Focus Boom Simulation Benchmark cases for the 182nd ASA Meeting May 2022

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November 30, 2021

2aCA. Validation and Verification (V&V) for Acoustics and Vibrations Simulations

Outline

1 Introduction
  - AIAA Sonic Boom Workshops

2 Background
  - Acceleration Focusing

3 Cases Overview
  - CFD set-up and off-body pressures
  - Trajectory information
  - Sample results

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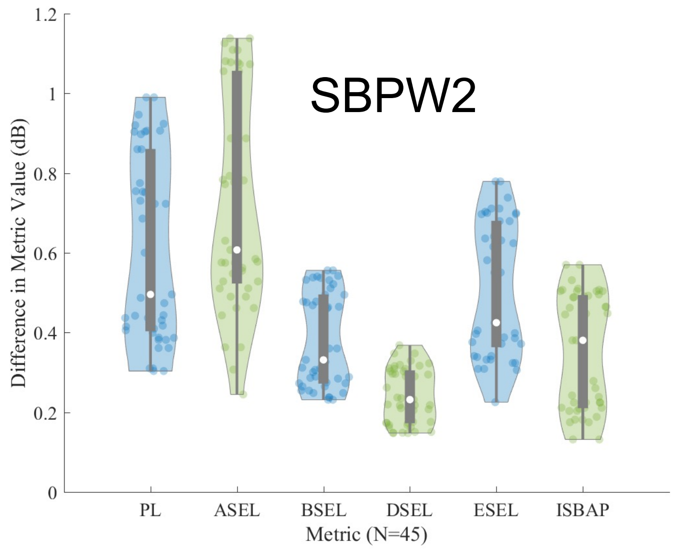
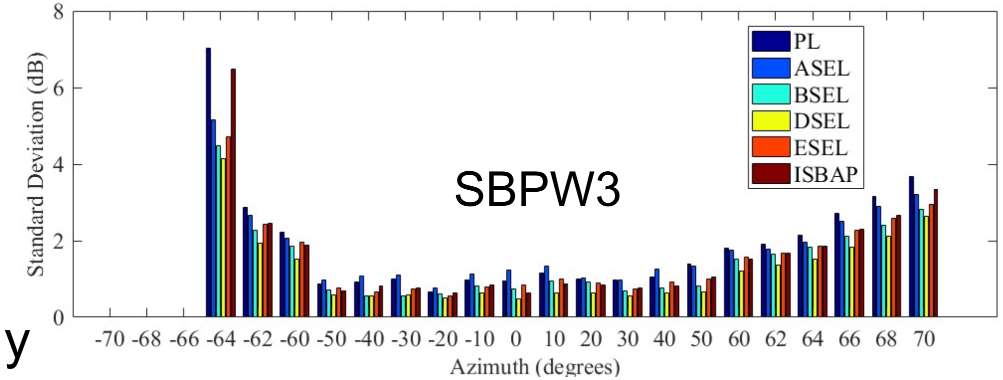
Thank You!

Introduction: AIAA Sonic Boom Prediction Workshops

- **2nd AIAA Sonic Boom Prediction Workshop** (SBPW2) (2017)
  - Cruise booms analyzed for non-shaped sonic booms (LM1021, Axisymmetric Body of Revolution)
  - Participants provided limited data
    - Significant post-processing to compare submissions
  - Lessons learned:
    - Different wind conventions
    - Atmospheric pressure computations (Linear/Hydrostatic)



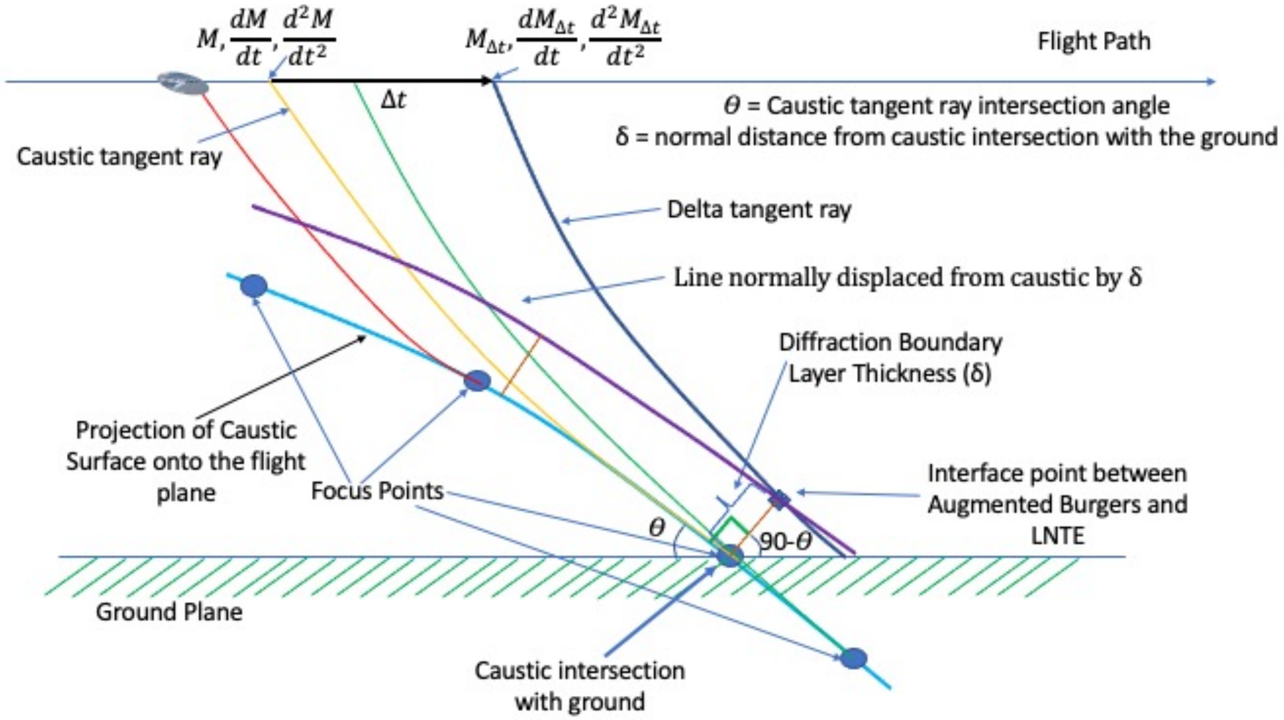
- **3rd AIAA Sonic Boom Prediction Worksho**p (SBPW3) (2020)
  - Cruise booms analyzed for shaped sonic booms (C25P, C609)
    - Optional level acceleration focus boom prediction/comparison
  - Requested multiple loudness metrics
  - Fairly good agreement
  - Lessons learned and next steps:
    - Investigate and compare focus boom cases thoroughly
    - Data hand-off between CFD and atmospheric propagation, Secondary booms etc.
      - Will be revisited at a future conference



Acceleration focus

- Sonic boom focusing is inevitable during acceleration to supersonic cruise Mach numbers
- Sonic boom focusing occurs when aircraft is accelerating (Level acceleration or otherwise), ray paths converge leading to imaginary surfaces called caustics
- Geometrical ray theory based sonic boom propagation breaks down around caustics due to ray tube area singularity
  - Need hand-off to implementations with diffraction effects
  - Use a different formulation
- **Objective**: Revisit the sonic boom focusing problem and compare relevant details between participants and identify any modeling gaps.

- **Approach**: Two test cases are proposed for comparing simulation methods of sonic boom focusing and verifying codes implementation. Participants are invited to apply their codes and provide their results for both test cases



Case 1: Overview

- General spirit:
  - As simple and academic as possible ("toy problem")
  - Minimize the complexity in the definition and input data to minimize the possible differences or errors in code-specific implementations (code's input data generation)
  - Not intended to be fully realistic or representative to an actual aircraft in-flight situation
  - But reproduce basic physical phenomenon of sonic boom focusing and caustic generation

- Near-Field data:
  - Near-field signature is defined by a single, constant, uniform $\Delta P/P_0=f(x)$ signal
    - Axisymetric
    - Not varying with time/position along the A/C trajectory
- Atmosphere:
  - Standard ISO atmosphere
- A/C trajectory:
  - Rectilinear, constant altitude, constant acceleration

Case 1: Near-Field Pressure Waveforms

- Pressure waveform from the AXIE test case from AIAA Sonic Boom Prediction Workshop II (mean value of RANS solutions, for Mach 1.6 condition, extracted at R/L=3)
- ${}^{\Delta P}/_{P_0} = f(x)$ assumed to be :
  - axisymmetric (no variation with azimuth)
  - constant along the trajectory (despite the evolution of the Mach number)

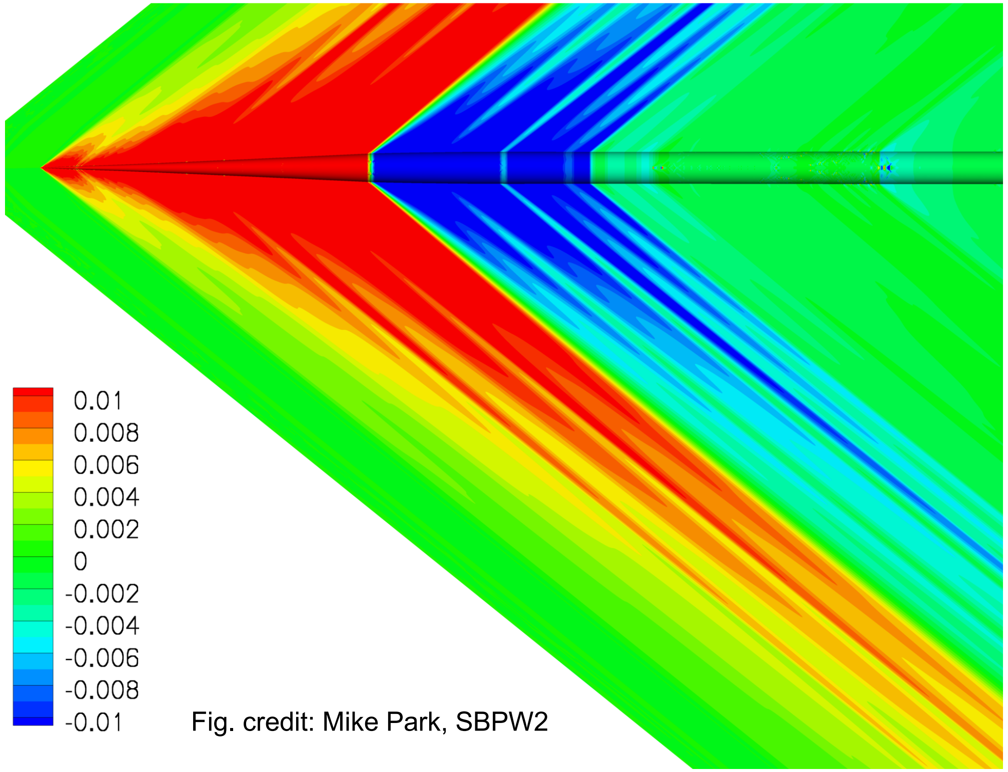
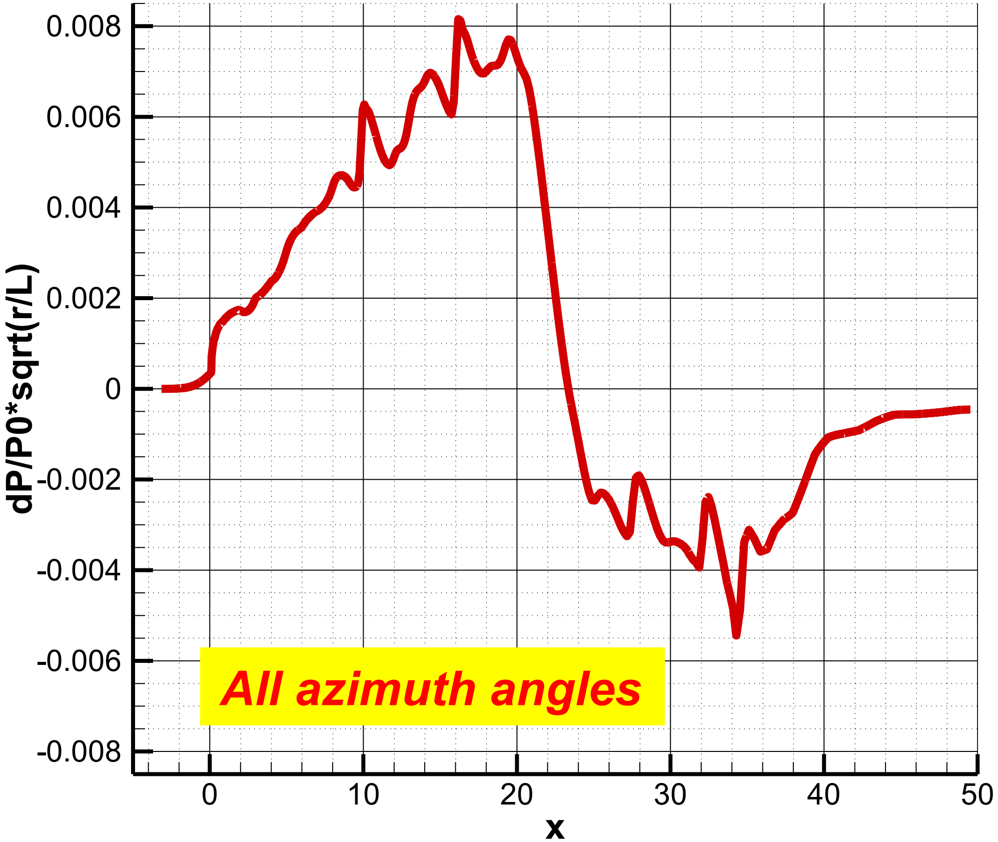
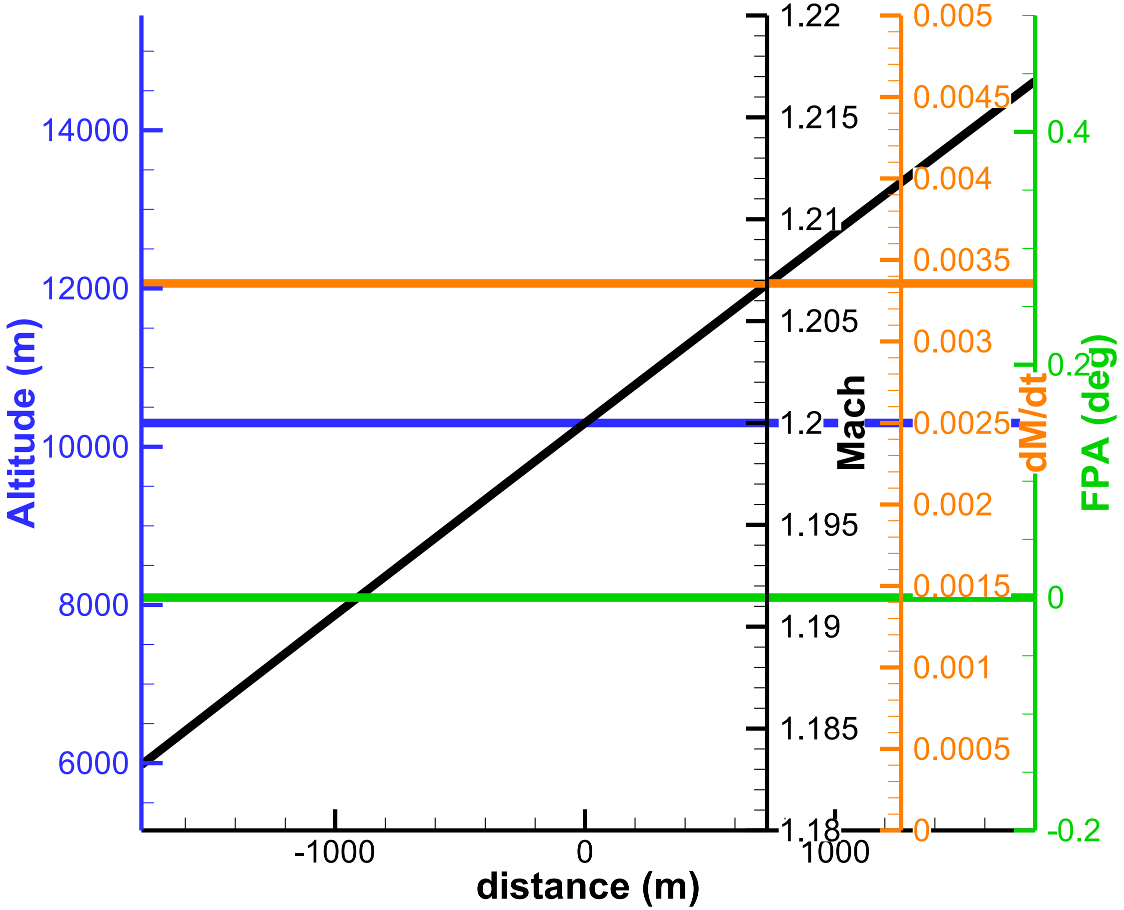


Fig. credit: Mike Park, SBPW2



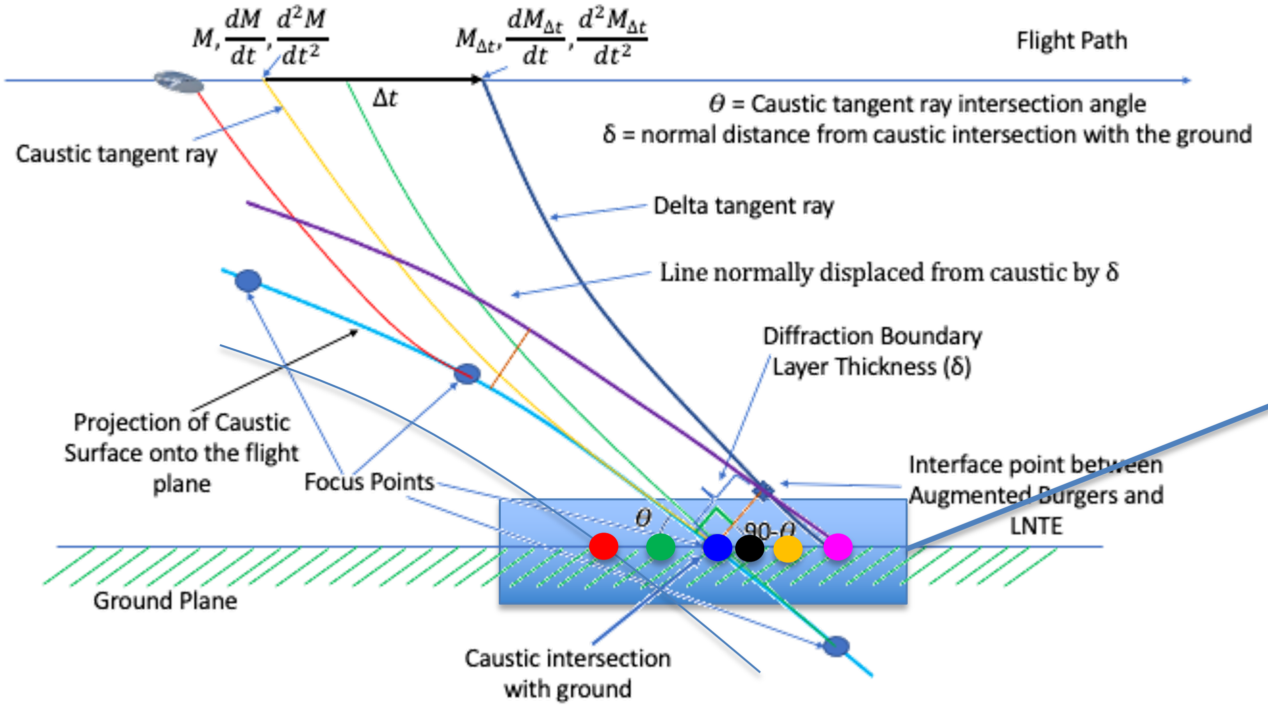
Case 1: Trajectory

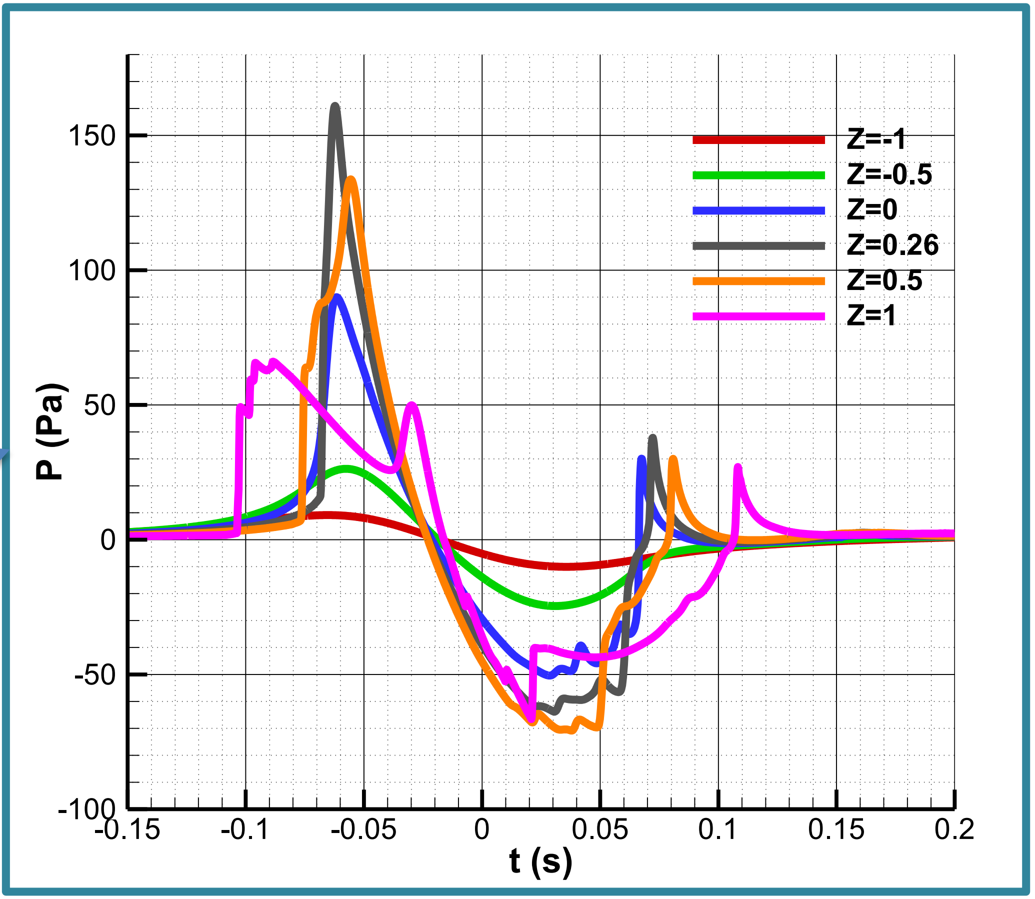
- Horizontal, constant altitude level flight (10,300 m)
- Constant in-line acceleration
- Focusing condition at Mach ~ 1.2



M = 1.2
Altitude = 10,300 m (33,793 feet)
dM/dt = 0.003356 s^{-1} (dV/dt = 1 m/s²)
d^2M/dt^2 = 0.0 s^{-2}
Level flight (FPA=0.°, dFPA/dt = 0.°/s)

Case 1: Ground pressure near caustic





Case 2: Near-Field Pressure Waveforms

- Underlying concept being used: C608 from near-field portion of SBPW3
- Leveraged automated meshing scripts from FUN3D runs (Thanks M. Park)
  - Inflated grid extruded at relevant Mach numbers
  - Data will be provided for azimuthal angles from 0 – 180^o at 2^o increments

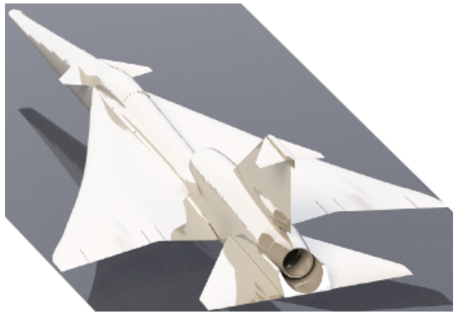
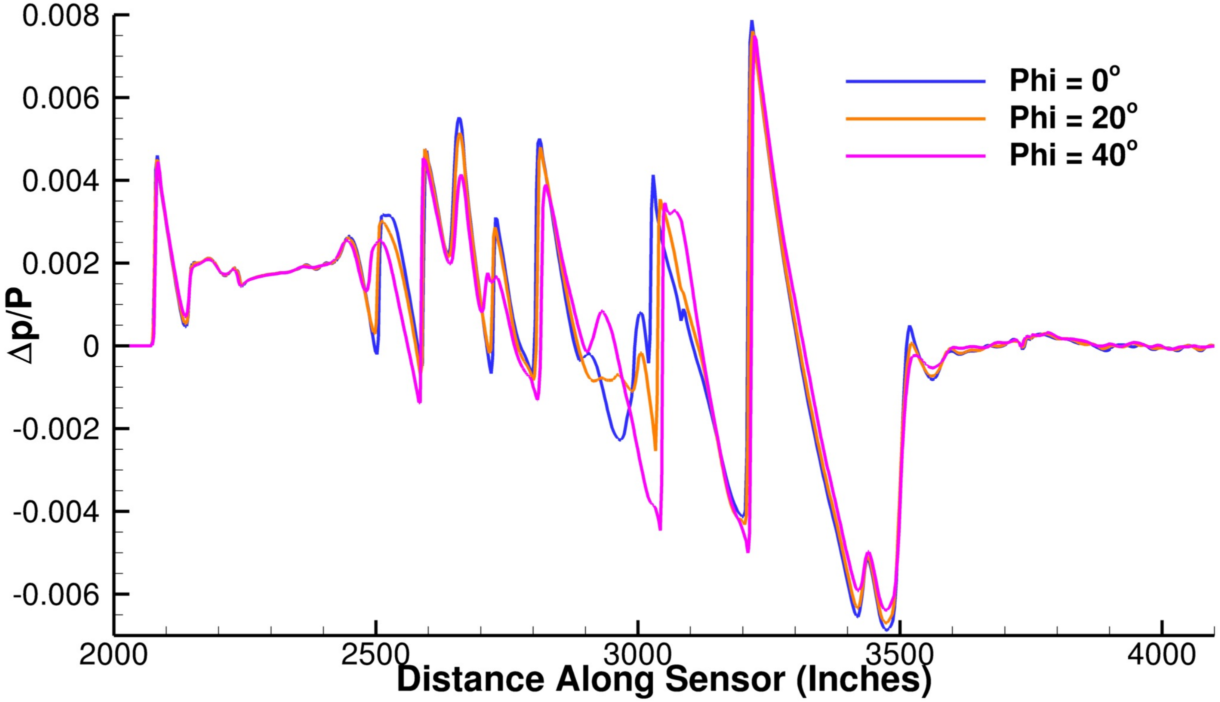
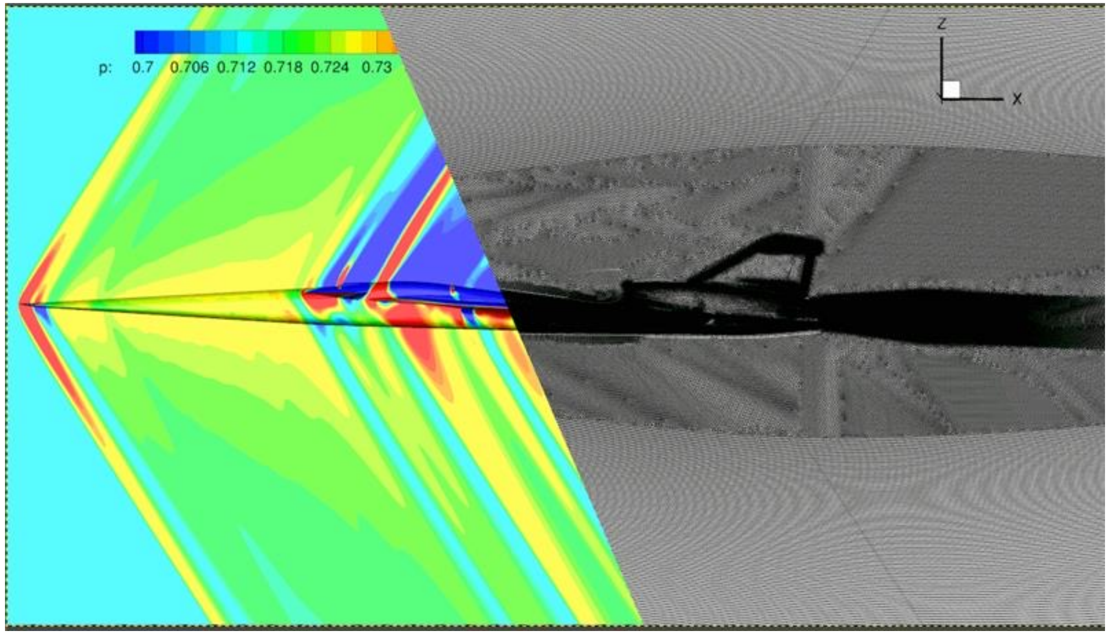


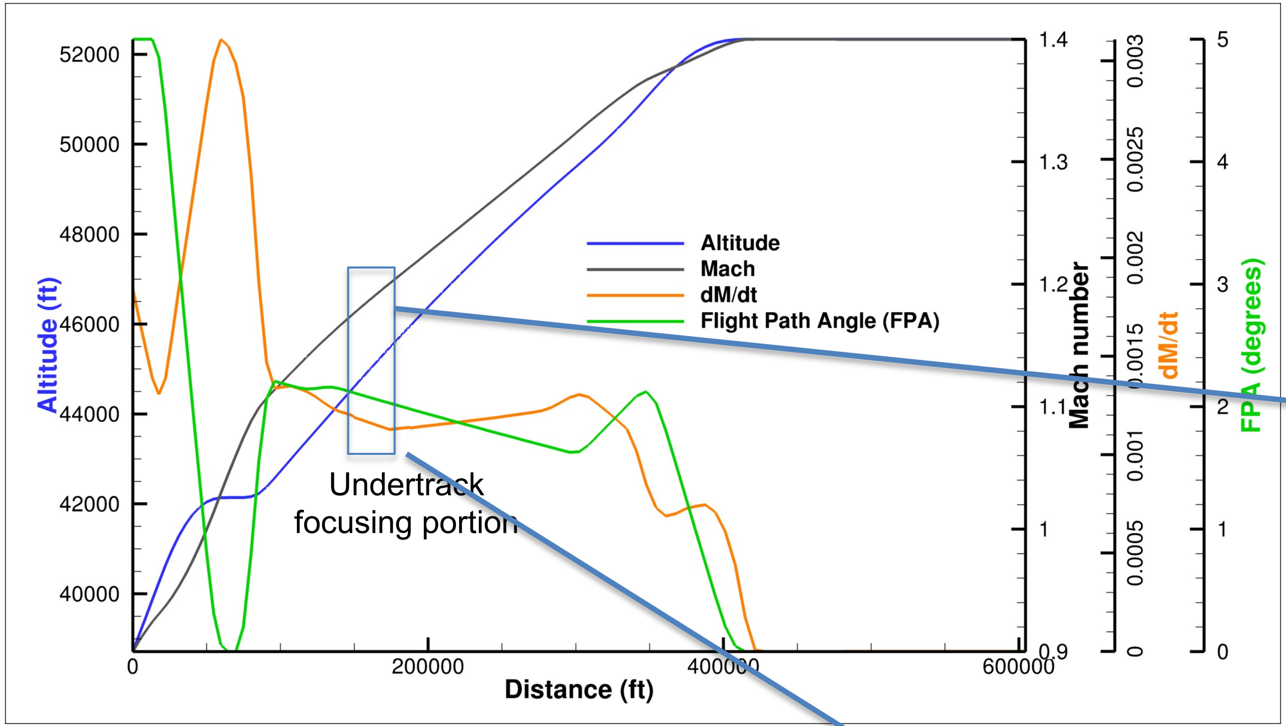
Fig. credit: Wade Spurlock et. al. SBPW3



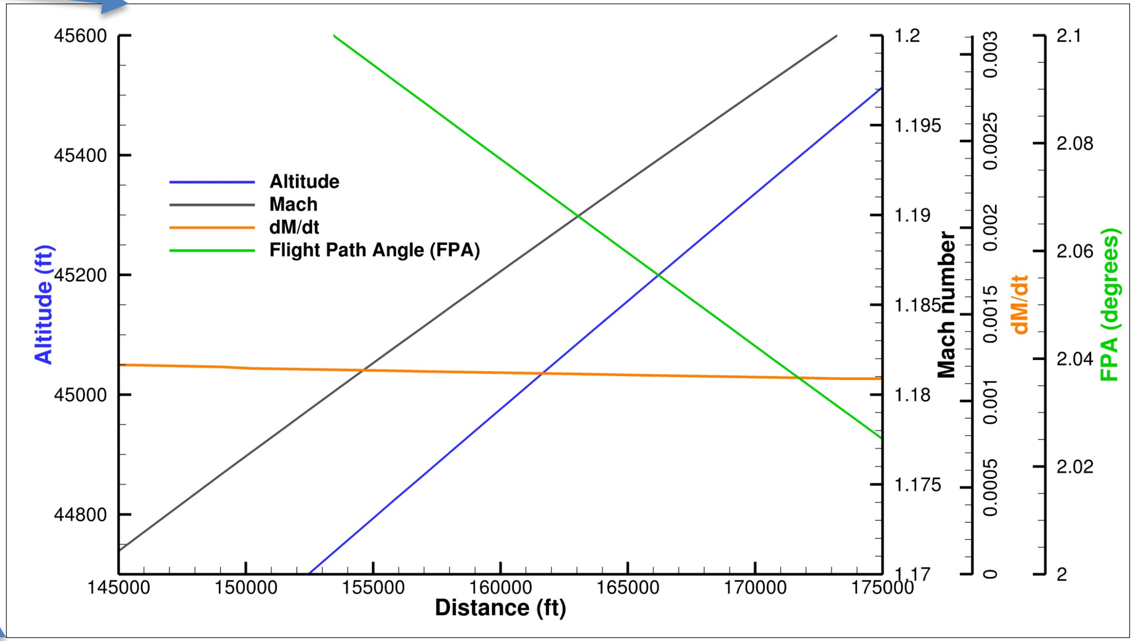


Case 2 Trajectory

- Mission profile trajectory
  - Identification of region leading to under-track sonic boom focusing



M = 1.194236
Altitude = 45241 feet
Flight Path Angle (FPA) = 2.0515 degrees
dM/dt = 0.001144274
d^2M/dt^2 = -2.94747e-6
Rate of change of FPA = -0.004 degrees/second



Requested Information

- Delta ray conditions
  - Mach, dM/dt, d^2M/dt^2
- Caustic surface geometry
  - Relevant radii of curvatures
  - Diffraction boundary layer thickness
- Augmented Burgers-Lossy Nonlinear Tricomi Equation (LNTE) interface information
  - Location w.r.t. aircraft nose when disturbance was emitted
  - Augmented Burgers propagation time
  - Augmented Burgers waveform that is input to LNTE
  - Characteristic acoustic frequency
- Relevant LNTE solution details
  - Reflected and evanescent waveforms at multiple requested distances from the caustic surface
  - Solution convergence plots
  - Requested loudness metrics associated with all the waveforms

Summary

Two test cases defined of increasing complexity:

Case 1:

Focus Boom Trajectory

- Constant altitude level flight with constant rectilinear acceleration

Near-Field Pressures

- Near-field pressures of AXIE geometry from SBPW2

Case 2:

Focus Boom Trajectory

- A realistic trajectory sub-segment, based on C608 mission profile, leading to under-track focusing at the ground level has been presented

Near-Field Pressures

- Near-field pressures generated for C608 corresponding to the initial focusing Mach number

Requested Data

- The details of the requested data have been presented

Timeline and Contact Information

Data Location: Low Boom Prediction Workshop url

https://lbpw.larc.nasa.gov

Contact Information

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- Juliet Page, Juliet.Page@blueridgeresearch.com

Anticipated Timeline

- Make data and case information available before end of 2021
- Request participant data by March 31, 2022

Questions?

Acknowledgements:

NASA Commercial Supersonic Technology (CST) Project
Mike Park, Alexandra Loubeau, Irian Ordaz @ NASA Langley
Low Boom Prediction Workshop (LBPW) Committee