Automation of Cart3D Meshing and Analysis for Prediction of Sonic Boom Carpets

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Outline

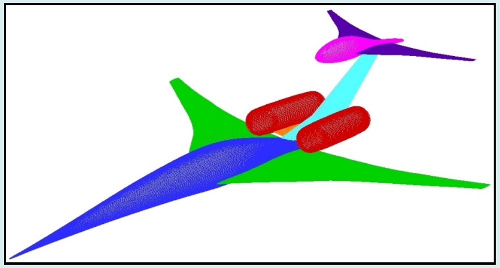
- Introduction
- Automated surface meshing
  - Parametric definition
  - Component-based point definition
    - Monolithic mesh (GEO2VSP)
    - Componentized mesh (HRM2GEO)
- Integrated off-track sonic boom analysis
- Verification
  - Off-body near-field location
  - CFD comparison
  - Volume mesh refinement
  - Off-track shock dissipation
- Demonstration of off-track analysis process
- Summary

Introduction

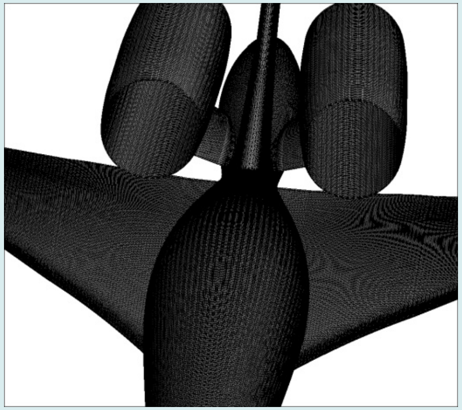
- **Objectives**
  - Rapid, automated, and accurate sonic boom evaluation of new supersonic design concepts
  - Infusion of design robustness into the conceptual design phase
  - Enable the evaluation and planning of future flight trajectories

- **Challenges**
  - Generation of water-tight geometries for CFD analysis
  - Surface and volume mesh generation
  - Intelligent and efficient volume mesh refinement to accurately capture shock features at off-body locations
  - Automation and integration of geometry generation tools, CFD, sonic boom propagation, and loudness analyses

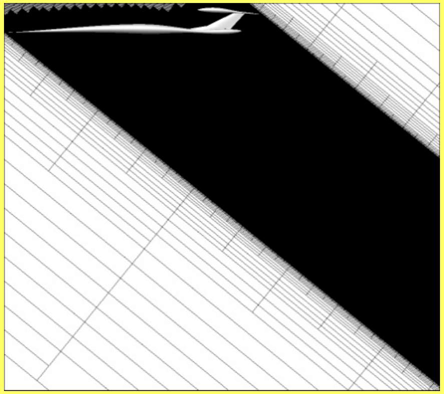
Integrated Off-Track Sonic Boom Analysis



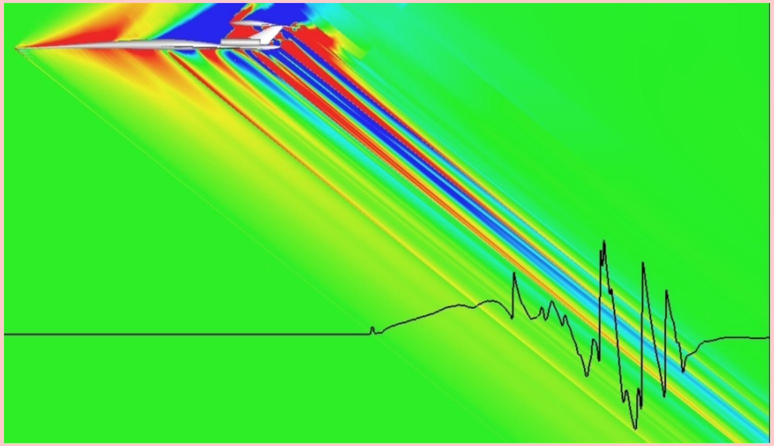
Conceptual Geometry



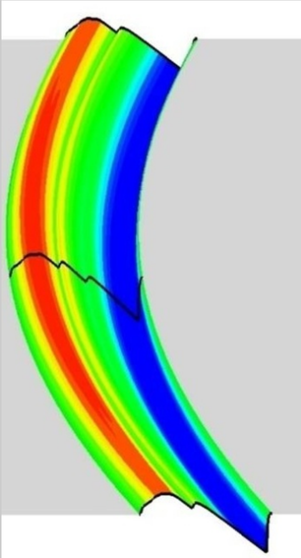
Surface Mesh

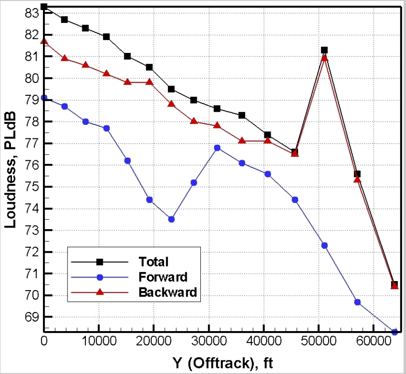


Volume Mesh



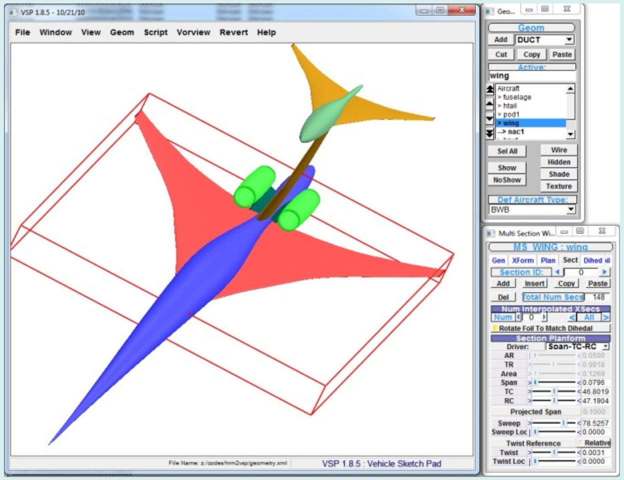
Off-Body Cart3D Analysis





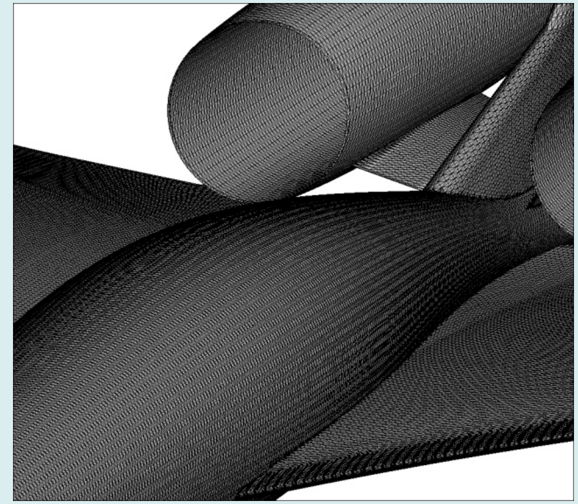
Sonic Boom Carpet and Loudness

Automated Surface Meshing



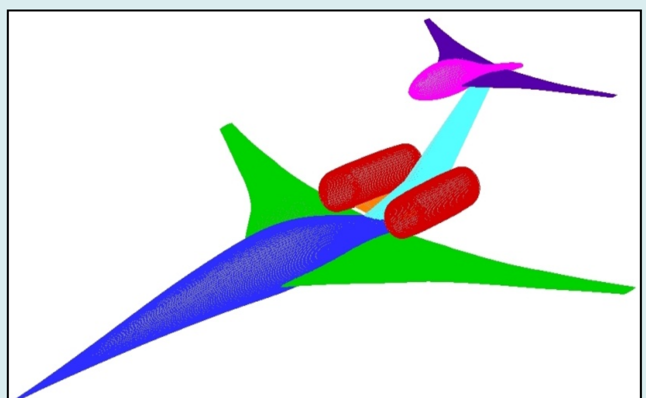
VSP Parametric Model

VSP Surface Meshing (Monolithic)



Triangulated Surface Mesh

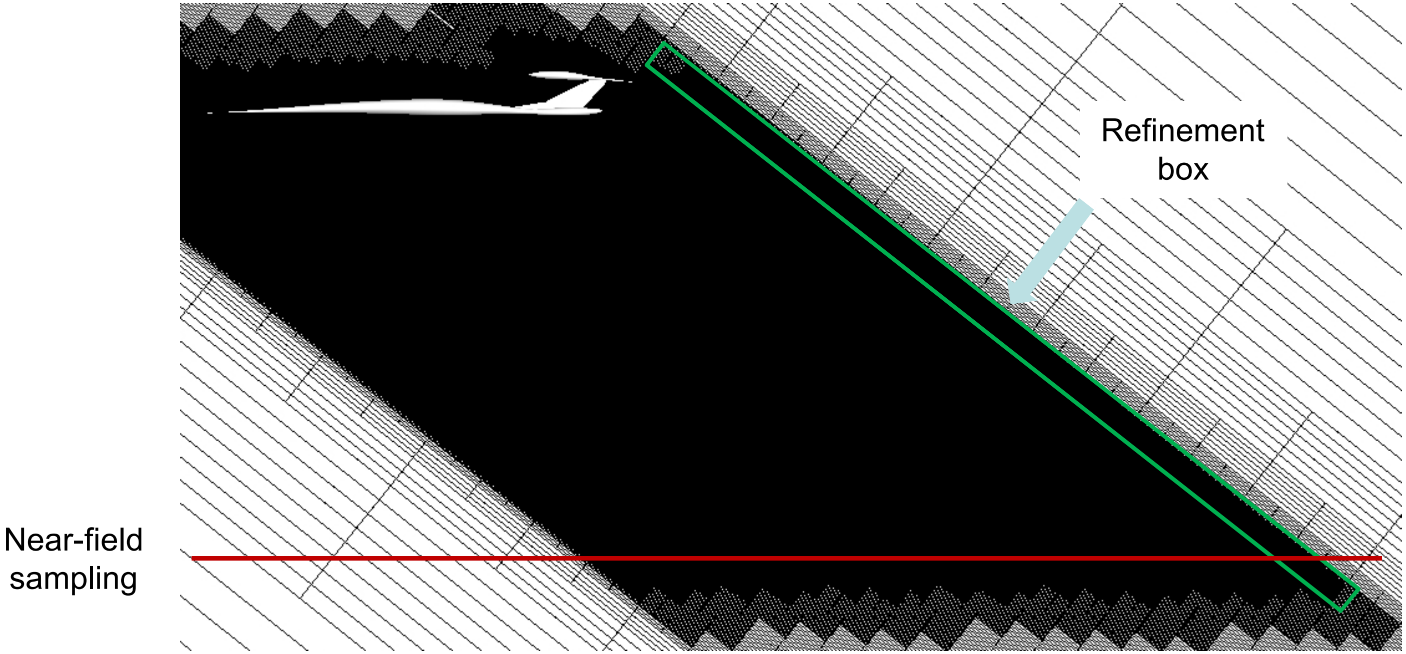
GEO2VSP Tool



Component-Based Point Definition

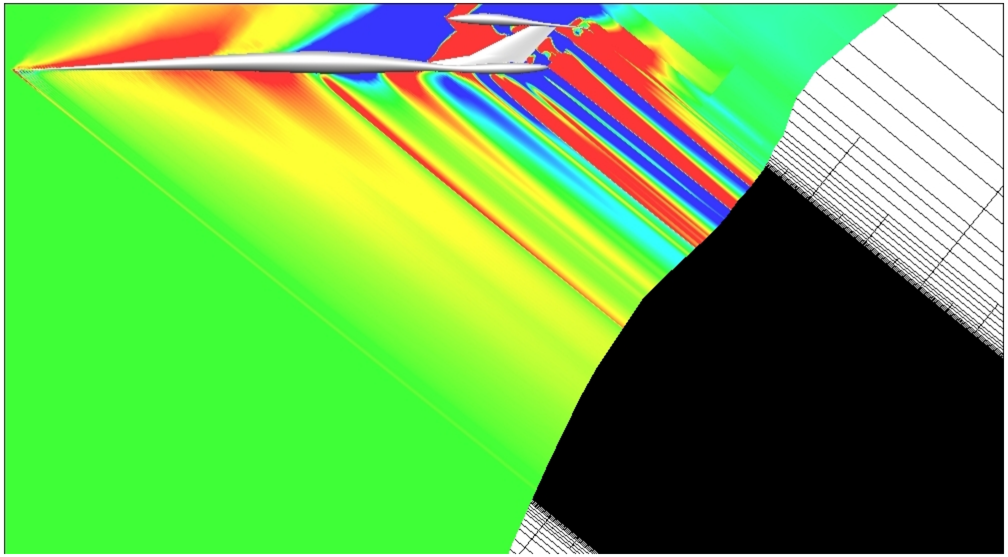
HRM2GEO Tool with Cart3D Triangulation (Component-Based)

Volume Mesh Refinement for Off-Body Pressure



- Volume mesh generation is automated with Cart3D package.
- Rotated geometry is based on Mach angle to align shocks with *z*-axis.
- Stacked refinement boxes are located in under- and off-track directions.
- Process is fully automated based on flight conditions and vehicle length.
- ModelCenter model provides control over:
  - Number of stacked boxes
  - Refinement levels
  - Cell aspect ratio
  - Distance of near-field sampling

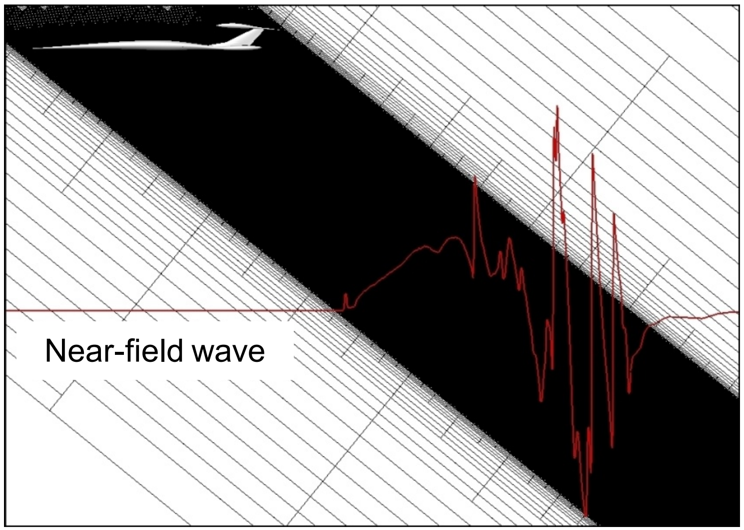
CFD Analysis for Off-Body Pressure

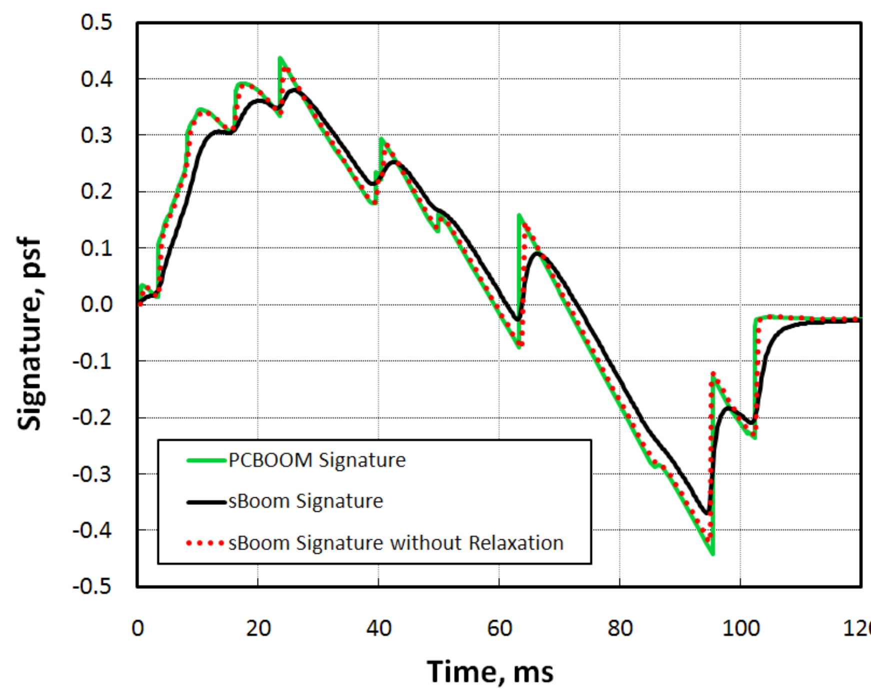


Cart3D is integrated for CFD analysis

- High-fidelity inviscid package
- Automated Cartesian volume mesh generation
- Capable of adjoint mesh adaptation
- Conceptual and preliminary design
- Flexible geometry input (accepts solid components instead of more difficult to generate watertight outer mold line)
- Fully integrated into ModelCenter model

Sonic Boom Propagation





Near-field wave propagated with sBOOM†

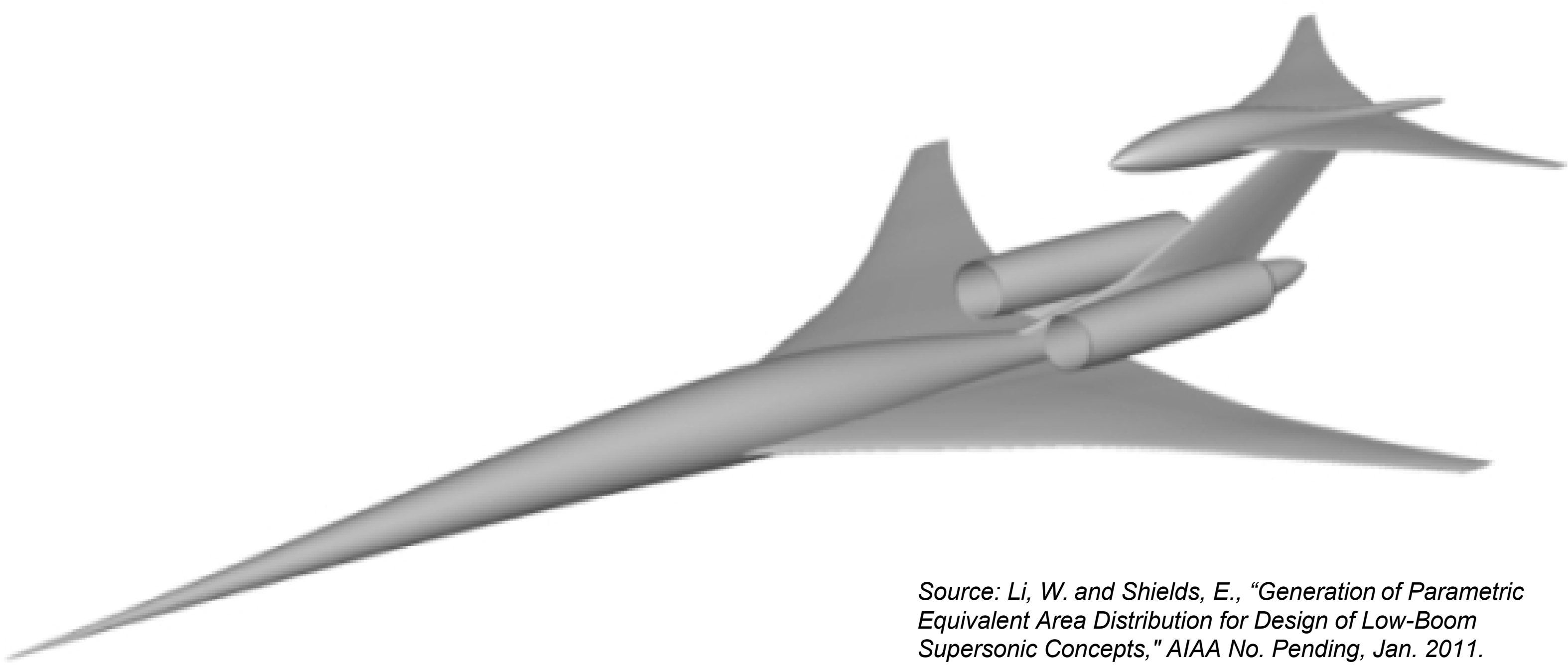
- Non-linearity, molecular relaxation, thermo-viscous absorption
- Finite shock rise-time can produce more accurate loudness calculations
- Off-track propagation

† Rallabhandi, S. K., "Advanced Sonic Boom Prediction Using Augmented Burger's Equation," AIAA No. Pending, January 2011. (AIAA Session 255-AA-11, January 7, 2011 at 1330 hrs)

Verification Cases

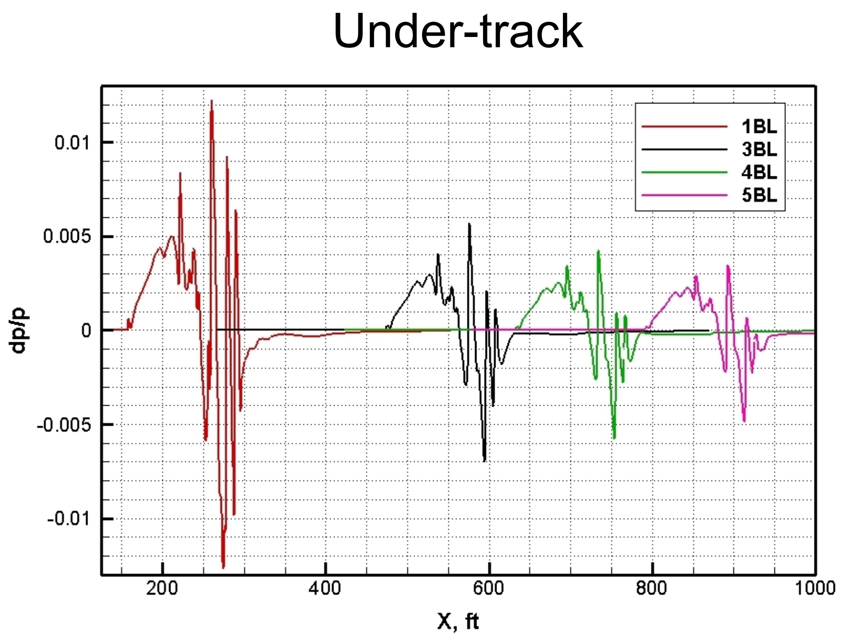
- **Verification Cases**
  - Off-body location
  - Meshing method and CFD tools
  - Volume mesh refinement
  - Off-track shock dissipation

- **Case study**
  - Low-boom demonstrator
  - Mach 1.6
  - Angle of attack of 0.49 deg
  - Altitude of 47,500 ft

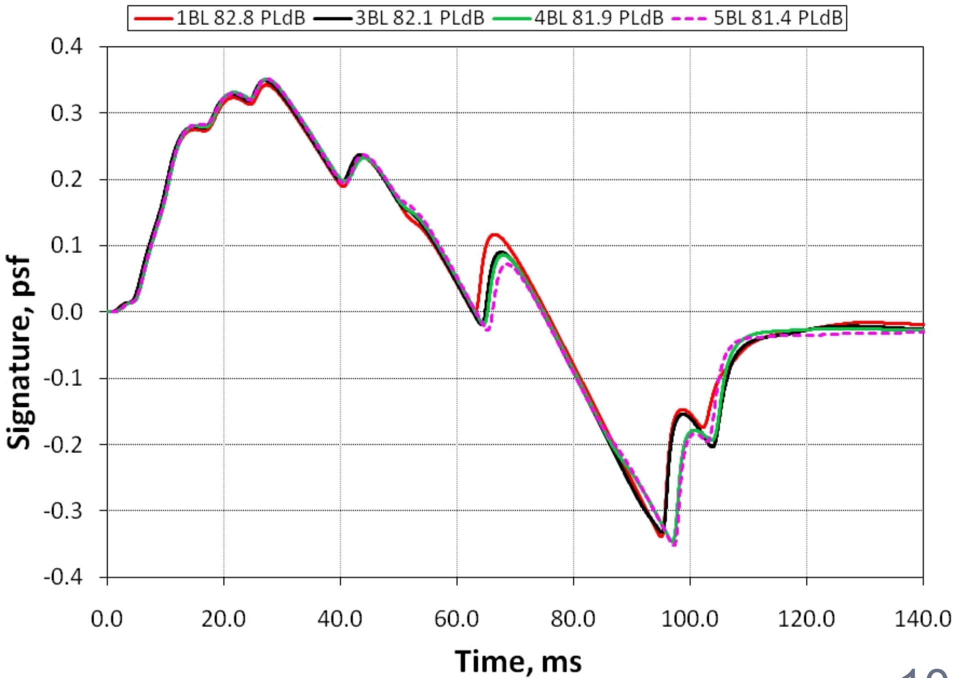


Source: Li, W. and Shields, E., "Generation of Parametric Equivalent Area Distribution for Design of Low-Boom Supersonic Concepts," AIAA No. Pending, Jan. 2011.

Sensitivity to Off-Body Location

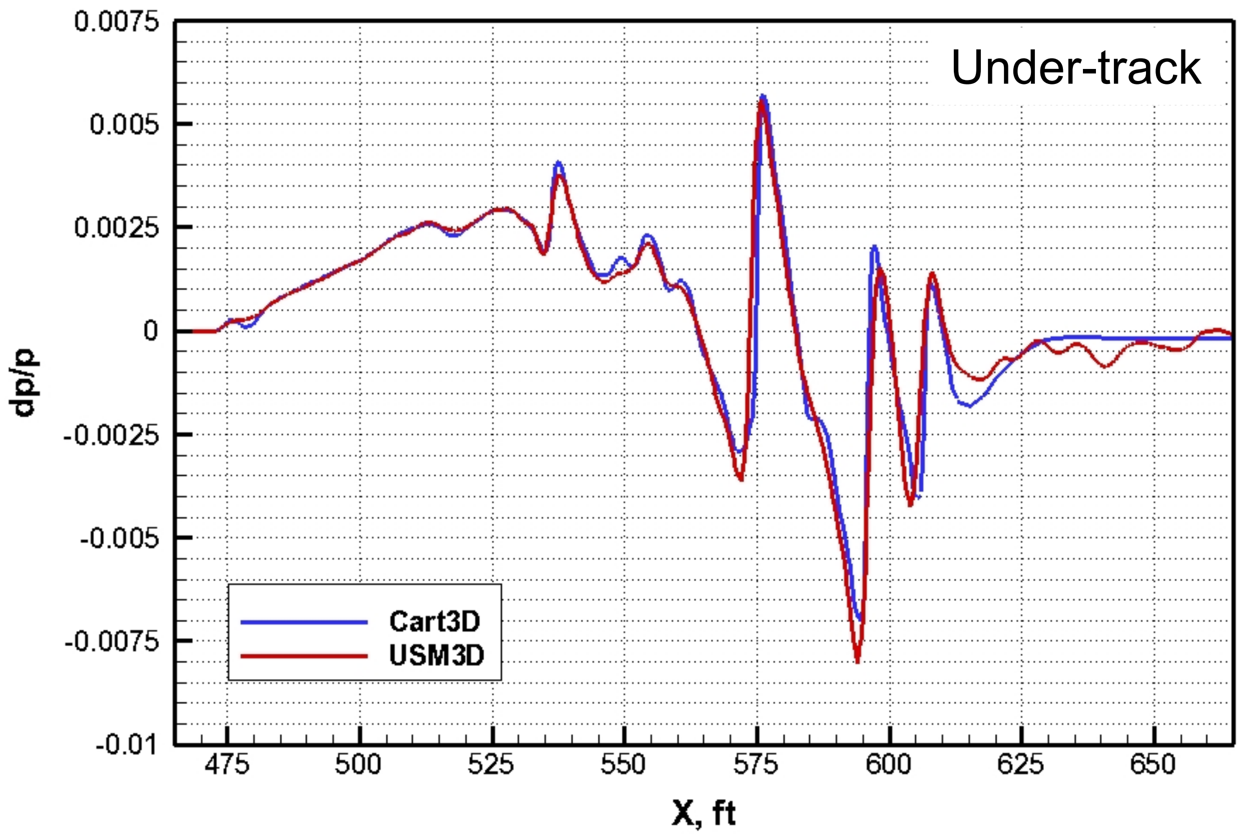


- Near-field shock structure is successfully captured at all off-body locations.
- Four body length off-body location successfully captures 3D effects.
- Accuracy is acceptable at one body length (loudness within 1.7%)

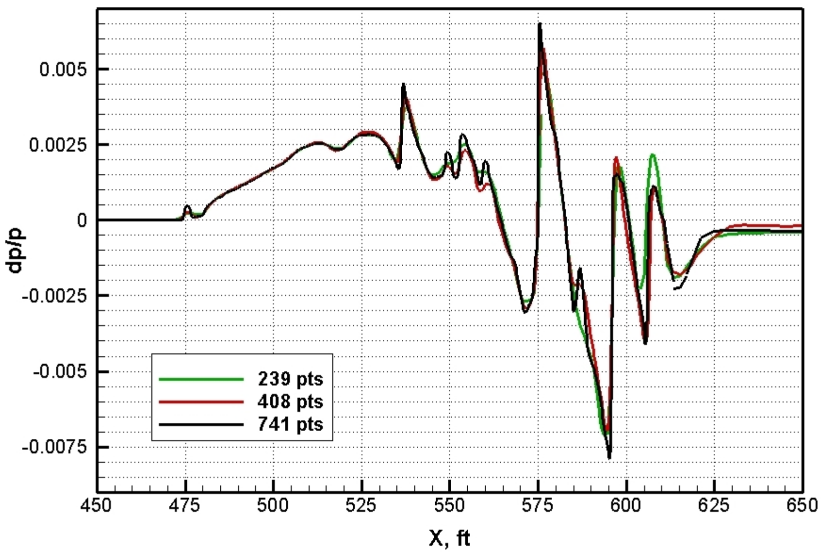


Sensitivity to Meshing and CFD Tools

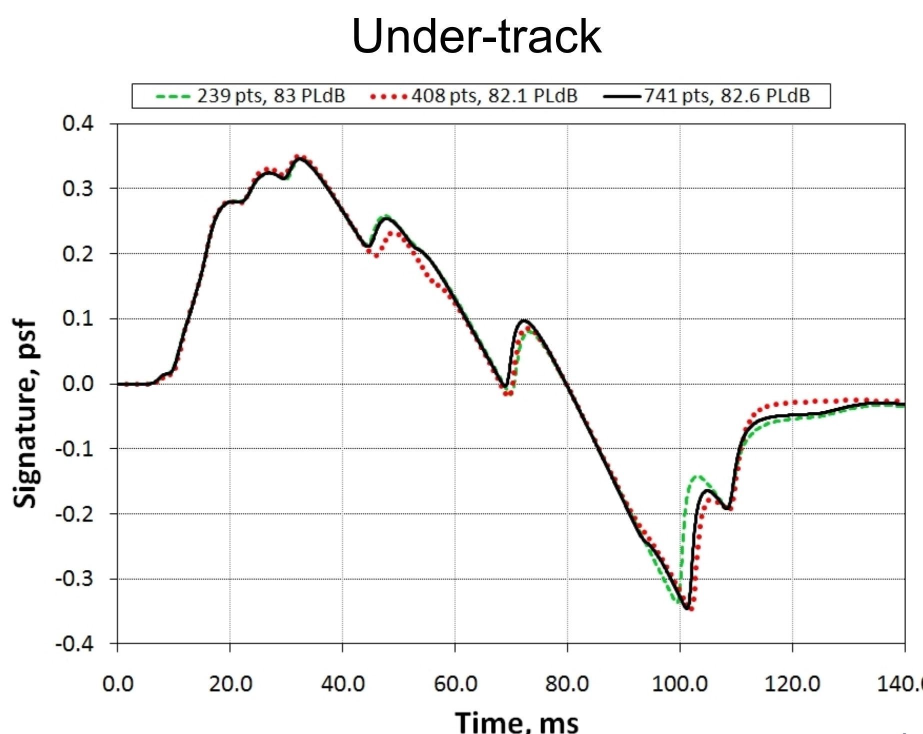
- Cart3D solution obtained using a rotated grid with stacked mesh refinement.
- USM3D solutions obtained using a grid stretching method.
- Good agreement despite the use of different meshing methods.



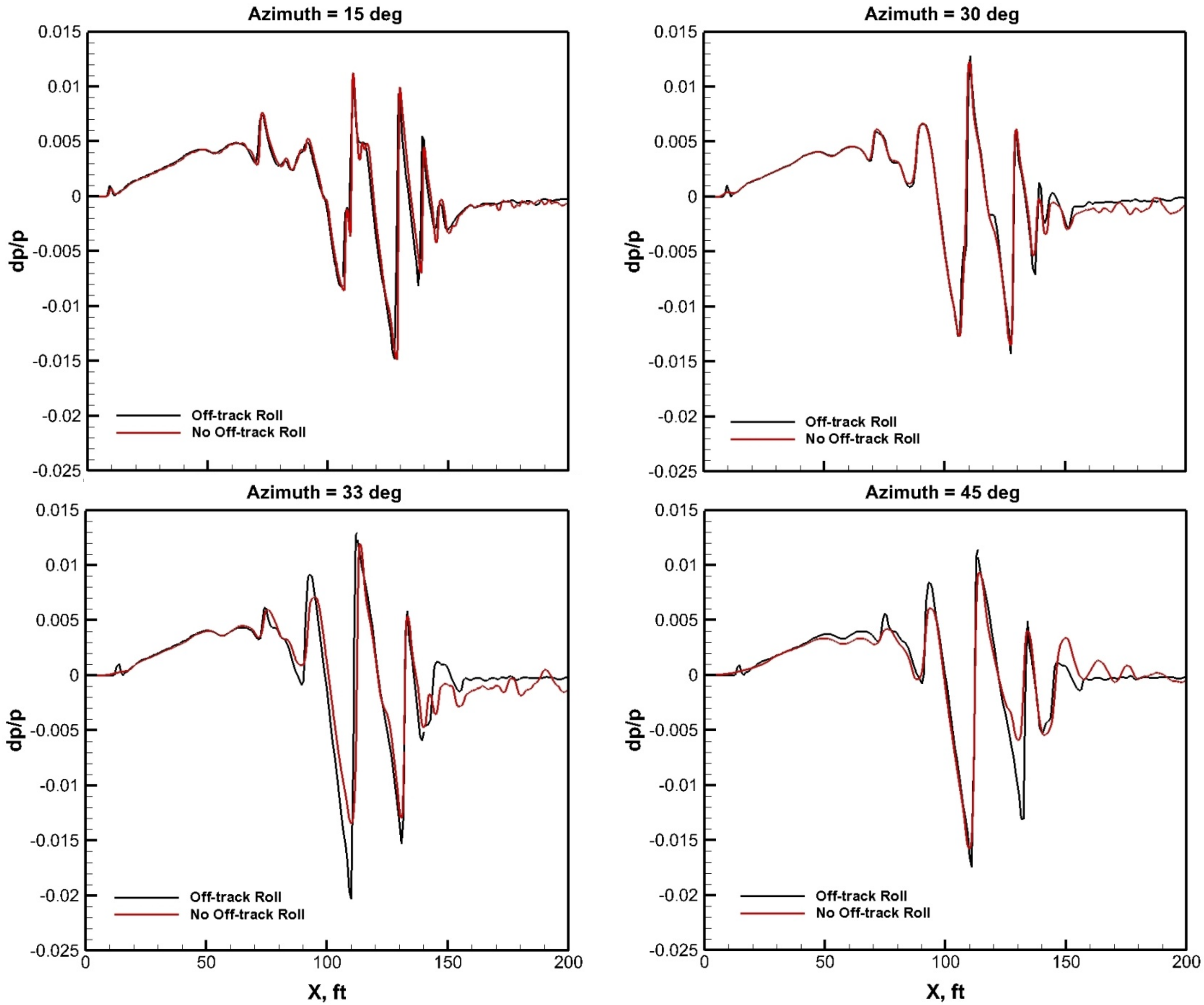
Sensitivity to Volume Mesh Refinement



- Near-field solution is located at three body lengths.
- Accuracy is acceptable for all mesh refinement levels (loudness within one PLdB).
- Approximately 400 points is a good compromise between computational cost and accuracy.
- Coarser grids are acceptable for larger computational domains (i.e. greater than 3 body lengths and off-track calculations).

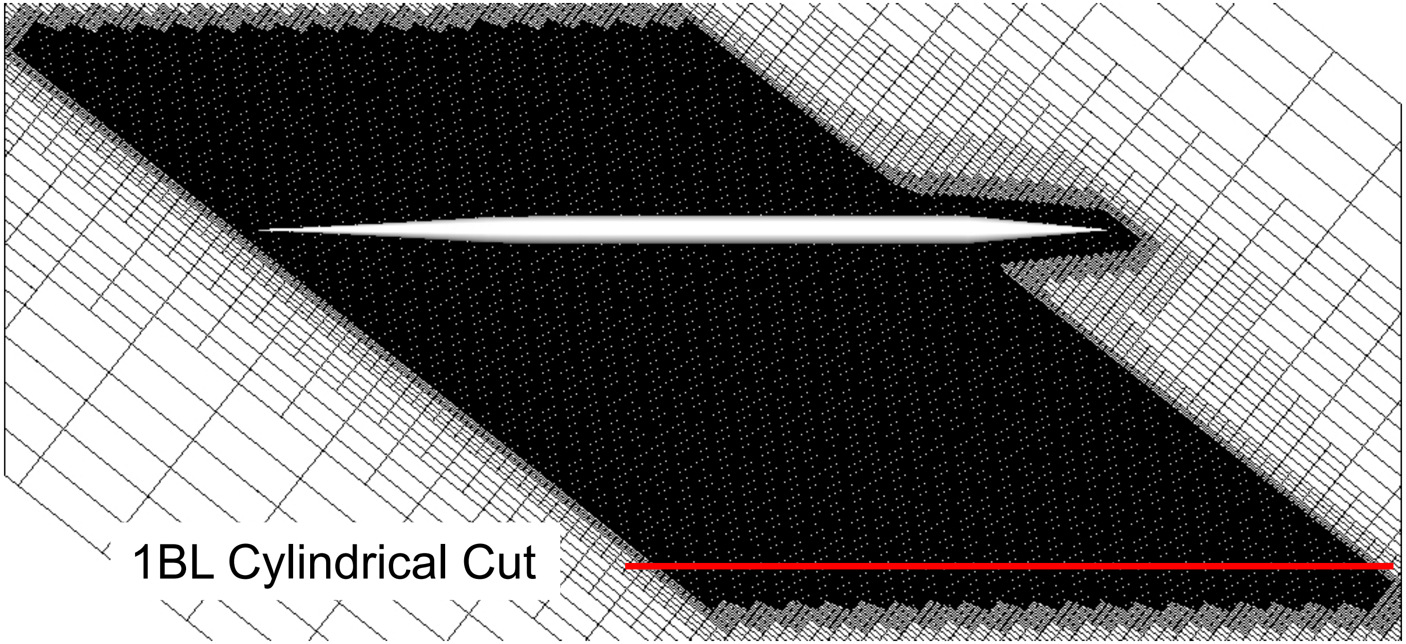


Off-track Shock Dissipation

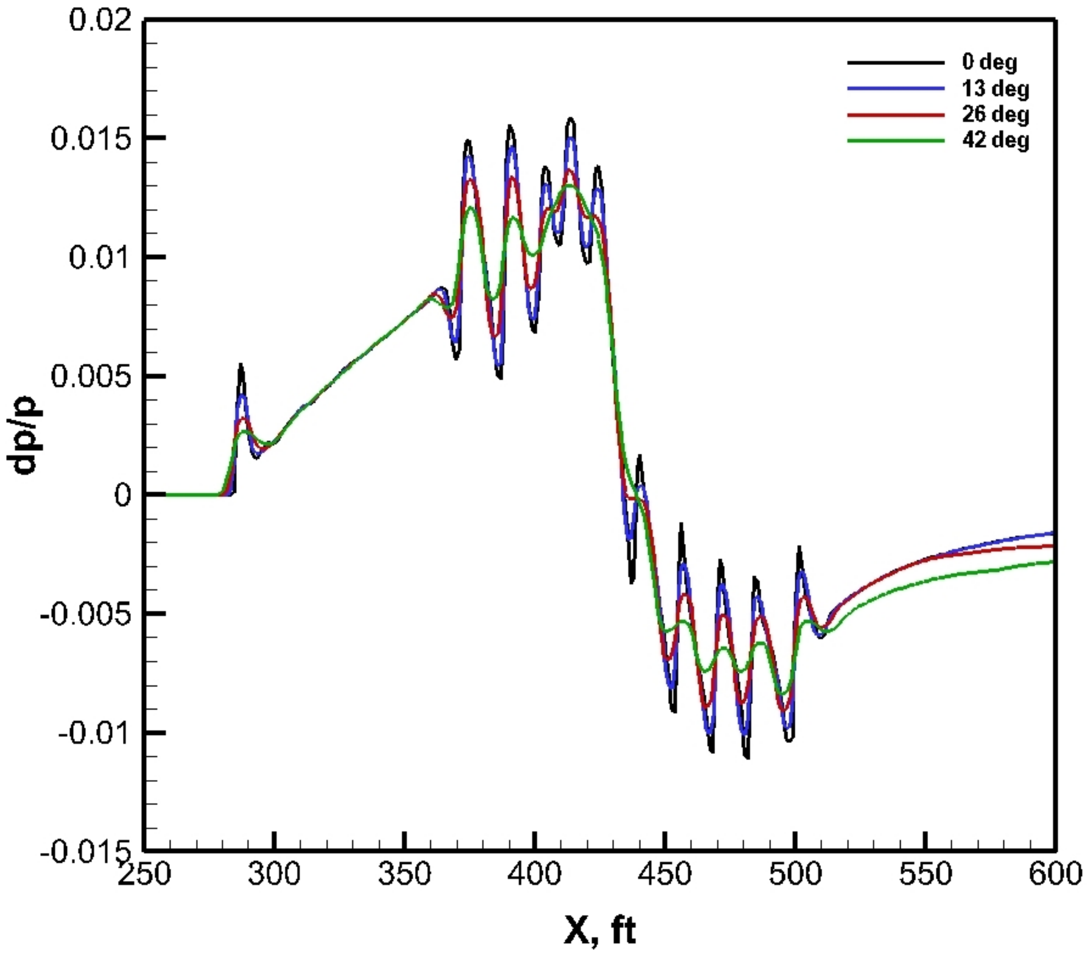


Further Off-track Verification

- **Verification Cases**
  - Baseline (~460 pts in *x*-dimension)
  - *X*-refinement (~2X Baseline)
  - *Y*-refinement (~2X Baseline)
- **Case study**
  - Lockheed Martin BOR
  - Length 231 ft
  - Mach 1.6
  - Angle of attack of 0 deg
  - Altitude of 47,500 ft

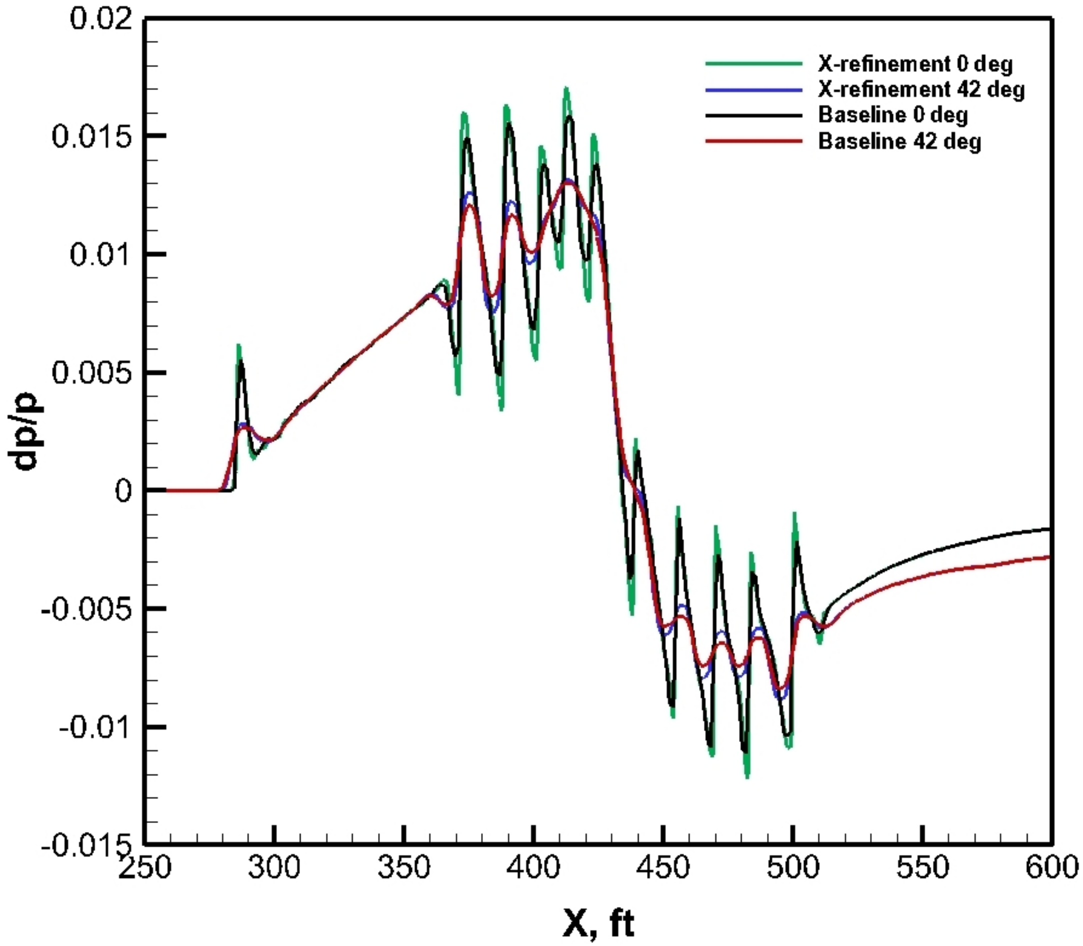


Off-track Shock Dissipation for Baseline



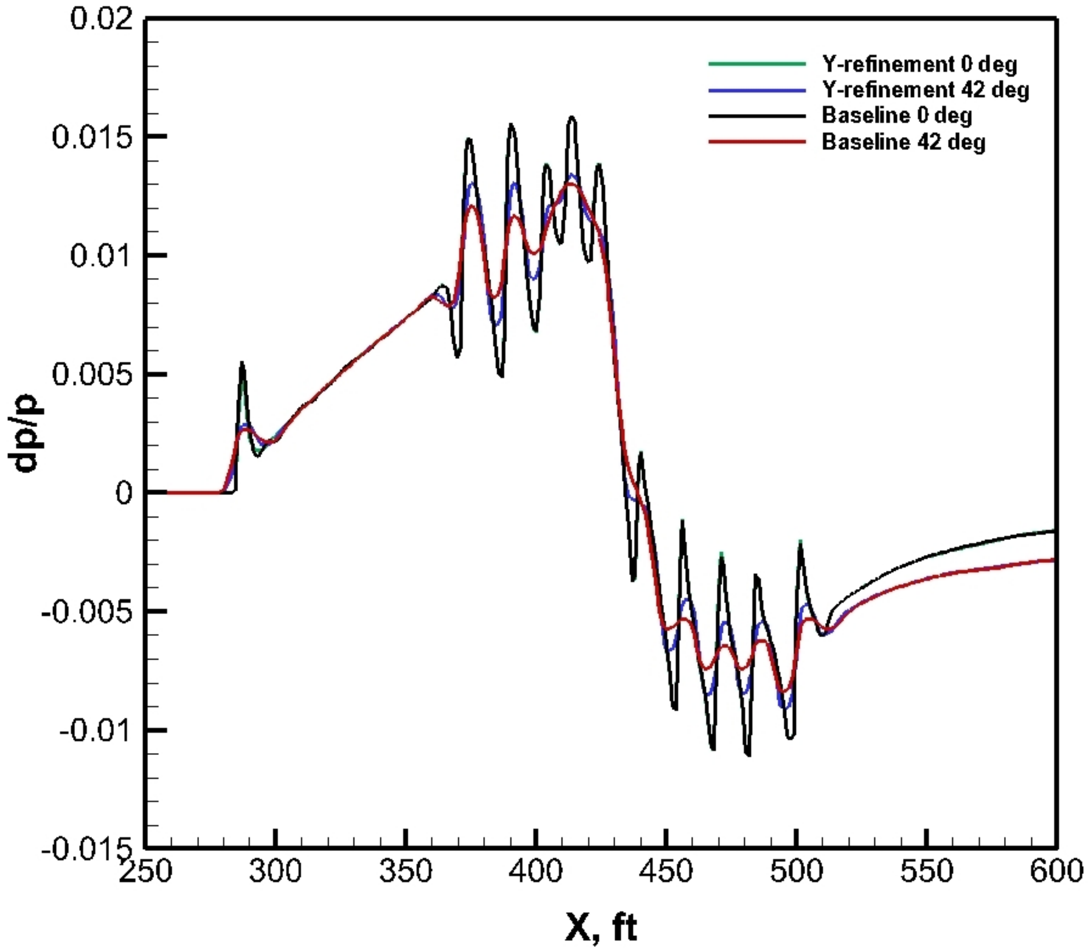
- Off-track shock dissipation exists due to lack of grid alignment in the *y*-direction (off-track).
- The dissipation is more severe for the BOR than for the low-boom demonstrator.
- The higher shock frequency of the BOR waveform may lead to greater error (lost shock features) as it propagates in the *y*-direction between cell boundaries.

Comparison of Baseline and *X*-Refined



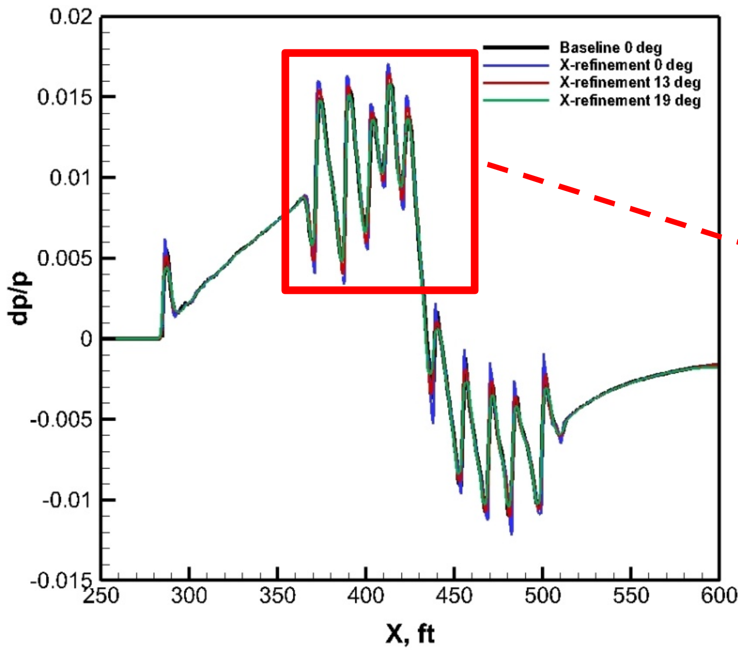
- The accuracy of off-track waveforms can be improved with greater grid refinement in the *x*-direction but off-track dissipation persists.

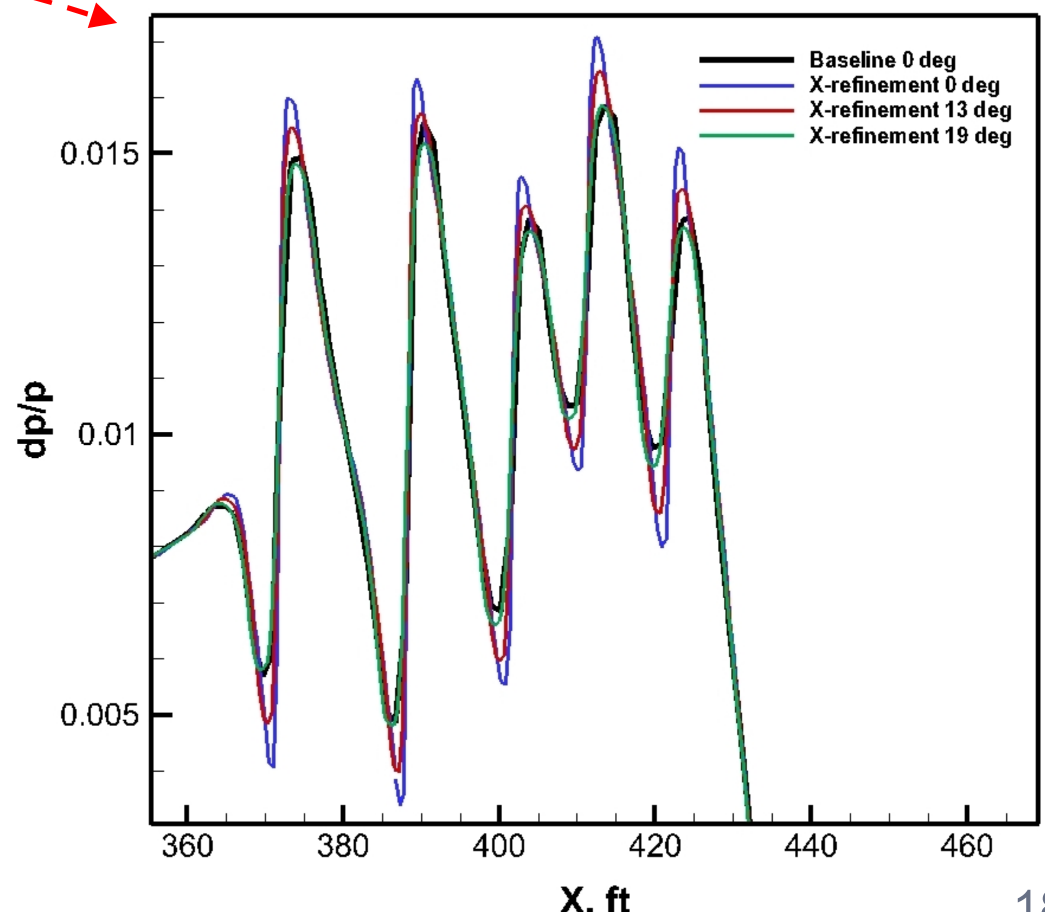
Comparison of Baseline and *Y*-Refined



- Off-track accuracy can be improved using greater grid refinement in *y*-direction (off-track).
- Second rotation about *z*-axis to align the shocks in off-track direction with the *y*-axis could improve mesh efficiency in the same way it is rotated for under-track solutions.

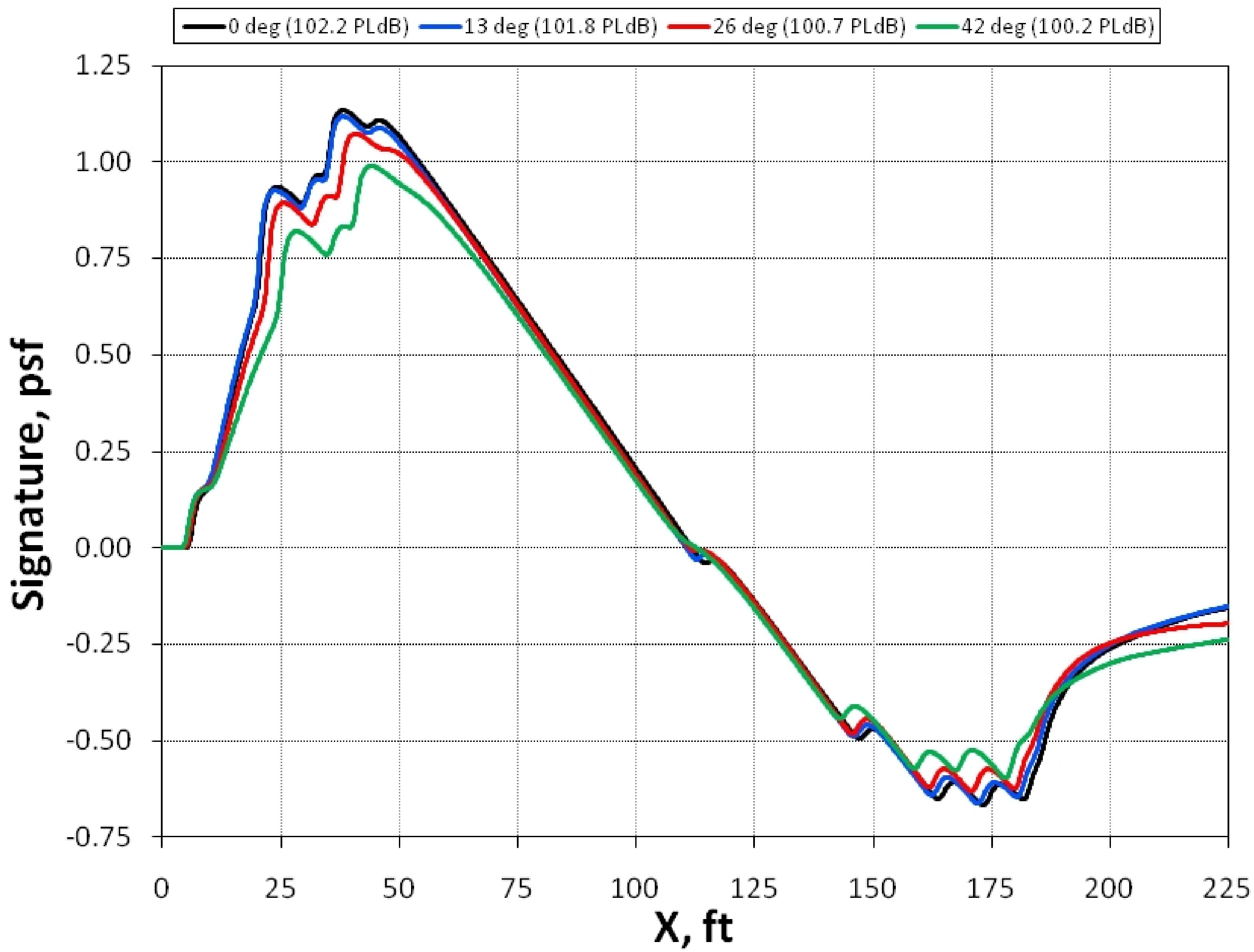
Solution Accuracy with *X*-Refinement



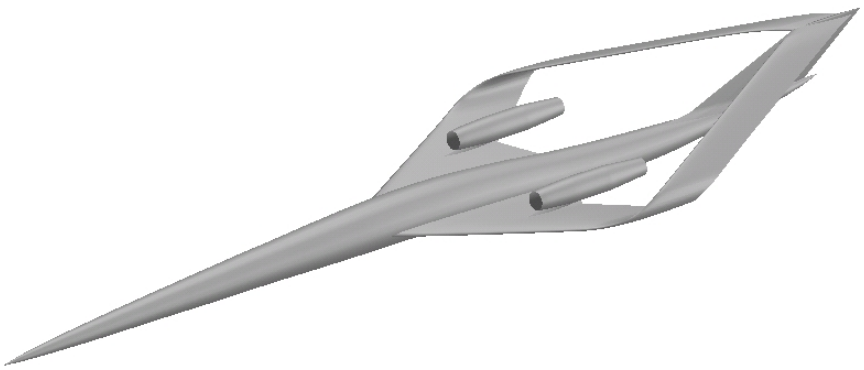


- ❑ Off-track dissipation is not resolved with *x*-refinement.
- ❑ Off-track solution accuracy is improved using higher *x*-refinement despite persistent dissipation.

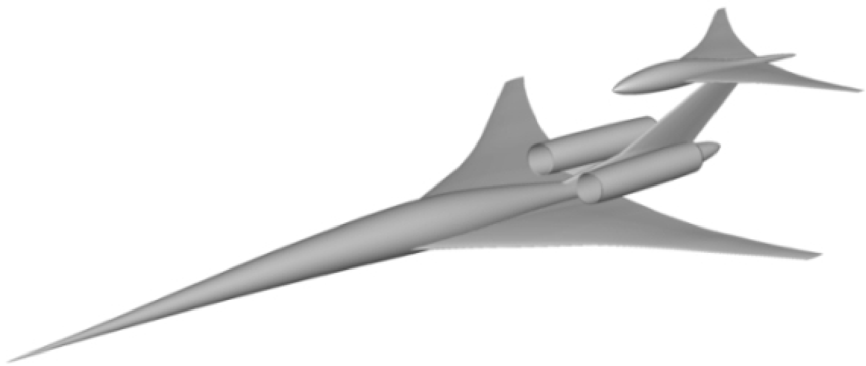
Off-track Signature Dissipation for *Y*-Refined



Demonstration of Off-Track Capability



- **Ring wing concept**
  - Length 170 ft
  - Angle of attack of 0.3 deg



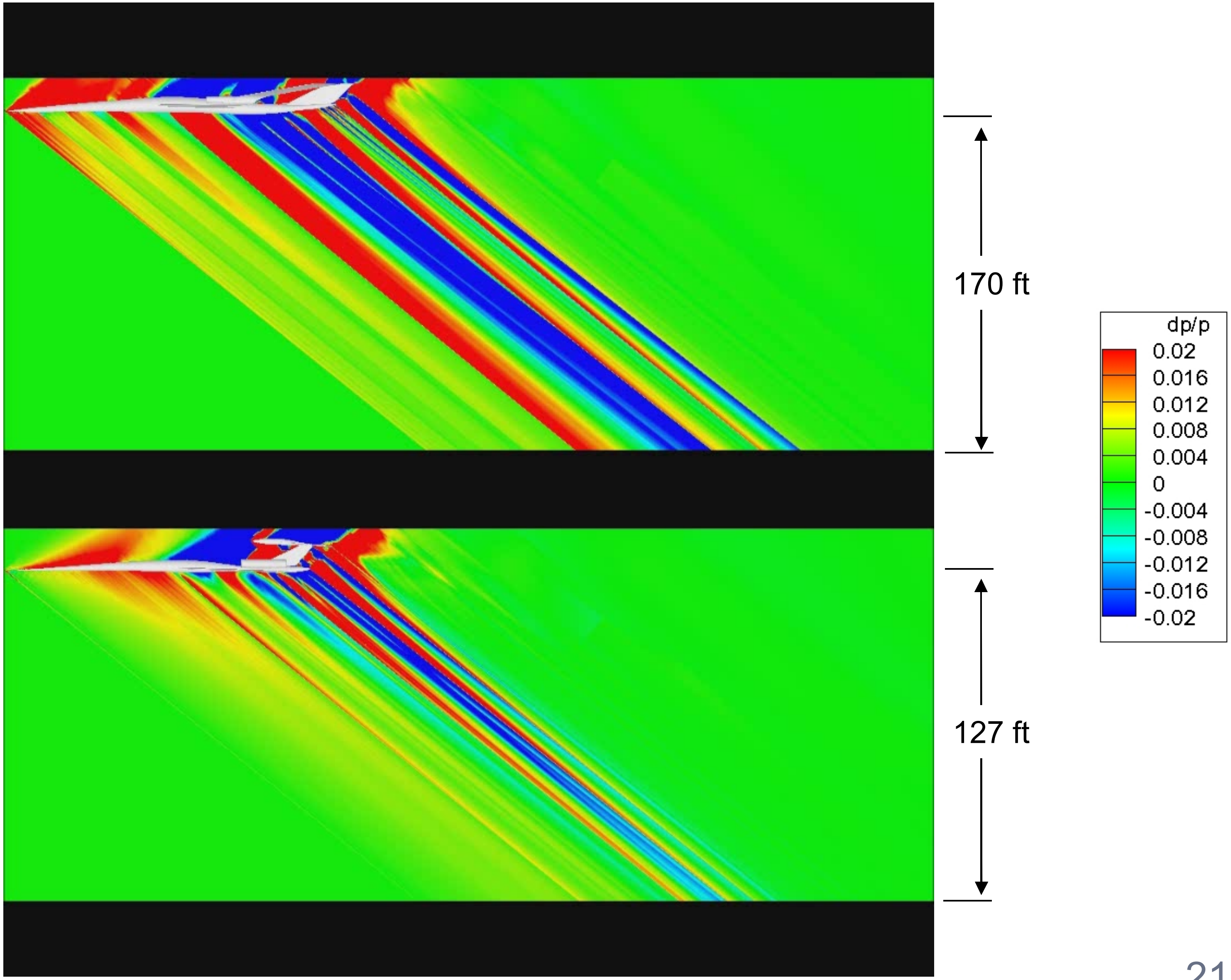
- **Low-boom demonstrator**
  - Length 127 ft
  - Angle of attack of 0.49 deg

- Mach 1.6
- Altitude of 47,500 ft
- One body length near-field location

Cart3D Near-Field Pressure Solution

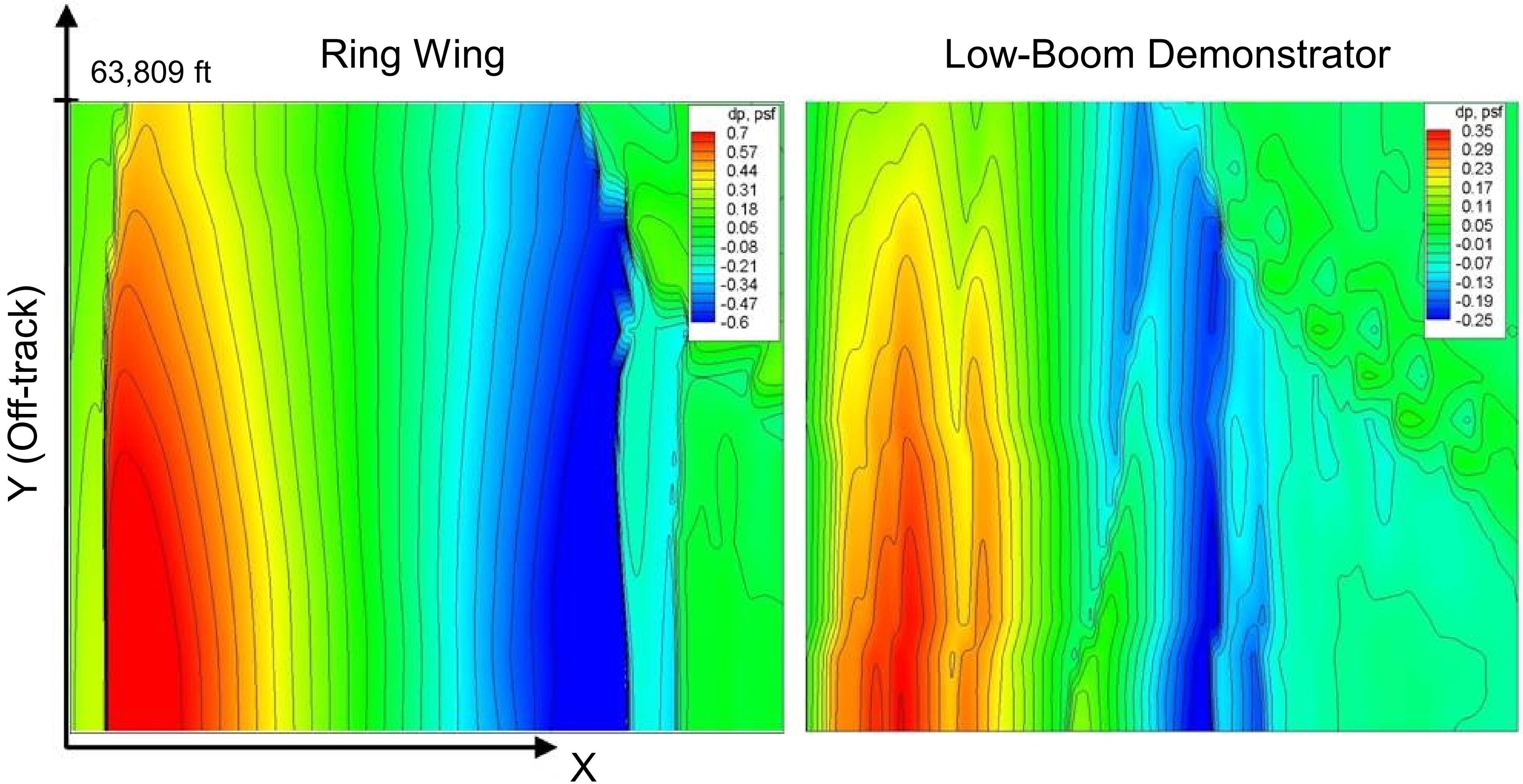
Ring Wing

Low-Boom Demonstrator

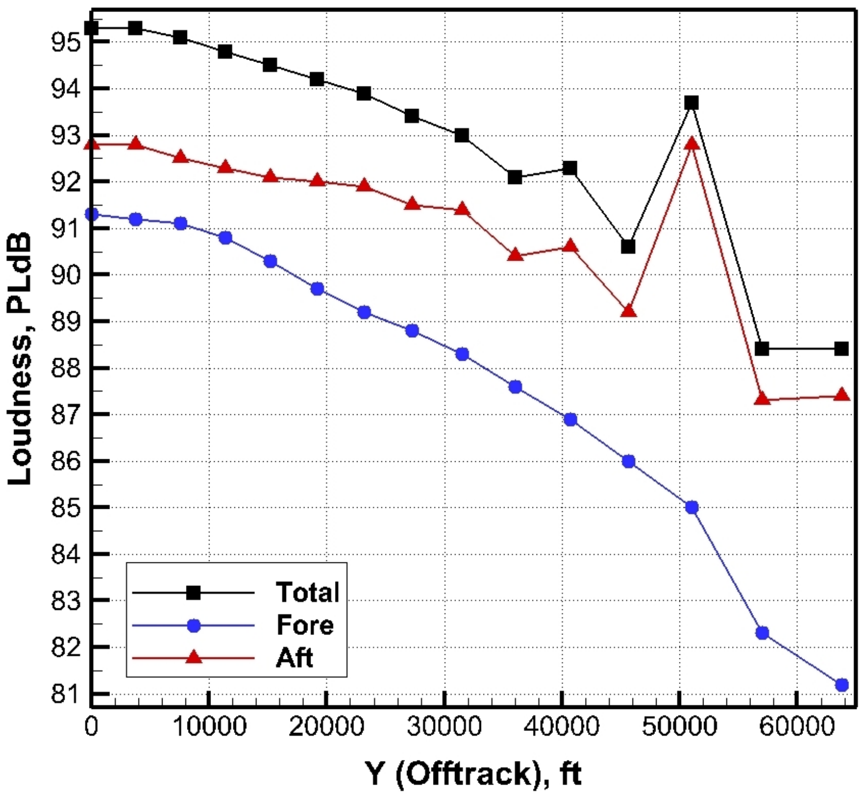


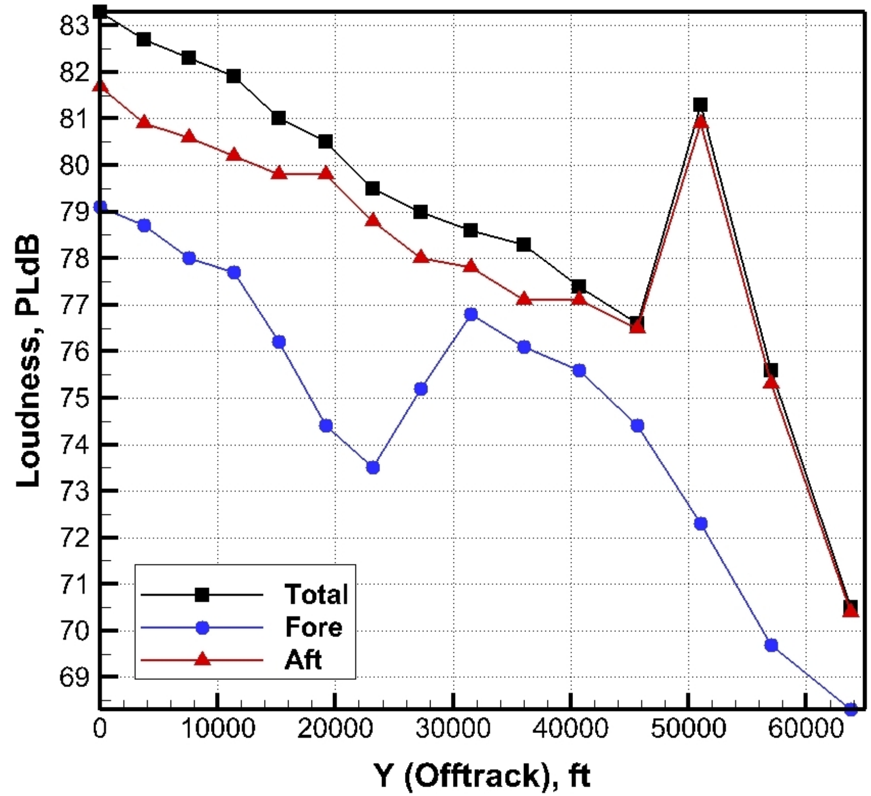
(click to play movies)

Sonic Boom Carpets



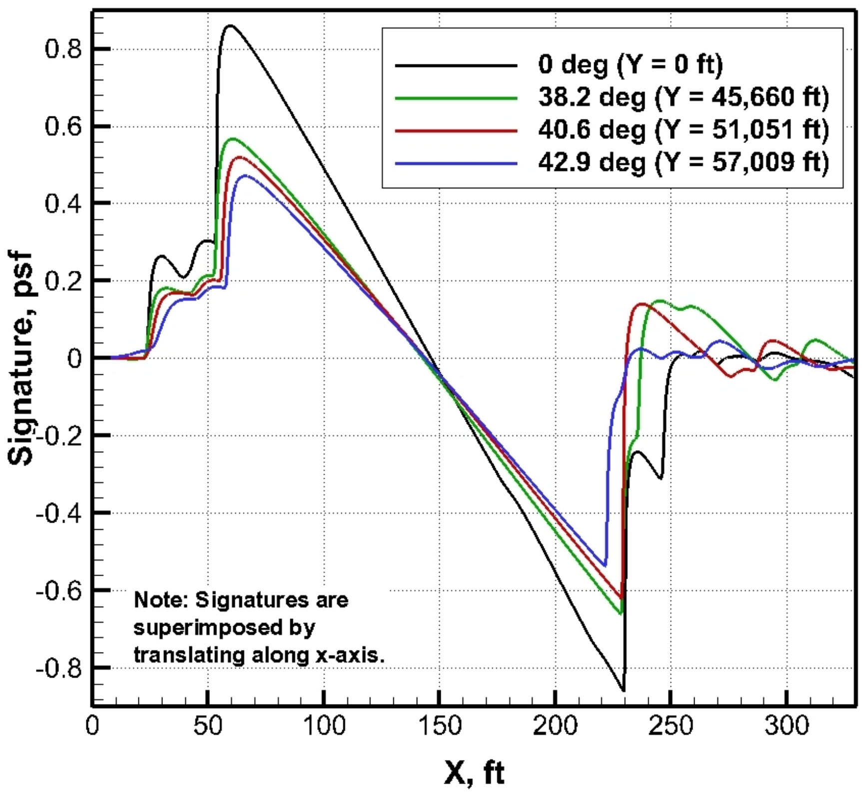
Off-Track Loudness Analysis

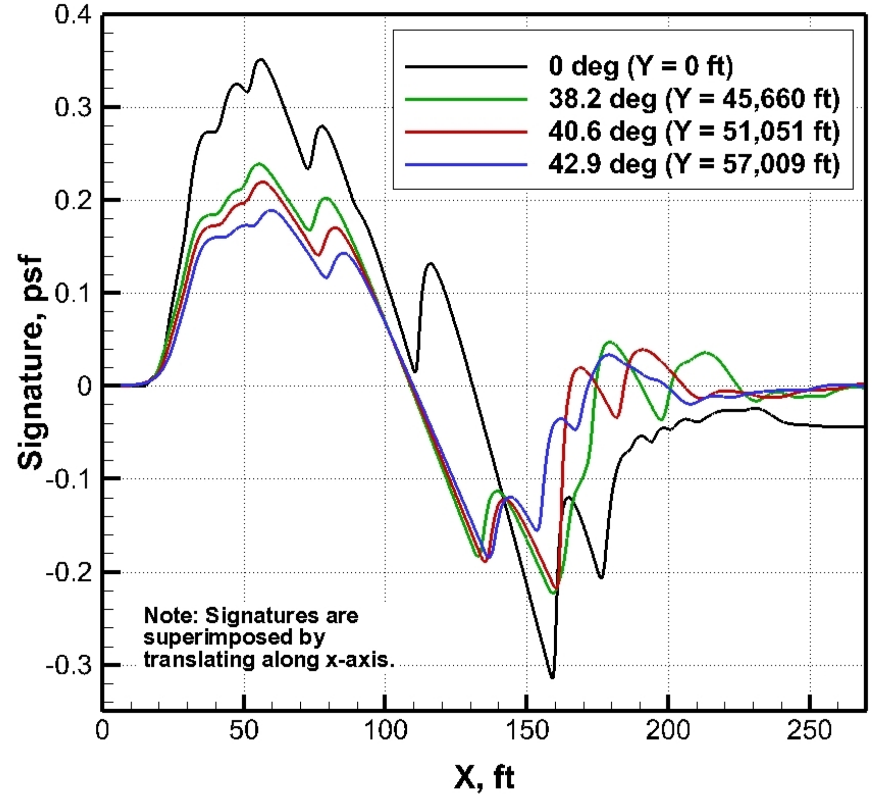




- Greater off-track shock dissipation exists for signature-shaped low-boom demonstrator.
- Shocks coalescing occurs at approximately 51,000 ft.
- Backward signature contributes the most to off-track shock coalescing.

Signature and Loudness Analysis





- Off-track loudness rise is observed in shock coalescing of signature.
- No further off-track shock coalescing is expected for ring wing concept.
- Additional shock coalescing is expected for low-boom demonstrator (aft shocks).
- Shaped-boom concepts are likely to exhibit stronger and greater number of off-track shock coalescing events.

Summary

- Demonstrated a flexible and fully automated process for under- and off-track sonic boom analysis in conceptual design.
- Assessed the sensitivity and requirements of sonic boom analysis to CFD volume mesh refinement and off-body location of the initial near-field waveform.
- Verified the accuracy of the Cart3D off-body pressure solution through comparison to USM3D.
- Quantified the degree of off-track shock dissipation for one-shot solutions with no alignment of the shocks with the grid in the off-track direction.
- Sonic boom carpets and loudness levels can be mapped over nonuniform terrain and population densities to quantify environmental impact and aid in the planning of future flight trajectories.

Questions

Acknowledgements

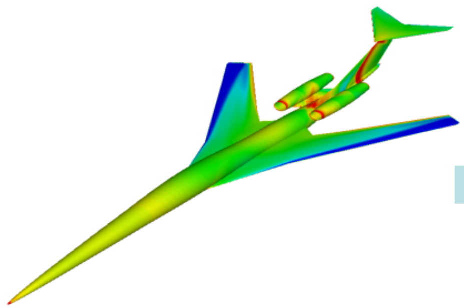
The authors would like to thank all members of the Fundamental Aero Supersonics Program SIA team as well as Richard Campbell at NASA Langley Research Center.

Additional Slides

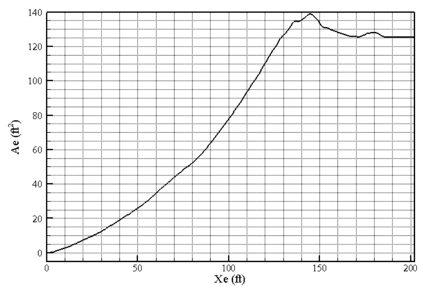
Approaches to Sonic Boom Analysis

Low Accuracy and Cost

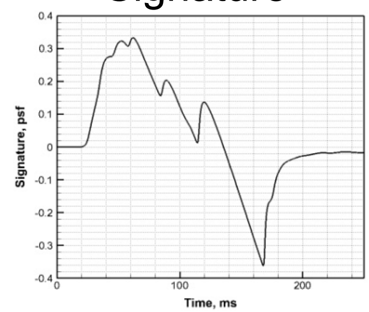
- Low-fidelity: Ground signature for low-fidelity equivalent area distribution
- Medium-fidelity: Ground signature for CFD equivalent area distribution



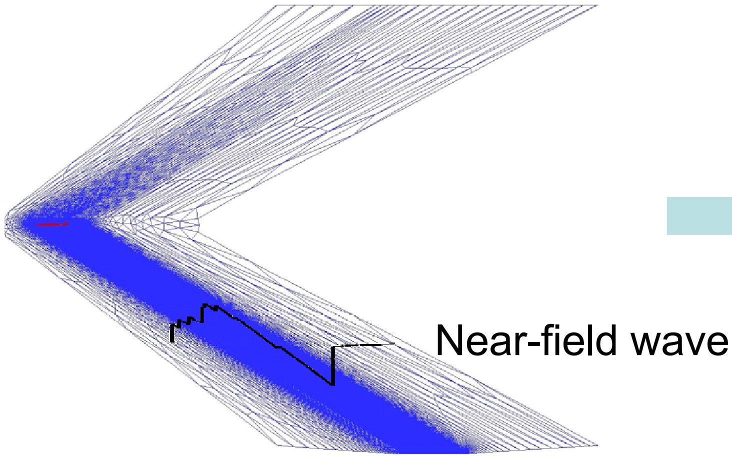
Equivalent Area



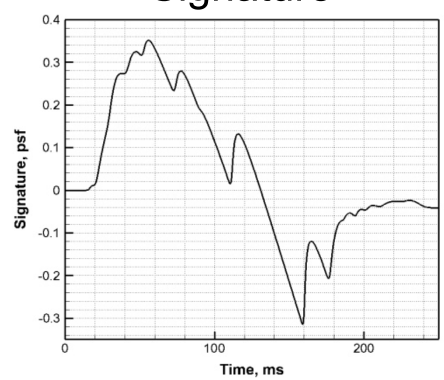
Signature



- High-fidelity: Ground signature for CFD near-field pressure distribution



Signature



High Accuracy and Cost

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