USM3D Simulations for Sonic Boom Workshop

Alaa Elmiligui, Melissa Carter, NASA LaRC, Hampton VA.
Susan Cliff, NASA Ames Research Center, Moffett Field, CA.
Sudheer Nayani, Analytical Services & Materials, Hampton VA.
Jason Pearl, University of Vermont, Burlington, VT.

AIAA Aviation and Aeronautics Forum and Exposition
AIAA AVIATION 2017
June 5, 2017
Denver, CO

Outline

- Introduction
- Workshop Test Cases
- Numerical Tools
- Computational Grids
- Numerical Results
- Summary

Introduction

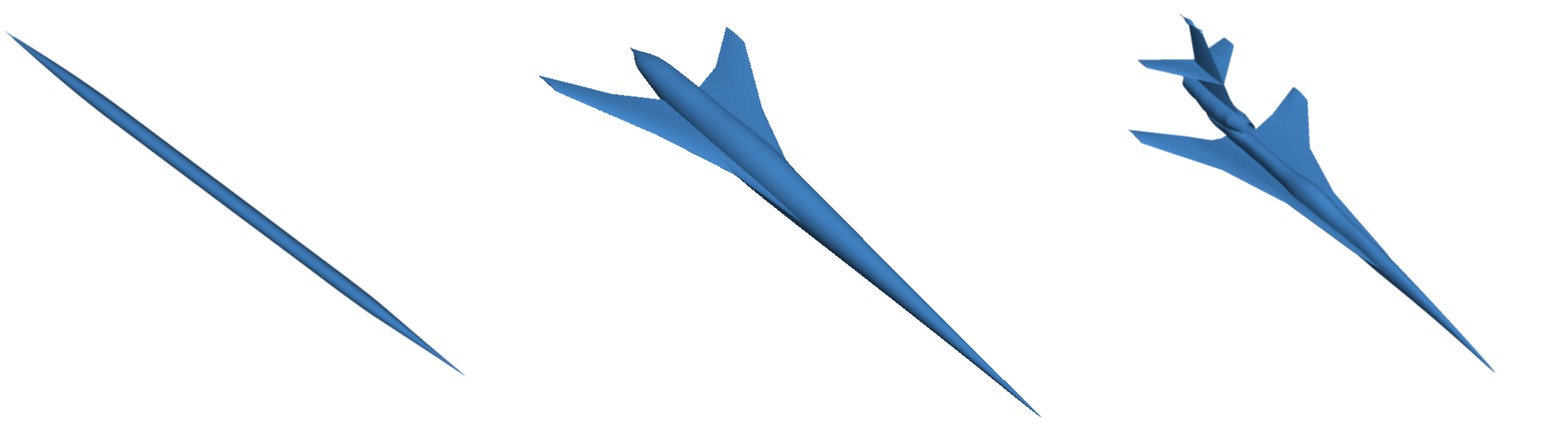
- Second AIAA Sonic Boom Prediction Workshop (SBPW2)
- First day focused on near field simulation.

  "Near Field Summary and Statistical Analysis of the Second AIAA Sonic Boom Prediction." by Michael A. Park & Marian Nemec, AIAA 2017-3256.
- Second day included both near field simulation and atmospheric propagation methods

  "Propagation Summary of the Second AIAA Sonic Boom Prediction Workshop." Sriram Rallabhandi & Alexandra Loubeau. AIAA-2017-3257
- Objective of the present study is to document USM3D results

2^{nd} AIAA Sonic Boom Prediction Workshop

- Four Configurations:
  - Axisymmetric Low Boom Body of Revolution
  - JAXA Wing-Body Configuration
  - NASA C25D Configuration with Flow Through Nacelles
  - NASA C25D Configuration with Powered Nacelles



2nd AIAA Sonic Boom Prediction Workshop

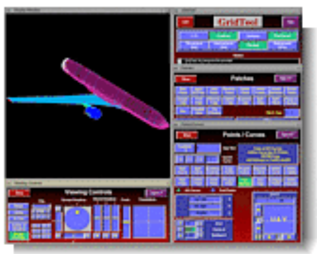
- Four Configurations:
  - Axisymmetric Low Boom Body of Revolution
  - JAXA Wing-Body Configuration
  - NASA C25D Configuration with Flow Through Nacelles
  - NASA C25D Configuration with Powered Nacelles

All four test cases were designed to generate, at three body lengths, similar on-track near field pressure signatures

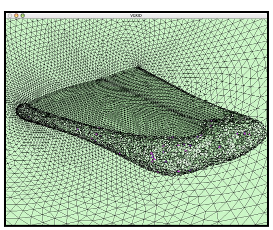
Tetrahedral Unstructured Software System

A proven, stable, and reliable multiplatform system for unstructured Euler and Navier-Stokes CFD analysis.

- *Complete flow analysis system*
- *Well developed infrastructure*
- *In-house experts*
- *Broad outside collaborations*
- *Design via. CDISC/SUSIE*
- *Workhorse system with large experience/confidence base*

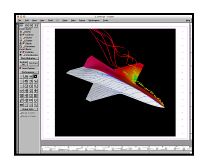


Geometry Setup
GridTool

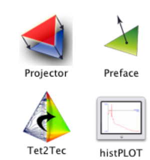


Grid Generation
VGRID OpenGL

Flow Solver
USM3D



Visualization
SimpleView
(Commercial Packages)



Tools & Utilities

Numerical Tools

- **USM3D Tetrahedral Flow Solver**
  - **Tetrahedral Cell-Centered, Finite Volume**
  - **Euler and Navier-Stokes**
  - **Time Integration**
    - LTS and 2^{nd} order time stepping
  - **Upwind Spatial Discretization**
    - FDS, AUSM, HLLC, LDFSS, FVS
    - Min-mod limiter
  - **Turbulence Models** SA, kε, SST
- **sBOOM, Loudness**

Computational Grids

- Two sets of grids:
  - The first set of grids was the tetrahedral grids provided by the SBPW2
  - The second set of grids was in-house family of grids generated by VGRID for the inner grid and BG for the outer collar grid

Axisymmetric Low Boom Body of Revolution

Low Boom Body of Revolution

Test Conditions:

- Mach 1.6
- Angle of attack 0.0°
- Reference length 32.92 m
- Altitude 15760 m
- Temperature 216.65 K
- Flight Reynolds Number per meter 5.70 million

Axisymmetric Low Boom Body of Revolution

- Workshop provided grids were a subdivision of the mixed-element grids
- Grids are in full scale meters and have a uniformly refined spacing

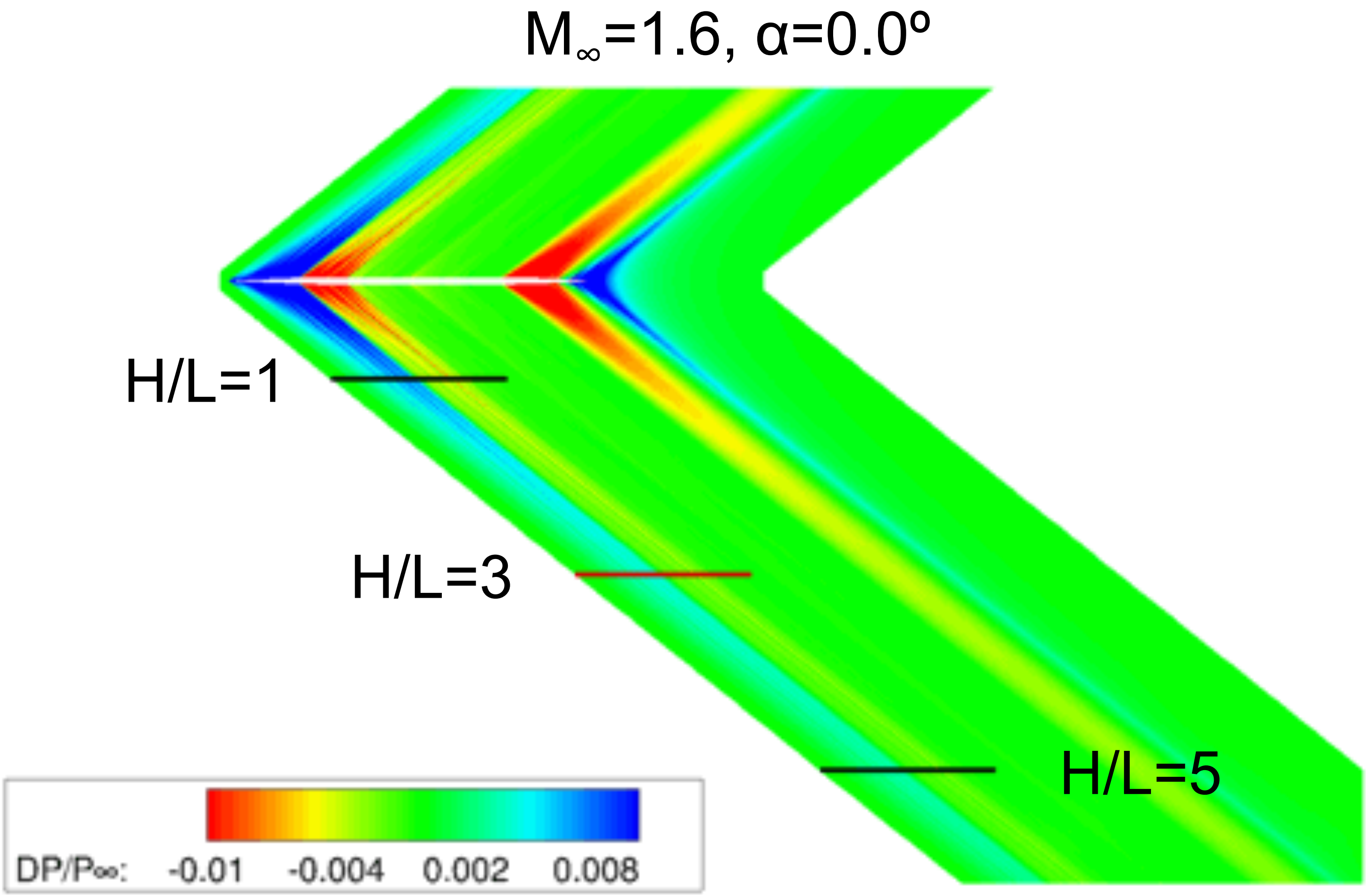
Grid	Nodes	Tetrahedra
AXIE_1	646,467	3,705,046
AXIE_2	1,601,681	9,243,626
AXIE_3	5,077,104	29,682,640
AXIE_4	15,911,412	93,751,314
AXIE_5	56,085,031	332,136,840

Low Boom Body of Revolution

- In-house VGRID grids

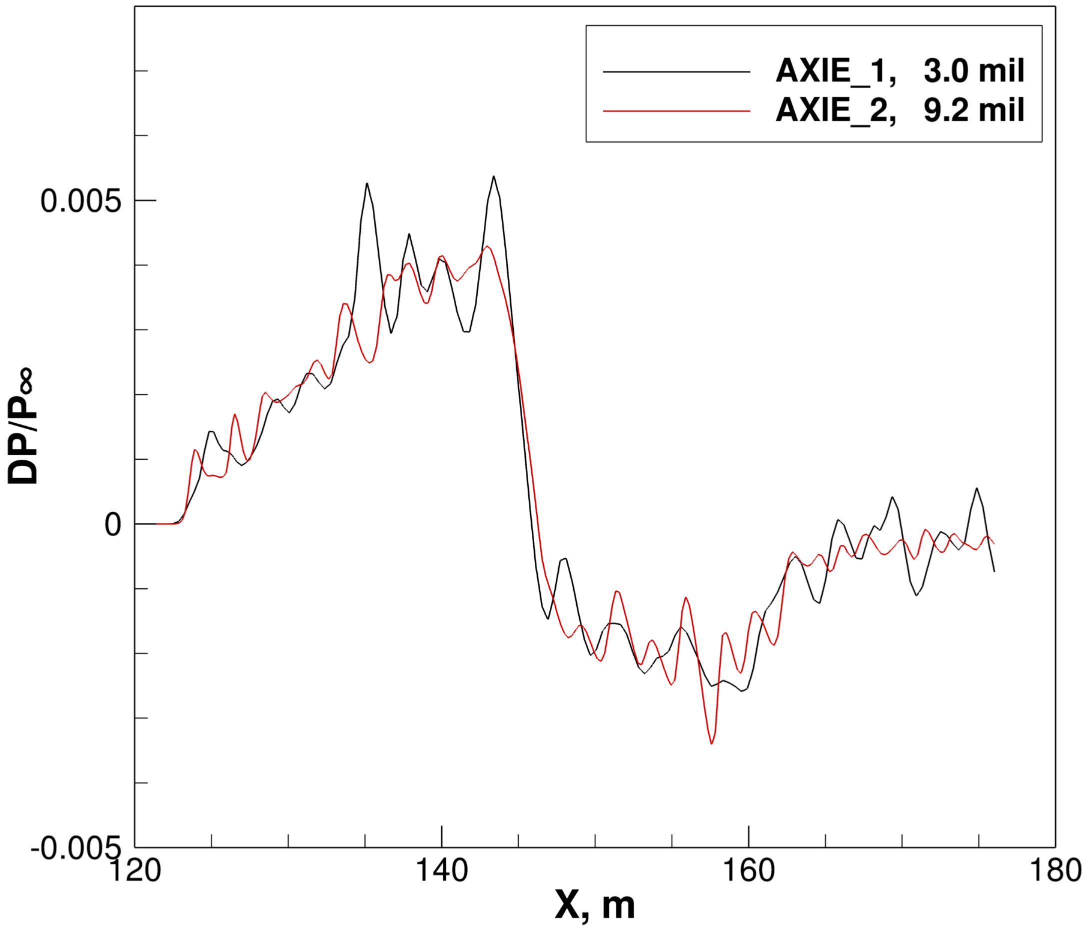
Grid	Nodes	Tetrahedra
VGRID_1	646,467	47,821,570
VGRID_2	15,918,977	93,341,956
VGRID_3	49,670,934	293,292,643

Symmetry Plane Overpressure Contours



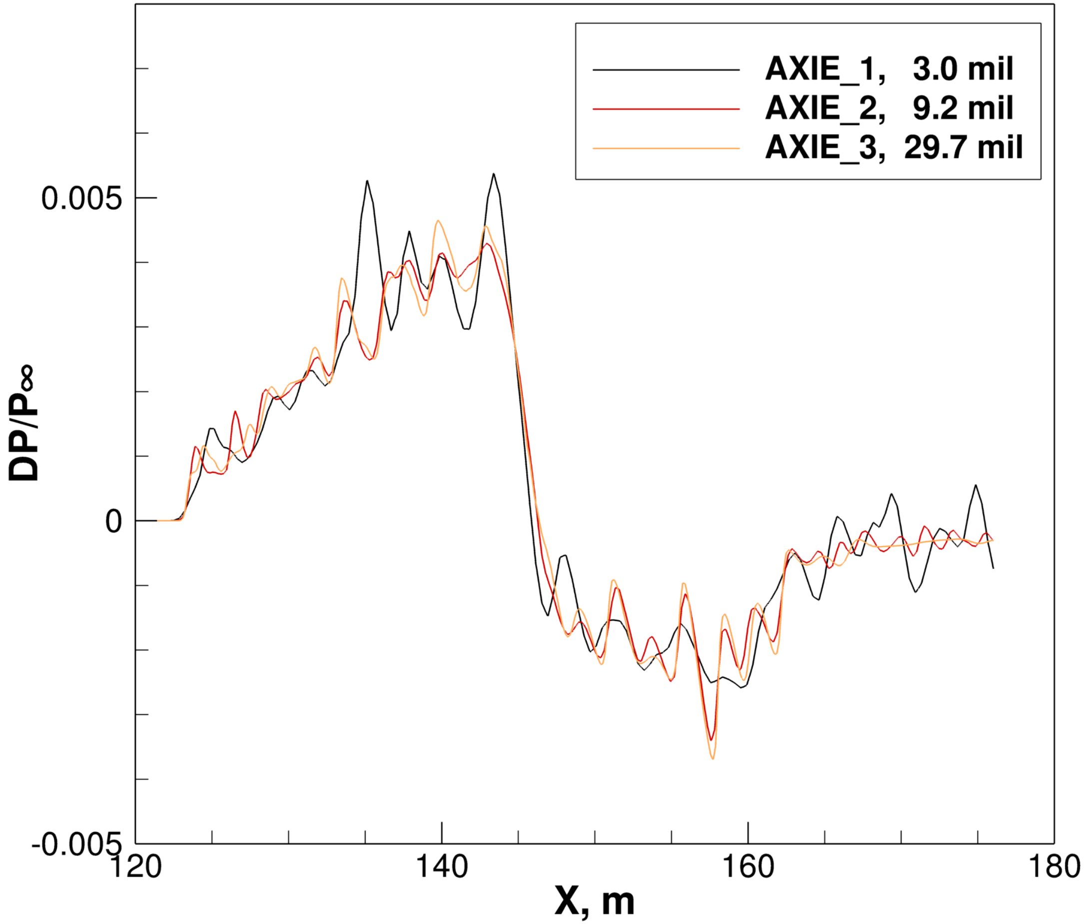
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0º, H/L=3



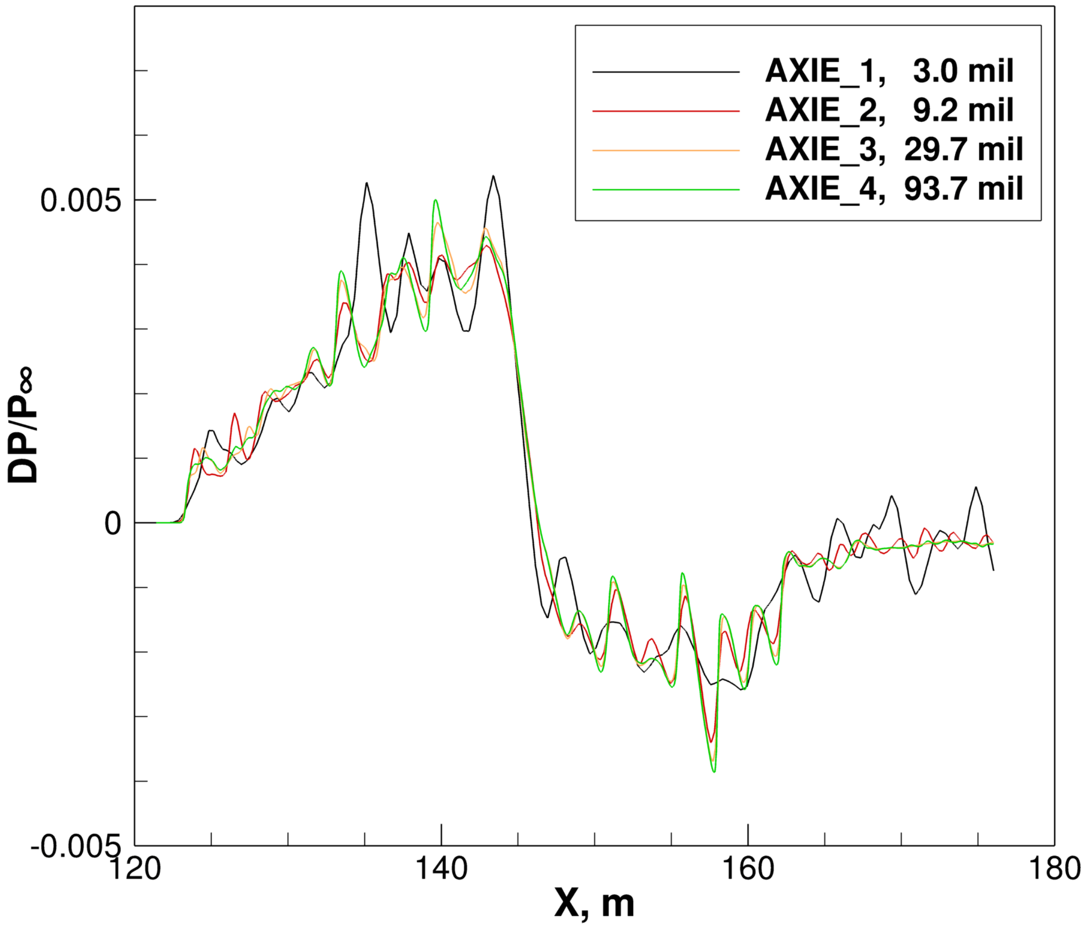
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0°, H/L=3



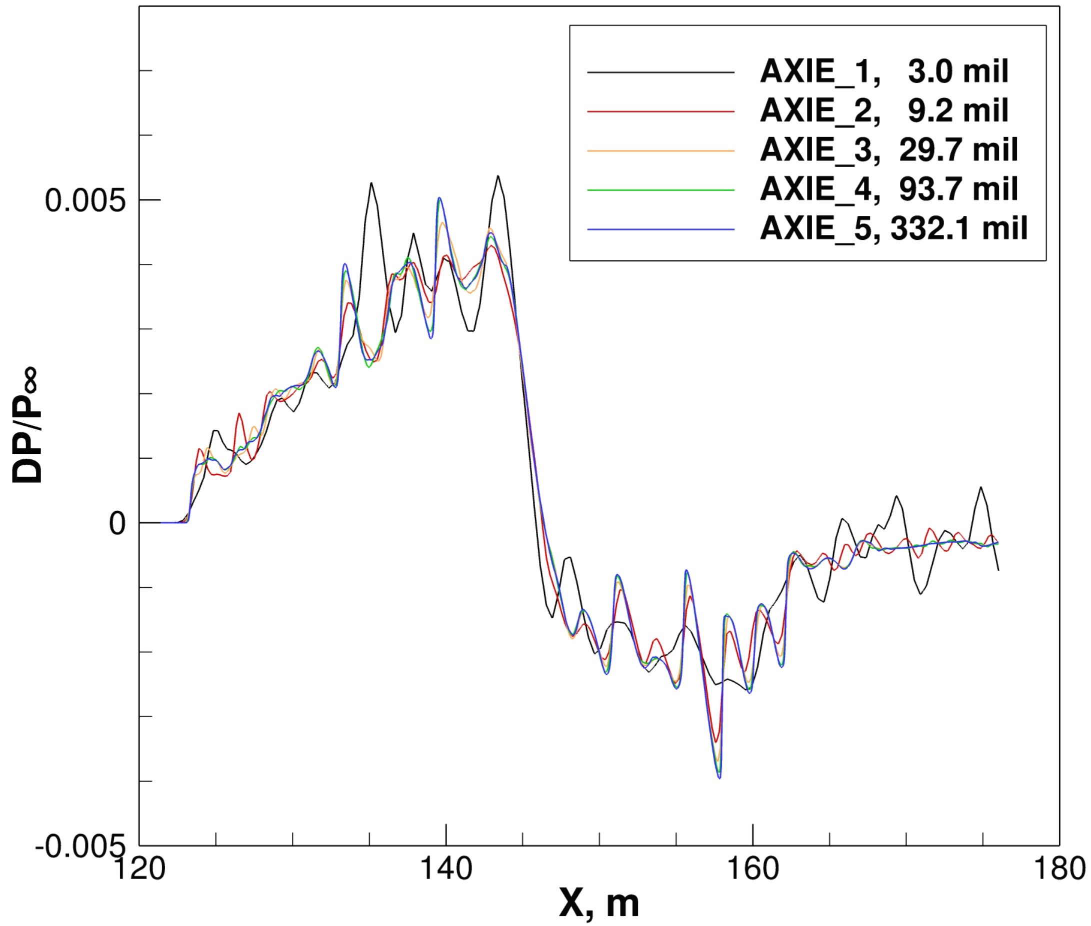
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0º, H/L=3

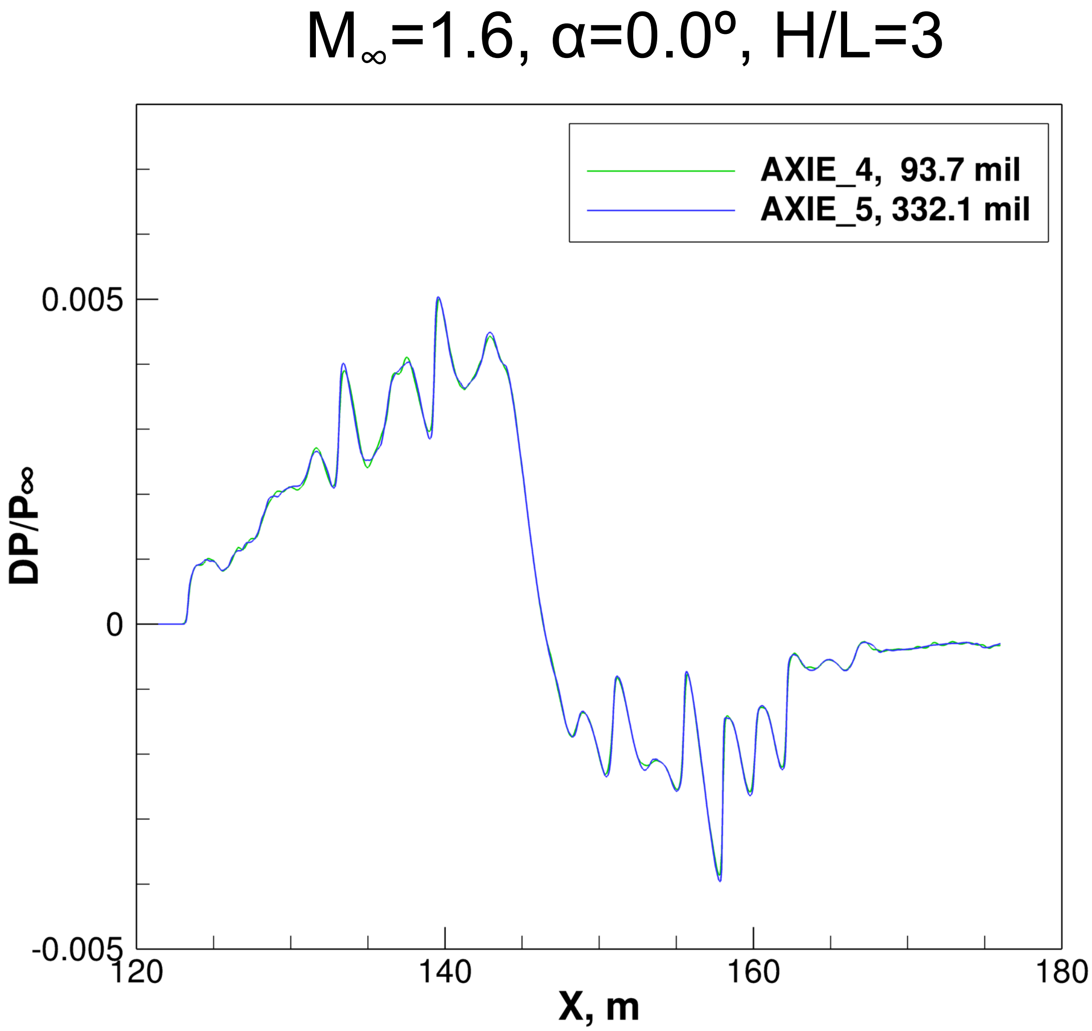


USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0°, H/L=3

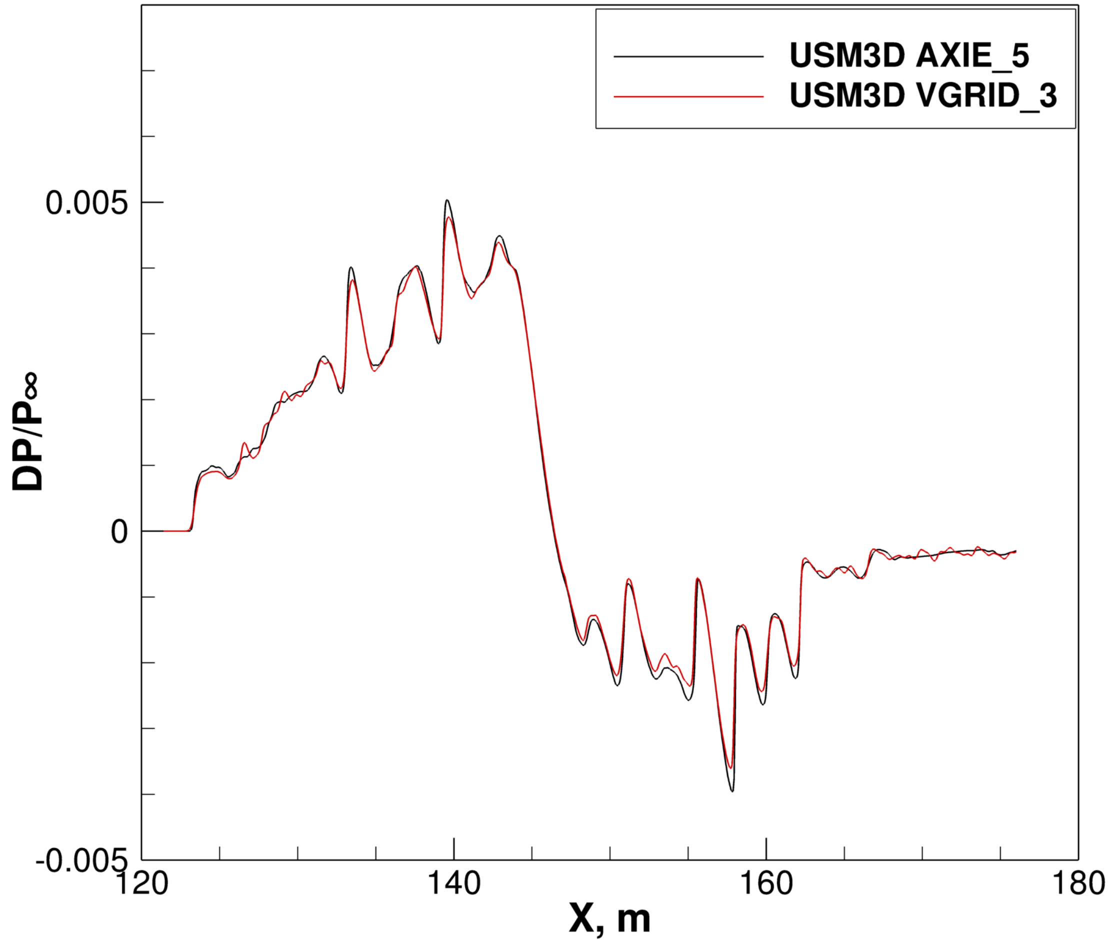


USM3D Near Field Pressure Signatures

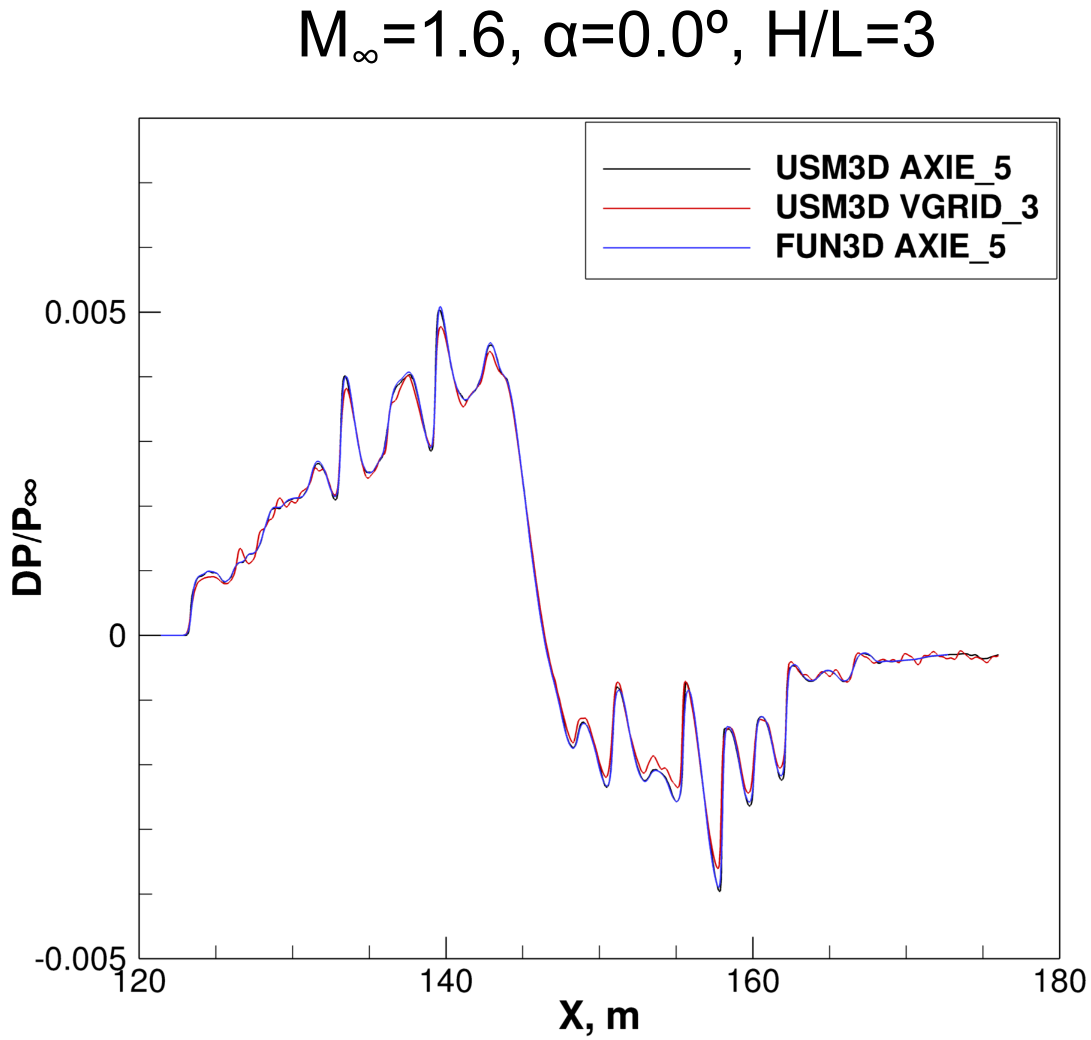


Comparison of Near Field Pressure Signatures

M_{∞}=1.6, α=0.0º, H/L=3

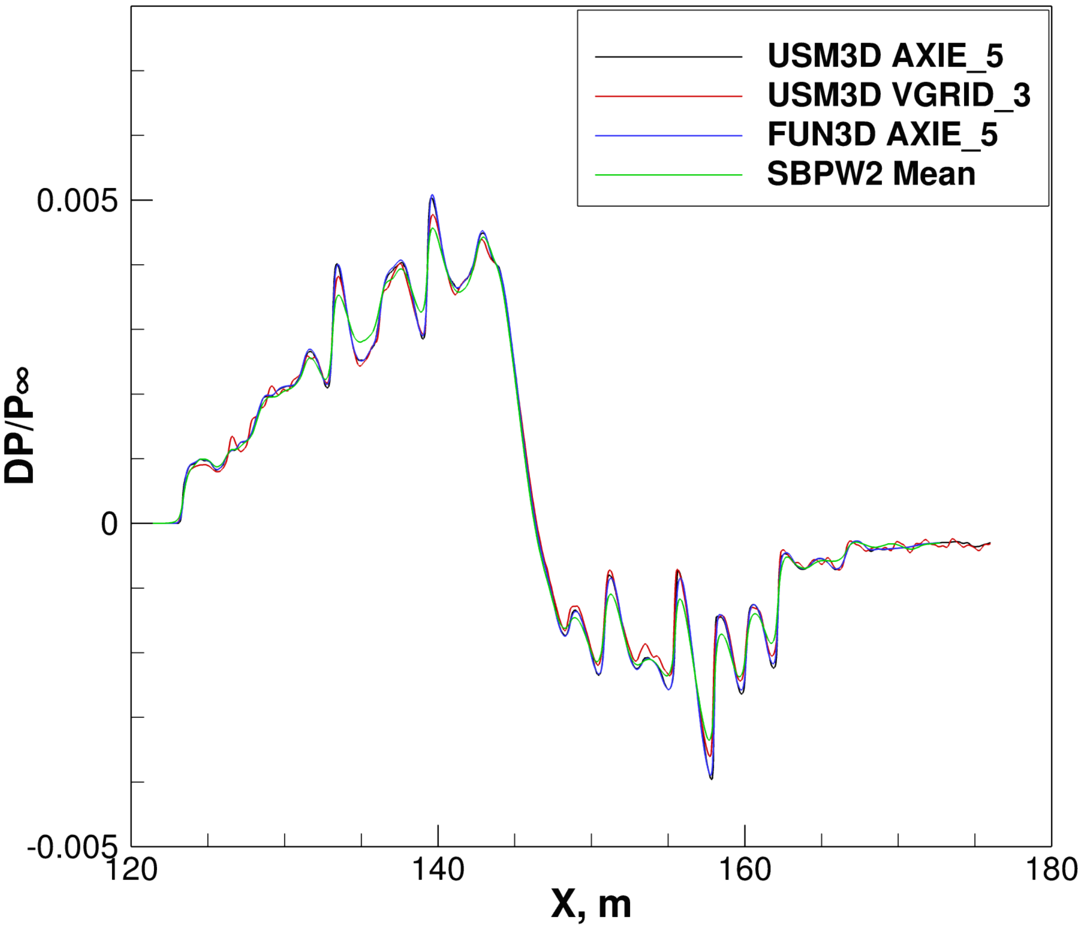


Comparison of Near Field Pressure Signatures



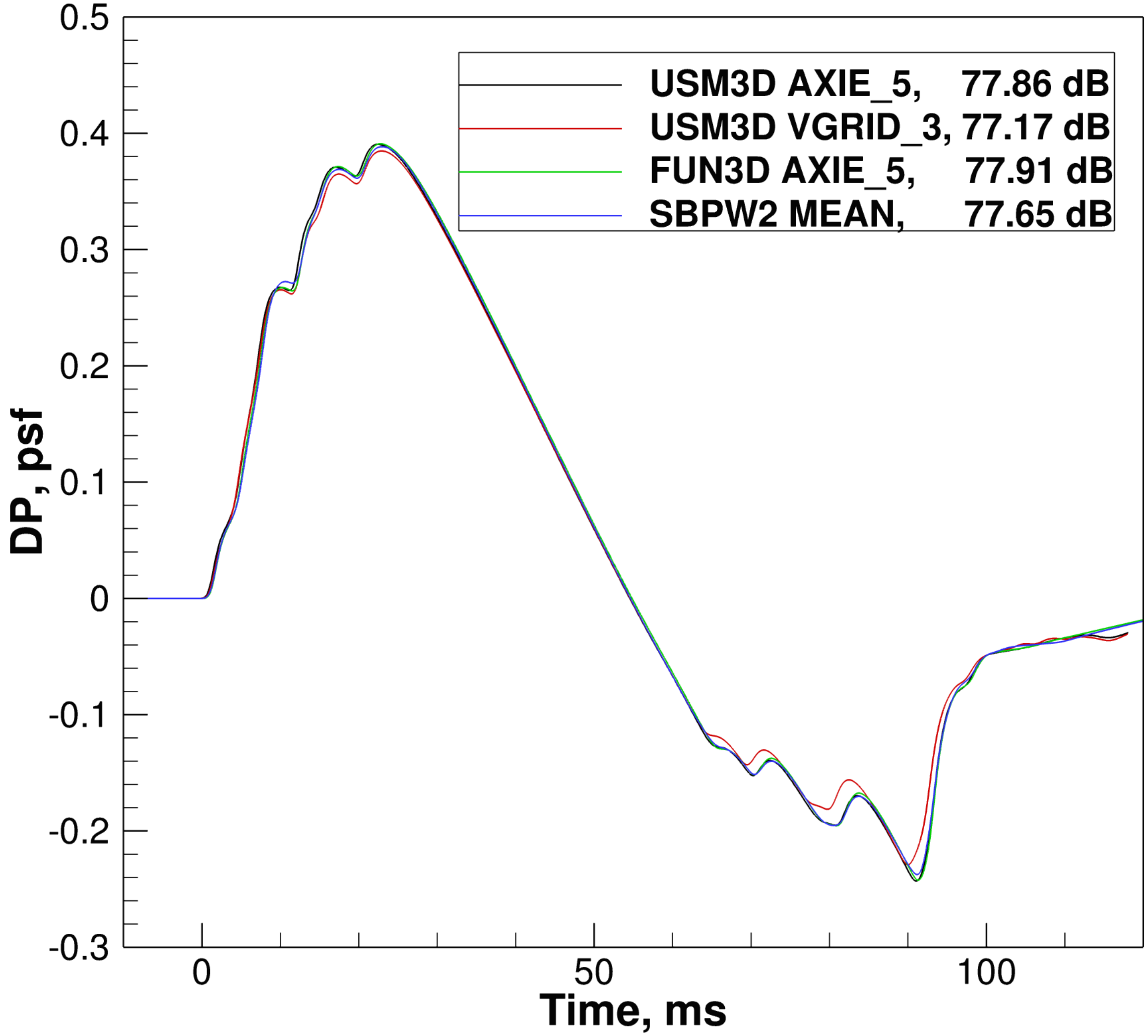
Comparison of Near Field Pressure Signatures

M_∞=1.6, α=0.0°, H/L=3

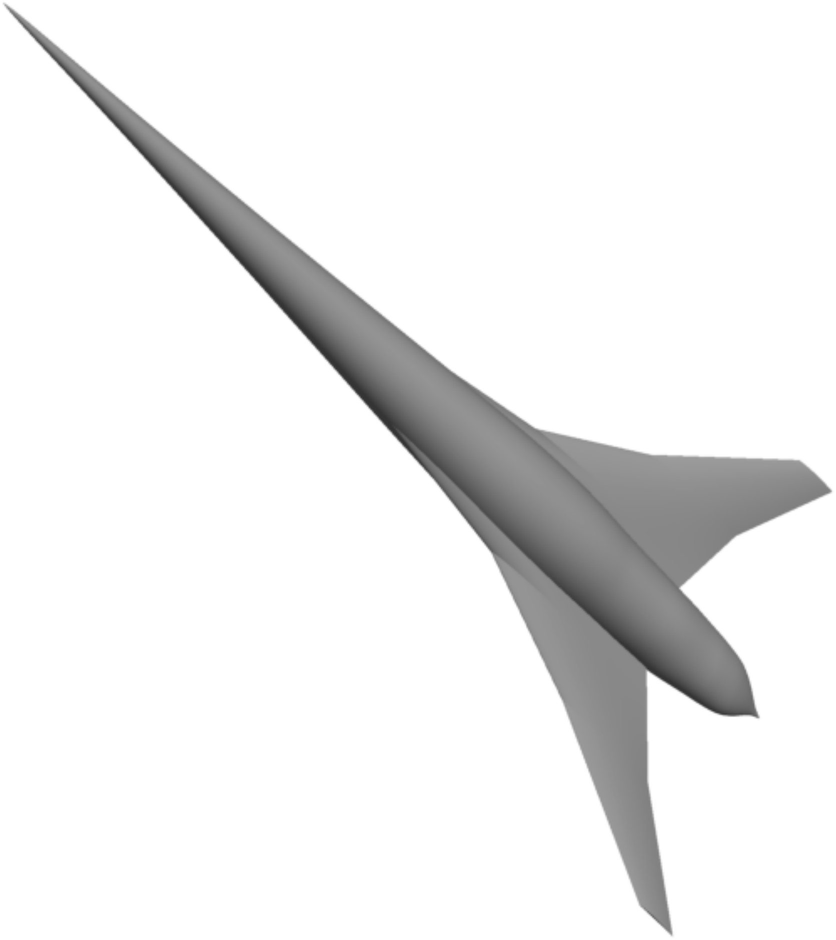


sBOOM Ground Signatures

M_∞=1.6, α=0.0º



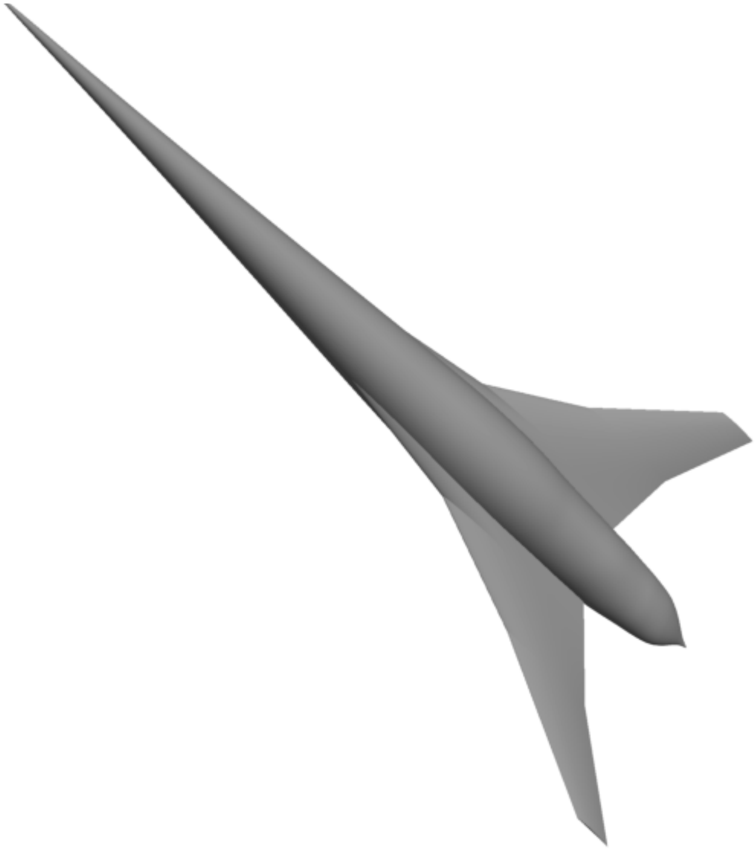
JAXA Wing-Body Configuration



JAXA Wing-Body Configuration

Test Conditions:

- Mach 1.6
- Angle of attack 0.0°
- Reference length 38.7 m
- Reference area 32.8 m^2
- Altitude 15760 m
- Temperature 216.65 K
- Flight Reynolds Number per meter 5.70 million



JAXA Wing-Body Configuration

- Workshop provided grids

Grid	Nodes	Tetrahedra
JWB-1	6,491,425	37,397,159
JWB-2	11,335,260	65,432,421
JWB-3	18,875,613	109,141,197

JAXA Wing-Body Configuration

- Workshop provided grids

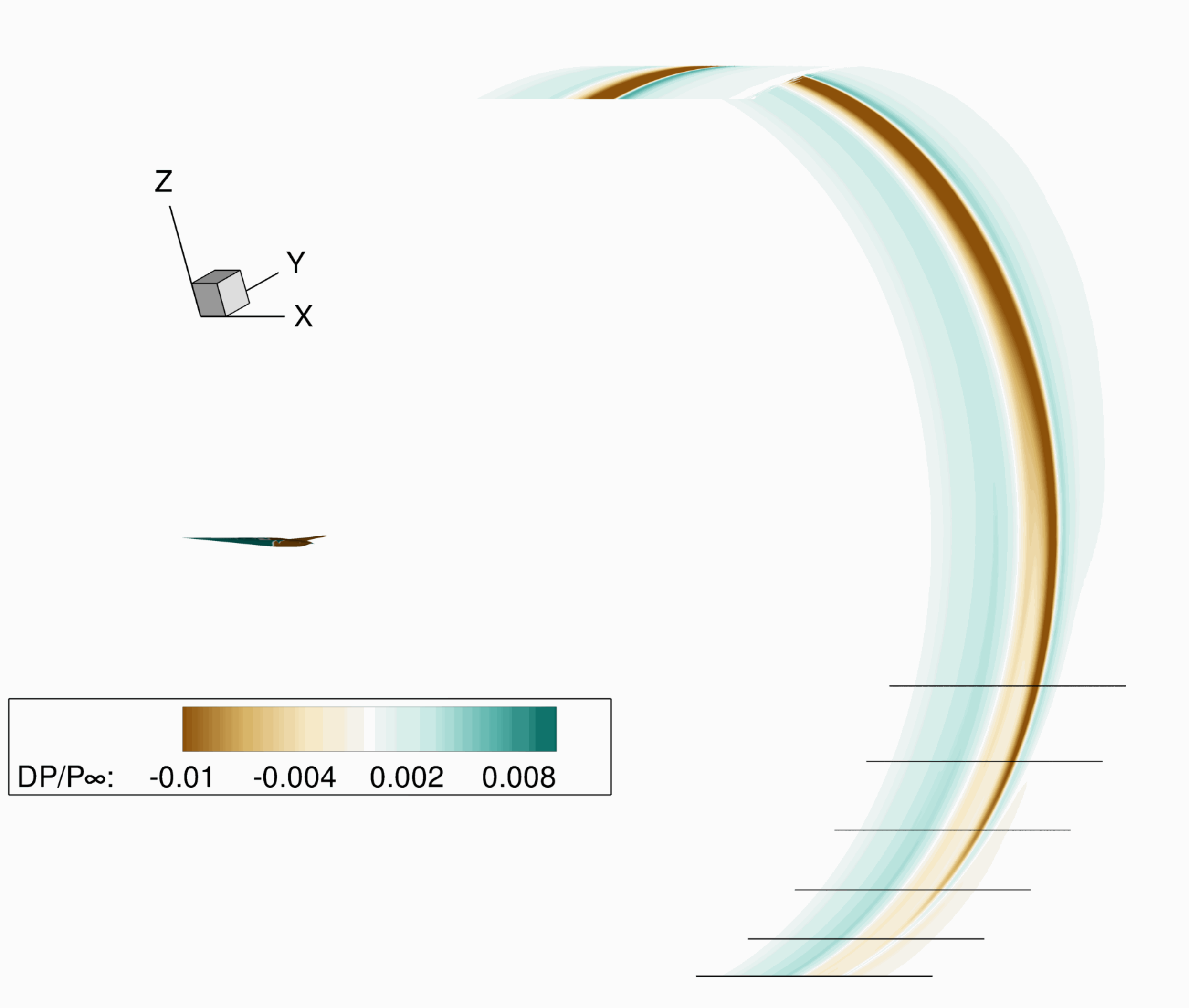
Grid	Nodes	Tetrahedra
JWB-1	6,491,425	37,397,159
JWB-2	11,335,260	65,432,421
JWB-3	18,875,613	109,141,197

- In-house VGRID grids

Grid	Nodes	Tetrahedra
VGRID_1	2,288,839	13,242,743
VGRID_2	4,469,805	25,999,618
VGRID_3	7,228,240	42,220,169

Overpressure Contours of the JWB

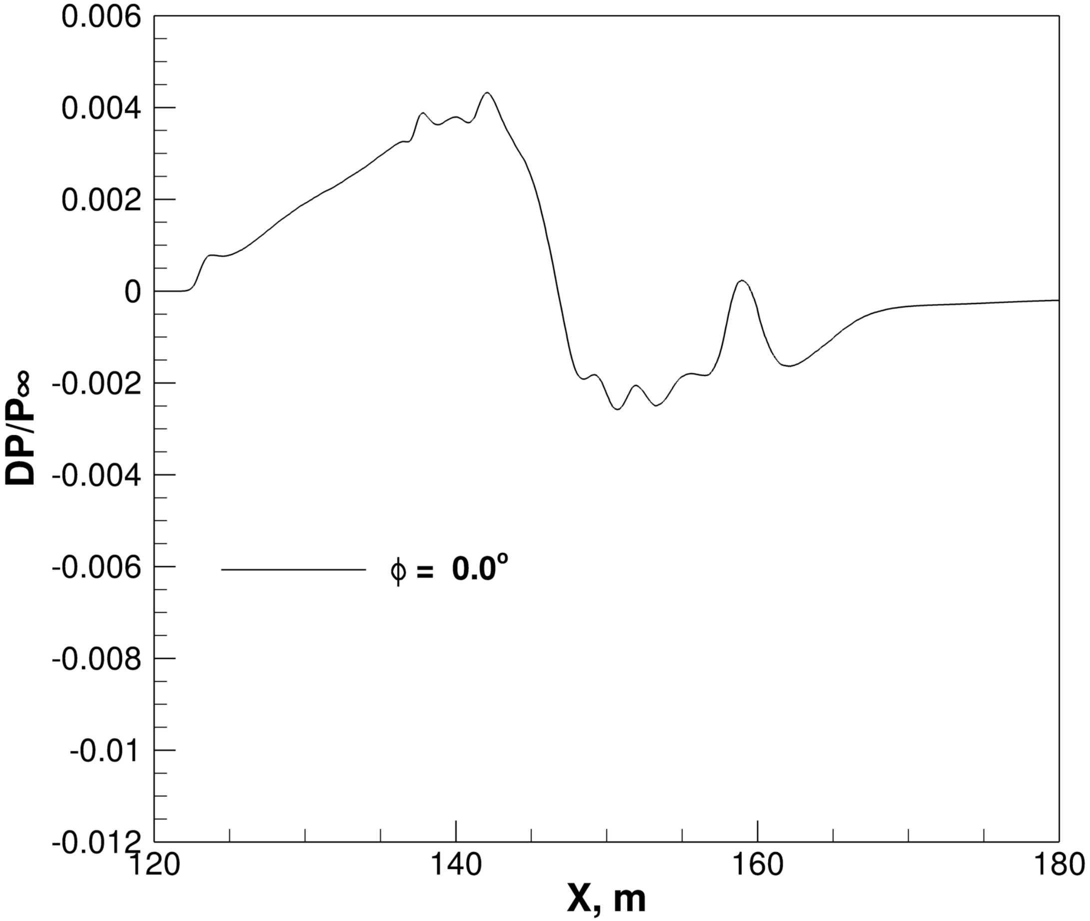
M_∞=1.6, α=0.0°, H/L=3



USM3D Near Field Pressure Signature

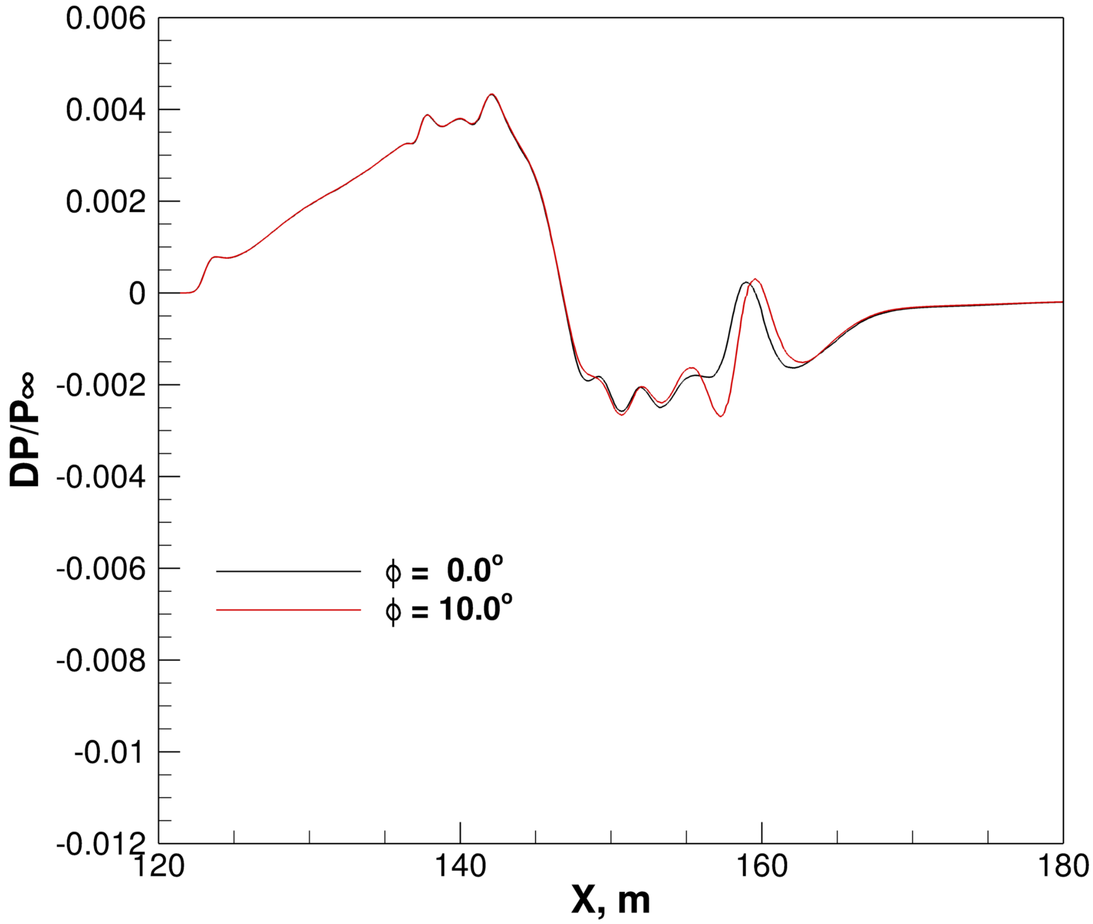
M_∞=1.6, α=0.0º, H/L=3

JWB-3
109 mil.



USM3D Near Field Pressure Signatures

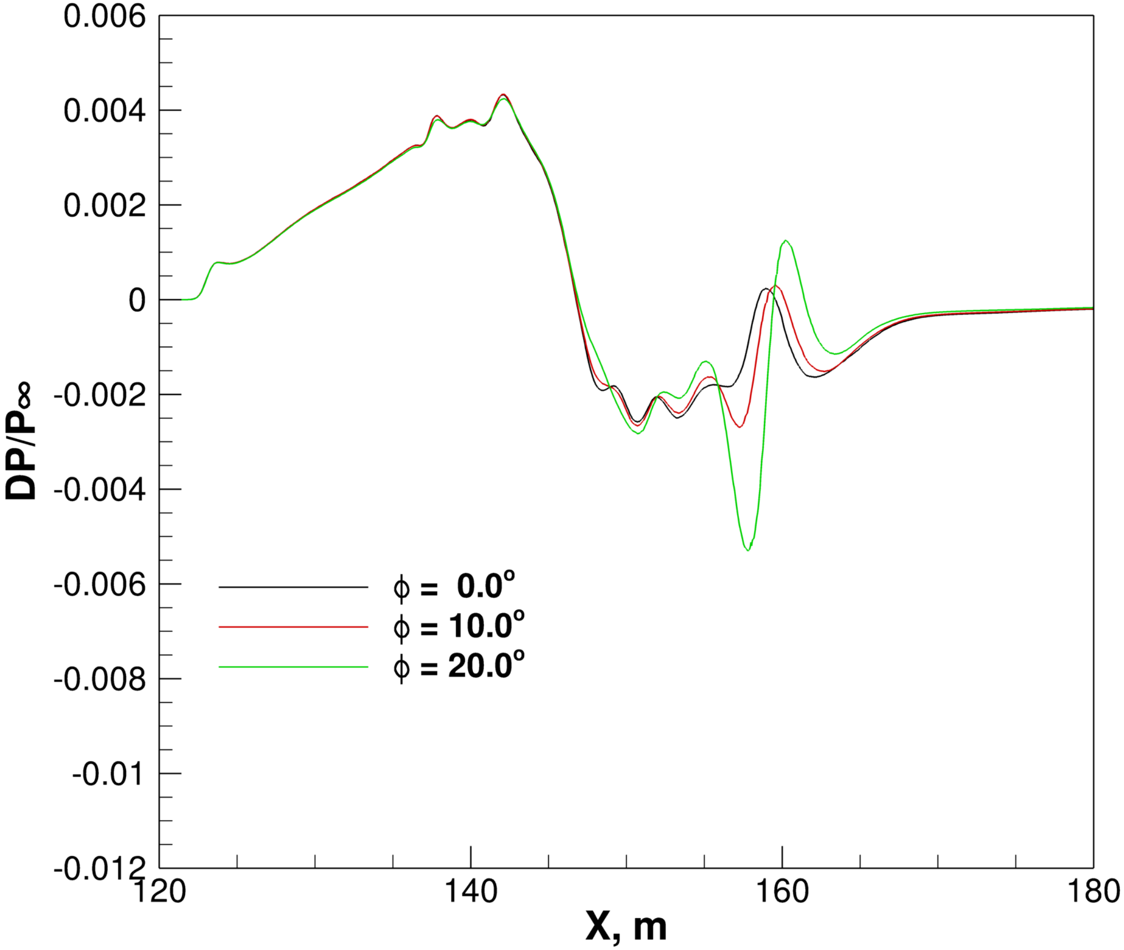
$M_\infty=1.6$, $\alpha=0.0°$, H/L=3



JWB-3
109 mil.

USM3D Near Field Pressure Signatures

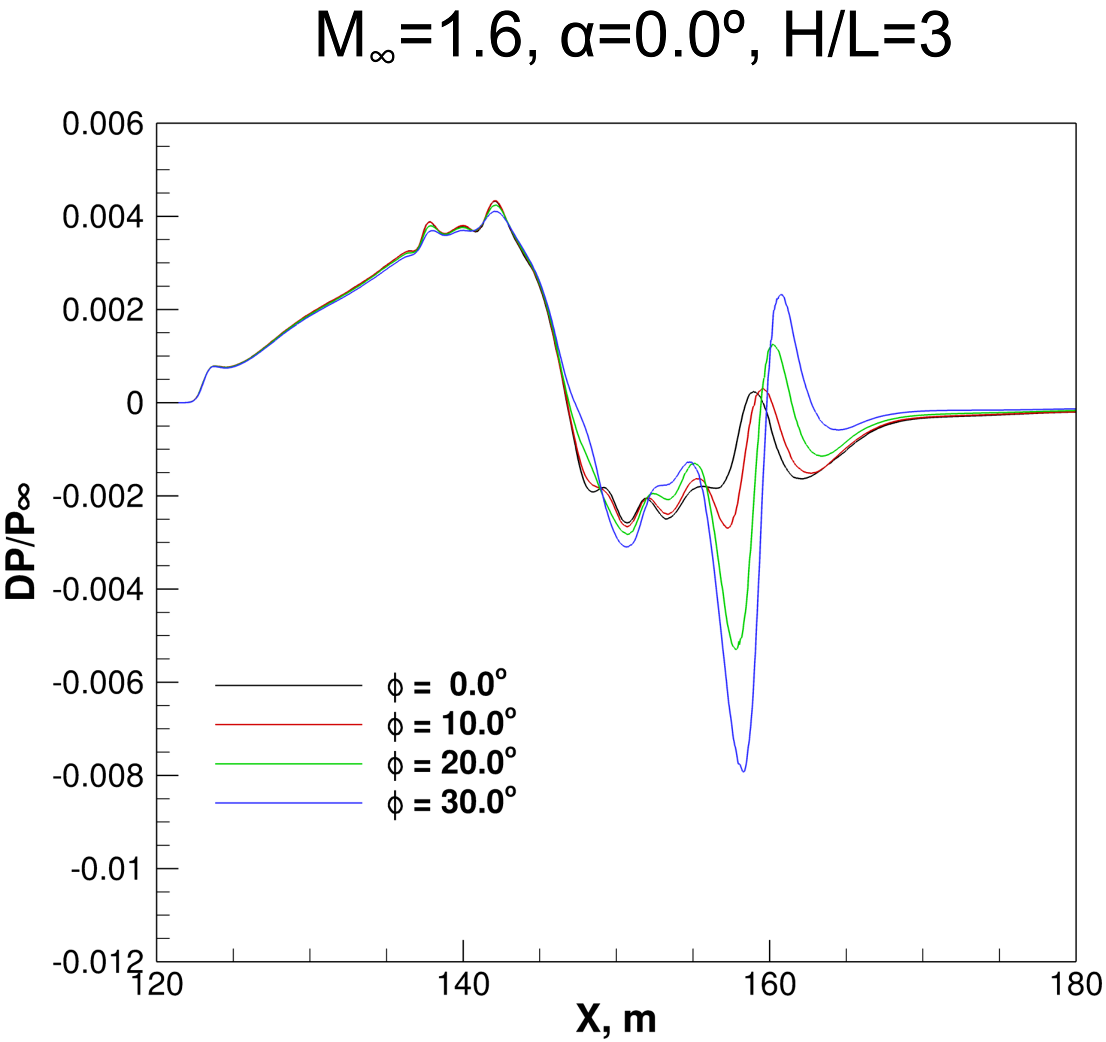
M_∞=1.6, α=0.0°, H/L=3



JWB-3
109 mil.

USM3D Near Field Pressure Signatures

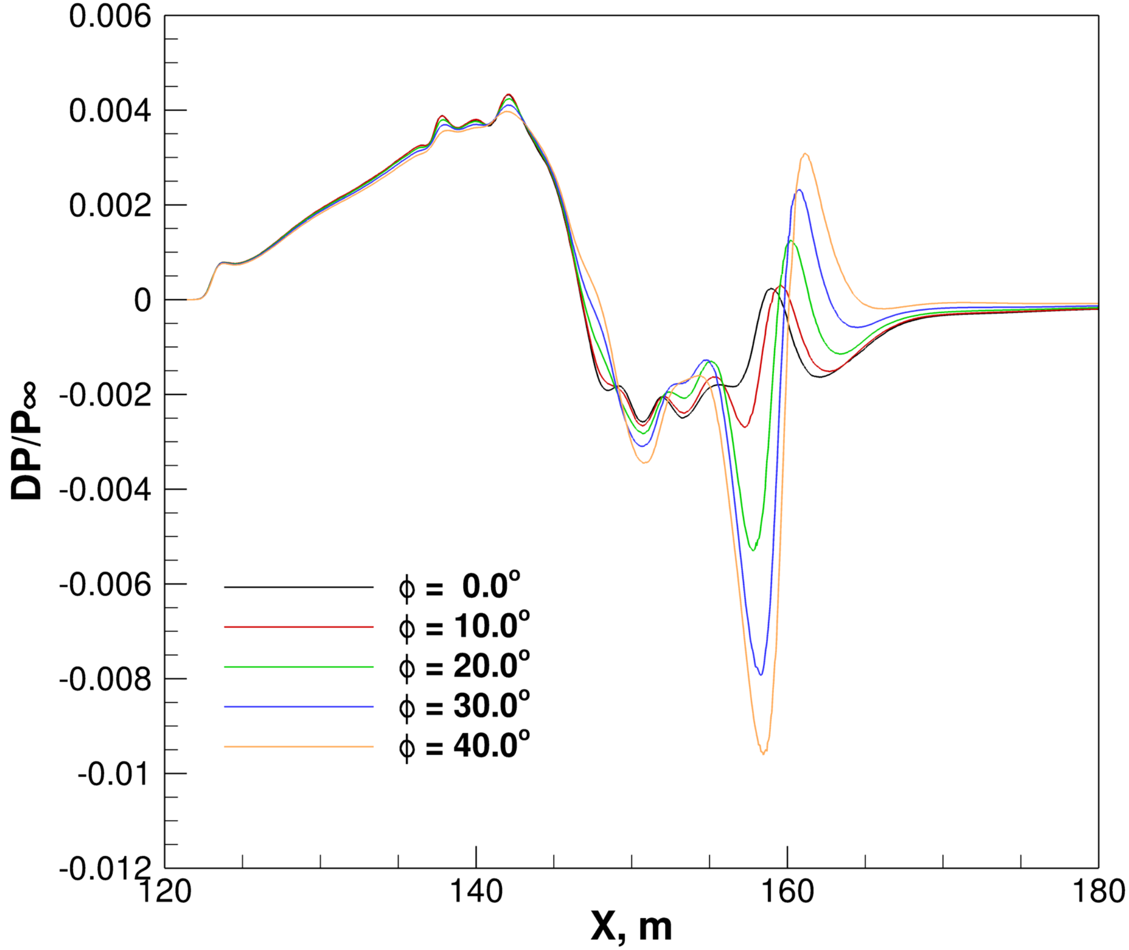
JWB-3
109 mil.



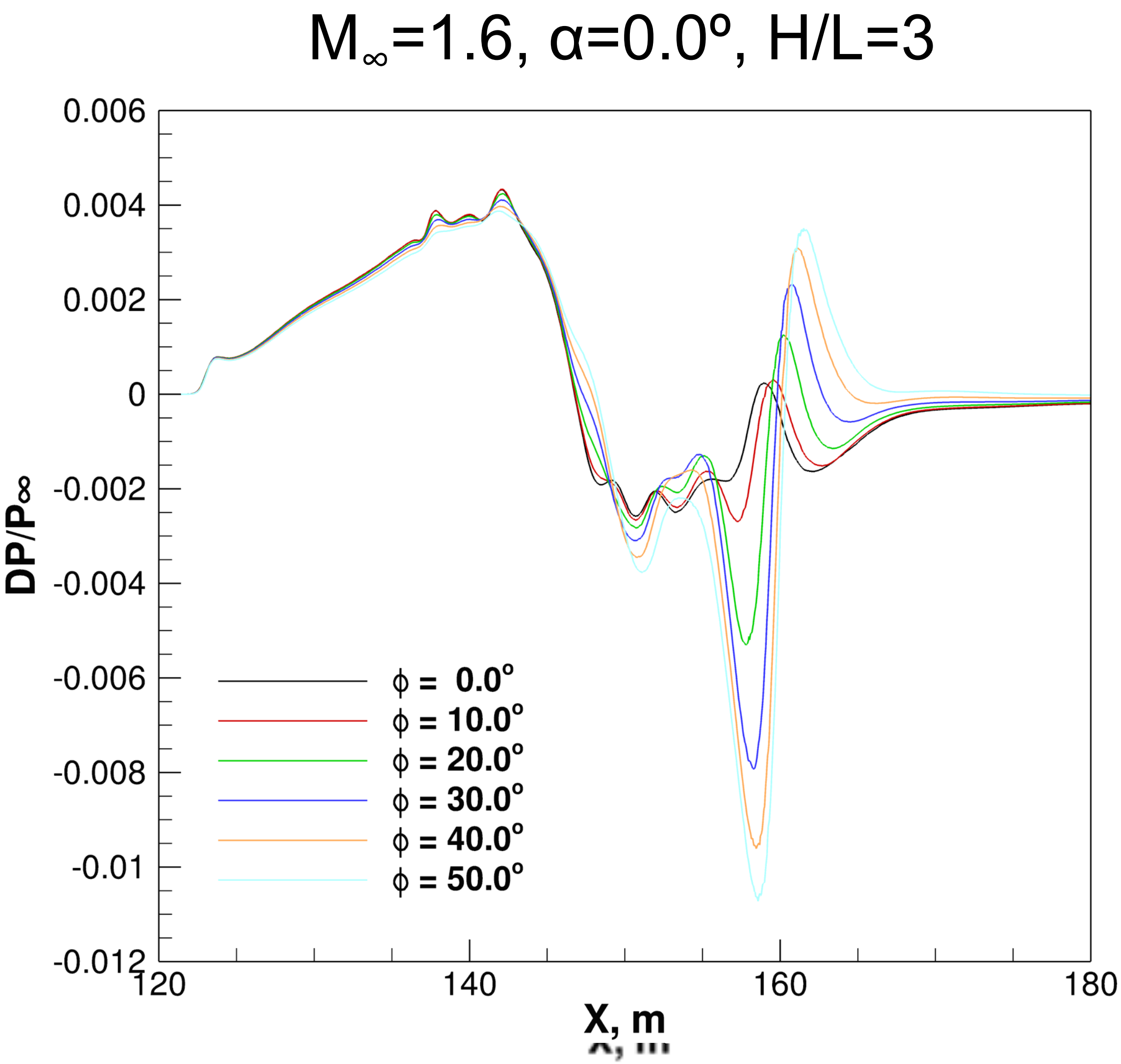
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0°, H/L=3

JWB-3
109 mil.



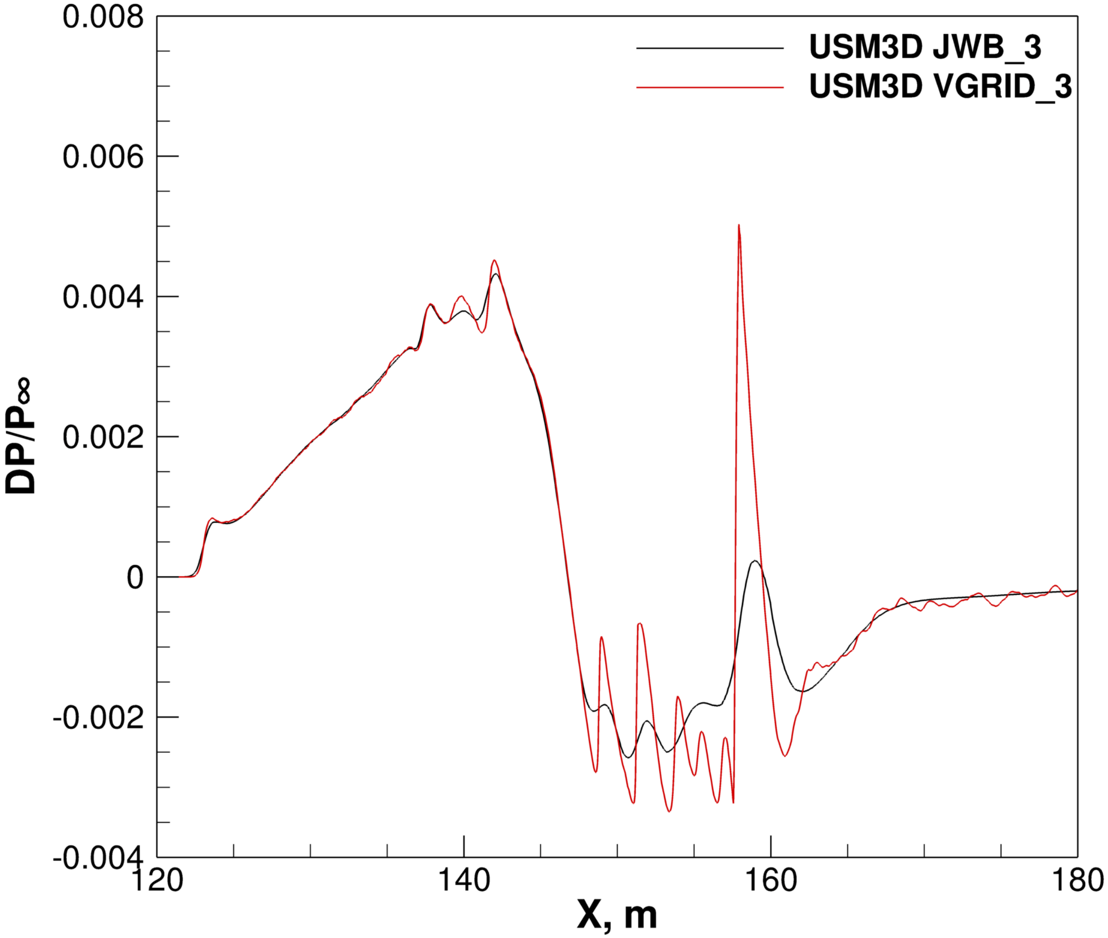
USM3D Near Field Pressure Signatures



JWB-3
109 mil.

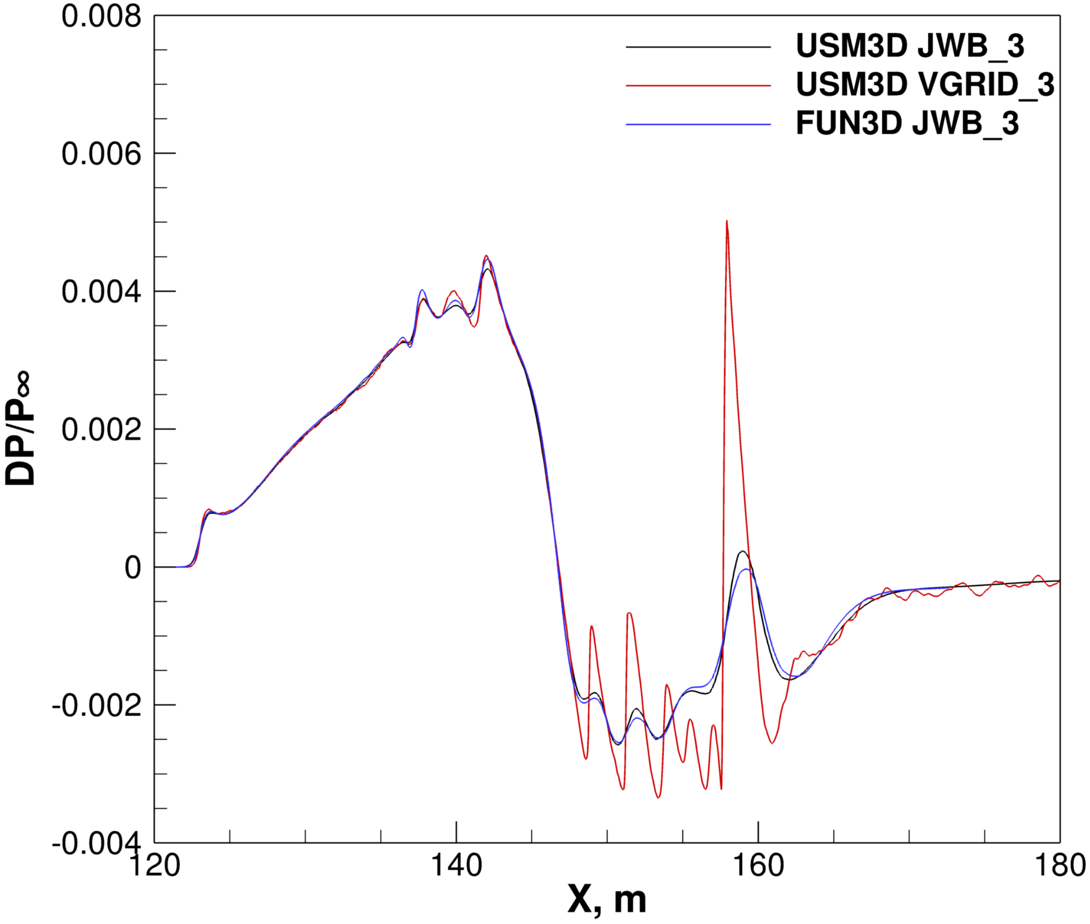
Comparison of Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3



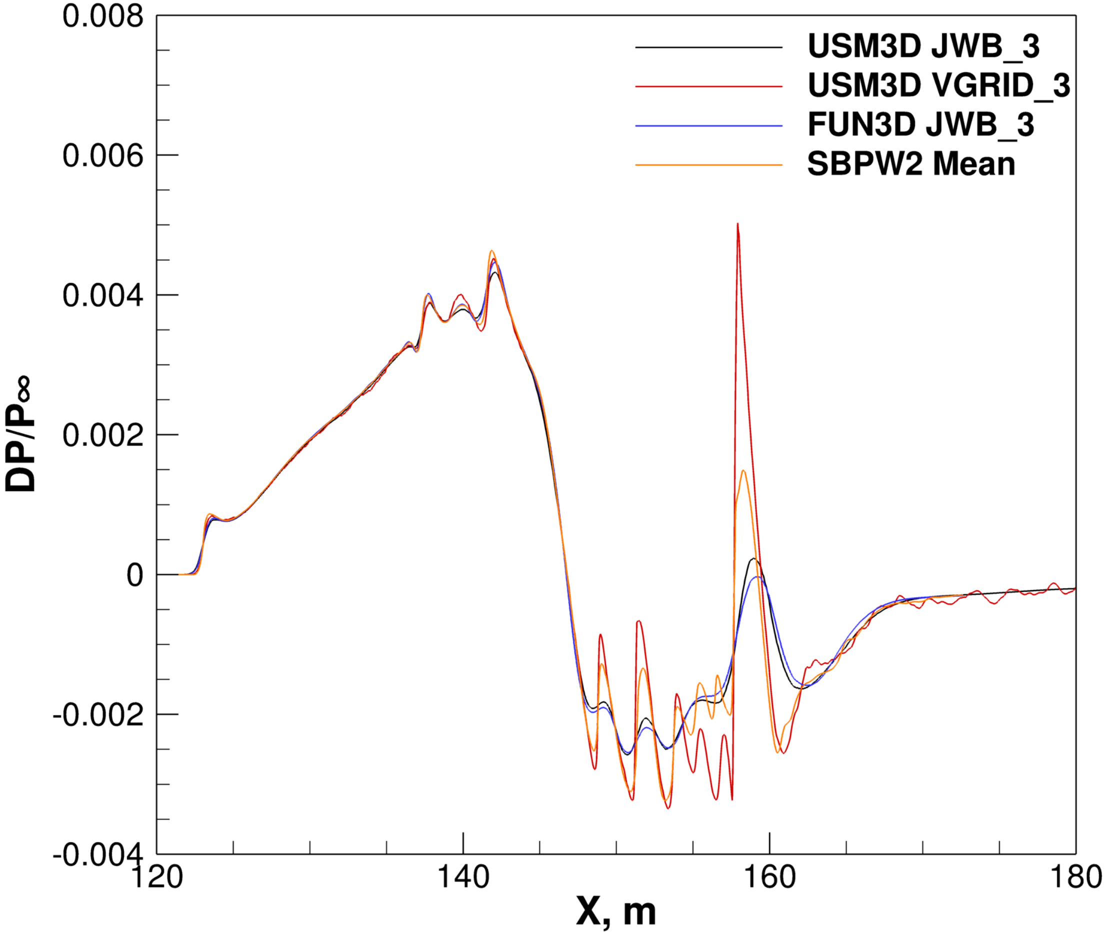
Comparison of Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3



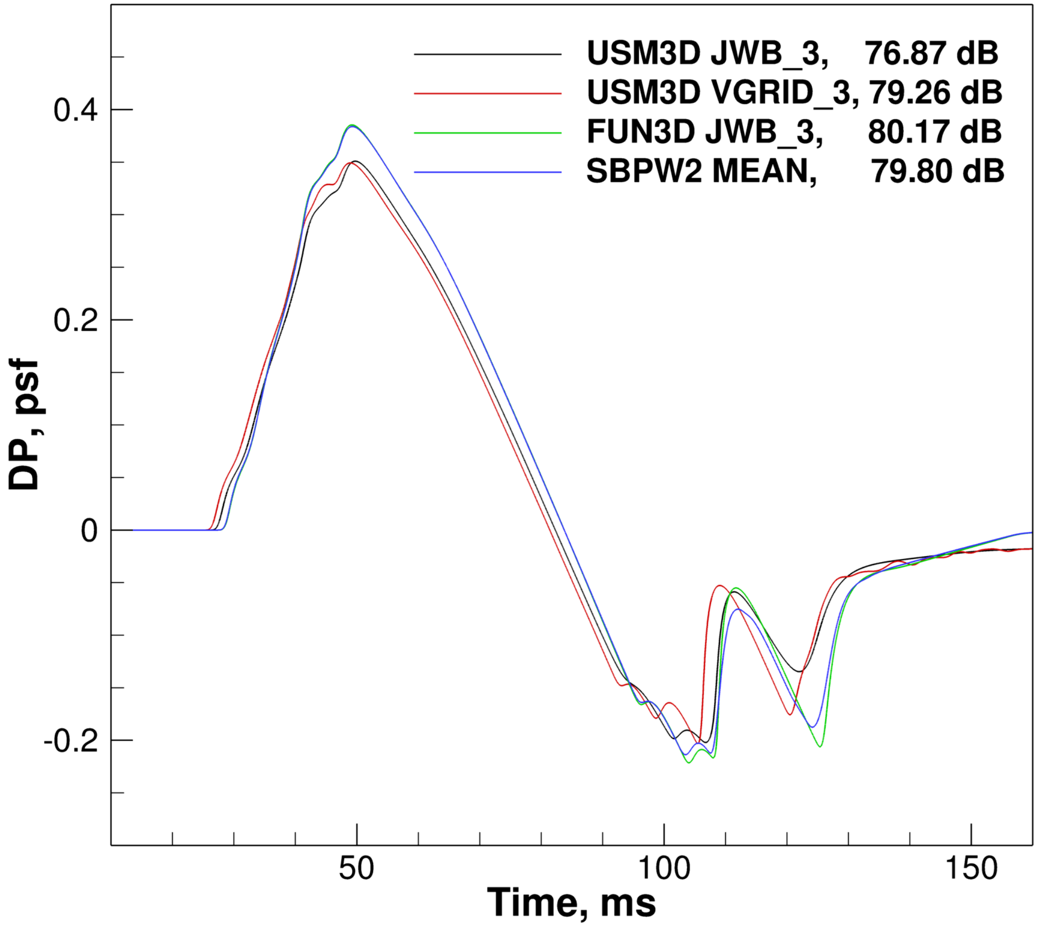
Comparison of Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3



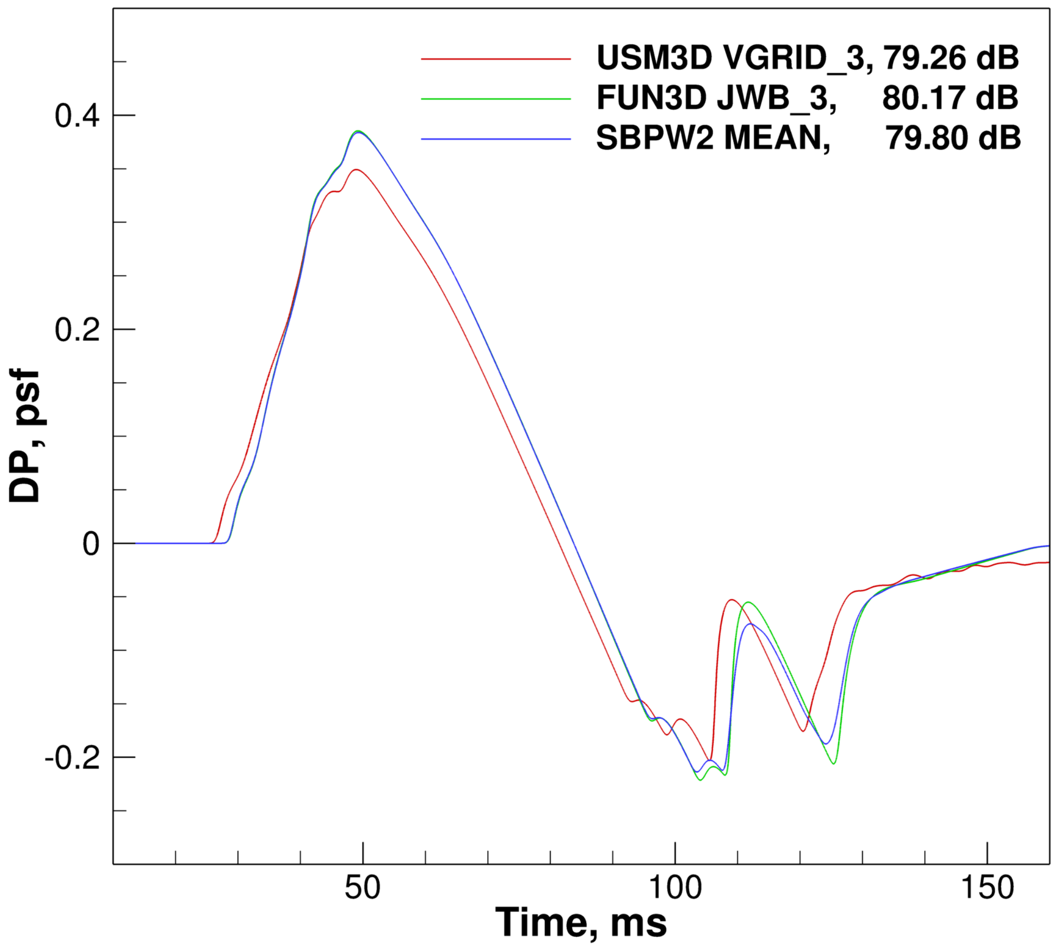
sBOOM Ground Signatures

M_∞=1.6, α=0.0º, Φ=0º

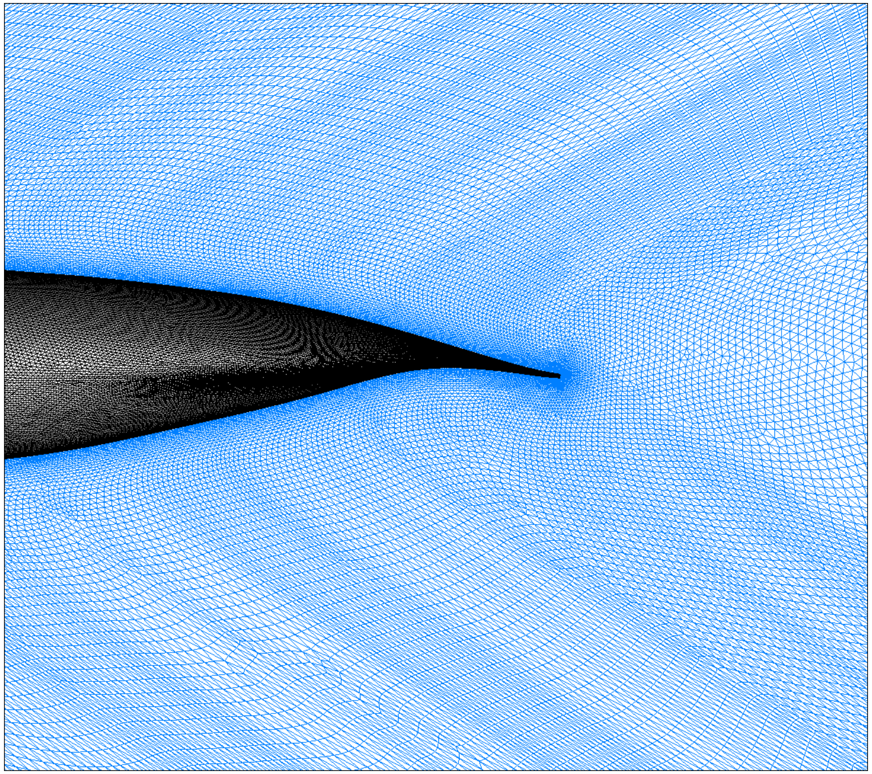


sBOOM Ground Signatures

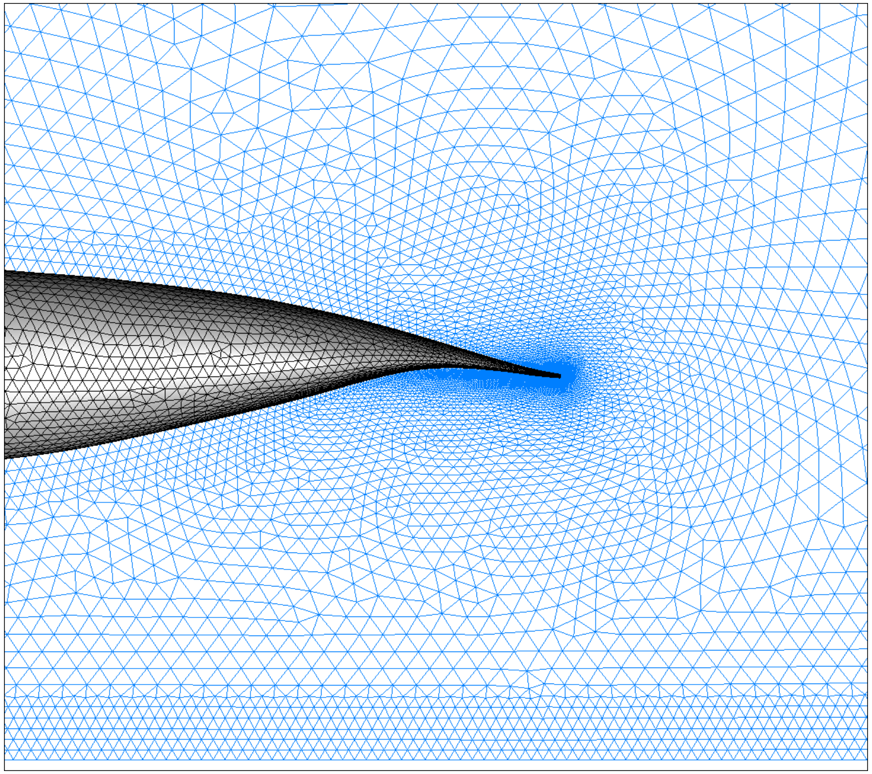
M_{∞}=1.6, α=0.0º, Φ=0º



JAXA Wing-Body Configuration



SBPW2

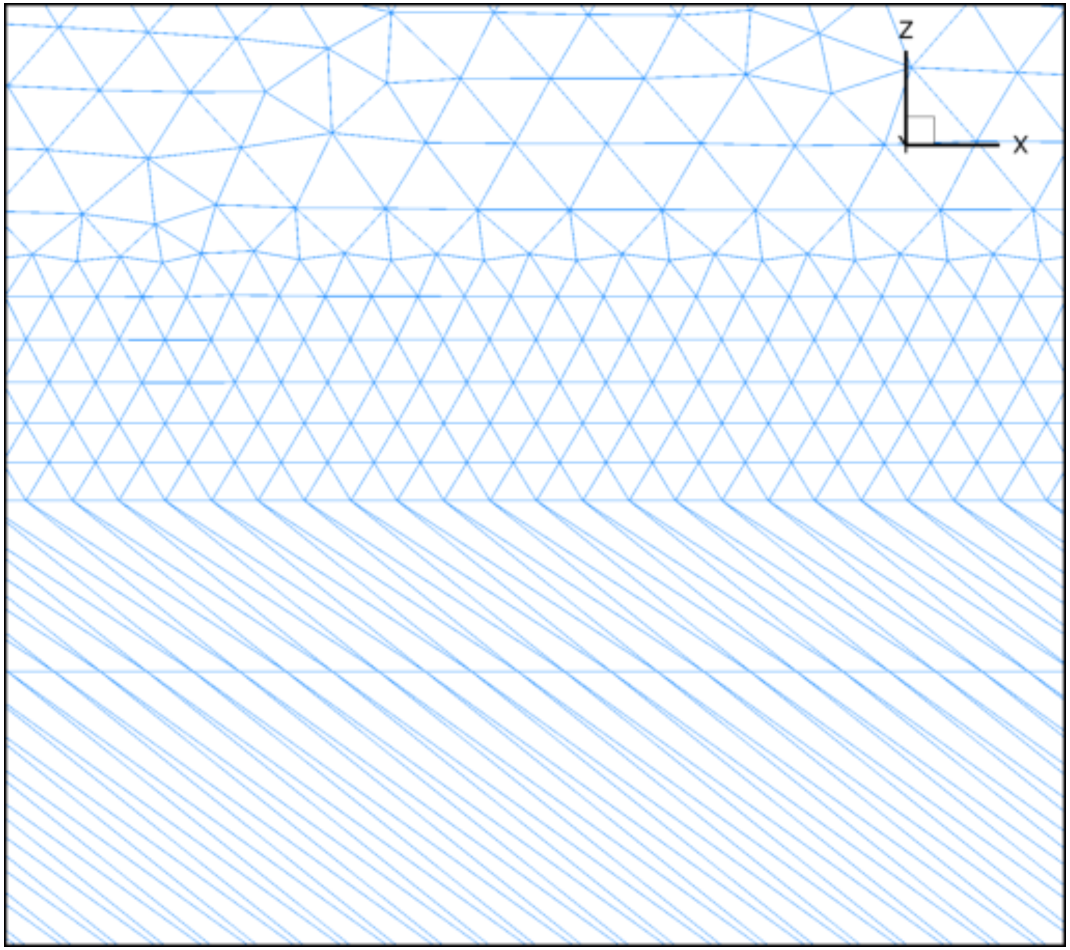


VGRID/BG

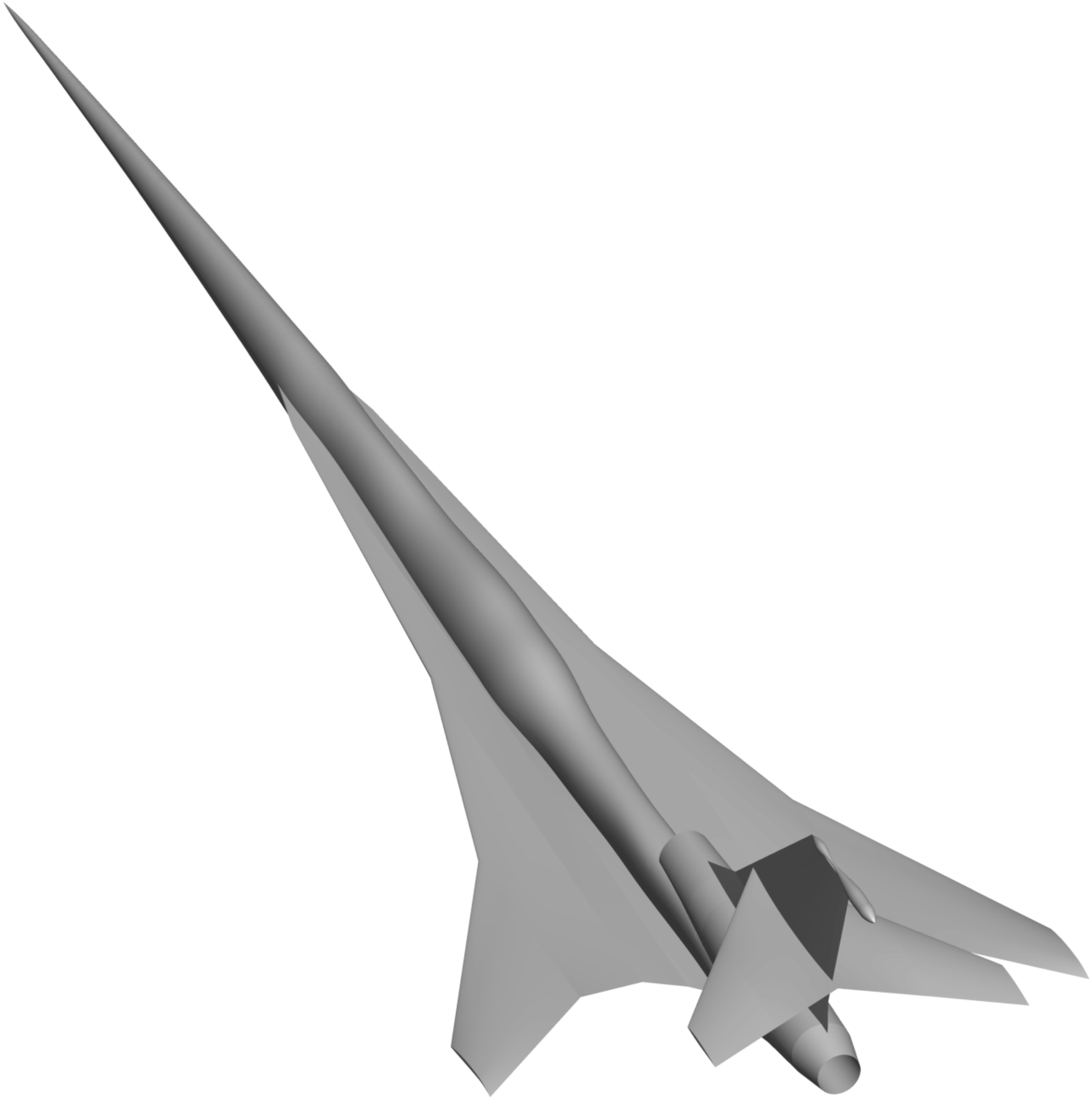
VGRID/BG Transition from Inner to Outer Grid

Inner Grid

Collar Grid



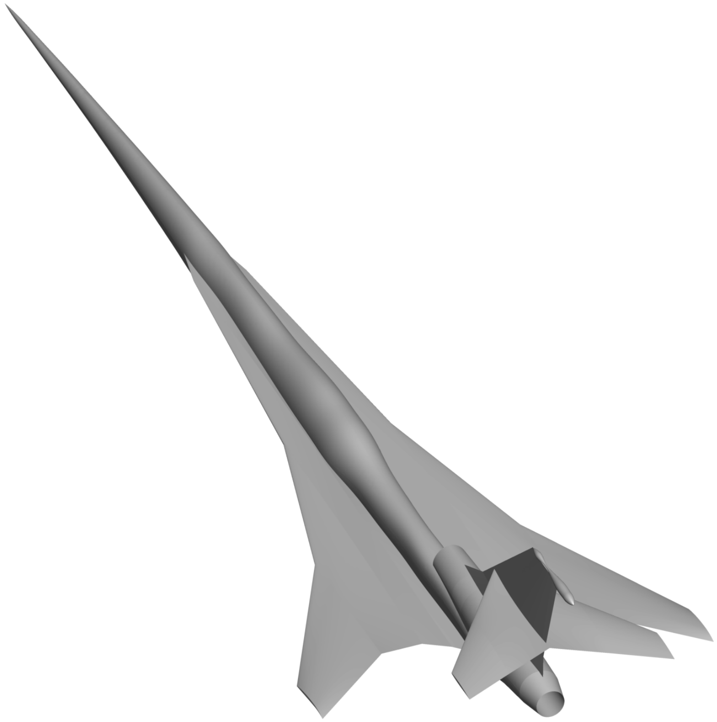
NASA C25D Configuration with Flow Through Nacelles



NASA C25D Configuration with Flow Through Nacelles

Test Conditions:

- Mach 1.6
- Angle of attack 0.0°
- Reference length 32.92 m
- Reference area 37.16 m^2
- Altitude 15760 m
- Temperature 216.65 K
- Flight Reynolds Number per meter 5.70 million



NASA C25D Configuration with Flow Through Nacelles

- Workshop provided grids

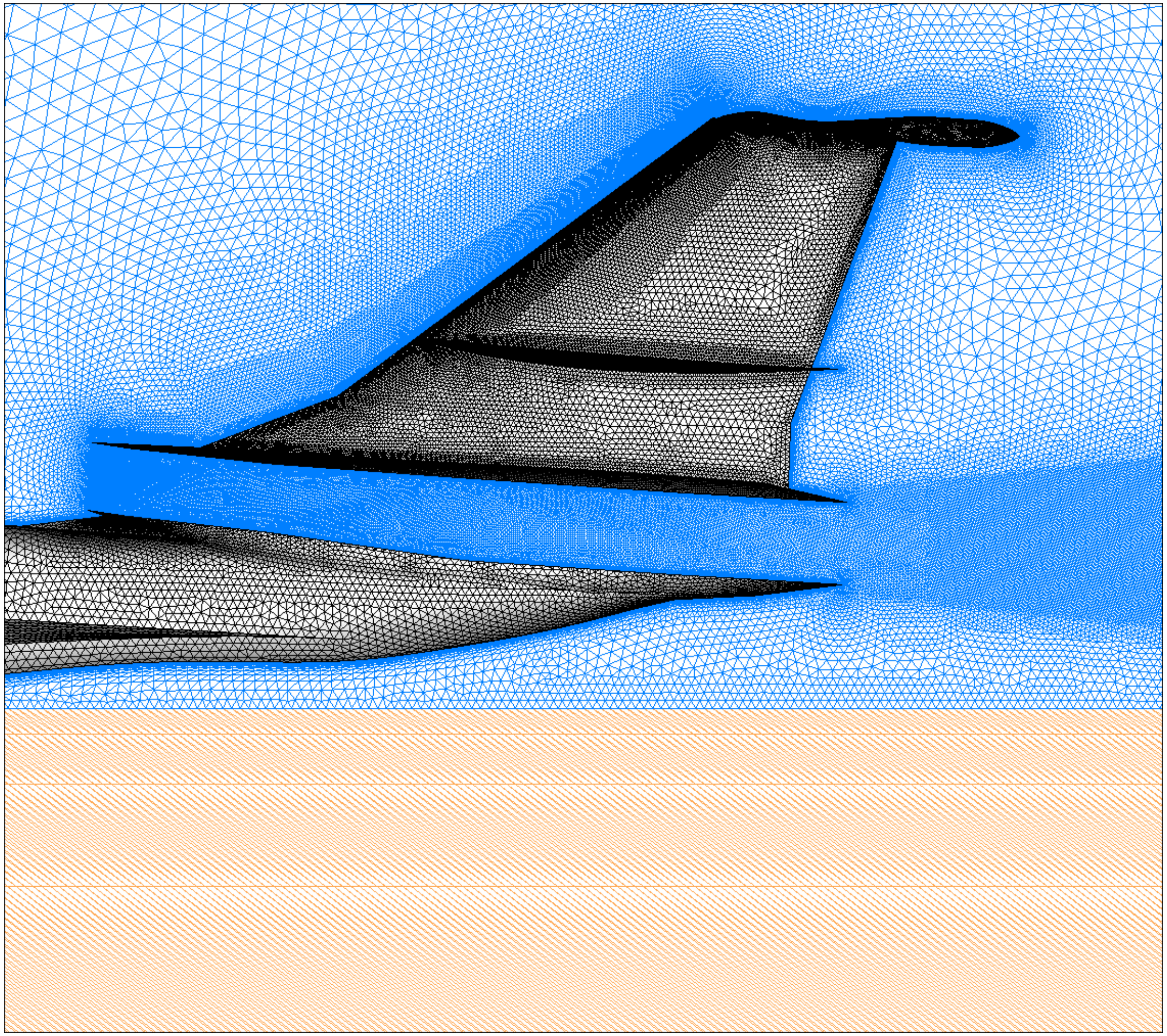
Grid	Nodes	Tetrahedra
C25D-F1	3,419,776	19,995,530
C25D-F2	6,323,343	37,082,947
C25D-F3	13,083,168	77,082,860
C25D-F4	26,923,206	159,106,053
C25D-F5	51,542,500	305,204,267
C25D-FV1	4,789,378	28,090,664

NASA C25D Configuration with Flow Through Nacelles

- In-house VGRID/BG grids

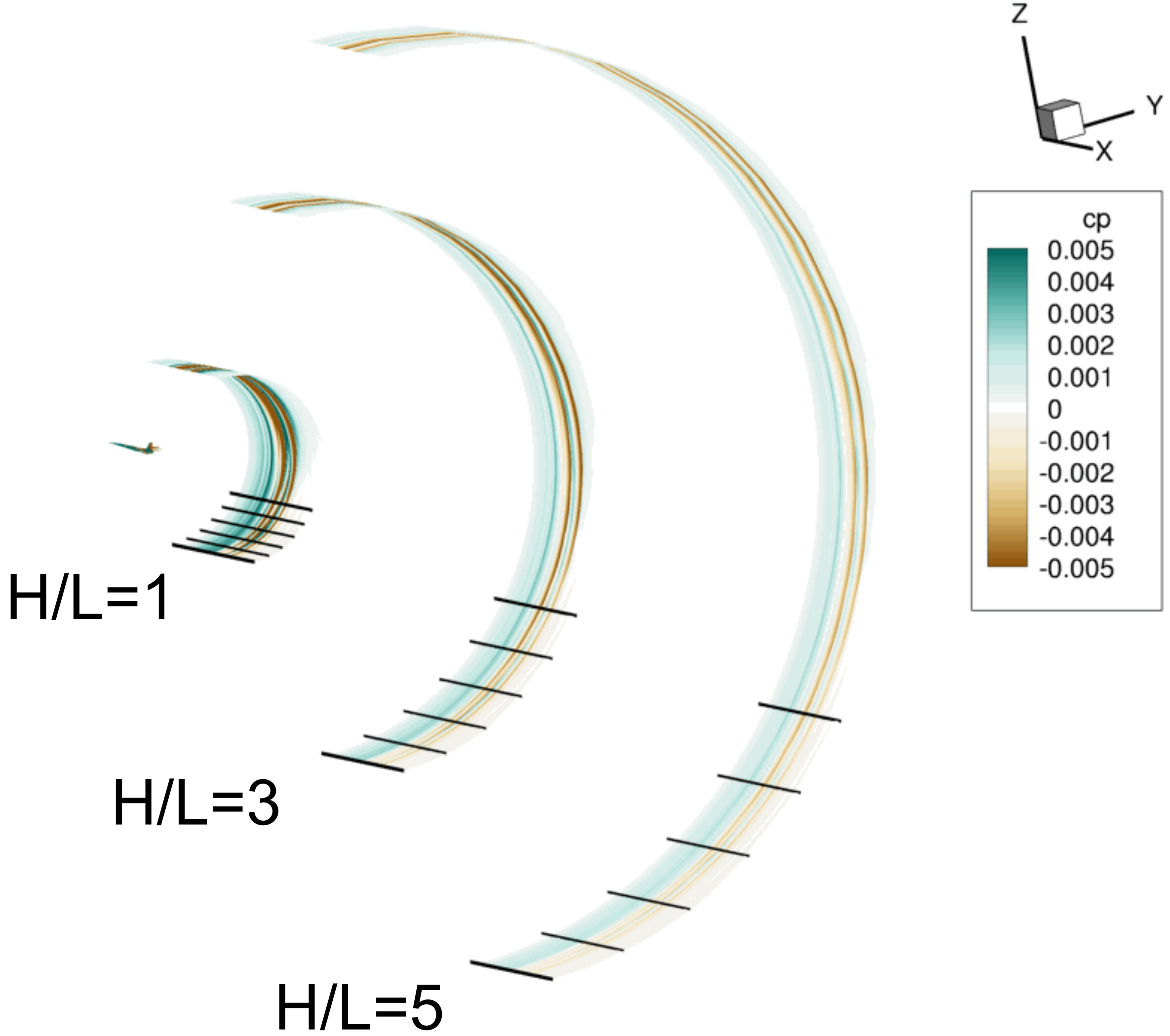
Grid	Nodes	Tetrahedra
VGRID_1	11,213,517	65,707,776
VGRID_2	22,429,694	131,941,166
VGRID_3	63,040,357	372,736,328

VGRID/BG Grid, 131.9 Million Cells



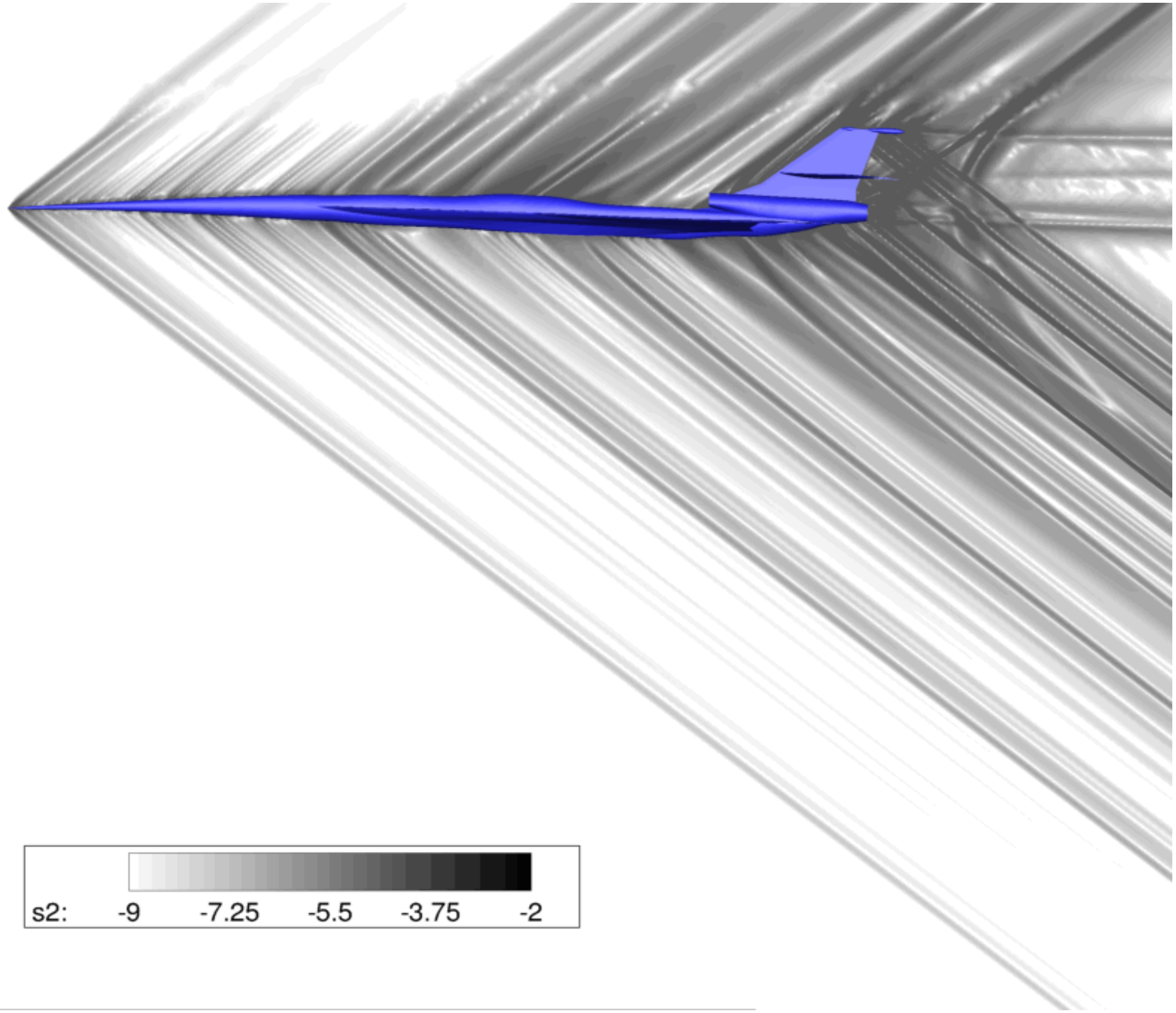
Overpressure Contours for the C25D-F

M_∞=1.6, α=0.0º, Φ=0º



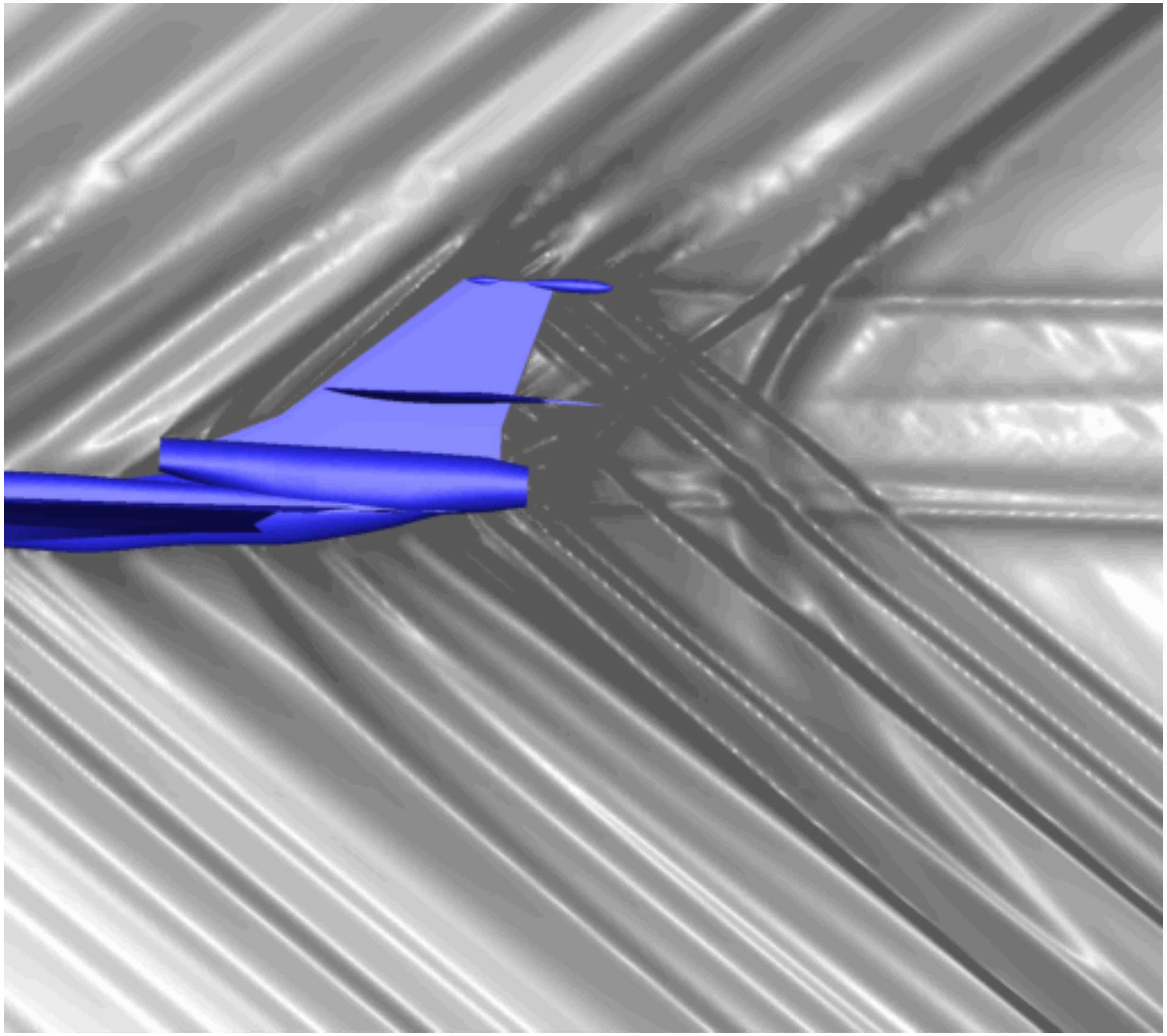
Symmetry Plane Density Gradient, Mach=1.6

M_∞=1.6, α=0.0º, Φ=0º



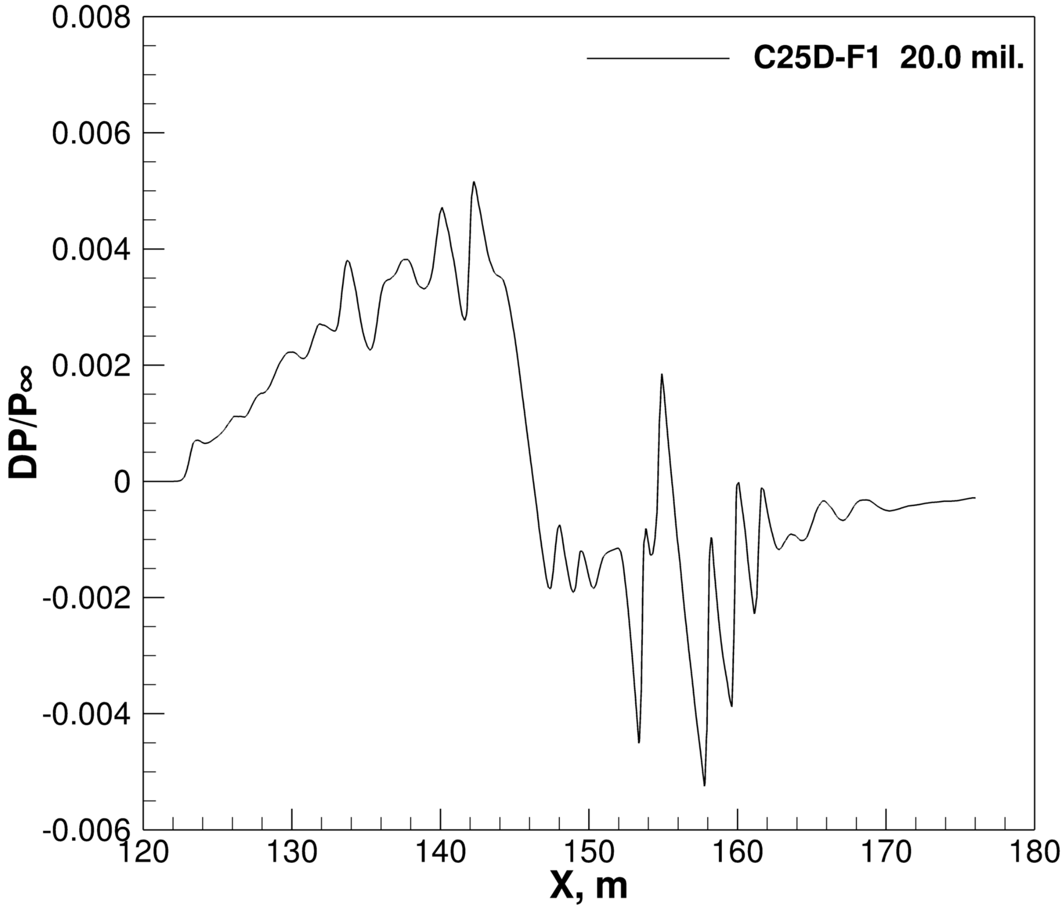
Symmetry Plane Density Gradient, Mach=1.6

M_∞=1.6, α=0.0°, Φ=0°



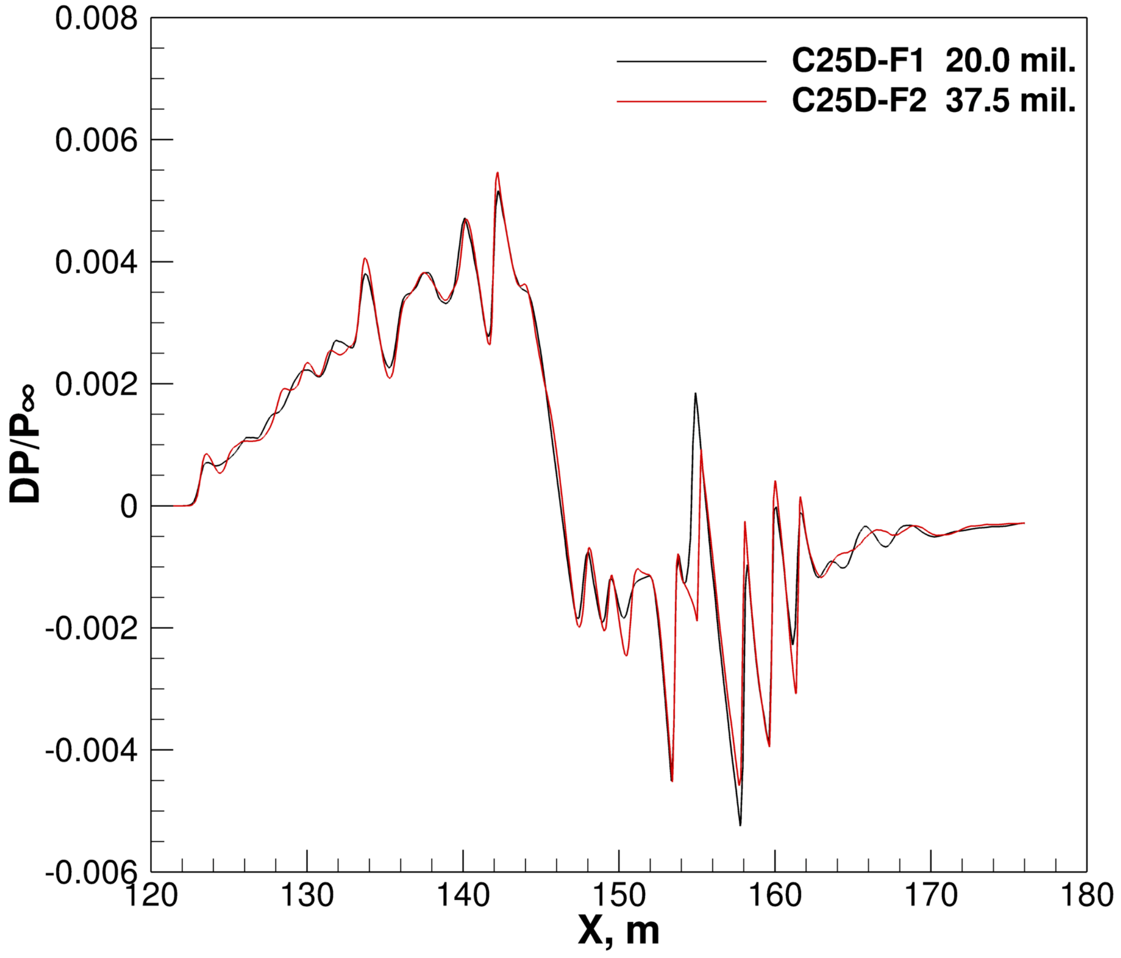
USM3D Near Field Pressure Signature

M_∞=1.6, α=0.0°, Φ=0°, H/L=3



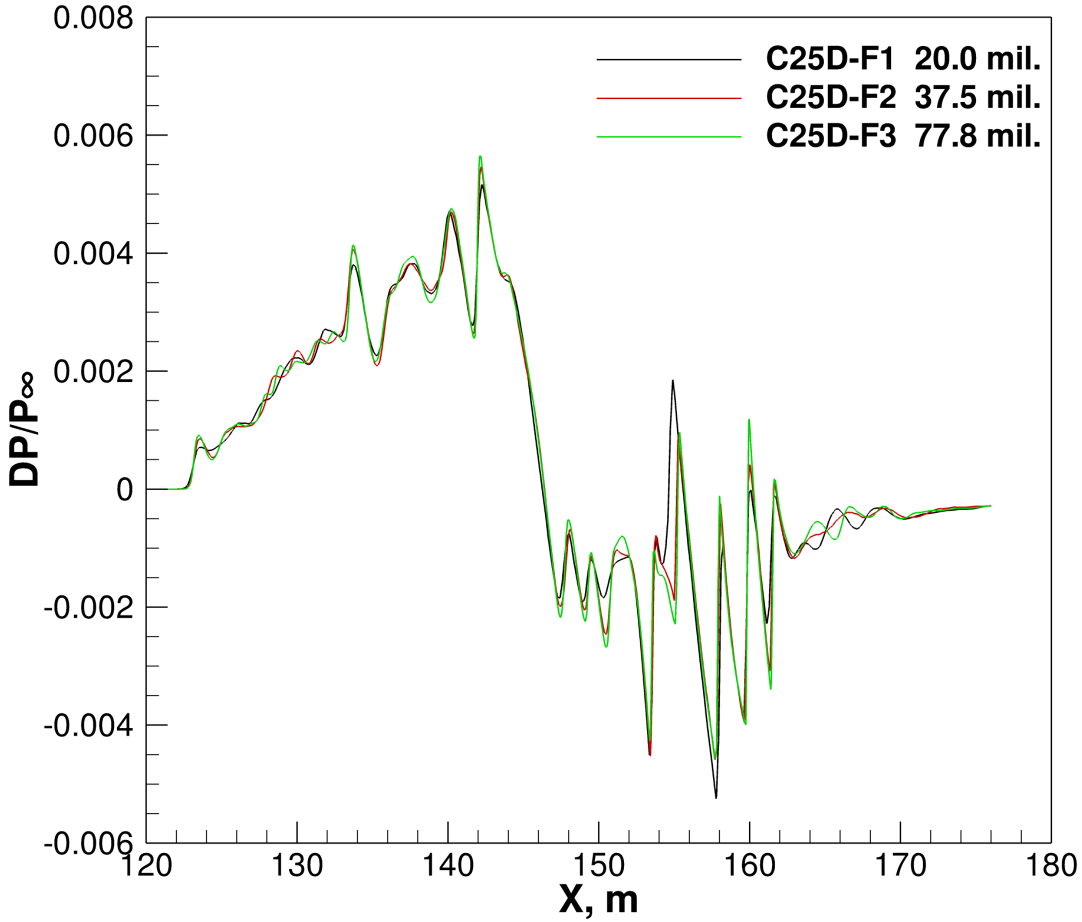
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3



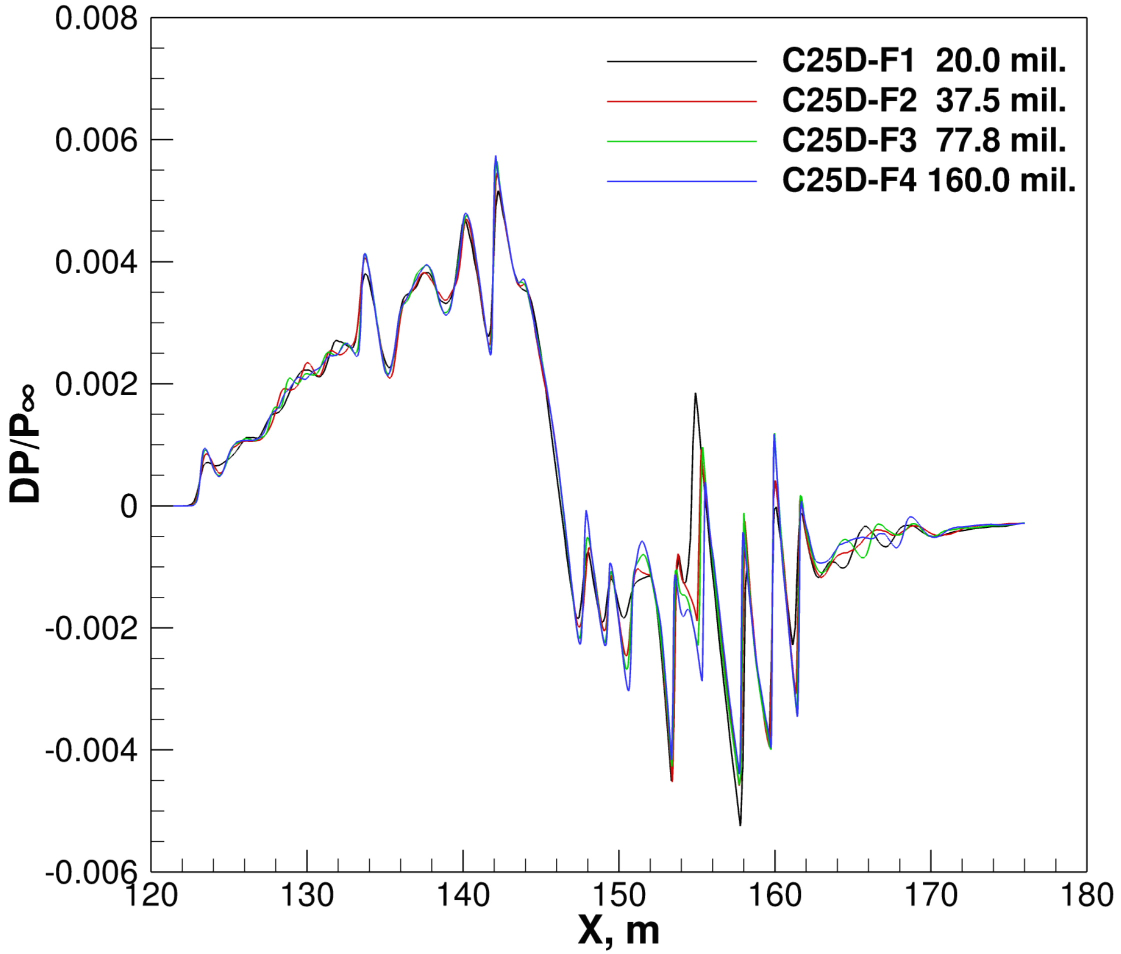
USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3

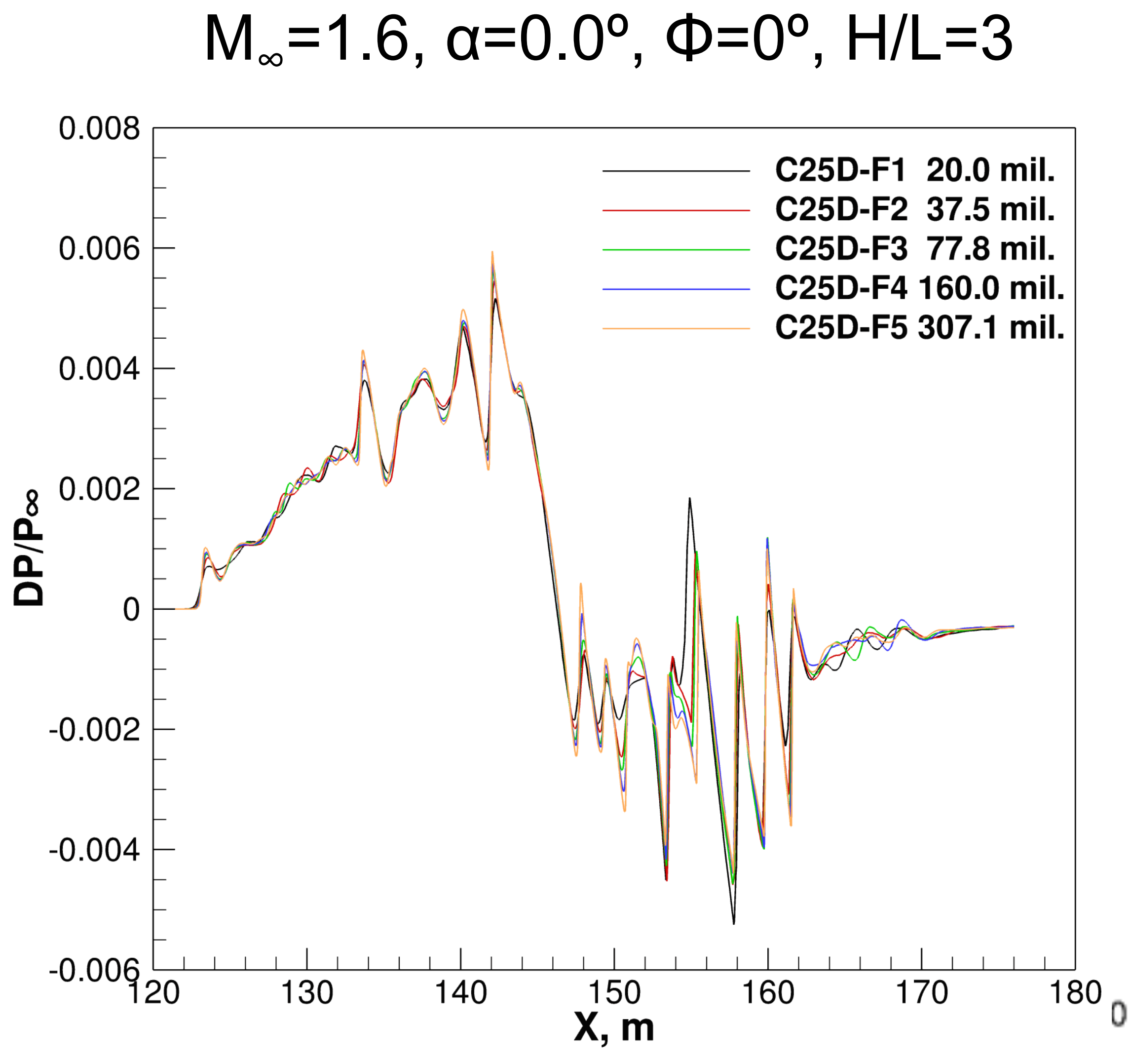


Near Field Pressure Signature

M_∞=1.6, α=0.0º, Φ=0º, H/L=3

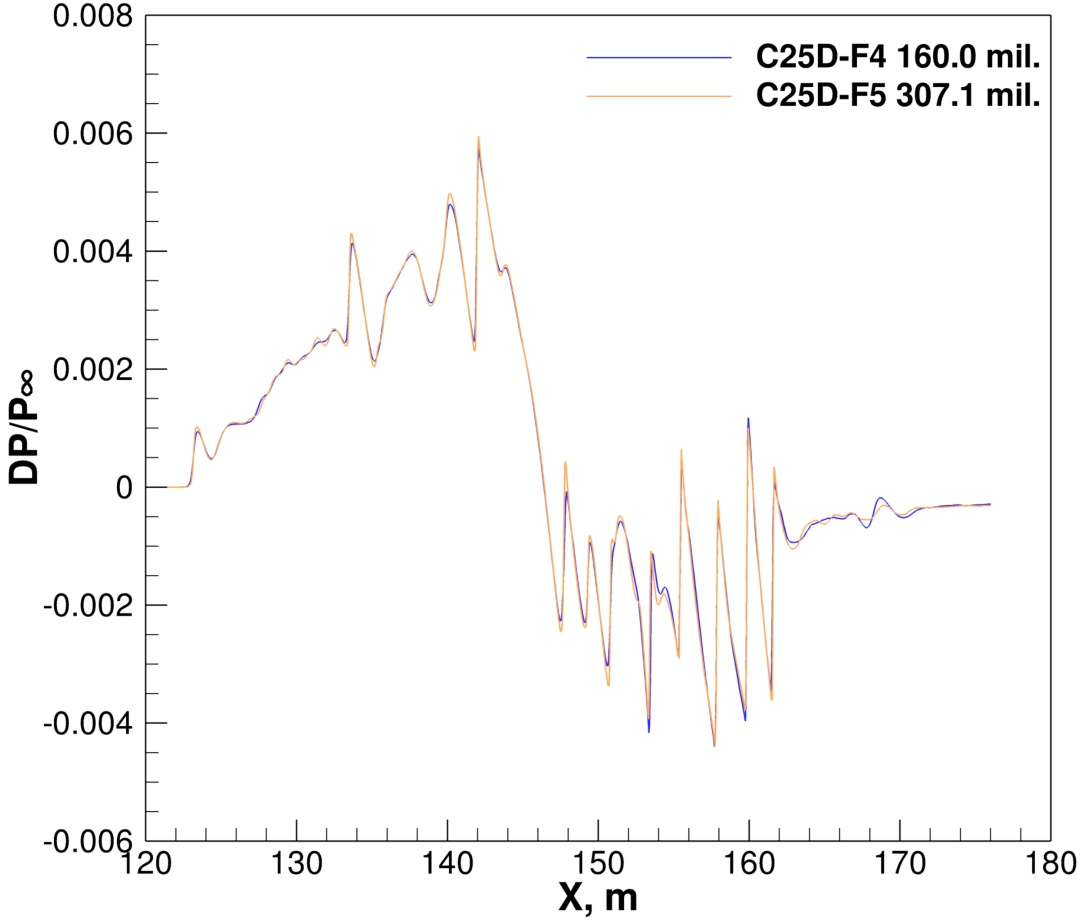


USM3D Near Field Pressure Signatures

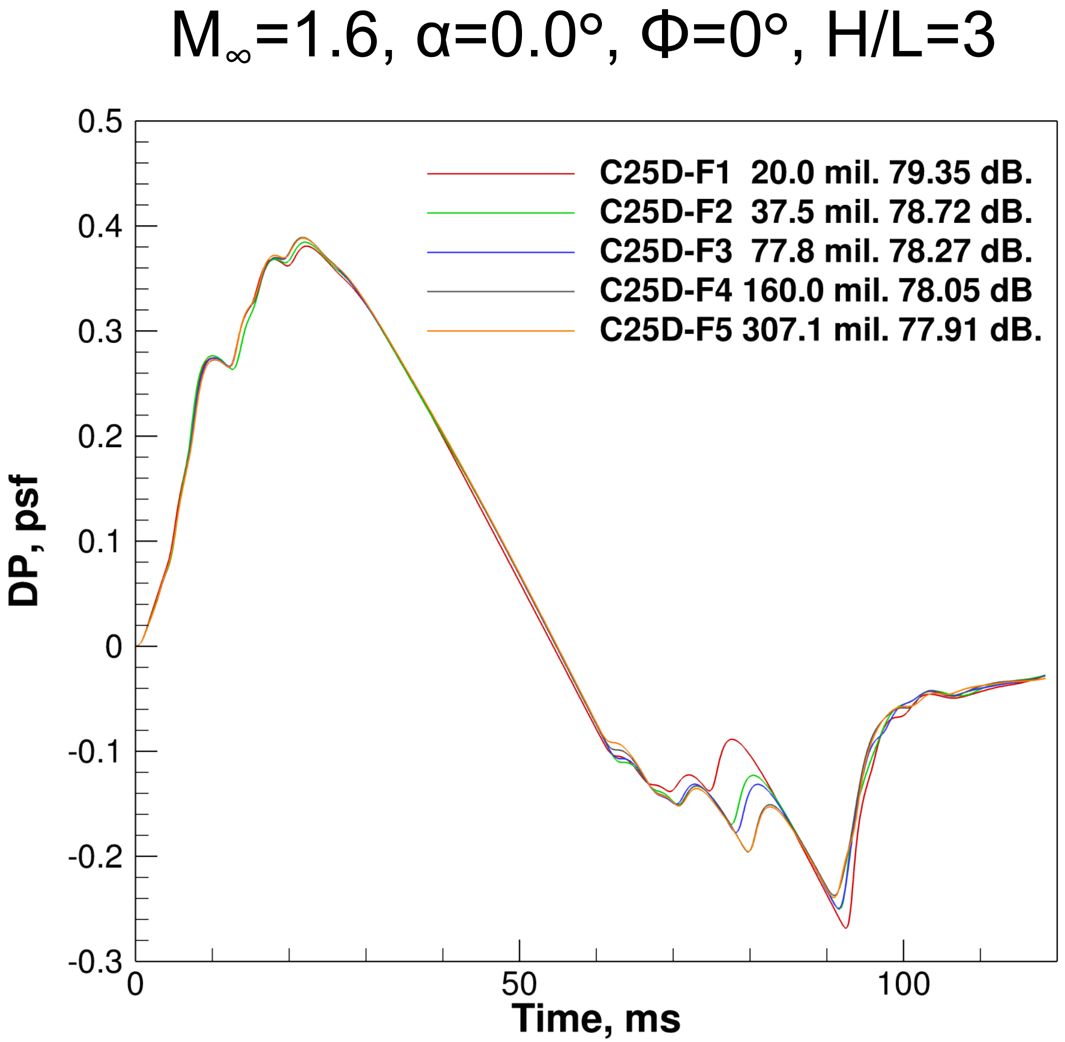


USM3D Near Field Pressure Signatures

M_∞=1.6, α=0.0º, Φ=0º, H/L=3

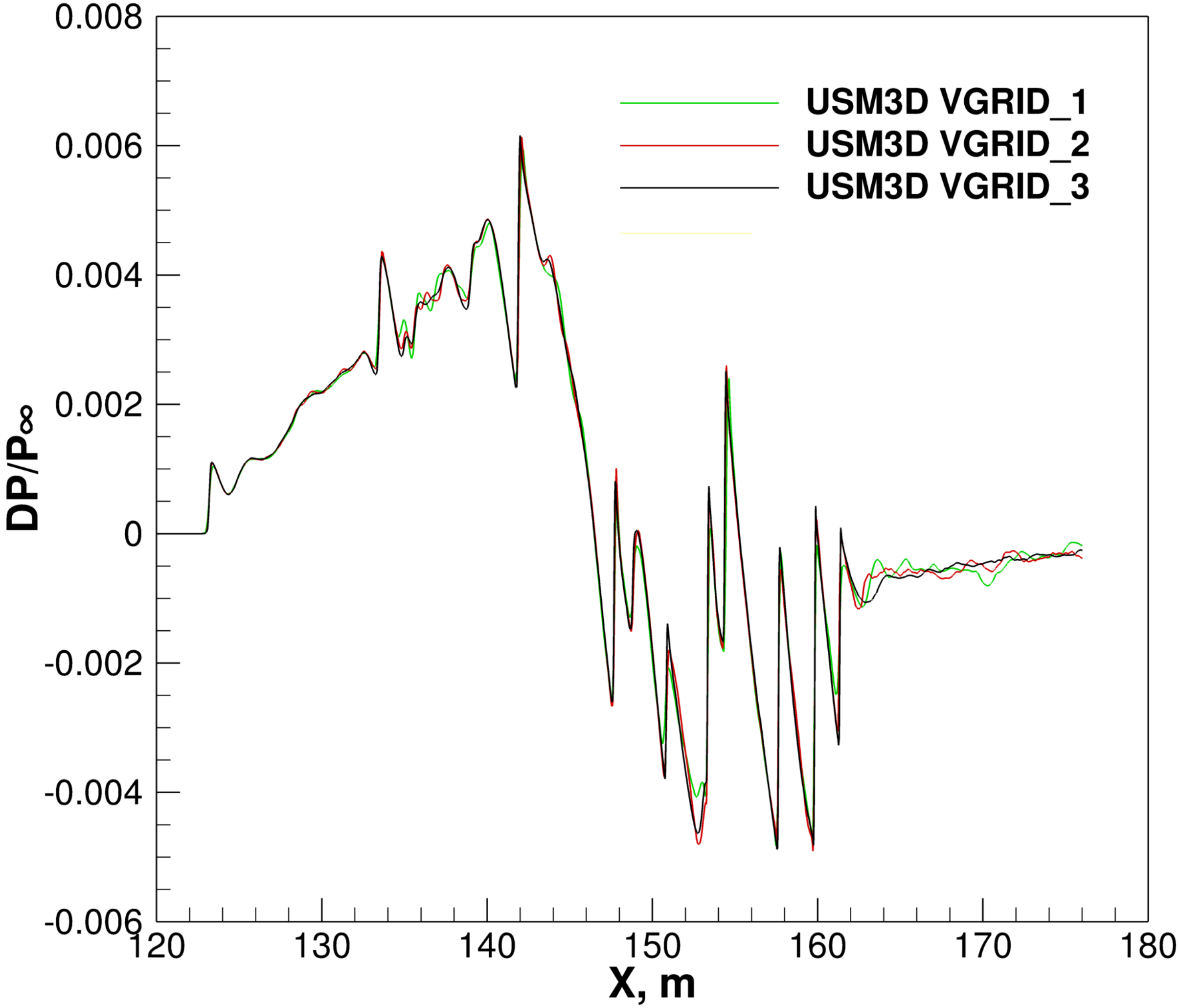


sBOOM Ground Signatures



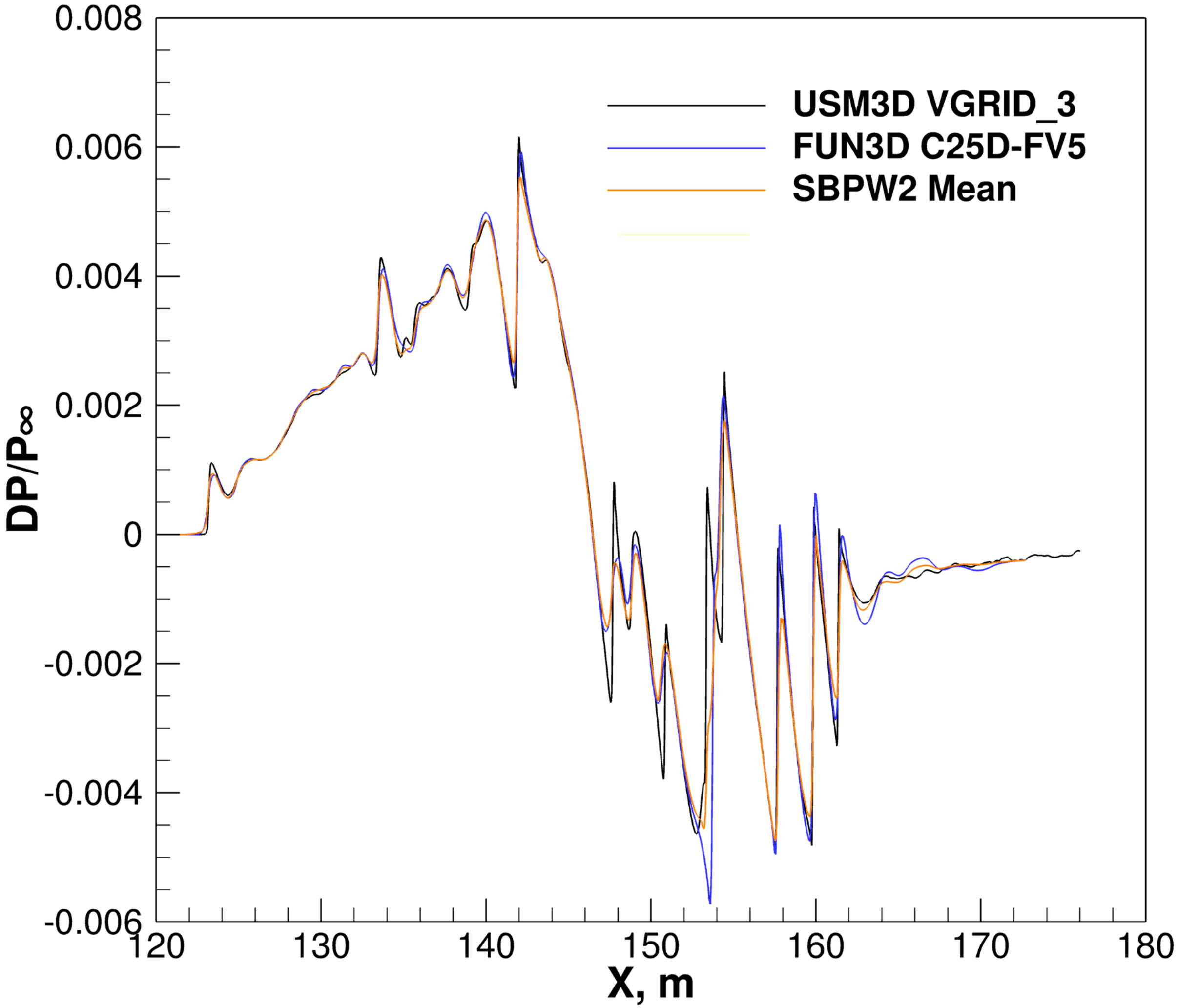
Near Field Pressure Signature, H/L=3

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



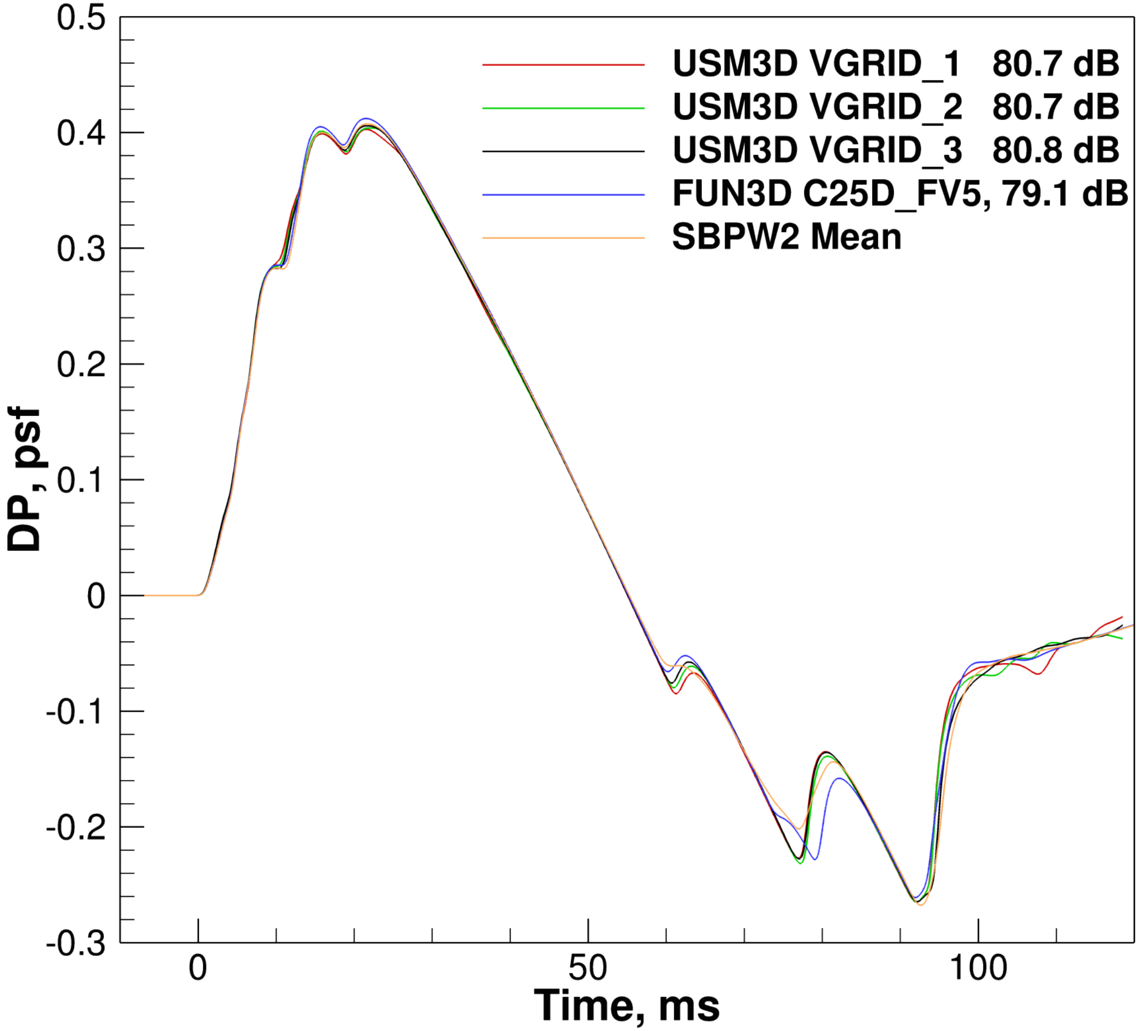
Near Field Pressure Signature, H/L=3

M_∞=1.6, α=0.0°, Rn=5.7 million per meter

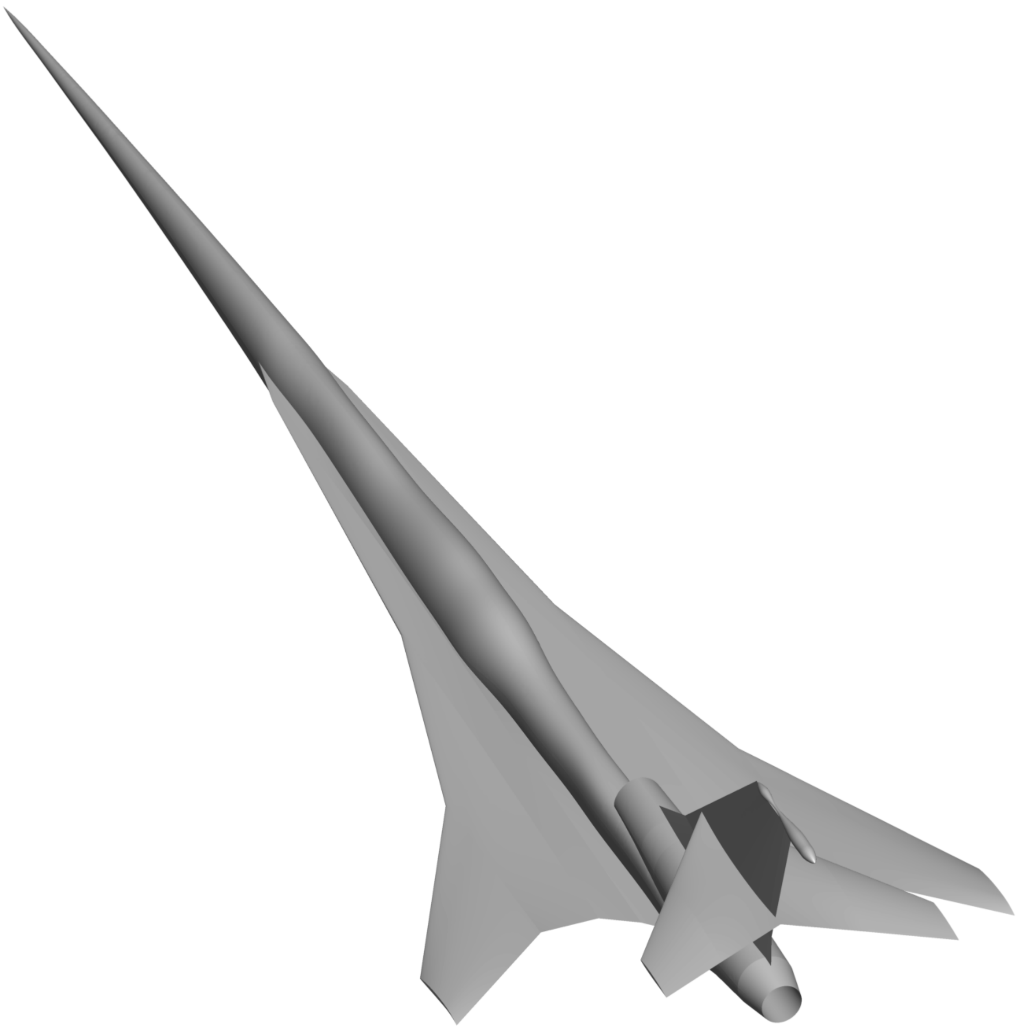


sBOOM Ground Signatures

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



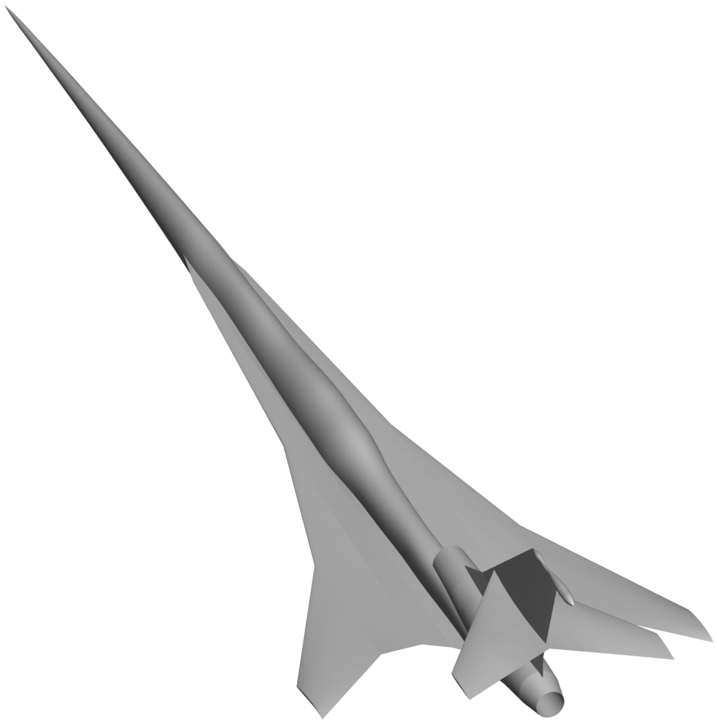
NASA 0.75C25D Configuration with Powered Nacelles



NASA 0.75C25D Configuration with Powered Nacelles

Simulation Conditions:

- Mach 1.6
- Angle of attack 0.0°
- Reference length 32.92 m
- Reference area 37.16 m^2
- Altitude 15760 m
- Temperature 216.65 K
- Flight Reynolds Number per meter 5.70 million



NASA 0.75C25D Configuration with Powered Nacelles

- Workshop provided grids

Grid	Nodes	Tetrahedra
C25D-P1	3,421,840	19,987,689
C25D-P2	6,393,433	37,486,198
C25D-PV1	4,856,211	28,470,874

NASA 0.75C25D Configuration with Powered Nacelles

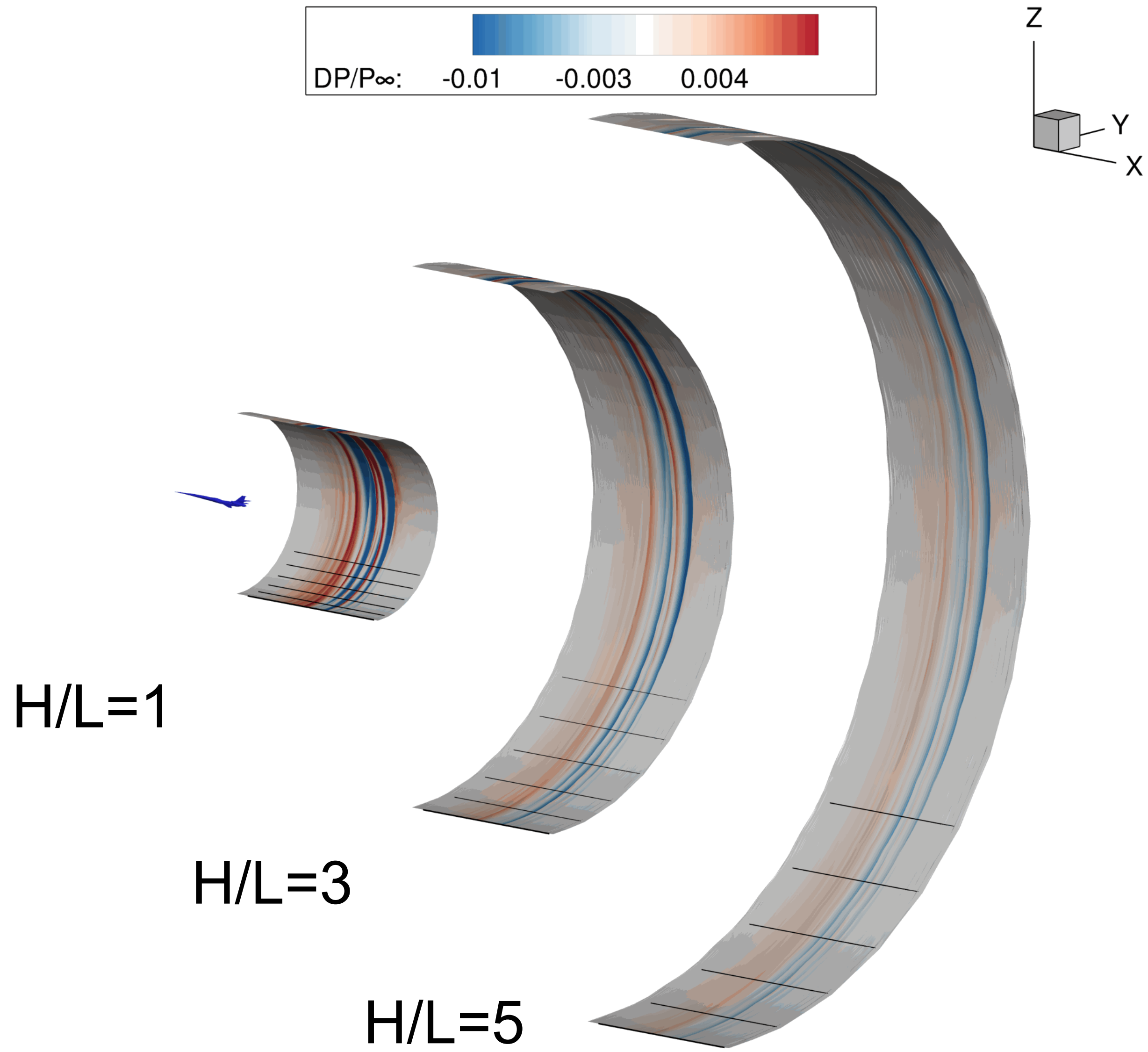
- Workshop provided grids

Grid	Nodes	Tetrahedra
C25D-P1	3,421,840	19,987,689
C25D-P2	6,393,433	37,486,198
C25D-PV1	4,856,211	28,470,874

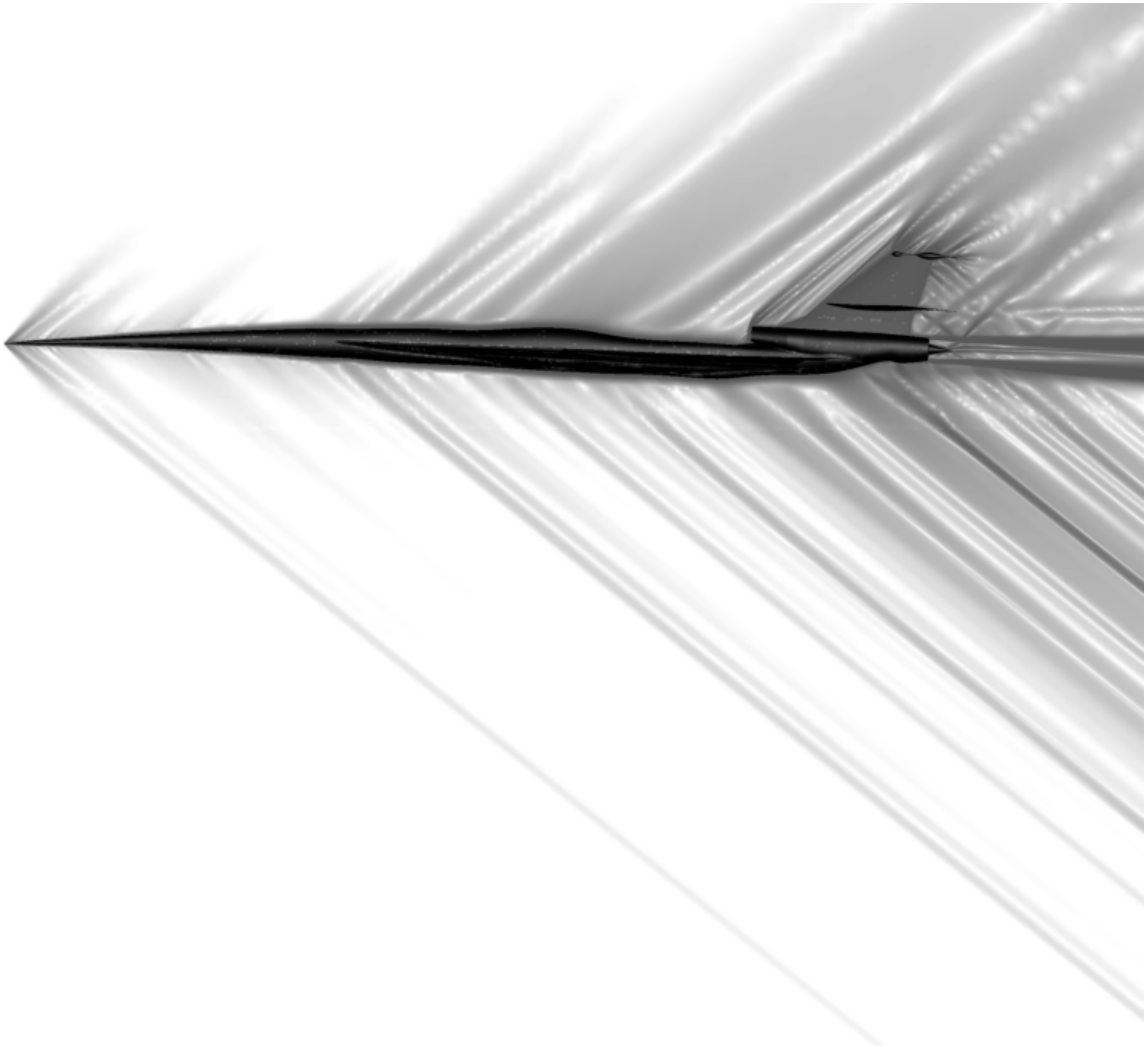
- In-house VGRID/BG grids

Grid	Nodes	Tetrahedra
VGRID_1	7,032,725	40,697,679
VGRID_2	10,475,401	60,769,047
VGRID_3	26,813,151	157,470,188

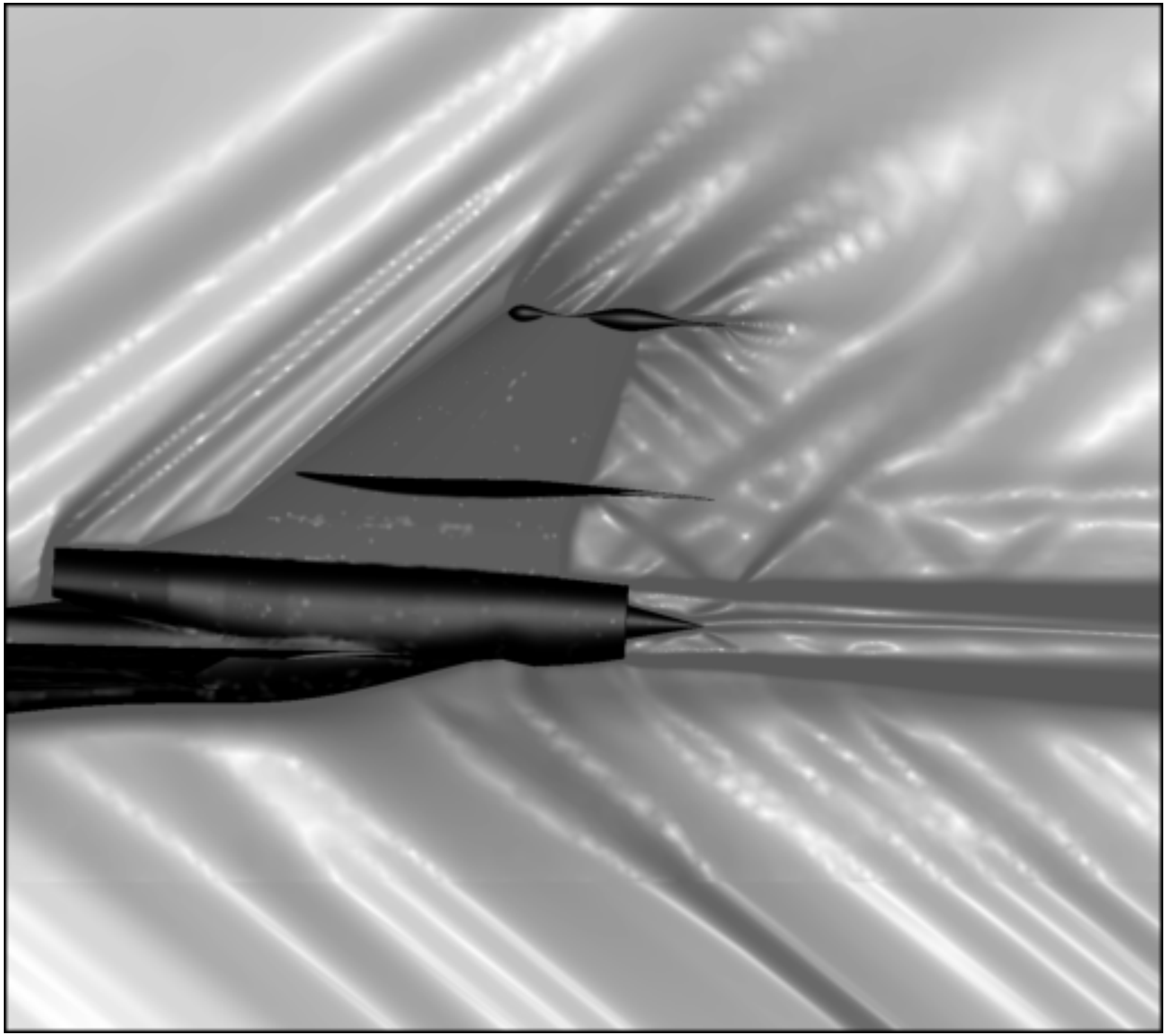
Symmetry Plane Overpressure Contours
Mach=1.6, α=0.0°



Symmetry Plane Density Gradient
Mach=1.6, α=0.0°

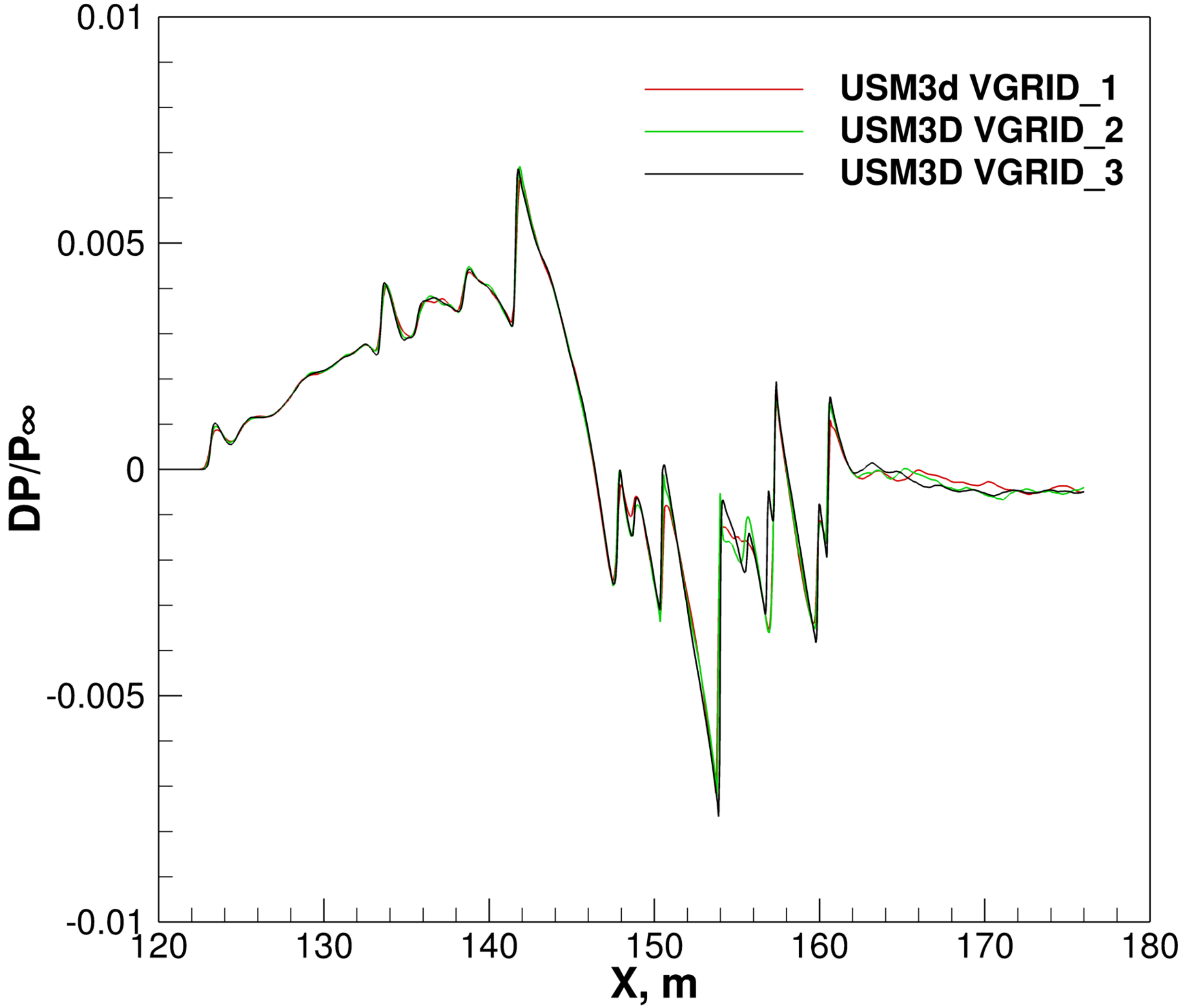


Symmetry Plane Density Gradient
Mach=1.6, α=0.0°



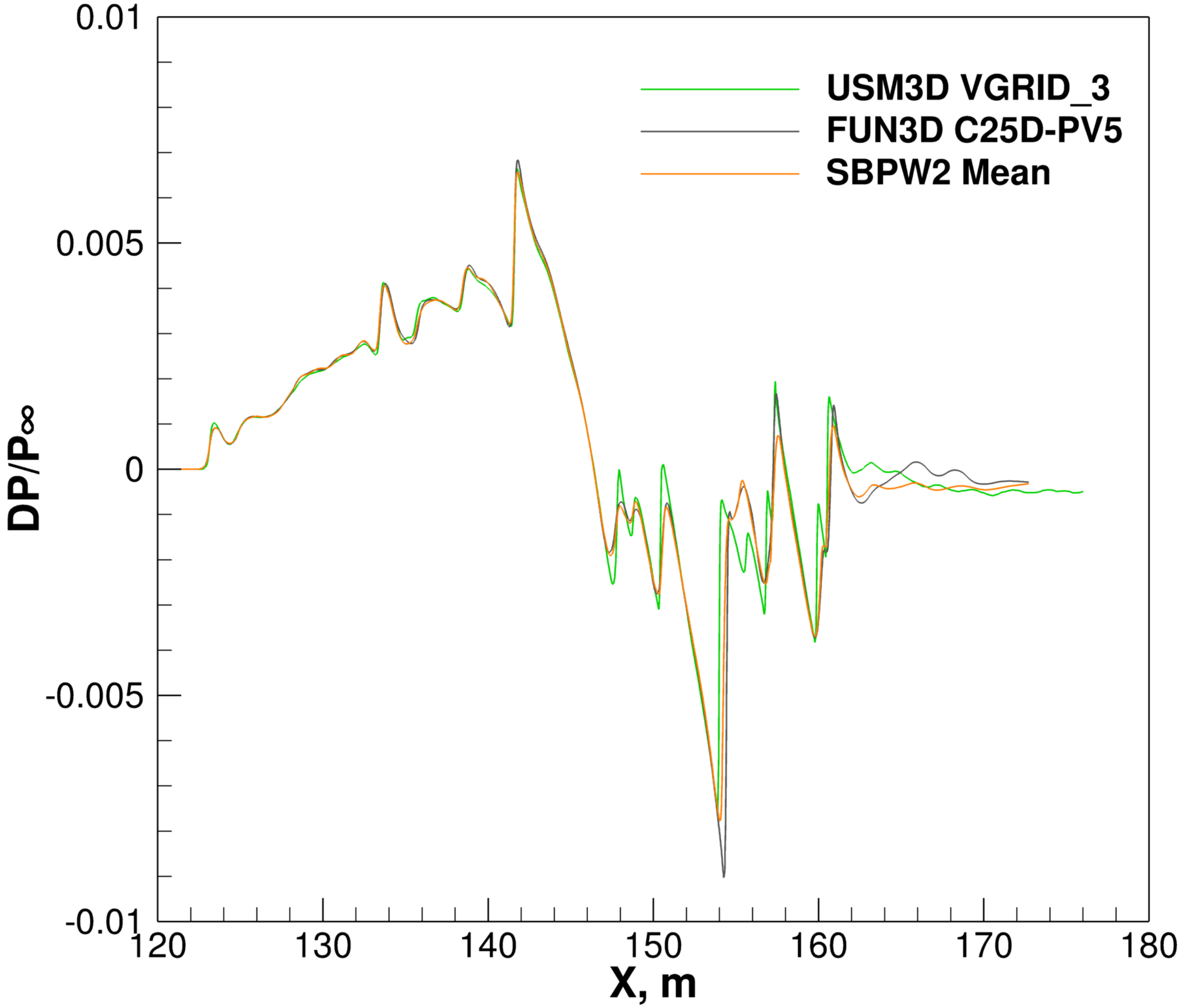
Near Field Pressure Signatures, H/L = 3

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



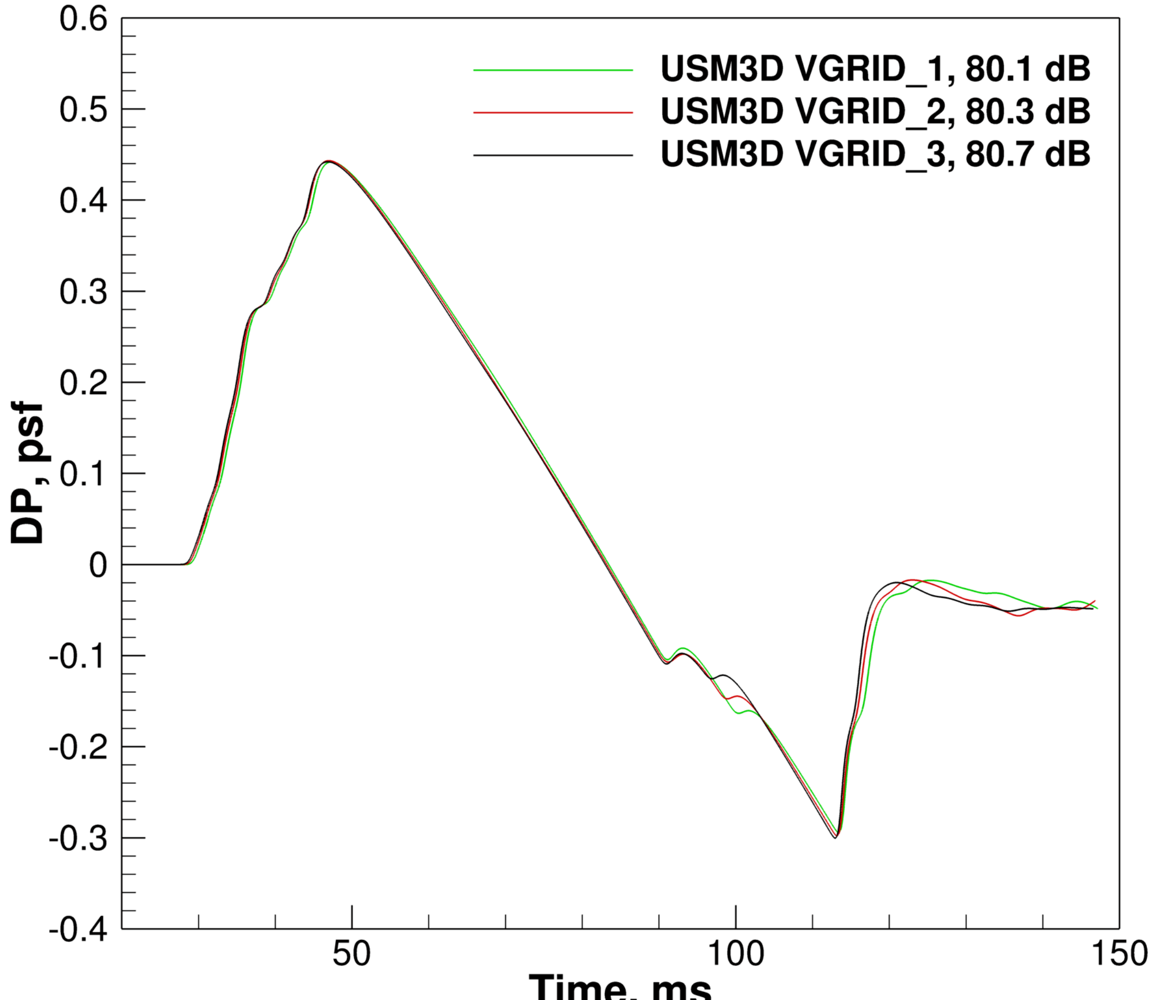
Near Field Pressure Signatures, H/L = 3

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



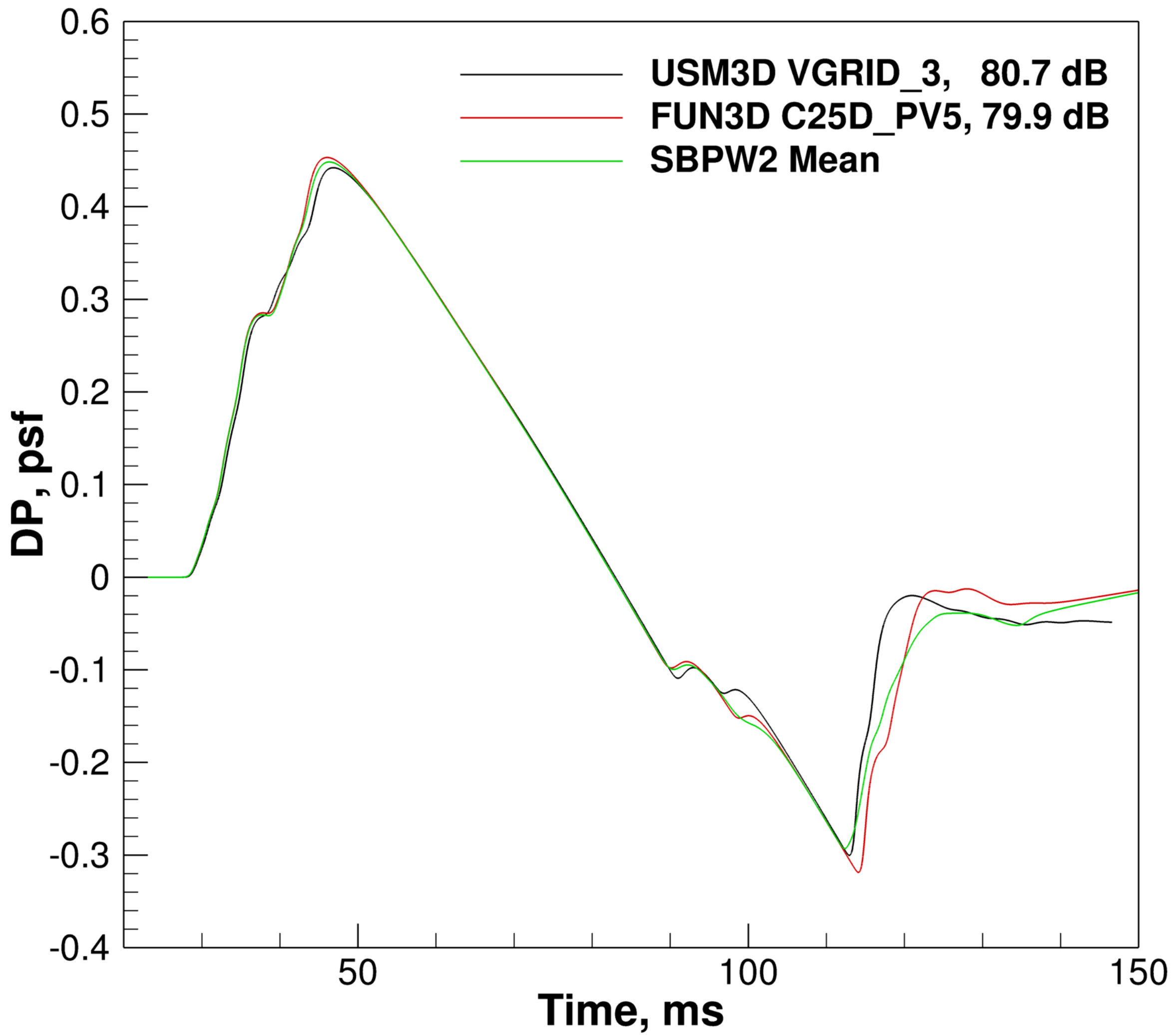
sBOOM Ground Signatures

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



sBOOM Ground Signatures

M_∞=1.6, α=0.0°, Rn=5.7 million per meter



Summary

- USM3D simulations were conducted on all four configurations provided by the SBPW2
- sBOOM was used to propagate the nearfield signature to the ground
- For the AXIE configuration, USM3D results were in excellent agreement with FUN3D pressure signatures and within the bounds of the error estimate of the participants' results

Summary

- USM3D solution for the JWB on the JWB_3 grid didn't accurately capture the compression and expansion waves
- USM3D predictions for JWB on VGRID_3 grid were in better agreement with FUN3D and the mean predictions of participant's results
- For the C25D, the comparison between USM3D and FUN3D near field pressure signatures, as well as ground propagated signatures, were in good agreement

Shaping the Future of Aerospace