# Unstructured Grids for Sonic Boom Analysis and Design

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# Outline

- Background
- Description of methods
  - Cylindrical Outer Boundary (COB)
  - Boom Grid (BG)
  - Near-Field Target (NFTARG)
- Results
  - Parametric grid generation studies
  - Exploratory design cases
- Concluding remarks

# Technology Challenge Goals

| Balanced Goals for Practical Civil Supersonic Aircraft (Technology Available) | N+1 Supersonic Business Class Aircraft (2015) | N+2 Small Supersonic Airliner (2020) | N+3 Efficient Multi-Mach Aircraft (Beyond 2030) |
|---|---|---|---|
| ***Design Goals*** | | | |
| Cruise Speed | Mach 1.6-1.8 | Mach 1.6-1.8 | Mach 1.3-2.0 |
| Range (n.mi.) | 4000 | 4000 | 4000 - 5500 |
| Payload (Passengers) | 6 - 20 | 35 - 70 | 100 - 200 |
| ***Environmental Goals*** | | | |
| Sonic Boom | 65 - 70 PLdB | 85 PLdB (Revised) | 65 - 70 PLdB Low Boom Flight 75 - 80 PLdB Overwater Flight |
| Airport Noise (cumulative below stage 4) | Meet with Margin | 10 EPNdB | 10 - 20 EPNdB |
| Cruise Emissions (Cruise Nox g/kg of fuel) | Equivalent to current Subsonic | < 10 | < 5 & particulate and water vapor mitigation |
| ***Efficiency Goals*** | | | |
| Fuel Efficiency (passenger miles per lb of fuel) | 1.0 | 3.0 | 3.5 - 4.5 |

N+1 Business Class

N+2 Small Supersonic Airliner

N+3 Efficient, Multi Mach Aircraft

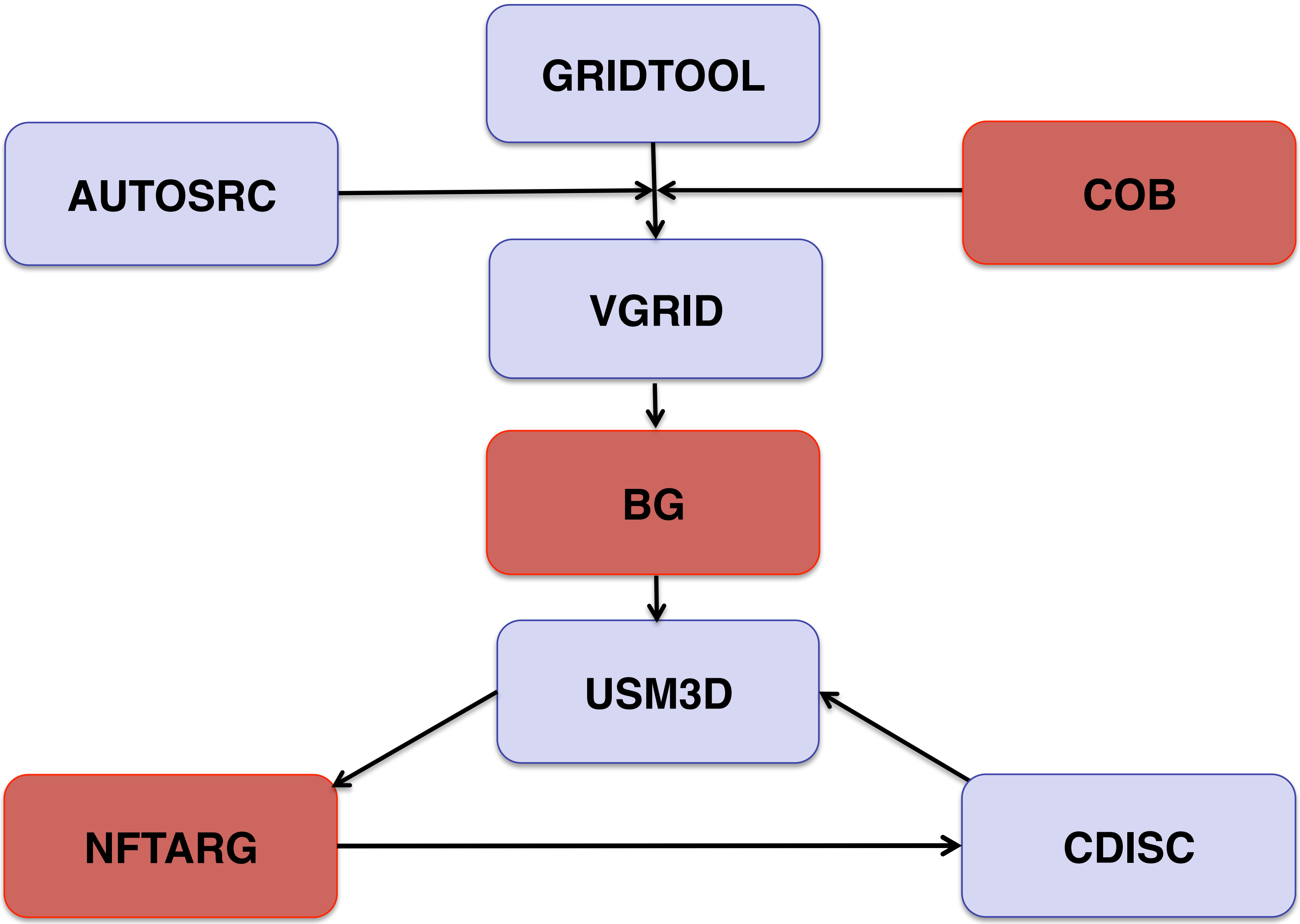
- NASA defined an initial set of design parameters and performance levels for practical supersonic airliners in the near, mid and far term time frames
- Systems Studies have been used to determine if these goals are valid and achievable

http://www.aeronautics.nasa.gov/fap/2012-PRESENTATIONS/SUP_2012_508.pdf

# Recent Sonic Boom Research Using CFD Analysis and Design

- Shaped Sonic Boom Demonstration (flight tests, 2005)
- Gulfstream Quiet Spike test program (flight tests, 2008)
- NASA Sonic Boom Workshop (2008)
- NRA N+2 Studies (CFD and WT tests, 2013)
  - Boeing
  - Lockheed
- AIAA 1st Sonic Boom Prediction Workshop (2014)
- NASA Sonic Boom Unstructured Grid Generation
  - Stretched: SSGRID, SSGN
  - Extrusion: MCAP, **BG**, INFLATE
  - Adaptive: FUN3D

# Flow Chart of Sonic Boom Analysis and Design Process Using TetrUSS



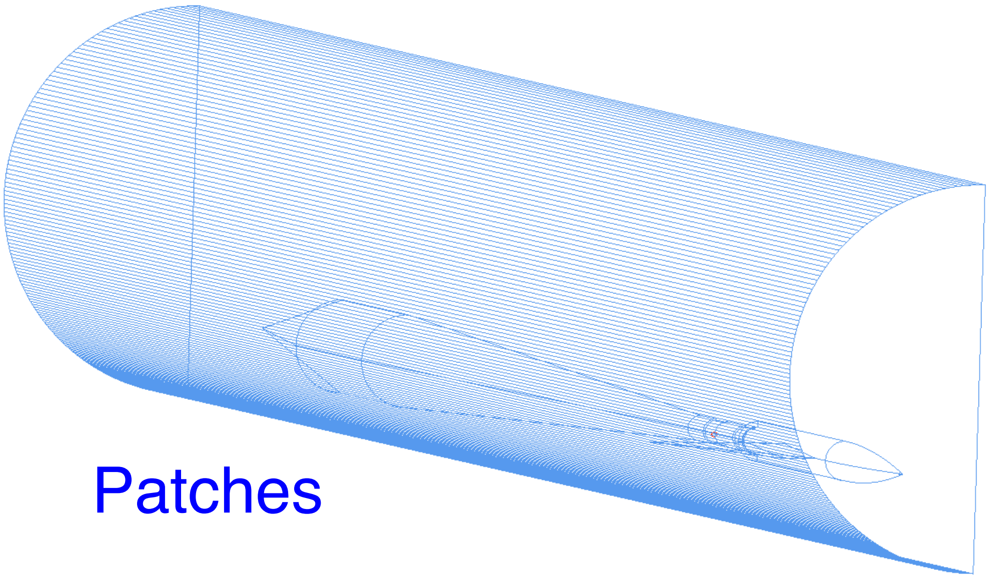
# Core Grid Generation Codes

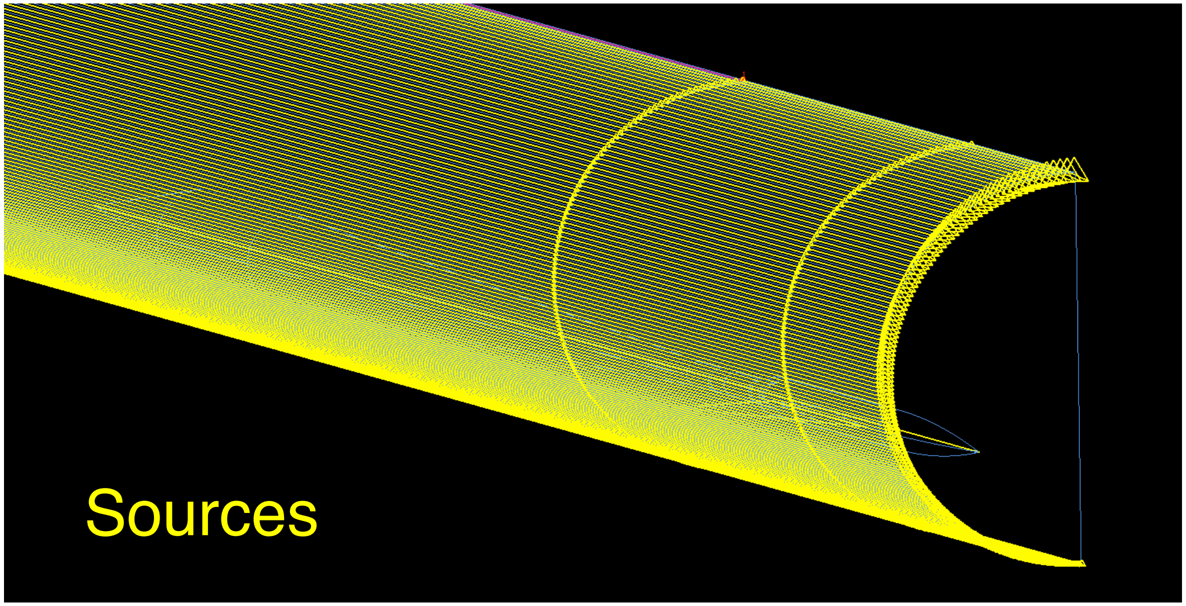
- Configuration setup
  - **GRIDTOOL:** define surface curves and patches from IGES or other geometry definition formats
  - **AUTOSRC:** automatically locate and size line sources that control surface grid spacing based on aircraft component type

- Outer boundary setup
  - **COB:** define curves, patches and sources for cylindrical or rectangular outer boundary for robust BG extrusion process

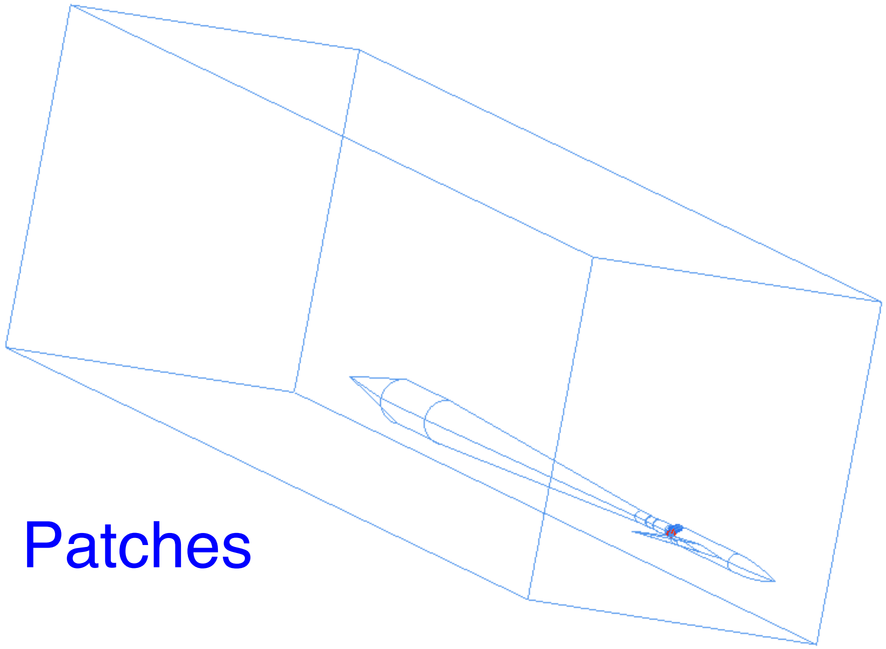
- Core grid generation
  - **VGRID:** generate body-fitted tetrahedral core grid using advancing layer and advancing front methods

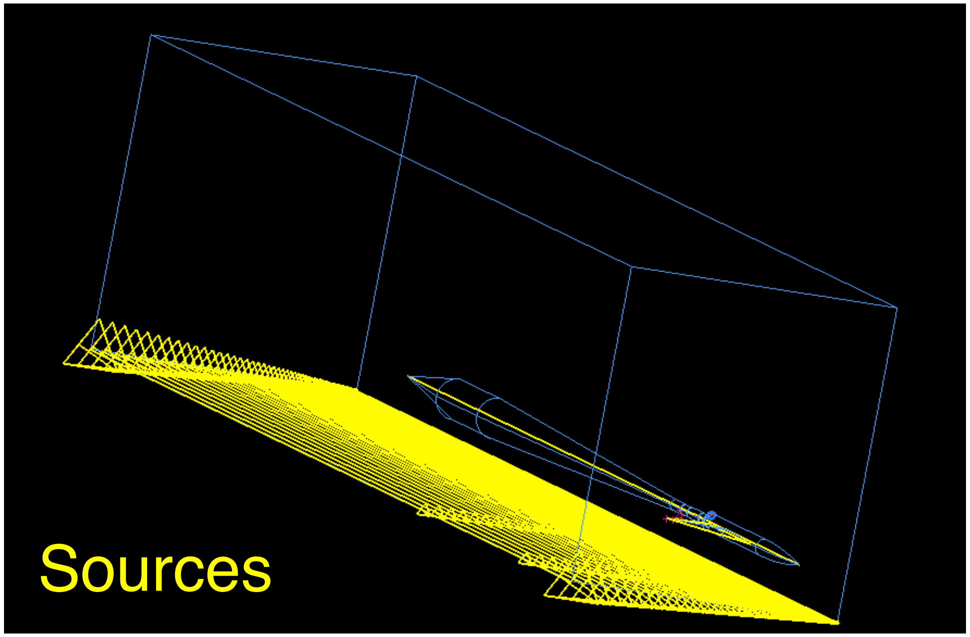
# COB Cylindrical Outer Boundary



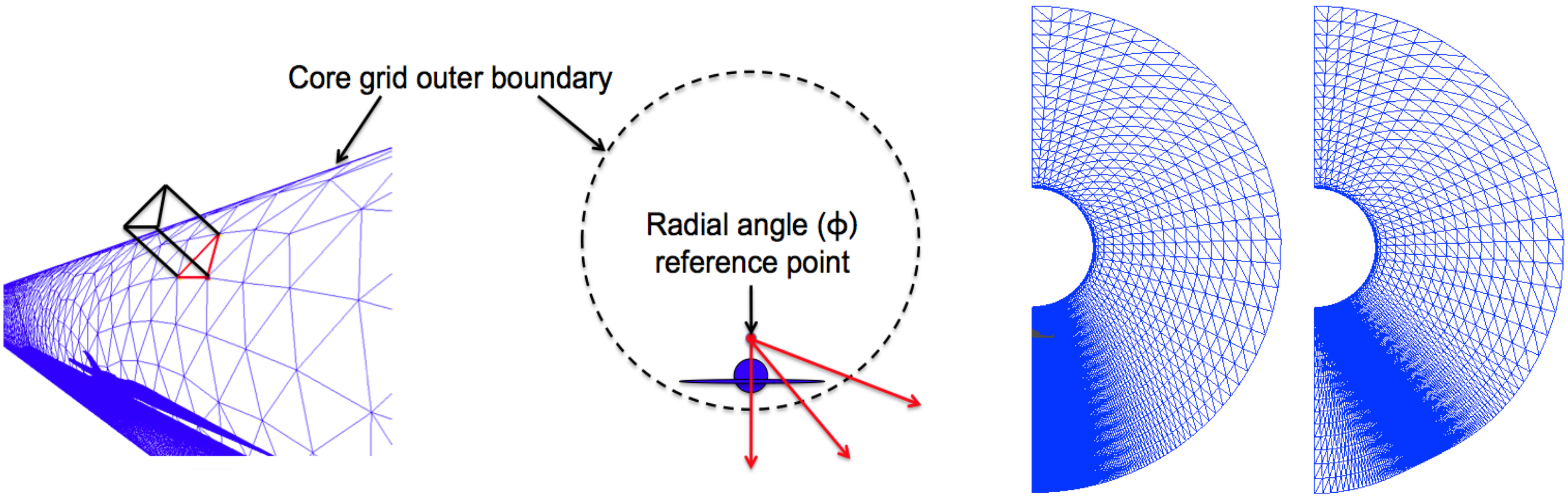



# COB Rectangular Outer Boundary



# BG Collar Grid Generation Code




- Extrude layers of prisms through faces on core grid outer boundary
- Split prisms into tetrahedral cells and merge with core grid
- Radial angle reference point for extrusion located close to configuration nose
- Vary height of reference point to focus grid at selected radial angles

# Analysis and Design Codes

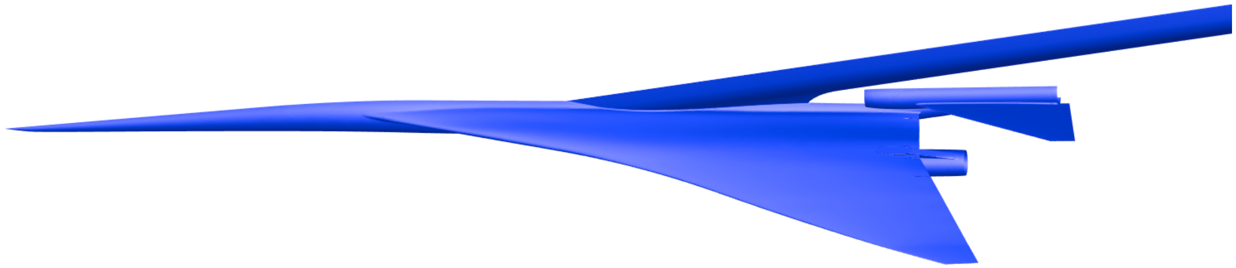
- Flow solver – **USM3D**
  - Solves RANS equations using a cell-centered, upwind scheme
  - SST turbulence model used for viscous cases
  - Minmod limiter used for solution stability for all cases
- Target Pressure Generation – **NFTARG**
  - Ray-tracing method to link surface geometry to near-field target
  - Several options available for target specification
- Design module – **CDISC**
  - Knowledge-based design to target pressure distribution
  - Prescribed flow/geometry sensitivity derivatives
  - Flow constraints automatically generate target pressures
  - Geometry constraints incorporate multidisciplinary influences

# Configurations Used in Code Evaluation Studies

Body of revolution (SEEB) - Euler

Delta wing-body (DWB) - Euler

Full aircraft (LM1021) - RANS

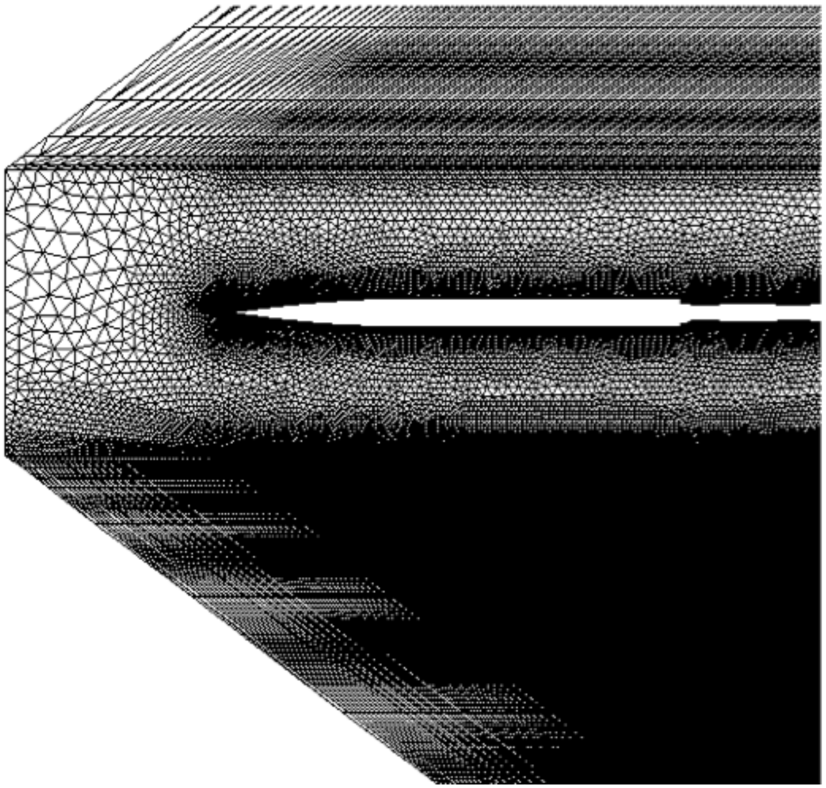


# Summary of Parametric Grid Generation Studies - COB

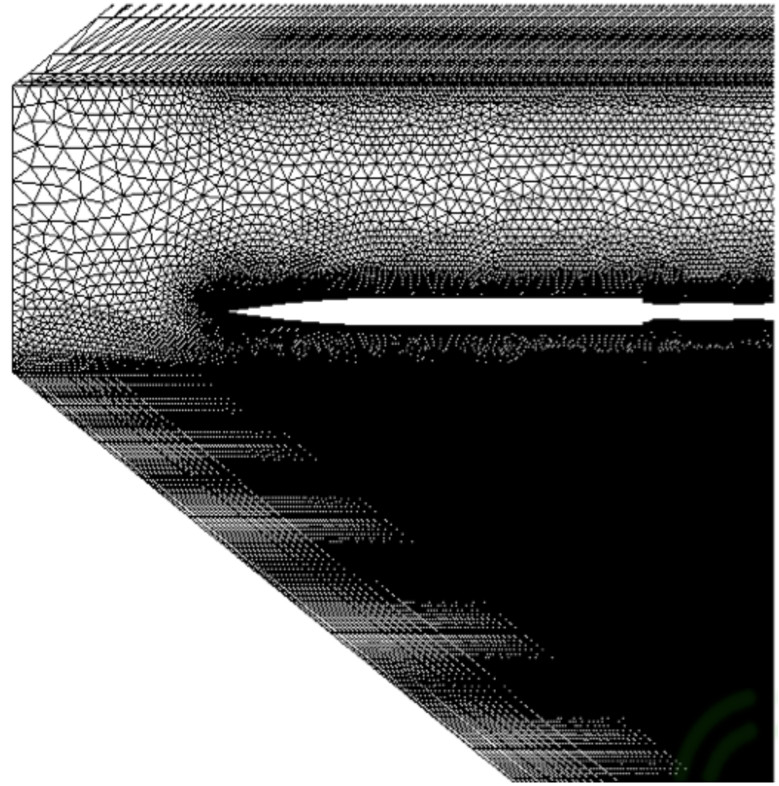
| Parameter | Configuration | Range | Significant |
|---|---|---|---|
| Core grid vertical location | DWB | center, low | yes |
| Axial spacing parameter | DWB | 100 – 500 | yes |
| Multi-zone axial spacing | DWB | 3,4 zones | yes |
| Off-track enhancements | DWB | 0, 30, 60 deg | no |
| | LM1021 | 0, 50 deg | no |
| Outer boundary shape | DWB | cyl, rec | yes |

# Symmetry Plane Grids for Different Core Grid Vertical Locations

Core grid centered at model nose

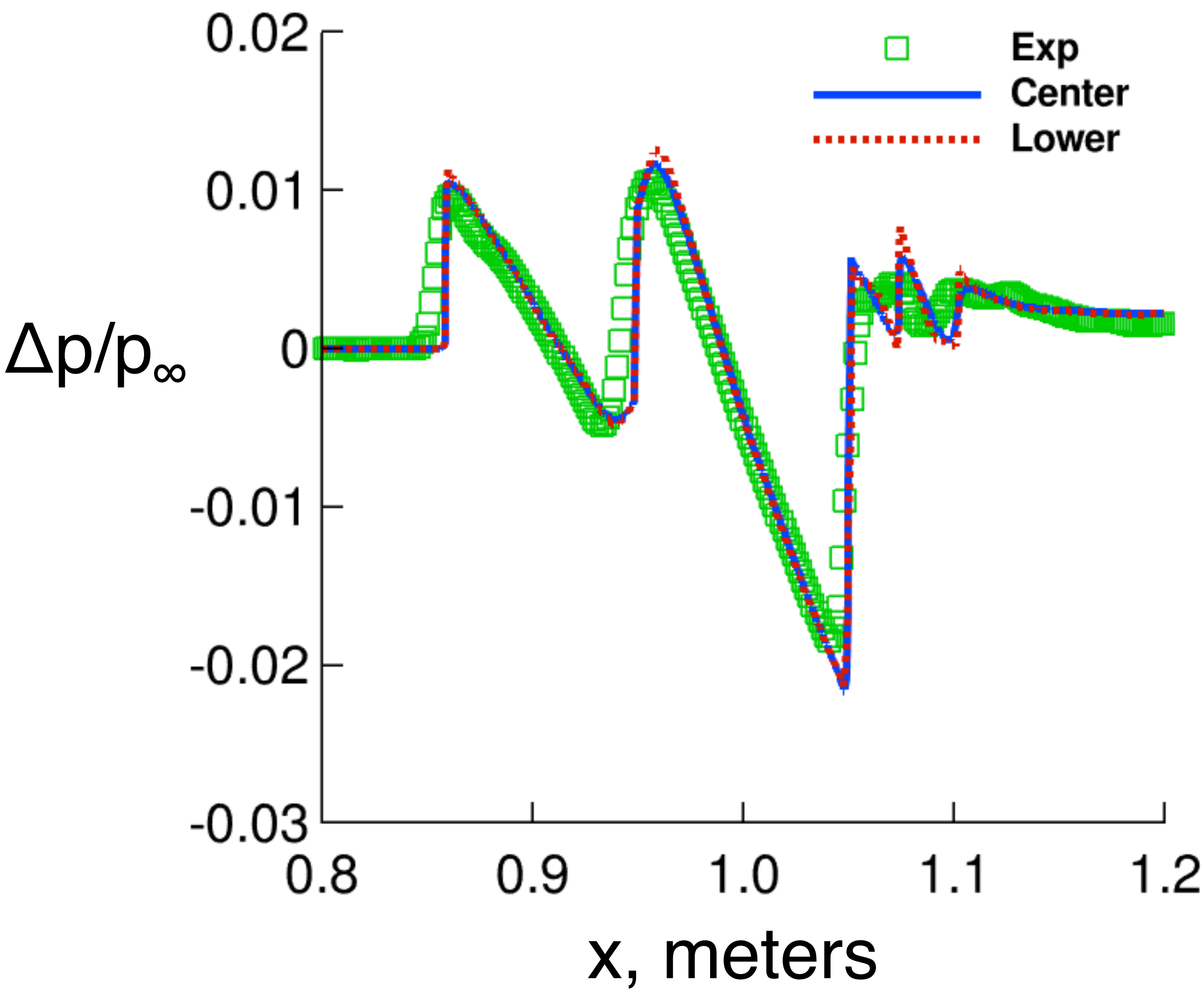


Core grid automatically positioned by COB



# Effect of Core Grid Vertical Location on DWB Near-field Boom Signature

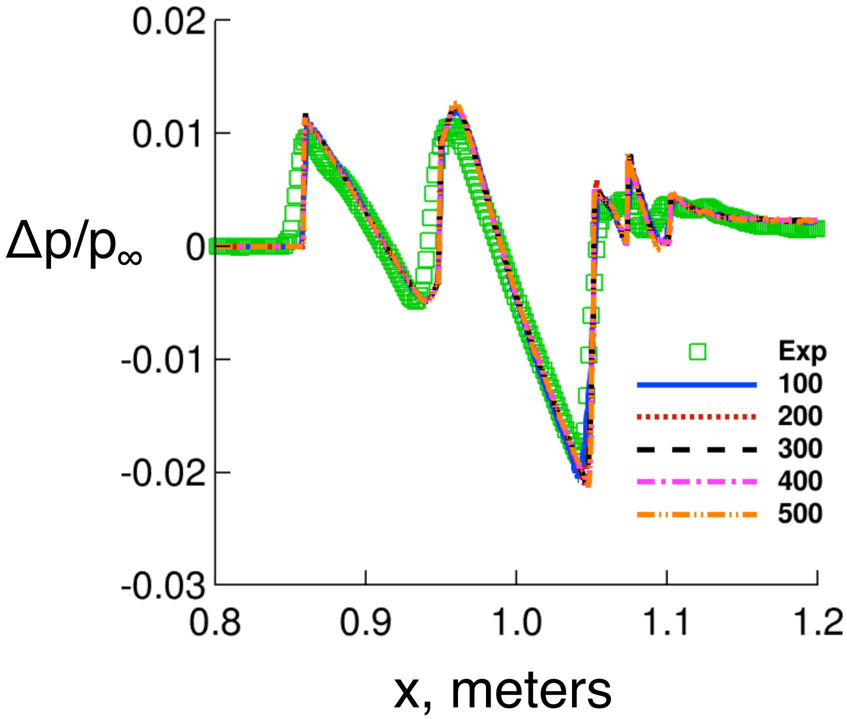
**M = 1.7 H/L = 3.6 Φ = 0 deg**

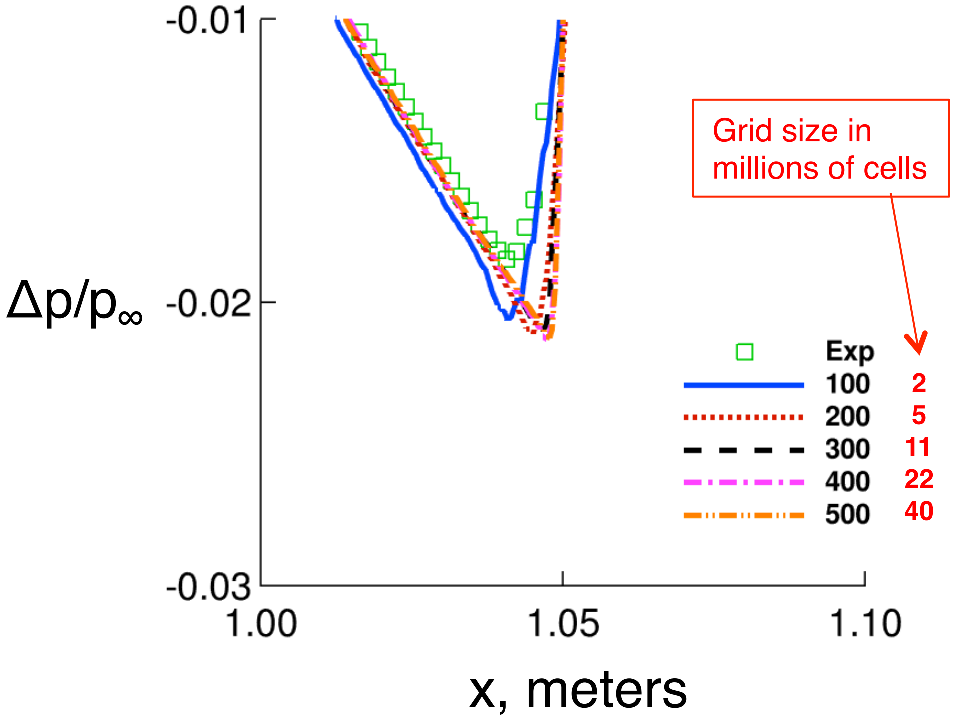


# Effect of Axial Spacing Parameter (ASP) on DWB Near-Field Boom Signature

M = 1.7     H/L = 3.6     Φ = 0 deg

Grid spacing = L / ASP

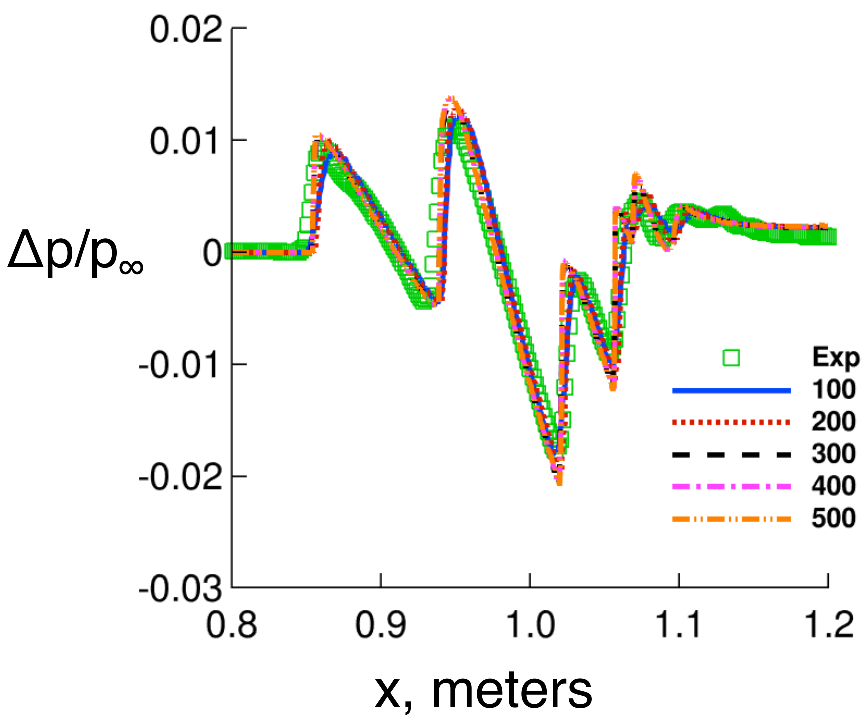


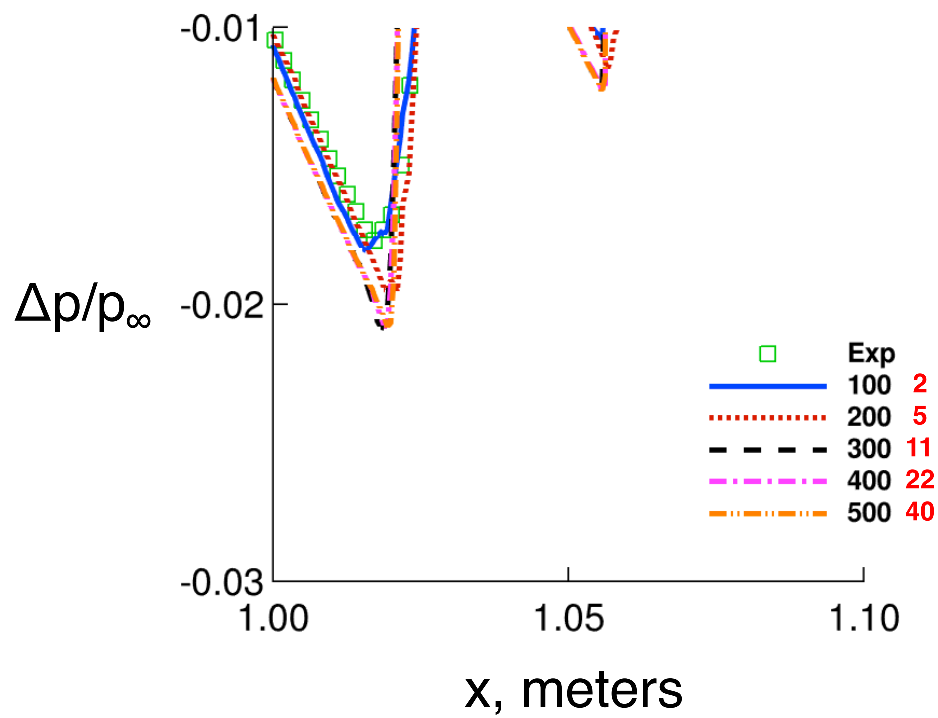



# Effect of Axial Spacing Parameter (ASP) on DWB Near-Field Boom Signature

**M = 1.7　H/L = 3.6　Φ = 60 deg**

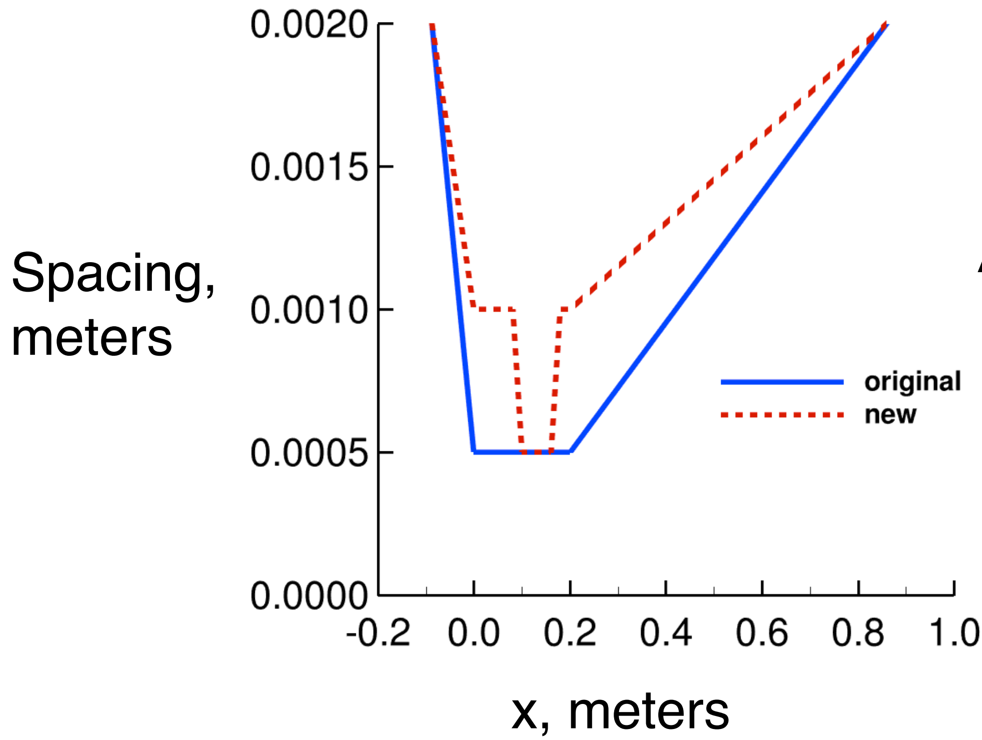
Grid spacing = L / ASP

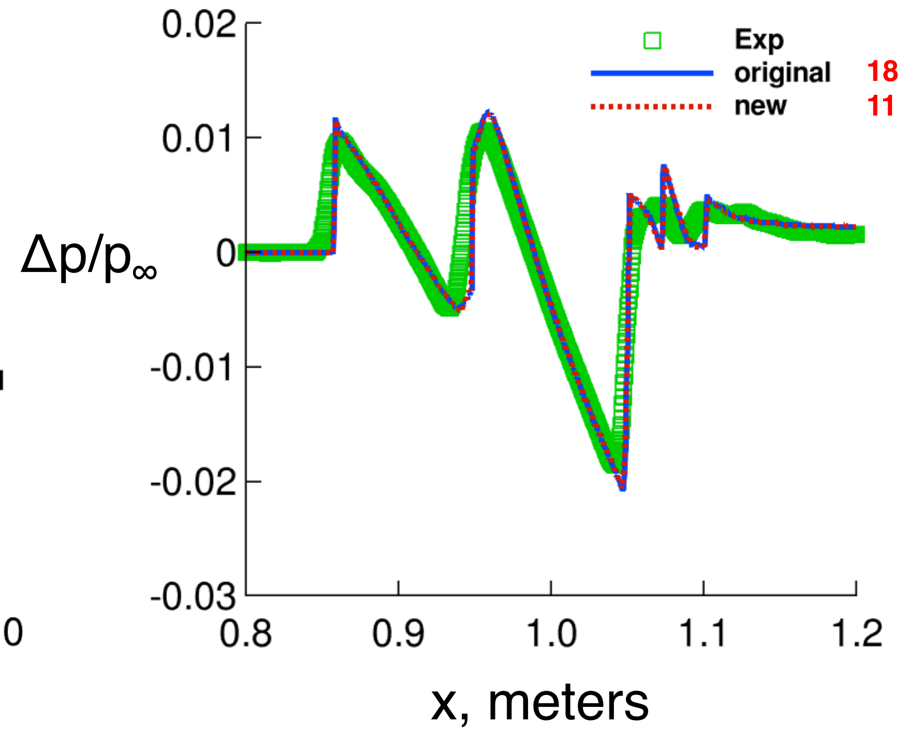


# Effect of Multi-zone Spacing Option on DWB Near-Field Boom Signature

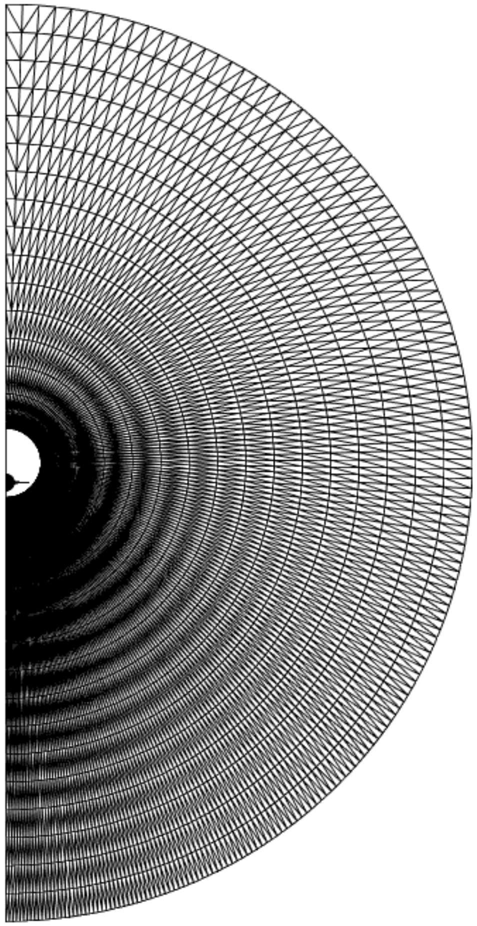
**M = 1.7 H/L = 3.6 Φ = 0 deg**



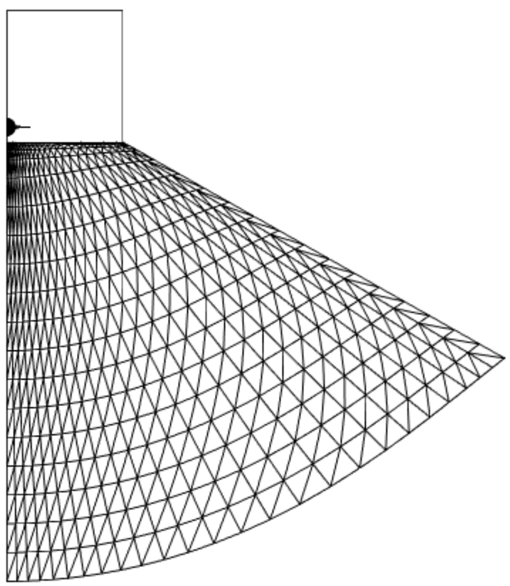



# Collar Grid Inflow Planes for Different Core Grid Outer Boundary Options

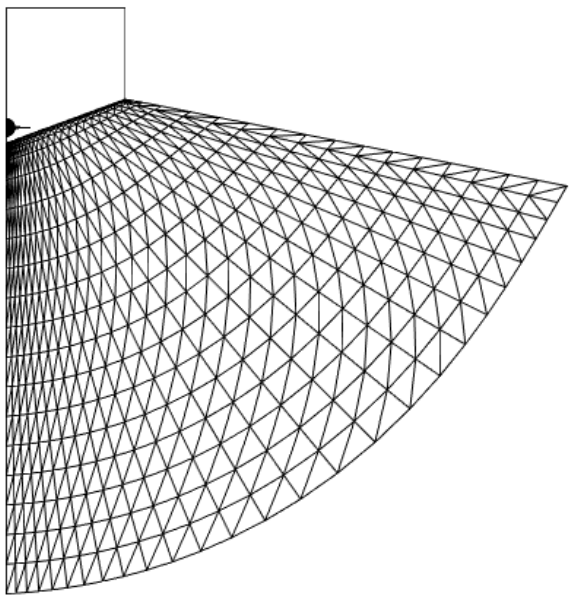
Cylindrical (COB)



Rectangular (ROB)

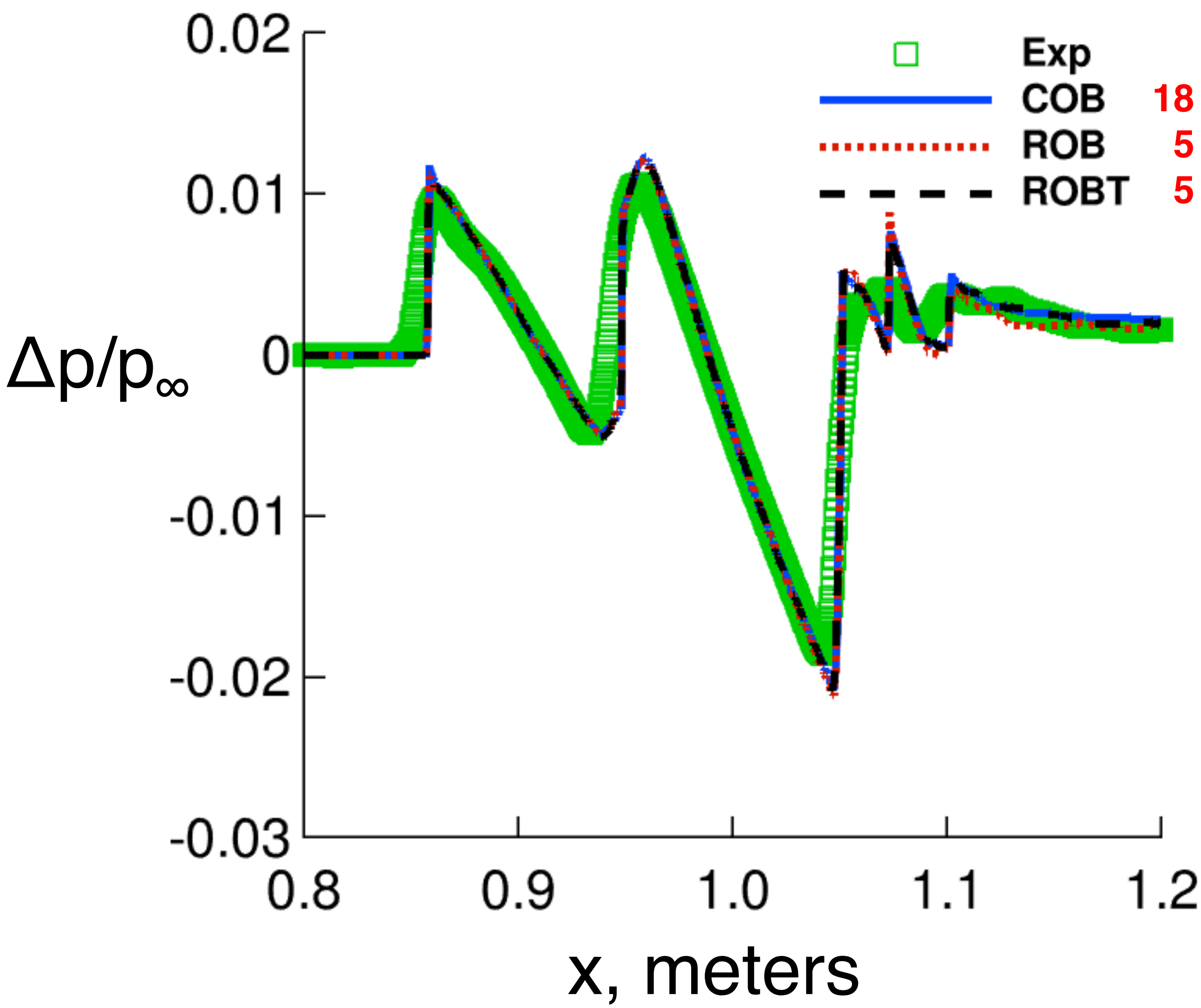


Rectangular with tilted lower boundary (ROBT)



# Effect of Core Outer Boundary Shape on DWB Near-field Boom Signature

M = 1.7     H/L = 3.6     Φ = 0 deg

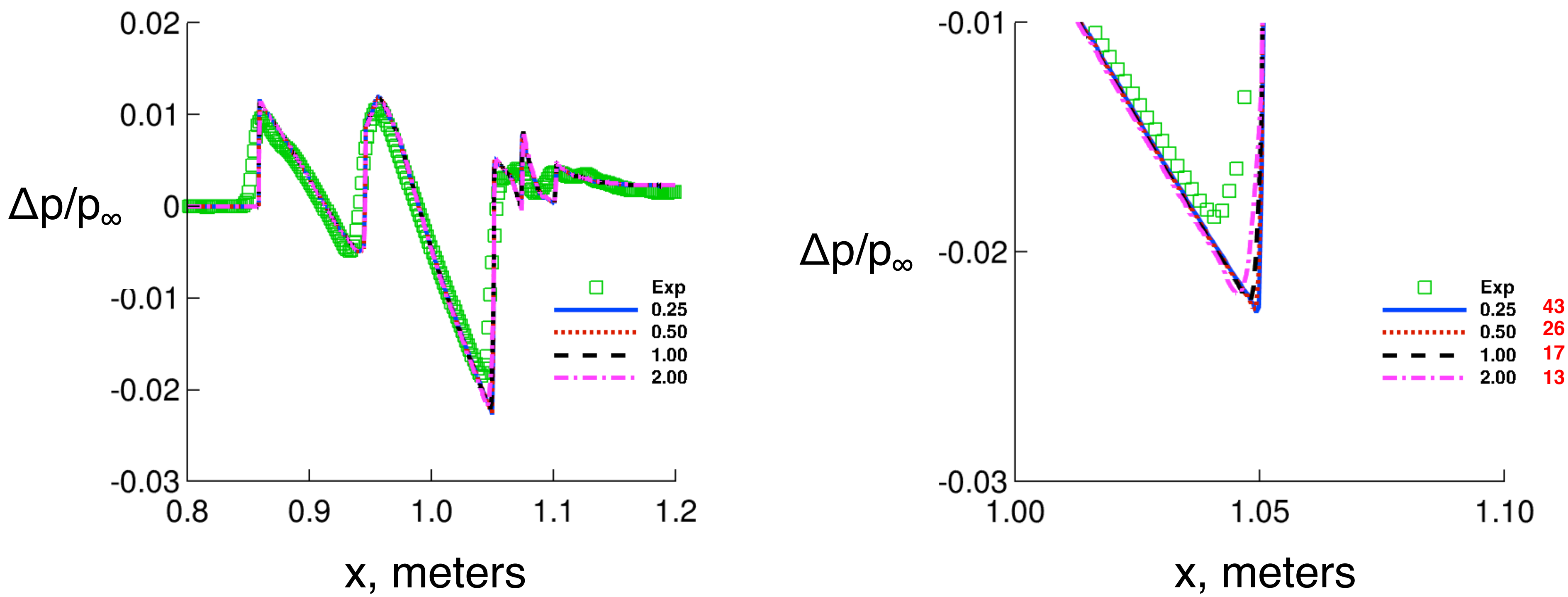


# Summary of Parametric Grid Generation Studies - BG

| Parameter | Configuration | Range | Significant |
|---|---|---|---|
| Cell stretching factor | DWB | 0.25 – 2.00 | yes |
| Outer boundary distance | DWB | 0.0, 0.5 | no |
| Alpha parameter | LM1021 | -2, 0, 2 deg | yes |

# Effect of BG Stretching Factor (SF) on DWB Near-Field Boom Signature

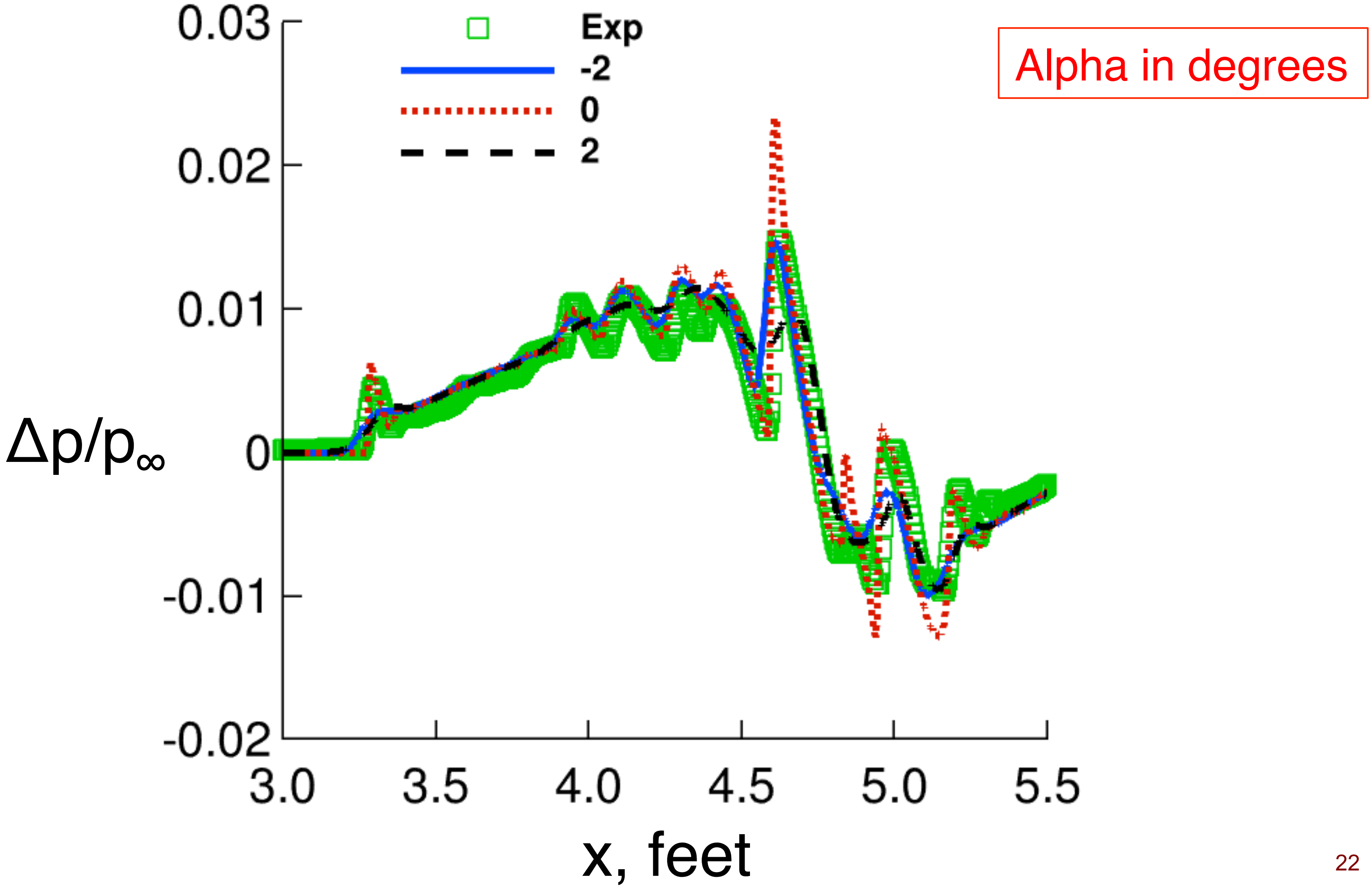
M = 1.7   H/L = 3.6   Φ = 0 deg




Maximum cell stretching = 50 * SF

# Effect of BG Alpha Parameter on LM1021 Near-field Boom Signature

**M = 1.6    H/L = 1.4    Φ = 0 deg**



# Recommendations for Generation of Sonic Boom Grids using COB and BG

- **COB**

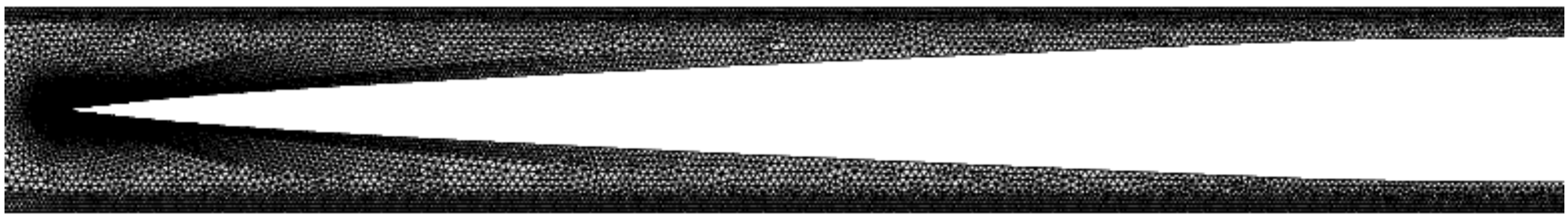
  - Automated vertical positioning of outer boundary
  - Axial spacing = 1/300 of the body length
  - Multi-zone option for better local resolution
  - ROB option for on-track, COB if off-track is needed

- **BG**

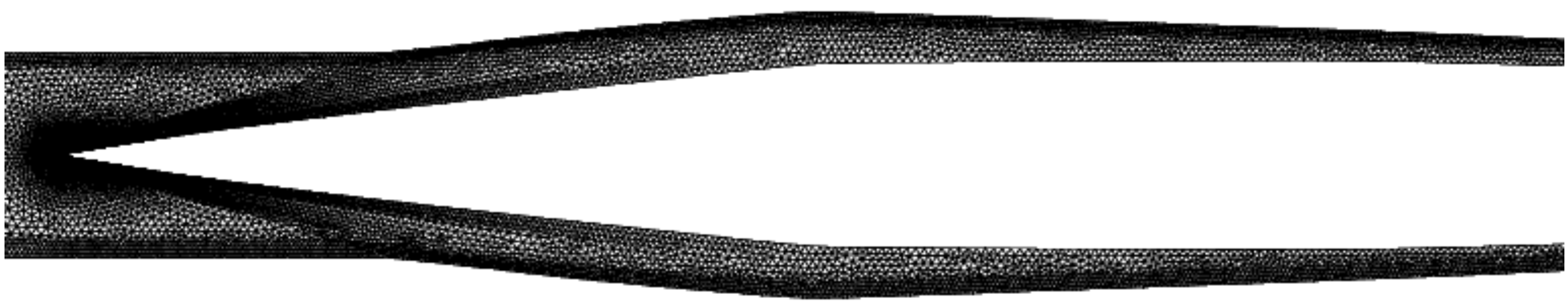
  - Collar grid radial extent = signature location
  - Cell stretching factor = 1.0
  - Alpha parameter = flow solver angle of attack

# Core Grid Symmetry Planes for Baseline and Modified SEEB Geometry

Baseline

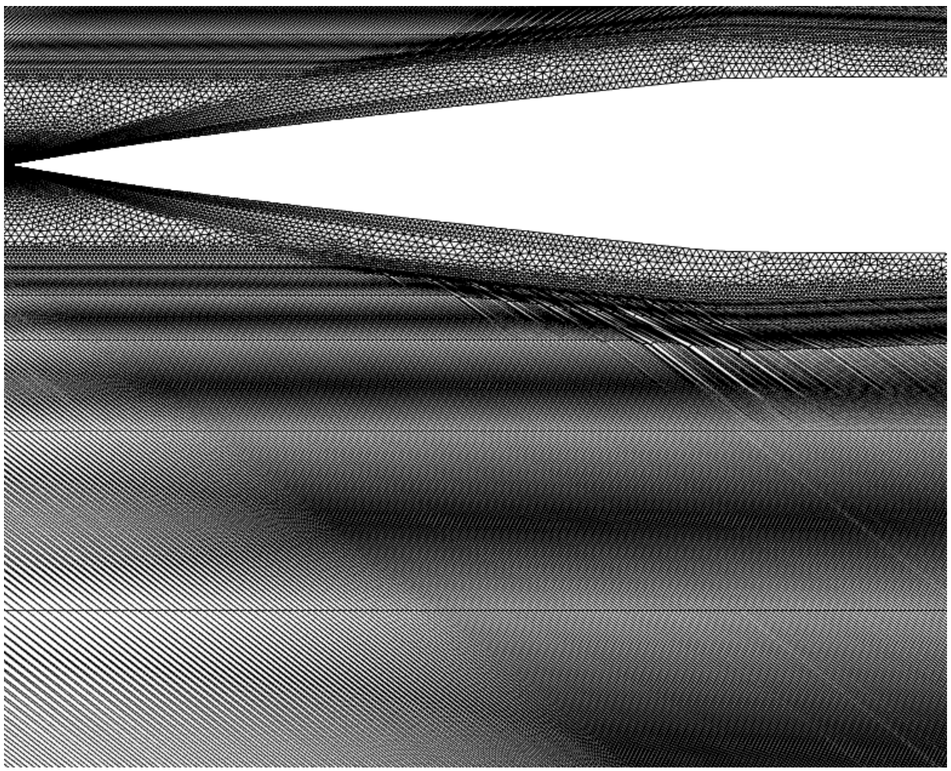


Modified

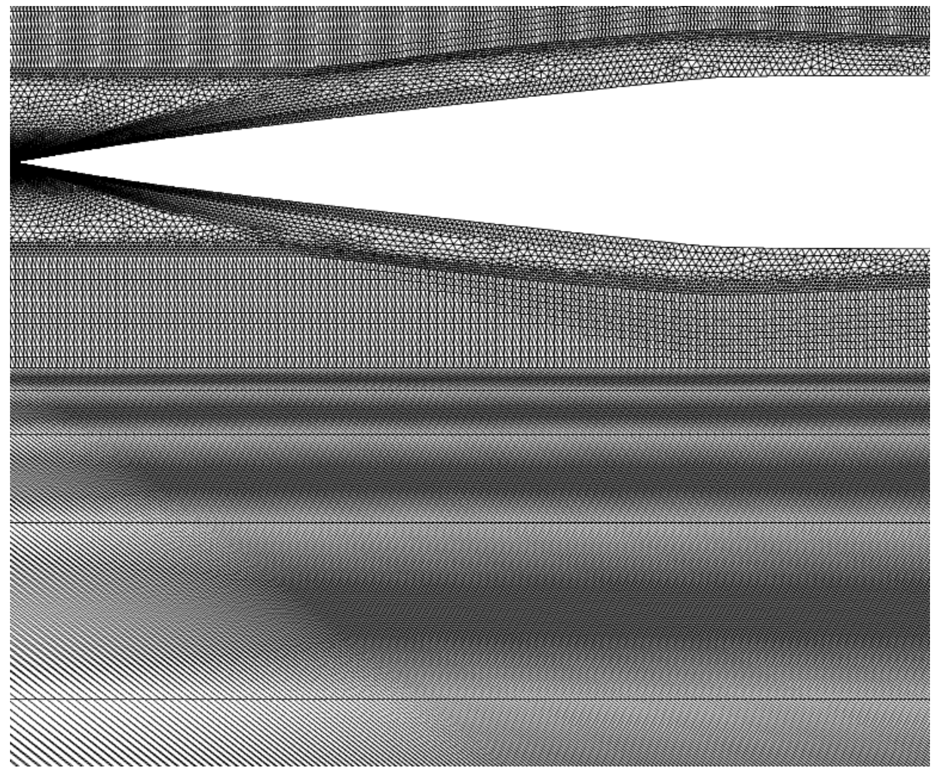


# Core Grid Symmetry Planes for Baseline and Modified SEEB Geometry

Original BG shearing

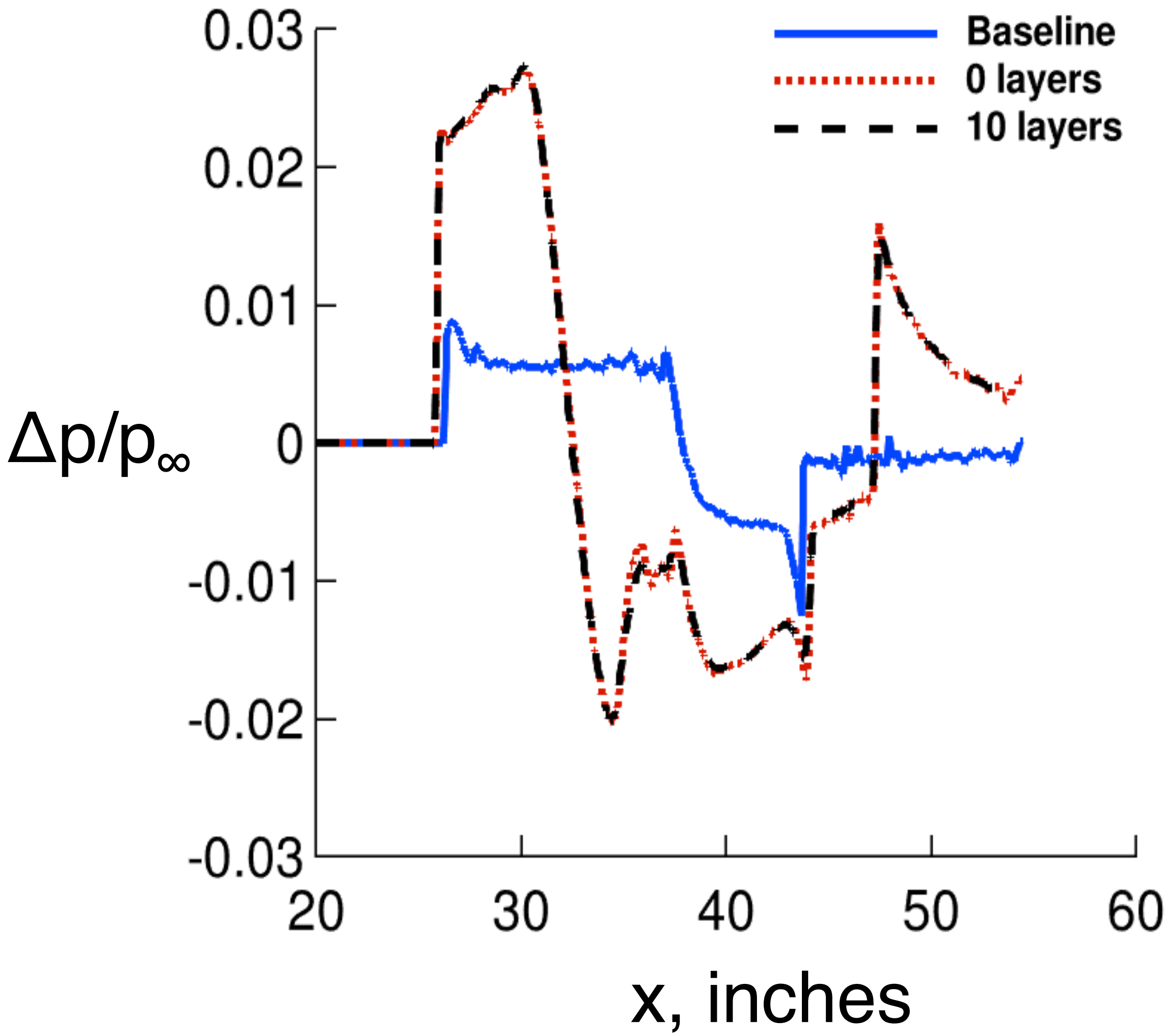


Initial uniform BG layers

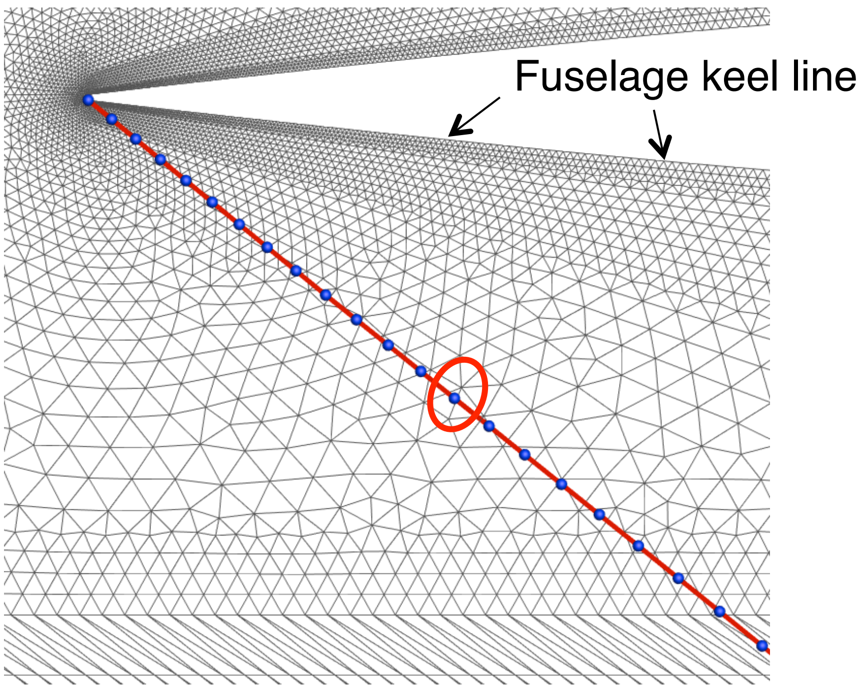


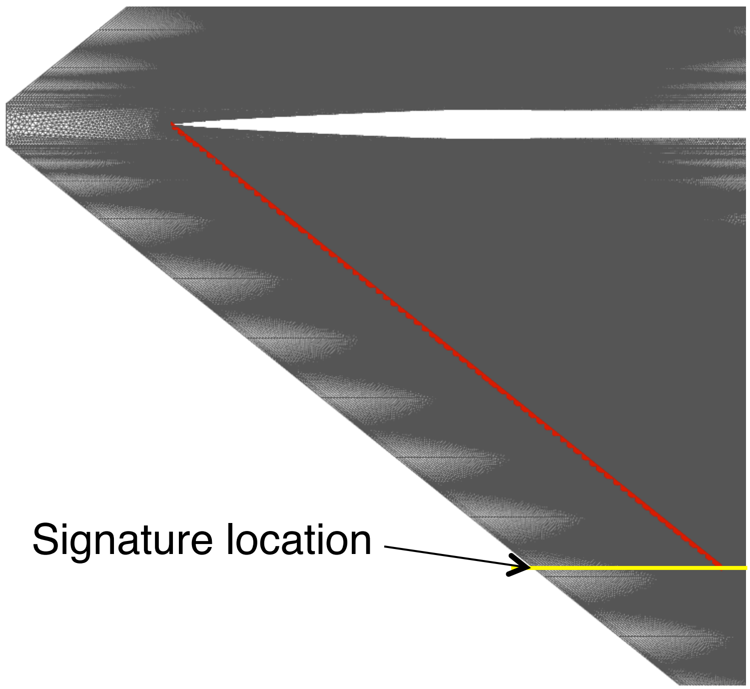
# Effect of Initial Uniform BG Layers on SEEB Near-field Boom Signature

**M = 1.6  H/L = 1.2  Φ = 0 deg**



# NFTARG Ray-Tracing Approach to Sonic Boom Design with CDISC

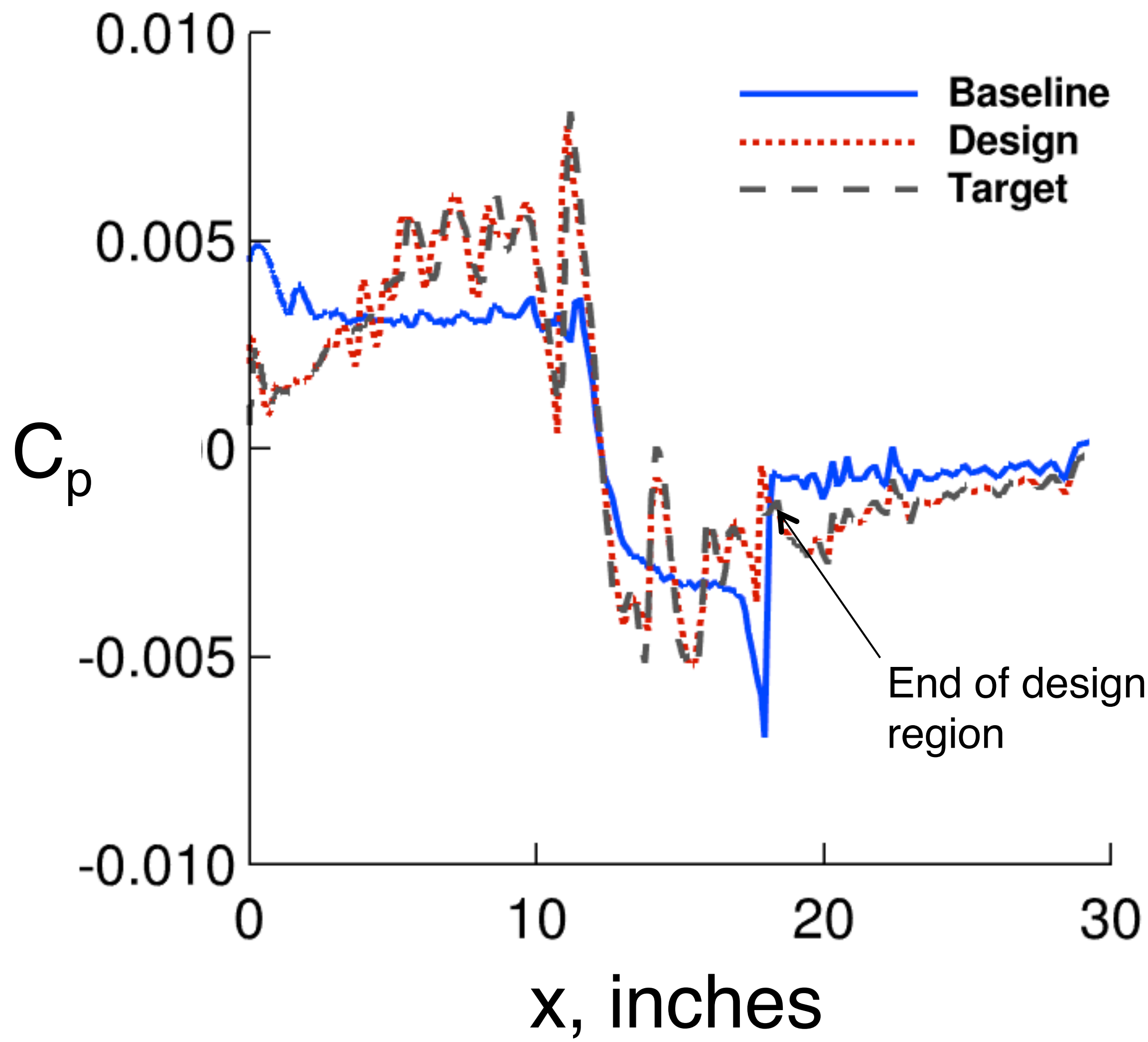


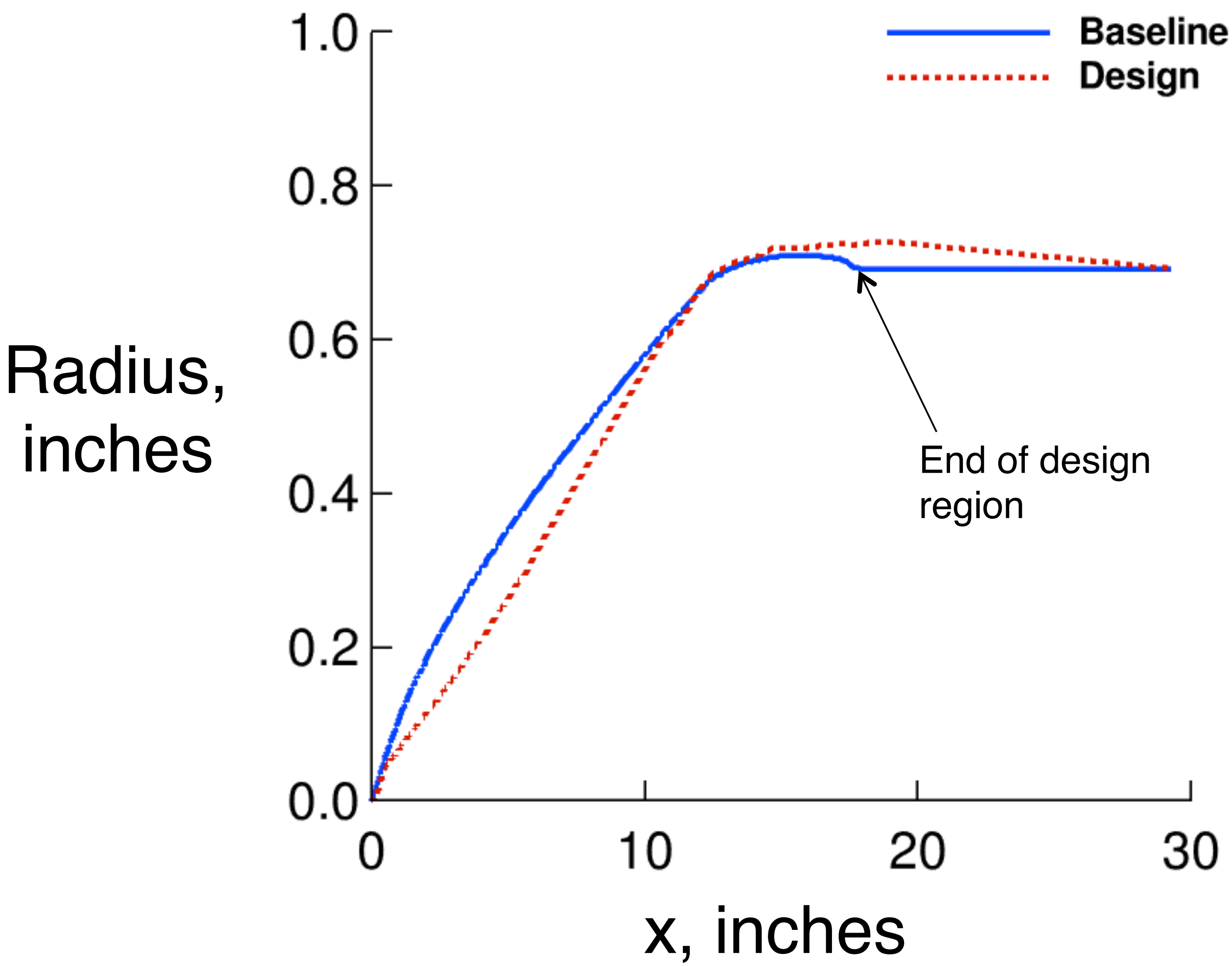

- Step from grid points on fuselage keel line to signature location
- Use Mach number from nearest grid point to determine direction for next step
- Shift beginning of signature to match ray trace from first keel point

# CDISC Design of SEEB to Near-Field Signature from LM1021 - Pressures

**M = 1.6     H/L = 1.2     Φ = 0 deg**

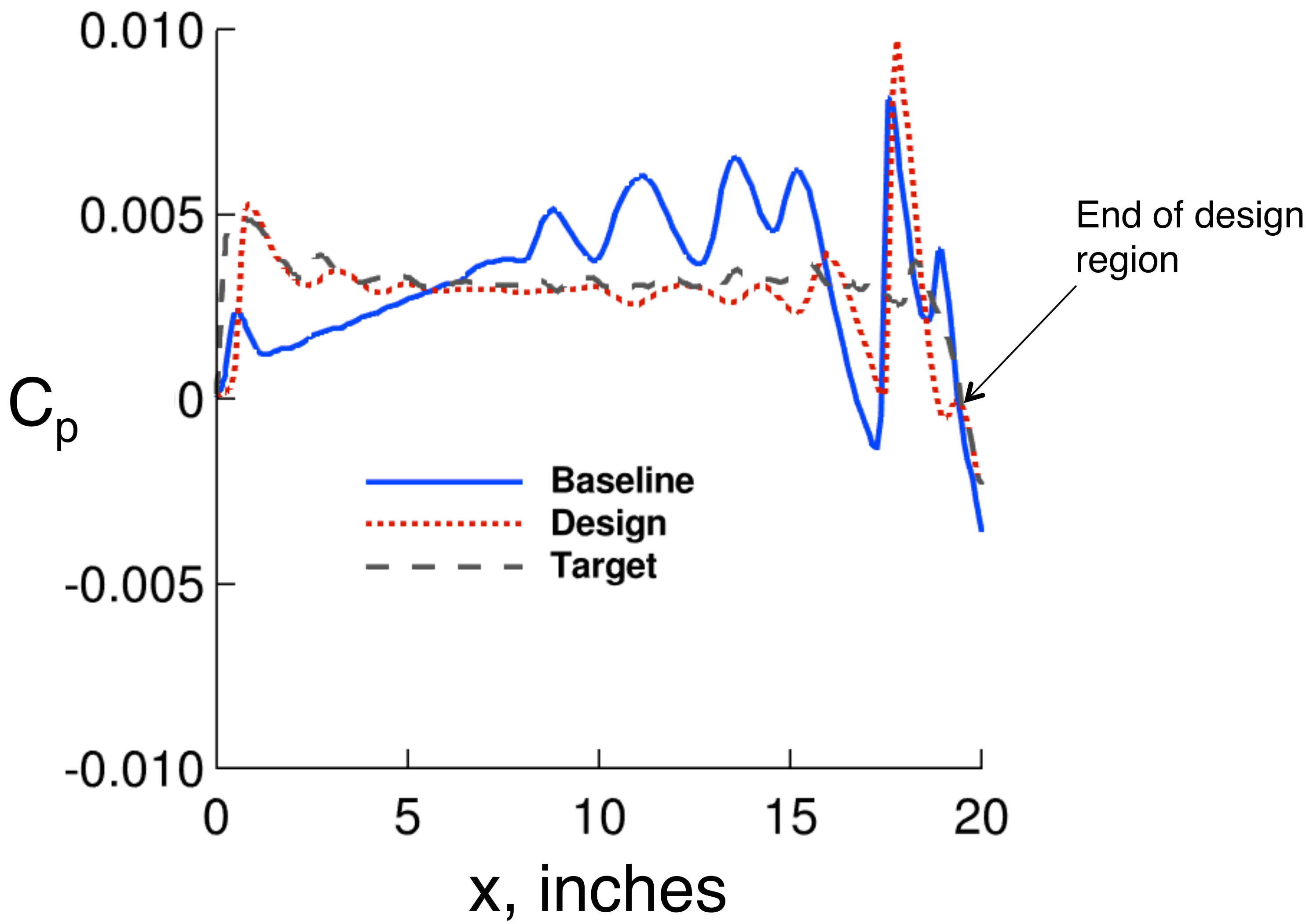


# CDISC Design of SEEB to Near-Field Signature from LM1021 - Geometry

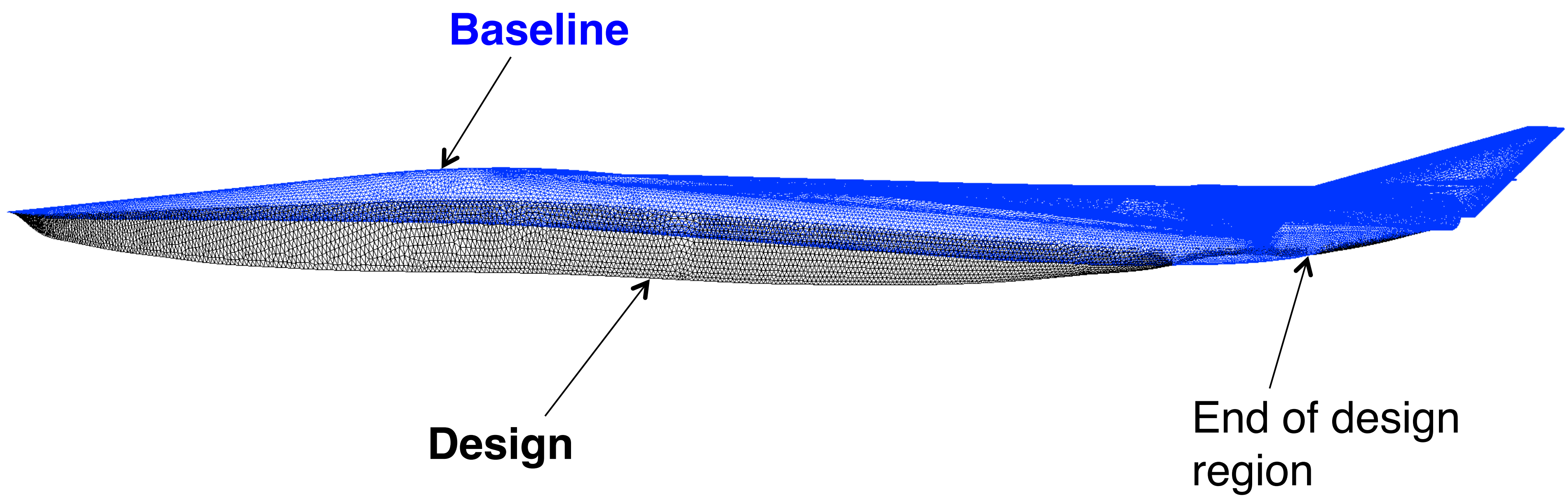


# CDISC Design of LM1021 to Near-Field Signature from SEEB - Pressures

M = 1.6 H/L = 1.4 Φ = 0 deg



# CDISC Design of LM1021 to Near-Field Signature from SEEB - Geometry



# Concluding Remarks

- COB and BG generally produced similar boom signatures across the range for parameters investigated
- Initial guidelines for COB and BG input parameters have been suggested
- CDISC with NFTARG was effective for designing to a target near-field boom signature
- Boom design requires 2-5x more flow iterations per design cycle than the traditional CDISC surface pressure design