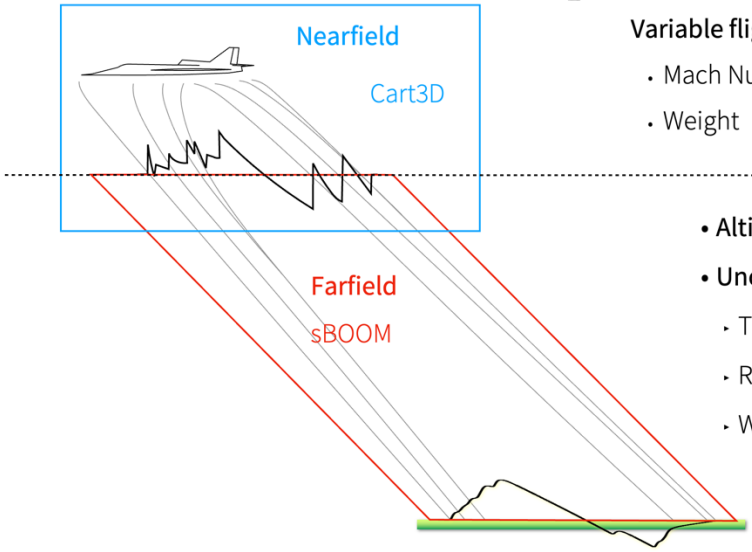


AIAA Paper 2024-4670, "**Evaluation of Finite Impulse Response Filters for Turbulence Effects on Sonic Booms**"

Quantifying Uncertainty in Computational Predictions



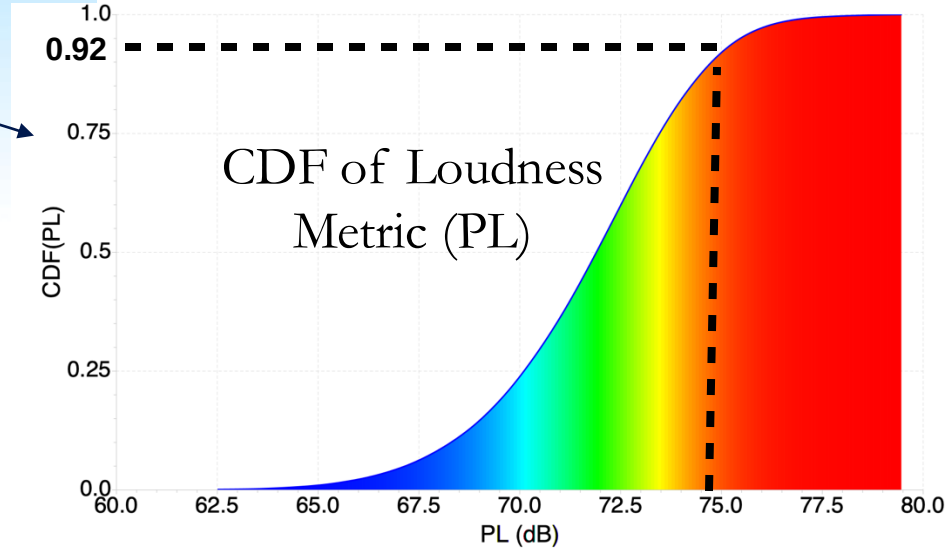
Multiple Sources of Uncertainty



Variable flight conditions

- Mach Number
- Weight

- **Altitude**
- **Uncertain state of atmosphere**
  - Temperature
  - Relative Humidity
  - Wind



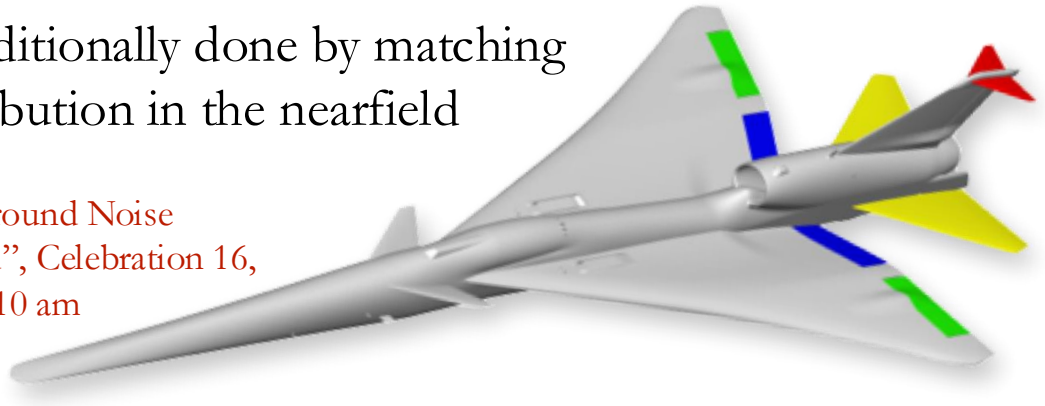
AIAA Paper 2024-4671, "**Acoustic Signature Uncertainty Quantification for Quiet Supersonic Aircraft**"

Ground Noise-Based Shape Optimization

- Developed integrated capability to directly optimize aircraft shape and/or control settings to minimize noise experienced at ground level

- Low-boom design traditionally done by matching a target pressure distribution in the nearfield

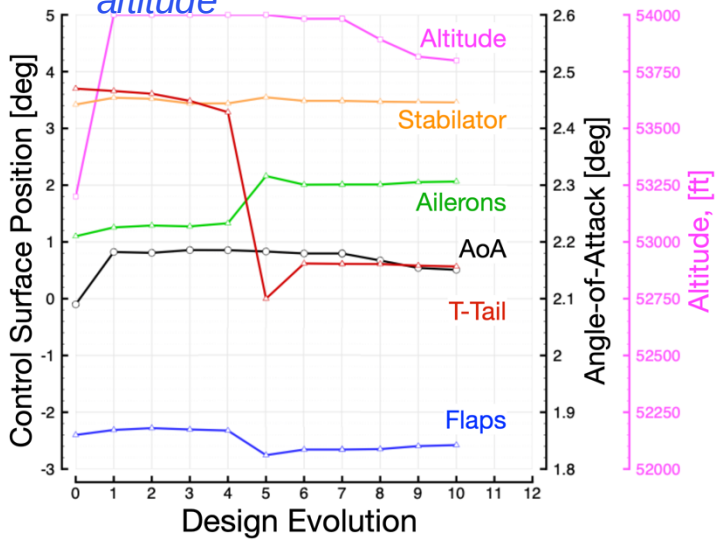
Rodriguez, D, "Sonic Boom Ground Noise Minimization via the Adjoint Method", Celebration 16, Tuesday, January 7 at 10:10 am



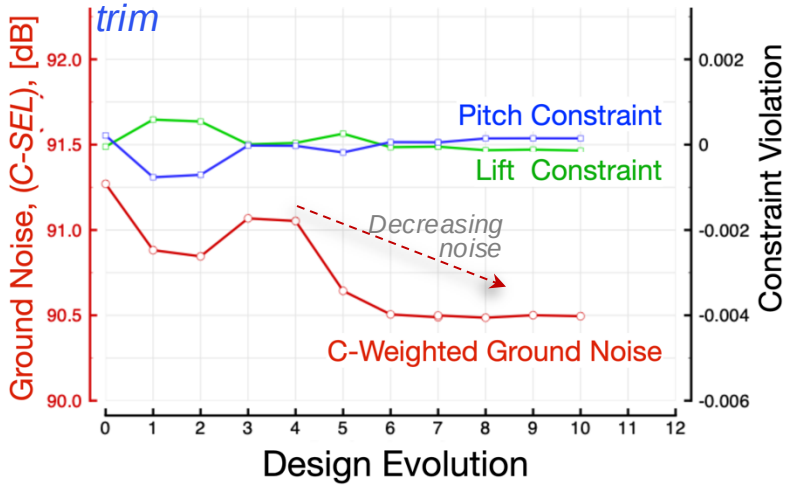
- Directly couple both nearfield CFD and atmospheric propagation codes and their sensitivities through the fully-coupled primal-adjoint system

- In use within the Quesst mission to optimize control surface deflections for low-boom flight testing

Control surface deflection & altitude



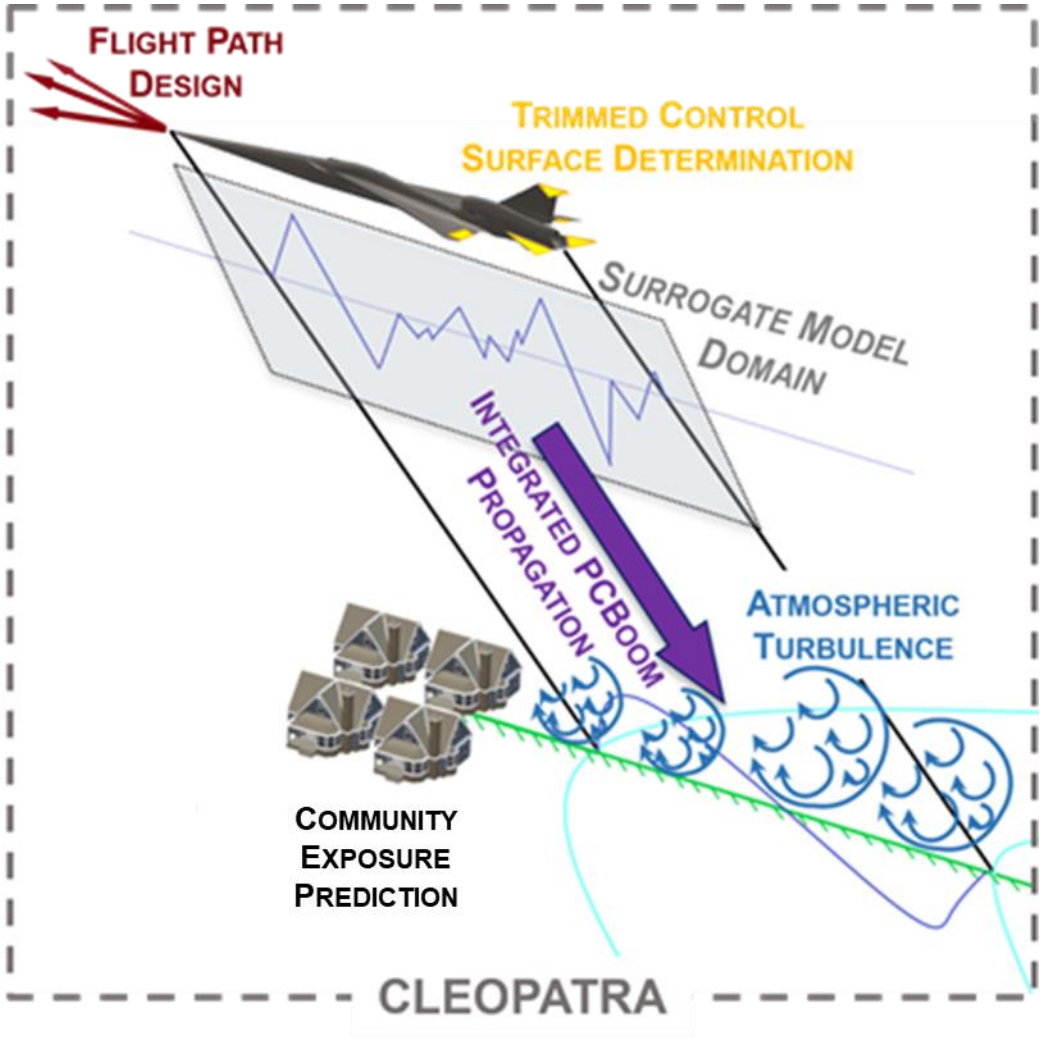
Noise reduction while maintaining trim



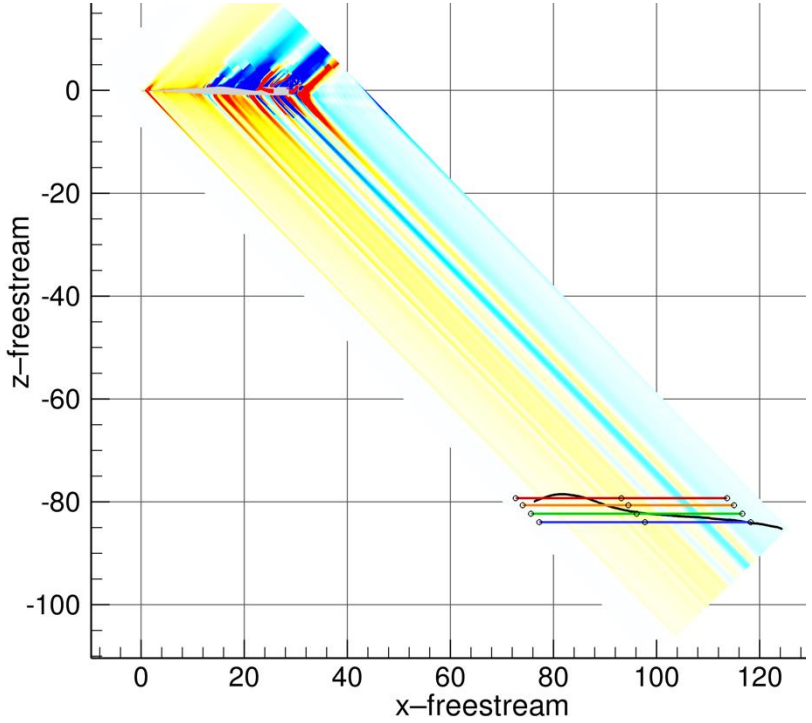
CLEOPATRA Trajectory Planning and Analysis Software

(Community Low-boom Exposure, Operations, Piloting, And Trimming Analyzer)

- CLEOPATRA is a software tool being developed for quick turn-around analysis during flights for actionable feedback and operational guidance
- CLEOPATRA integrates
  - Nearfield CFD database
  - PCBoom
  - Atmospheric turbulence model
  - Focus mitigation routines
  - Terrain
  - Real flight effects
- CLEOPATRA flight path planning exercised in CarpetDIEM III
- Will be validated in Quesst Phase 2
- Updated CLEOPATRA with validated CFD database will become a workhorse tool in Quesst Phase 3 for planning and analyzing aircraft trajectories for desired boom carpet placement and/or loudness



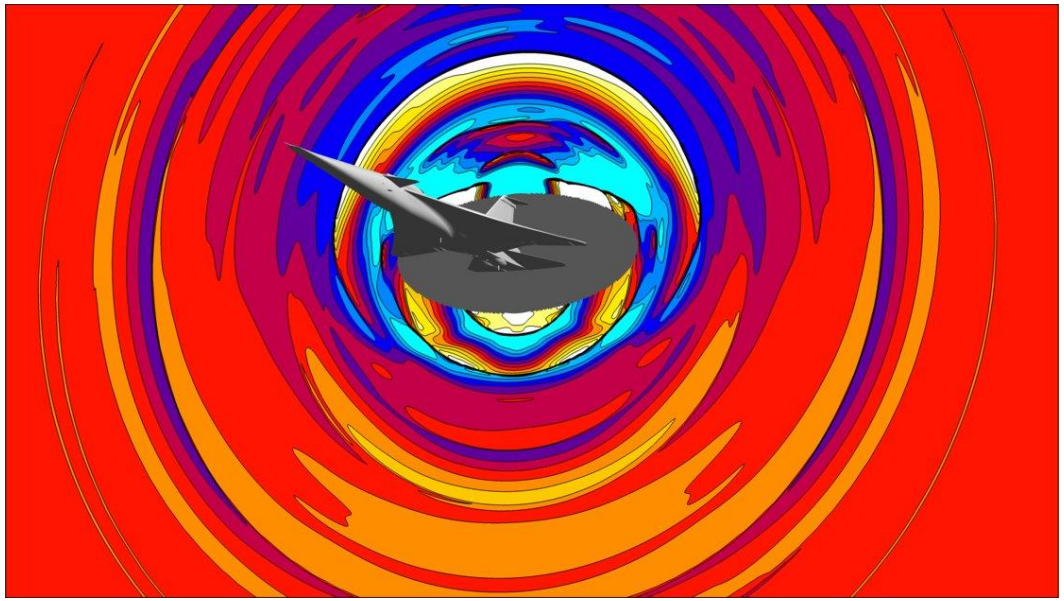
Computational Dry Runs & CFD Improvements for Sonic Boom Prediction



- Developing a series of successively challenging data collection cases envisioned for Quesst Phase 2 to exercise the various CFD solvers and acoustic propagation tools
  - Tools/process have failed at times and updates were required
  - Lessons learned being incorporated into best practices documentation

- Cloud sensors for extracting arbitrary flight paths

- Developed an Euler Space-Marching scheme that interfaces viscous solutions on smaller meshes with inviscid outer regions to rapidly and reliably get pressures at large off-body distances



- Prepping for Quesst Phase 2
  - Development of automated scripts to modify nozzle and throat geometry, adjusting engine BCs to properly account for mass-flows

Wind Tunnel Campaigns

- NASA GRC 8x6 X-59 sonic boom test provided valuable data for comparison with CFD
- X-59 model also tested at the JAXA 1-x 1-Meter supersonic wind tunnel in 2022
    - Gathered data similar to GRC 8x6
    - Data compared and contrasted with different set-ups
        - Blow-down Vs. continuous flow tunnel
        - Narrow tip (NASA) Vs. Flat top (JAXA) rail shapes and different rail orientations
        - Different interference characteristics between rail and model shocks
- X-59 boom model is returning to the JAXA 1-x 1-meter supersonic wind tunnel for a follow-up test this Spring

Collaborated effort between NASA, JAXA, and Boeing

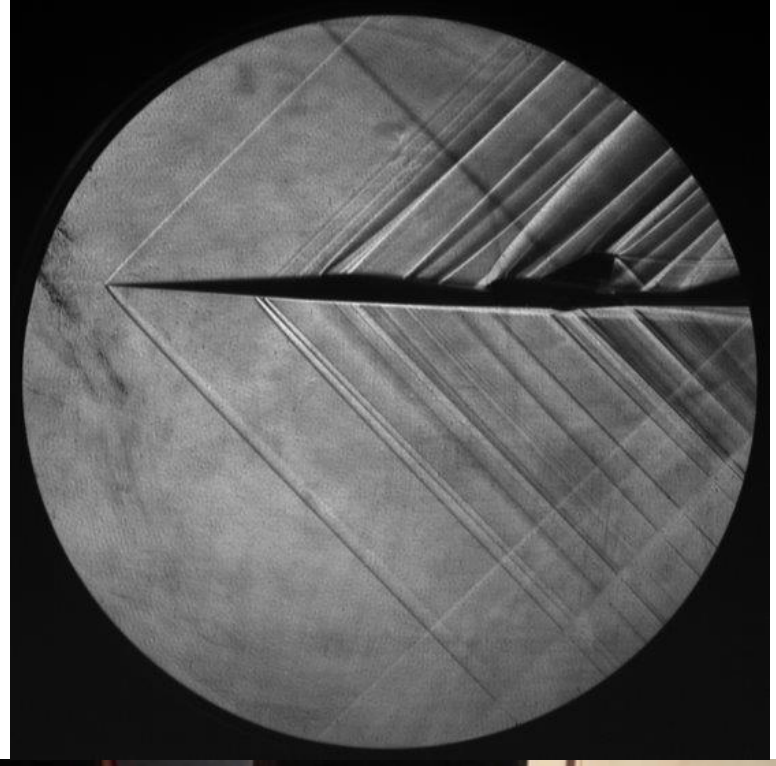


Photo Credit: NASA

Photo Credit: JAXA

AIAA Paper 2023-4320, "**X-59 CFD and Wind Tunnel Data Comparisons**"

Closing Remarks

- Continued updates on all fronts of the computational toolset in preparation for the Quesst Acoustic Validation Phase
  - Sonic boom prediction tools to be validated with flight data from Quesst Phase 2
- Validated tools will be used during Quesst Phase 3 community testing
- Computational toolset being refined to tackle efficient design and analysis of future supersonic concepts

Quesstions?

NASA: X-59/Quesst Mission:
www.nasa.gov/aeronautics/supersonic-flight

NASA Software: https://software.nasa.gov/

Photo Credit: Lockheed Martin

nasa.gov/quesst