USM3D Simulations for Sonic Boom Workshop

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2nd AIAA Sonic Boom Prediction Workshop, 7-8 January 2017, Grapevine, Texas

Outline

- Test Cases
- Grid Generation
- Numerical Results
- Summary

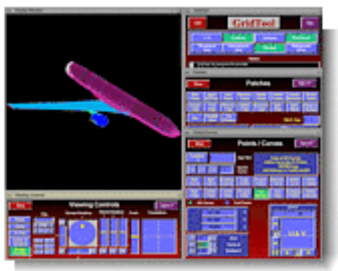
Second AIAA Sonic Boom Prediction Workshop

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

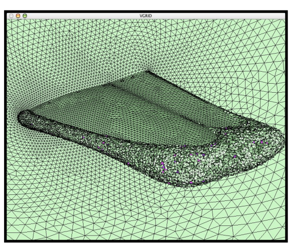
Tetrahedral Unstructured Software System, TetrUSS

A proven, stable, and reliable multi-platform 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*

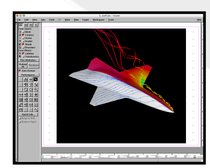


Geometry Setup
GridTool

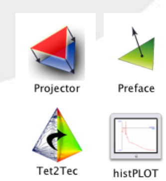


Grid Generation
VGRID OpenGL

Flow Solver
USM3D



Visualization
SimpleView
(Commercial Packages)



Tools & Utilities

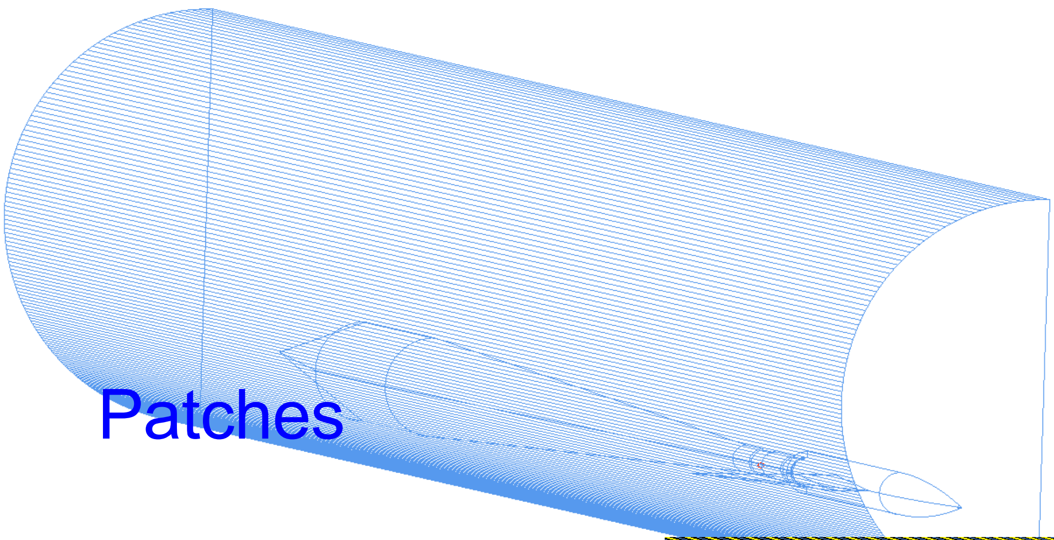
Numerical Tools

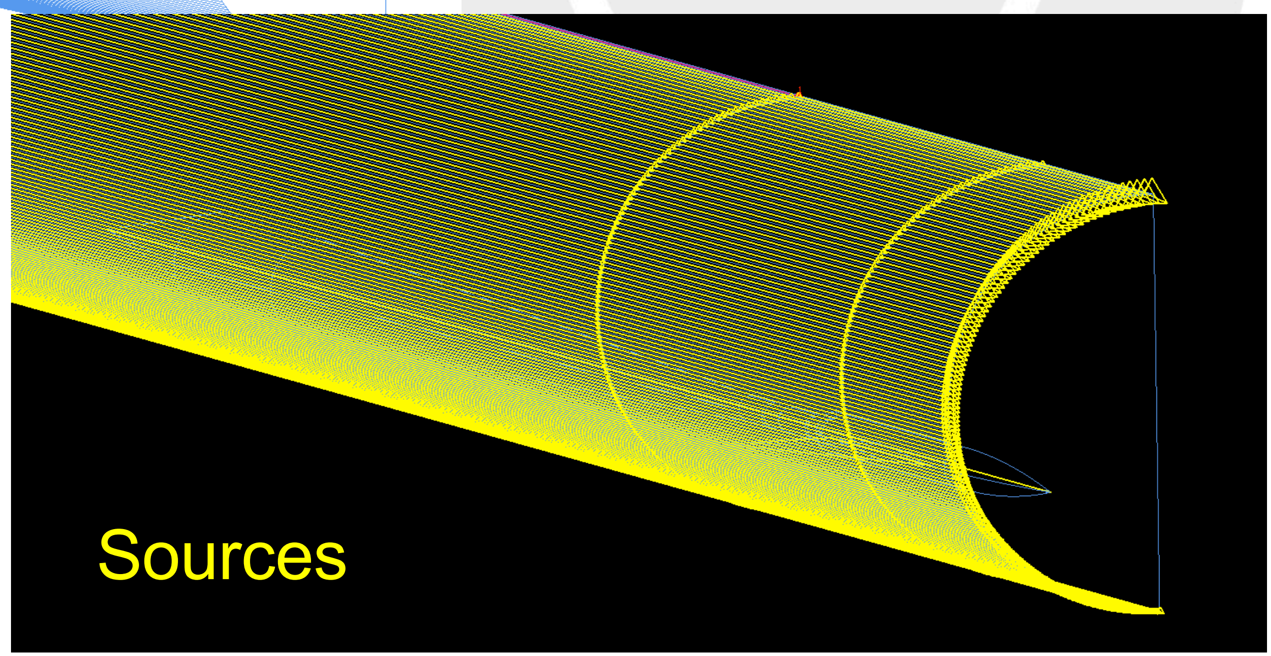
- **USM3D Tetrahedral Flow Solver**
  - **Tetrahedral Cell-Centered, Finite Volume**
  - **Euler and Navier-Stokes**
  - **Time Integration**
    – LTS and 2nd order time stepping
  - **Upwind Spatial Discretization**
    – FDS, AUSM, HLLC, LDFSS, FVS
    – Min-mod limiter
  - **Turbulence Models** SA,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

Computational Grids

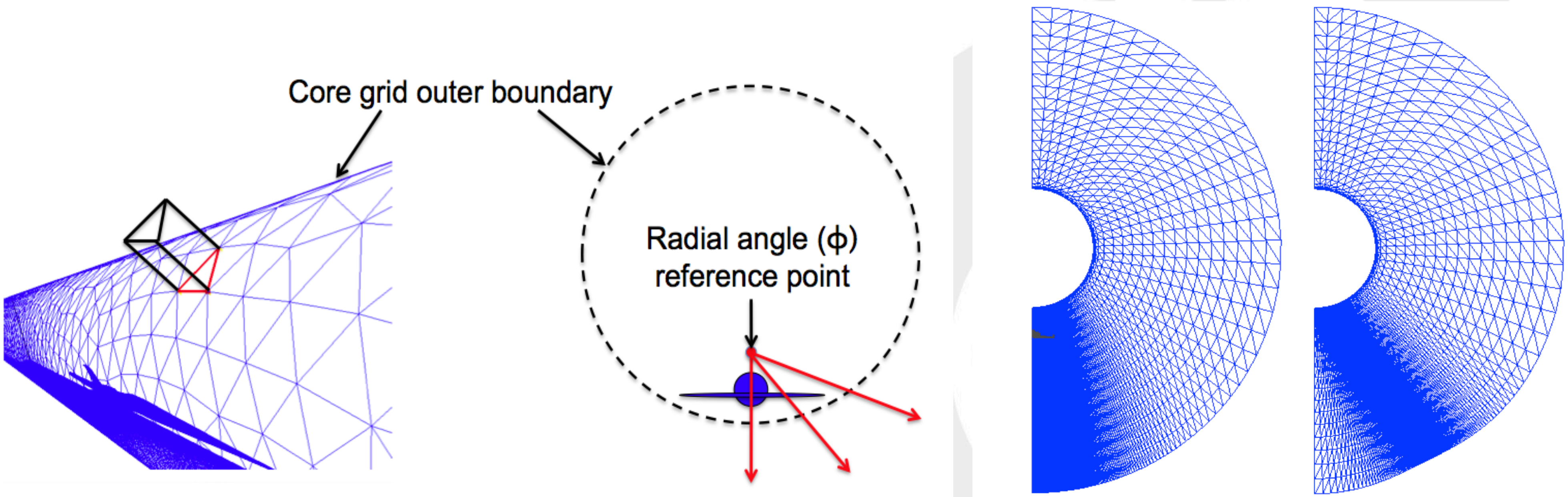
- Workshop provided grids (AFRL3)
- In-house grids generated by VGRID
  - Used best practices for grids
  - Time permitting, scaled the grids to try to match workshop grid count
- In-house grids generated by Pointwise® Software
  - Low Boom Body of Revolution, JAXA wing-body and C25D Configuration with Flow Through Nacelle grids generated with automated system
  - C25D Configuration with Powered Nacelles grids generated with MCAT

VGRID Grid Generation Process



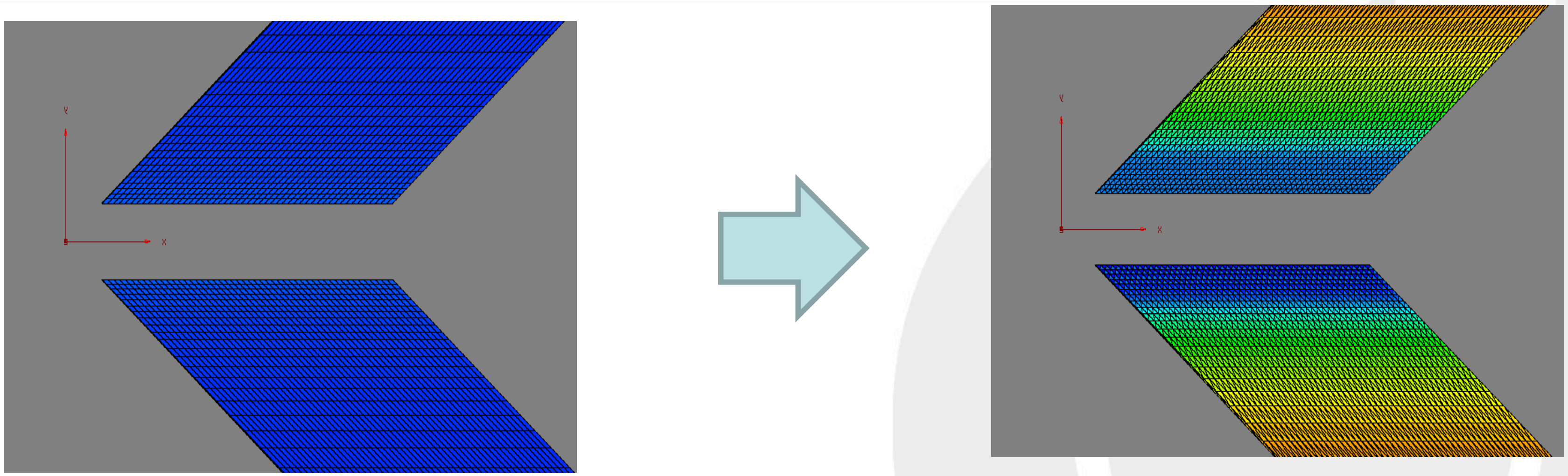


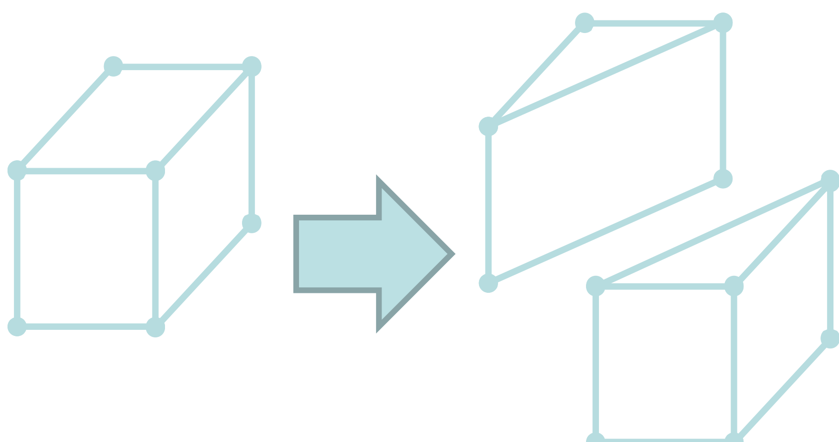
BG Collar Grid Generation Code



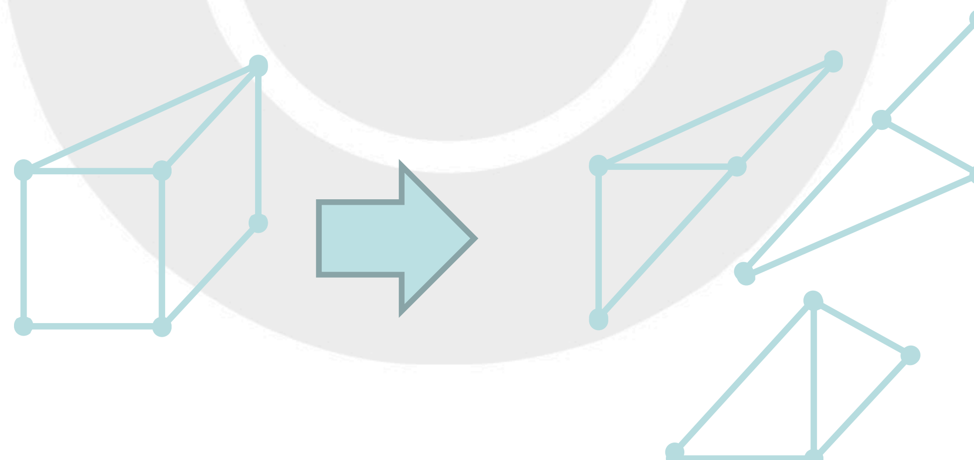
- Extrude layers of prisms through faces on core grid outer boundary
- Split prisms into tetrahedral cells and merge with core grid
- Radial angle reference point for extrusion located close to configuration nose
- Vary height of reference point to focus grid at selected radial angles

Conversion of Pointwise® Grid to Tetrahedra





Each hexahedron sliced into 2 prisms



Each prism sliced into 3 Tetrahedra

Low Boom Body of Revolution

Low Boom Body of Revolution

Simulation 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

Low Boom Body of Revolution

- Workshop provided grids were a subdivision of the mixed-element grids generated by AFLR3. Grids are in full scale meters and have a uniformly refined spacing.

Grid	Nodes	Tetrahedra
1	646,467	3,705,046
2	1,601,681	9,243,626
3	5,077,104	29,682,640
4	15,911,412	93,751,314
5	56,085,031	332,136,840

Low Boom Body of Revolution

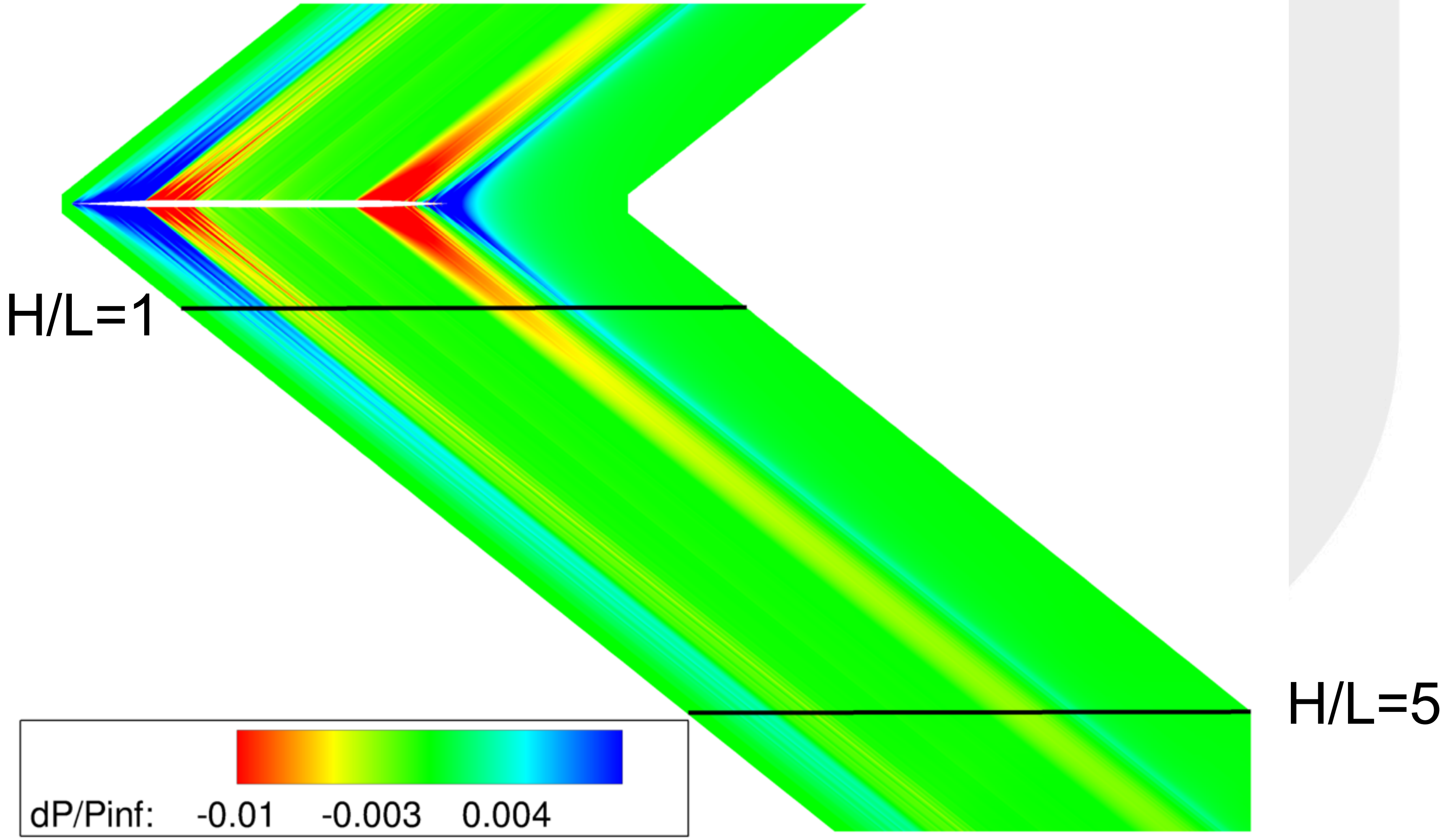
- In-house Pointwise® grids

Grid	Nodes	Tetrahedra
1	513,059	2,827,119
2	2,058,461	11,883,313
3	4,108,837	23,972,083

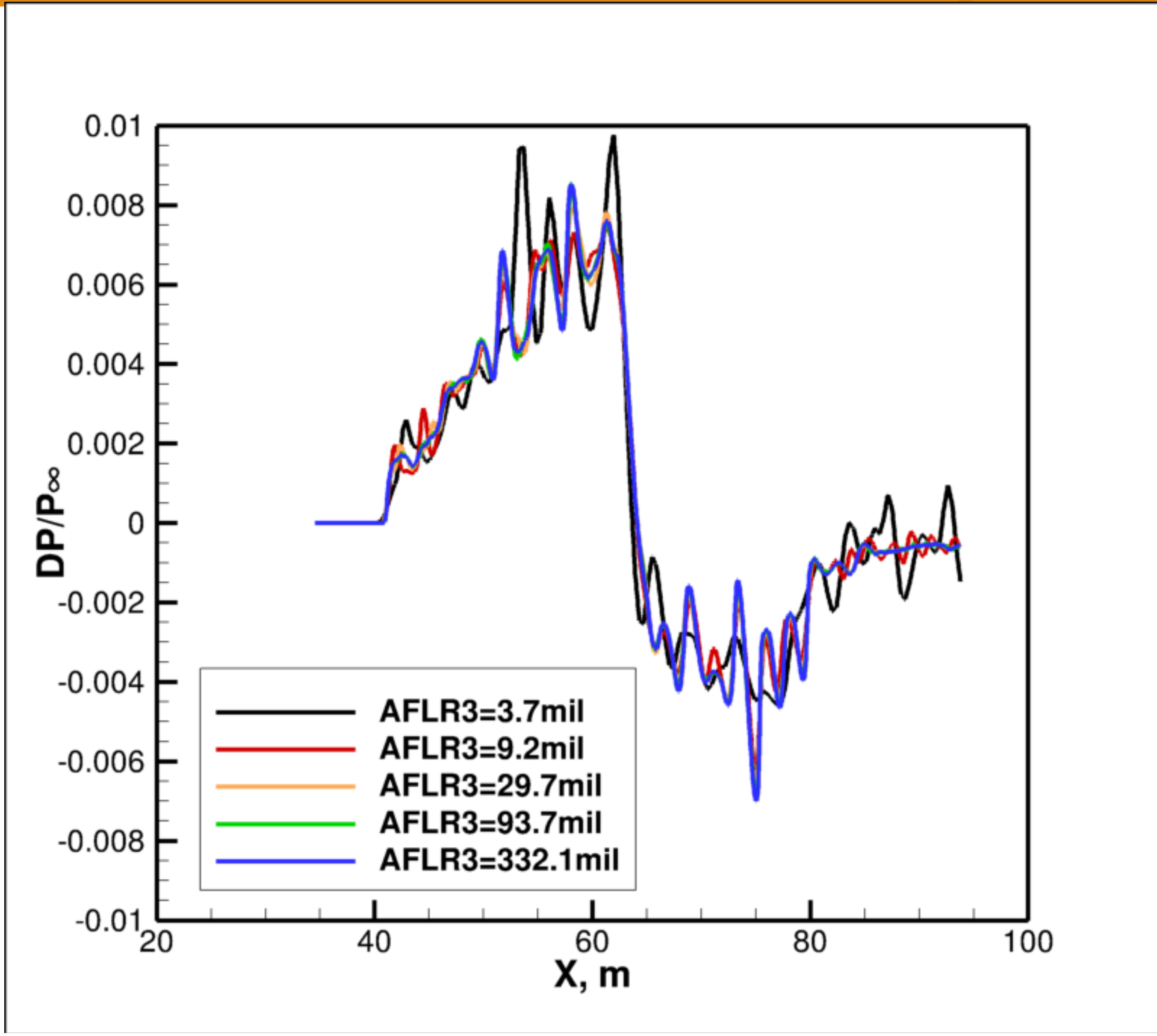
- In-house VGRID grids

Grid	Nodes	Tetrahedra
BG 0	3,035,706	17,578,723
BG 1	15,918,977	93,341,956
MCAP 1	18,857,954	110,829,694

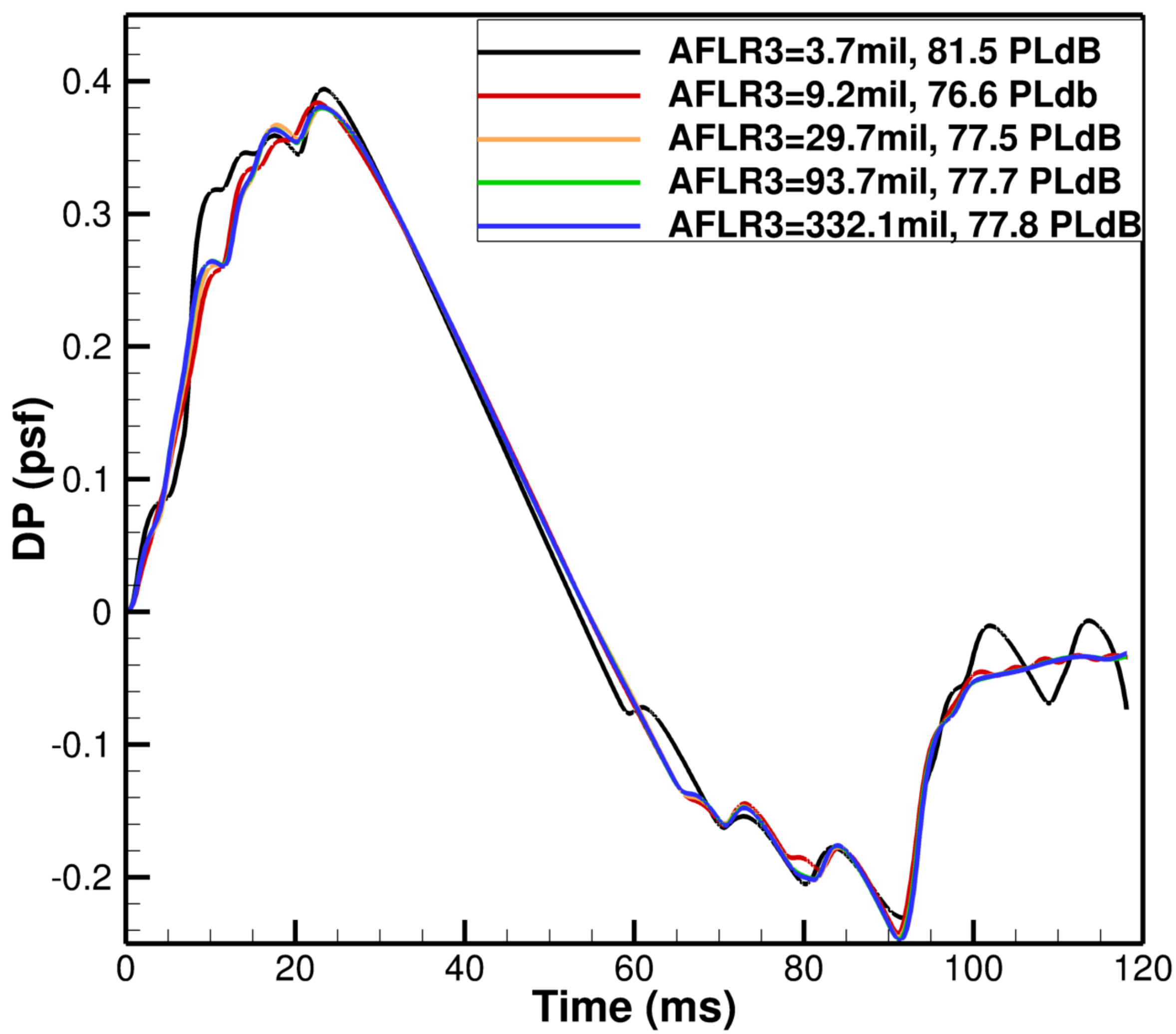
Symmetry Plane Overpressure Contours, Mach=1.6



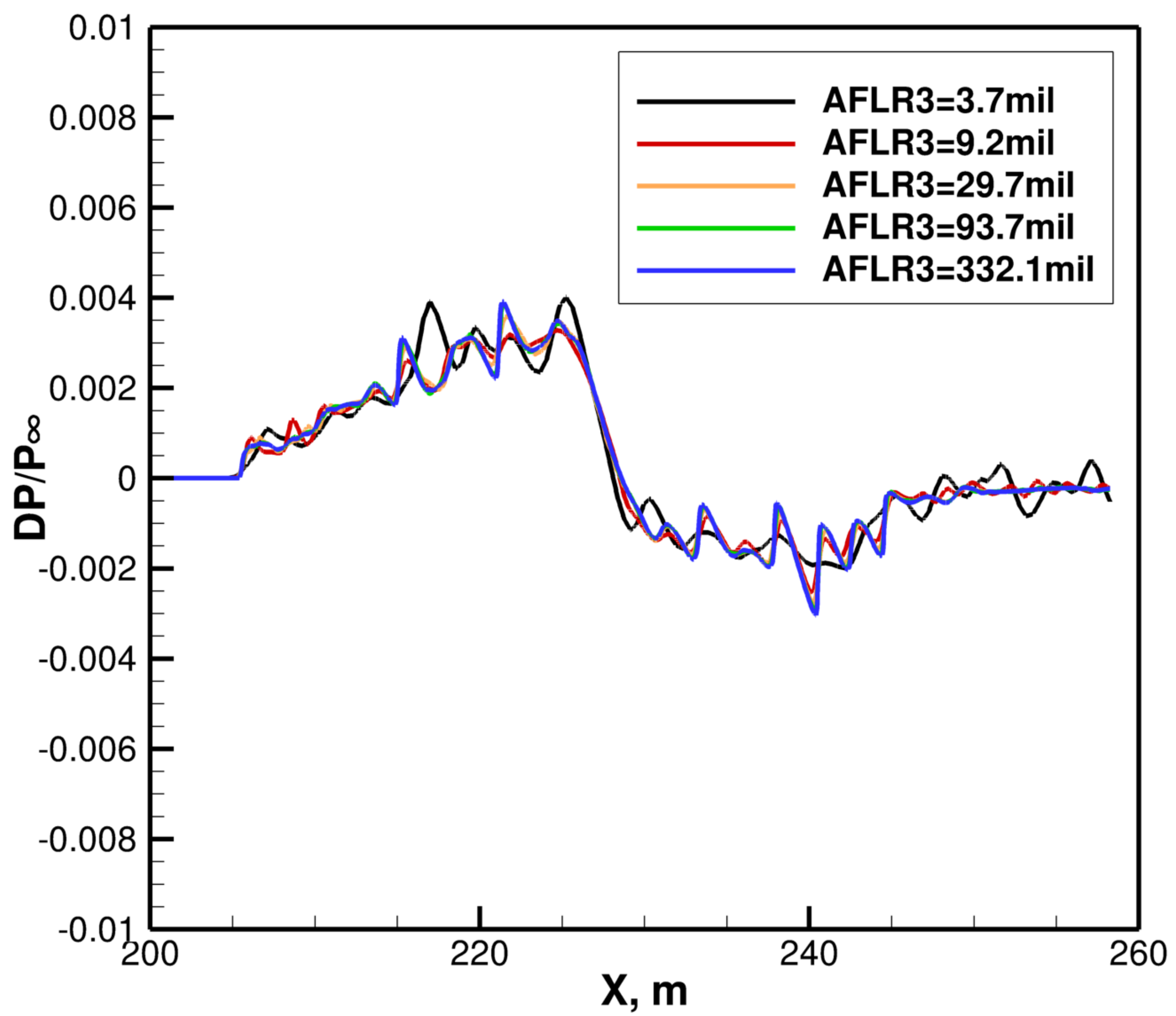
Near Field Pressure Signature, H/L=1



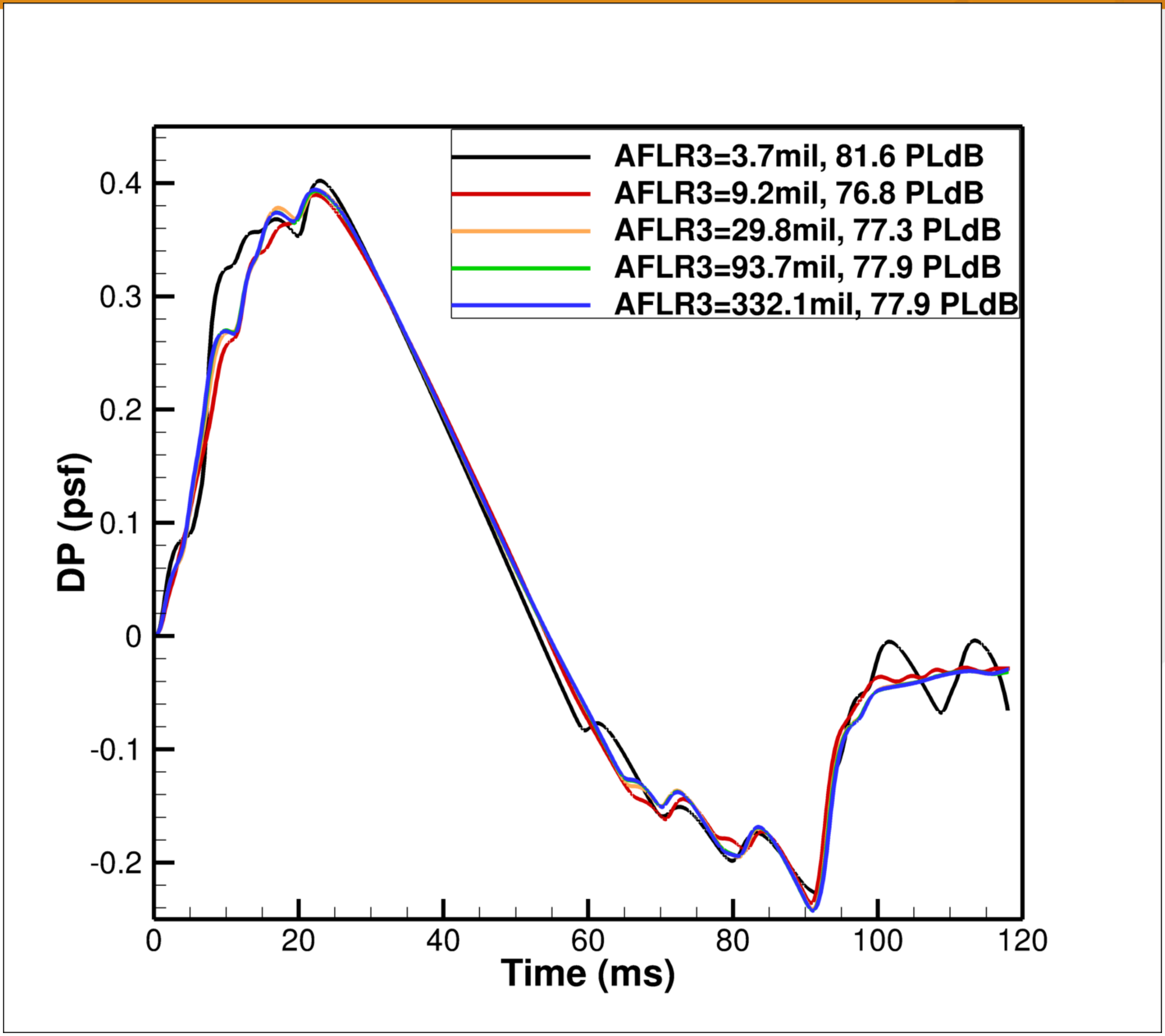
Ground Signature Computed from H/L=1



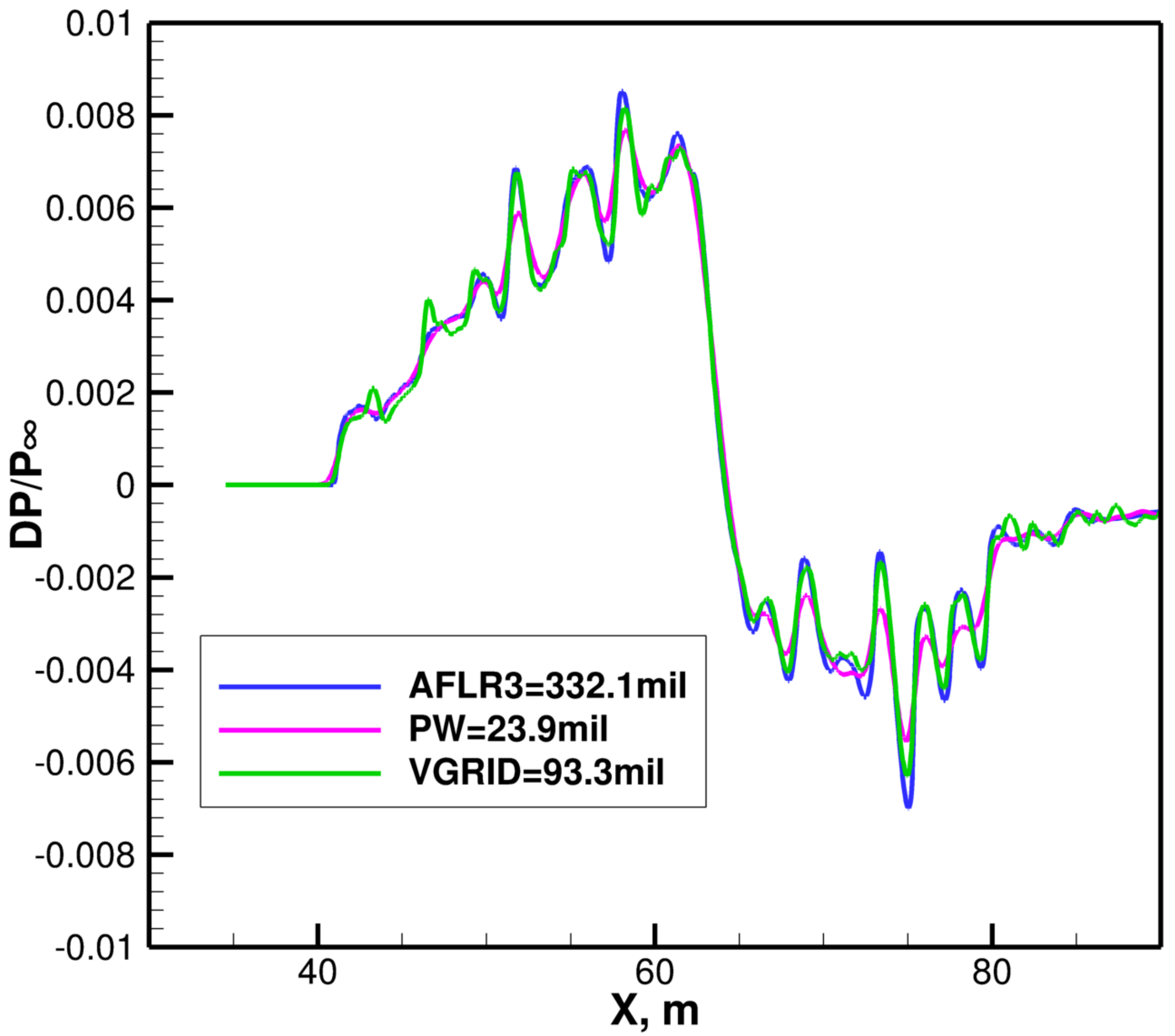
Near Field Pressure Signature, H/L=5



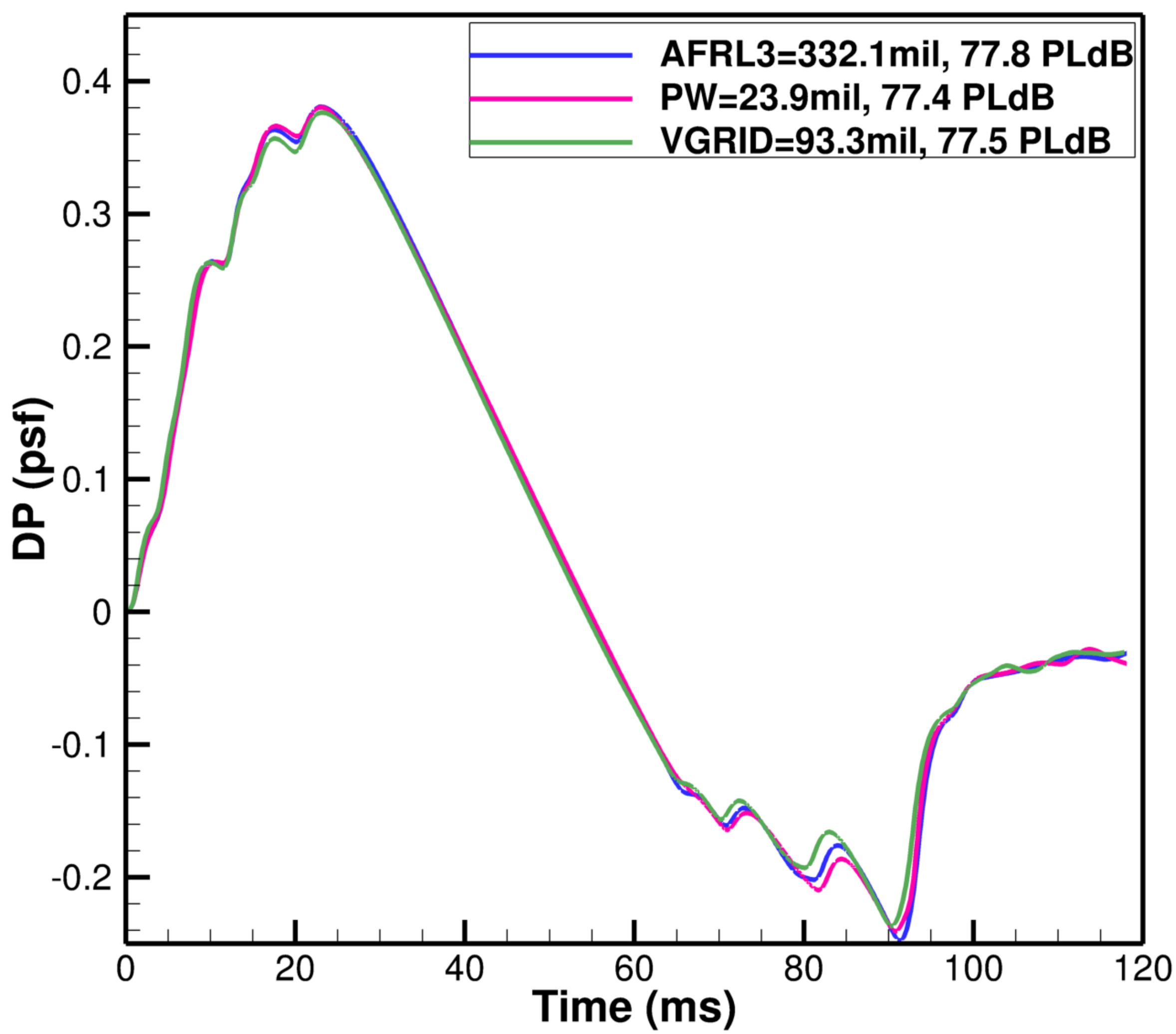
Ground Signature Computed from H/L=5



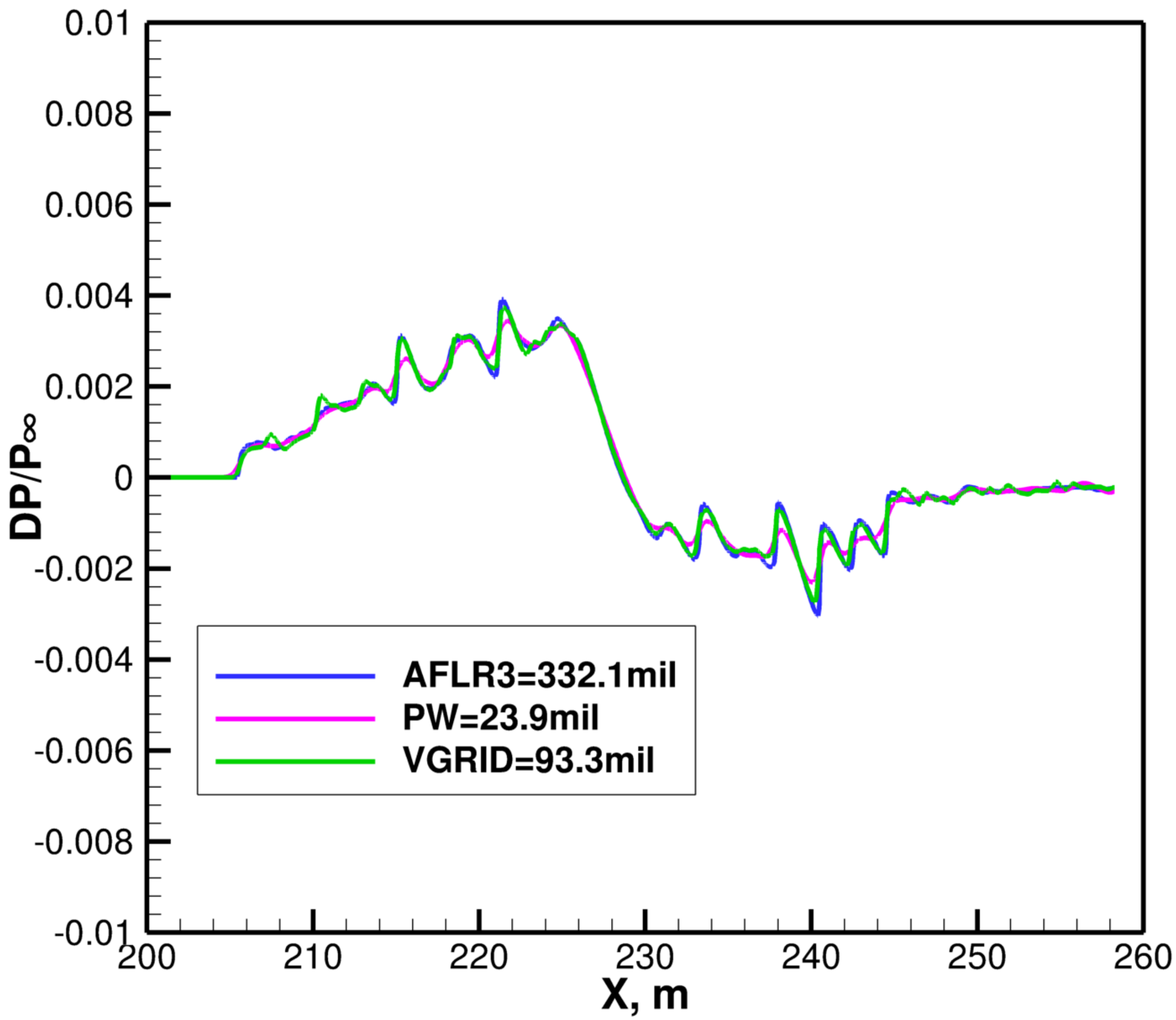
Comparison of Near Field Pressure Signature, H/L=1



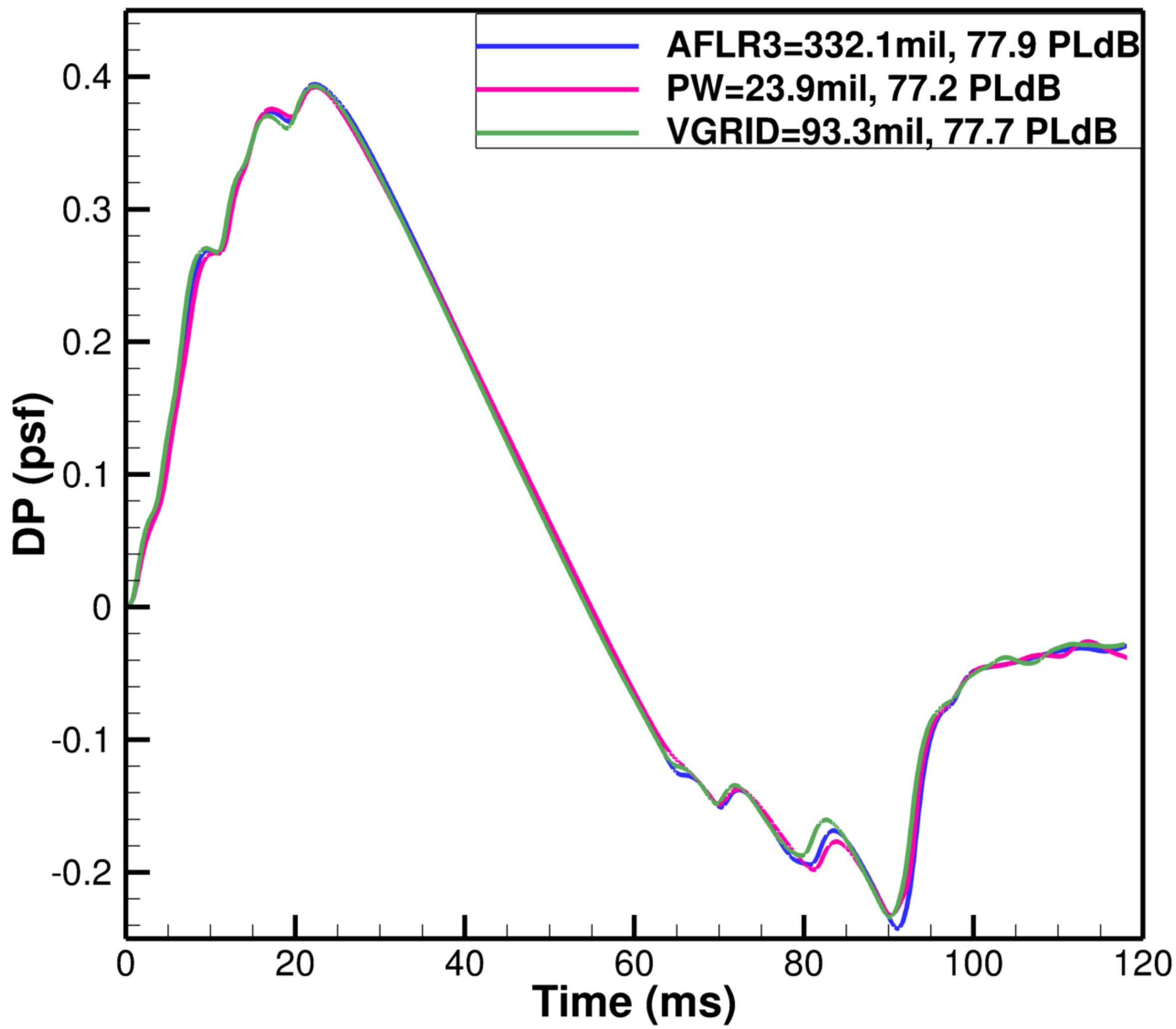
Ground Signatures Computed from H/L=1



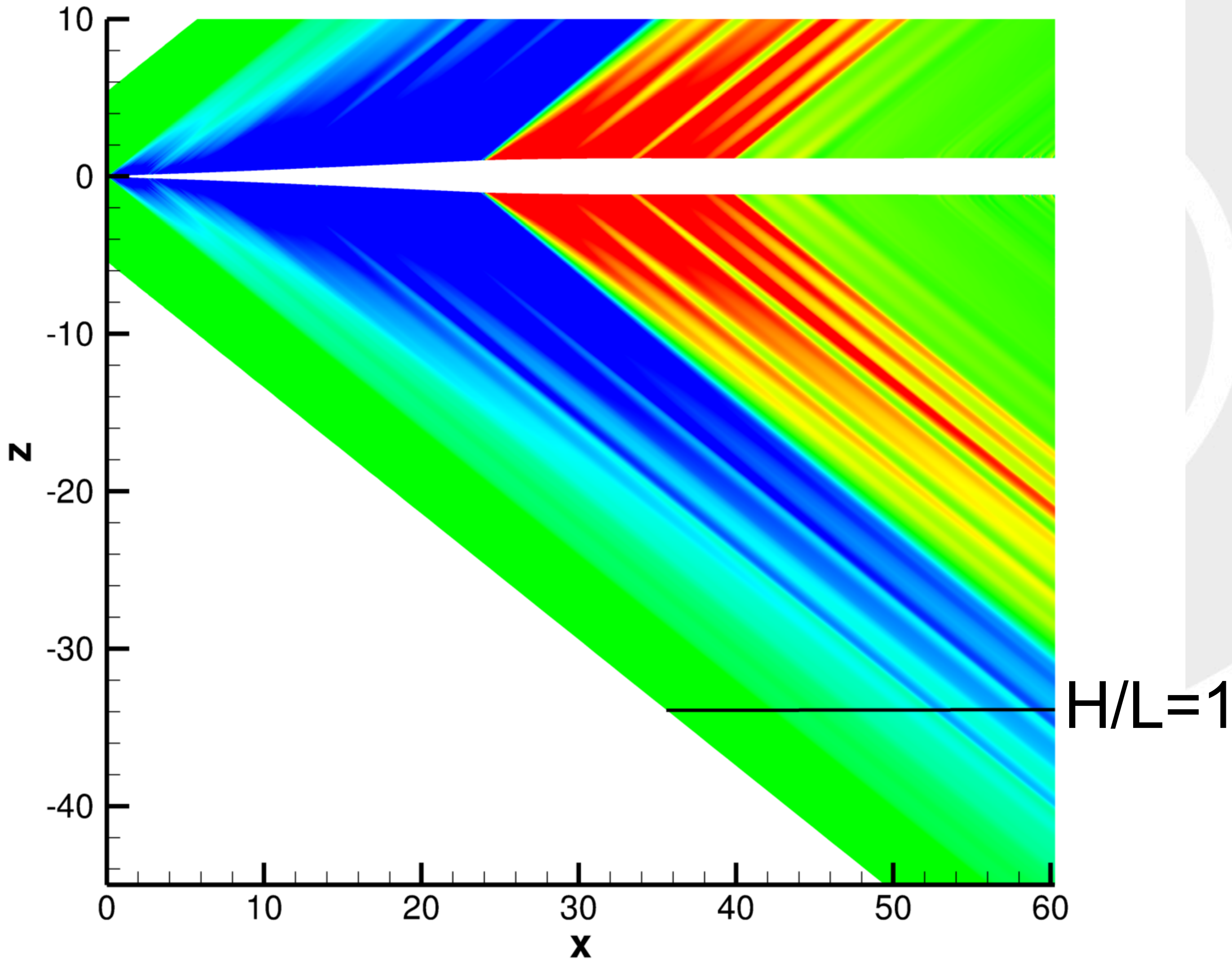
Comparison of Near Field Pressure Signature, H/L=5



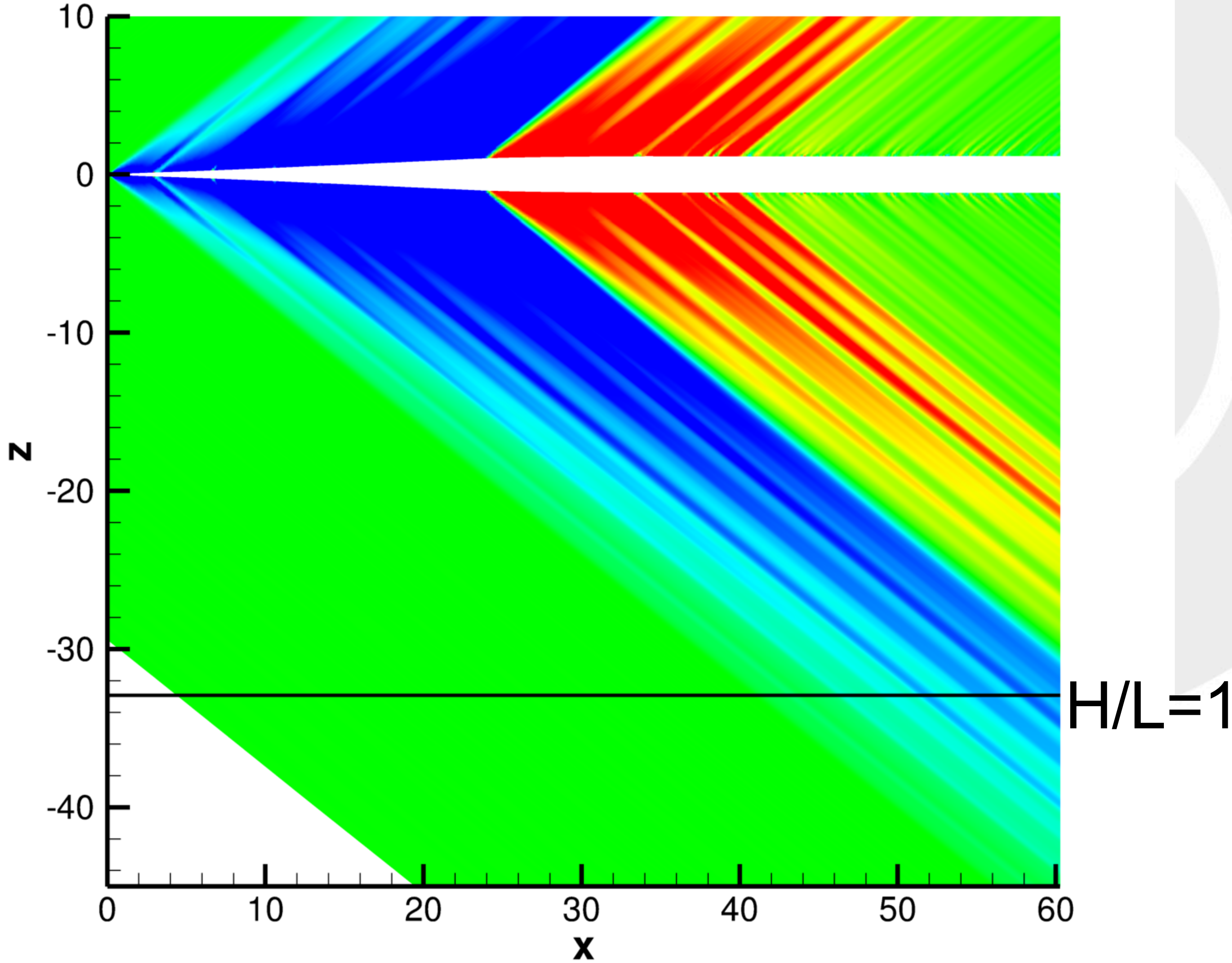
Ground Signatures Computed from H/L=5



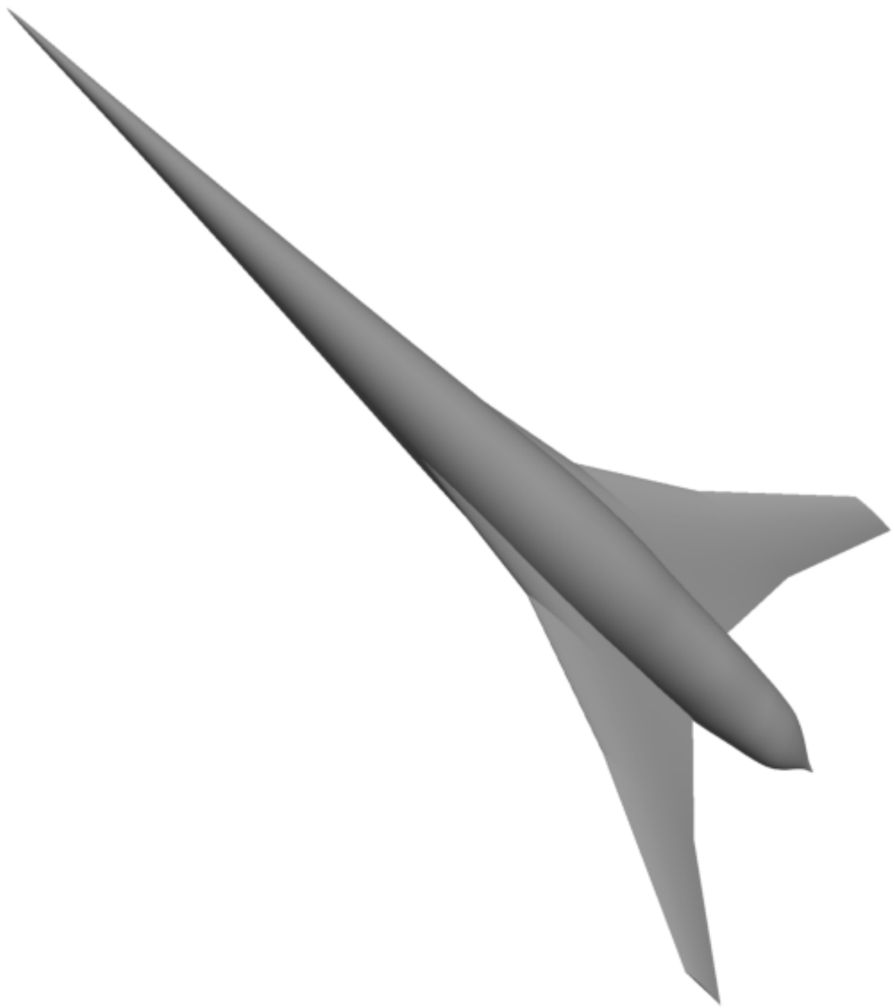
AFRL3 Grid Results



VGRID Grid Results



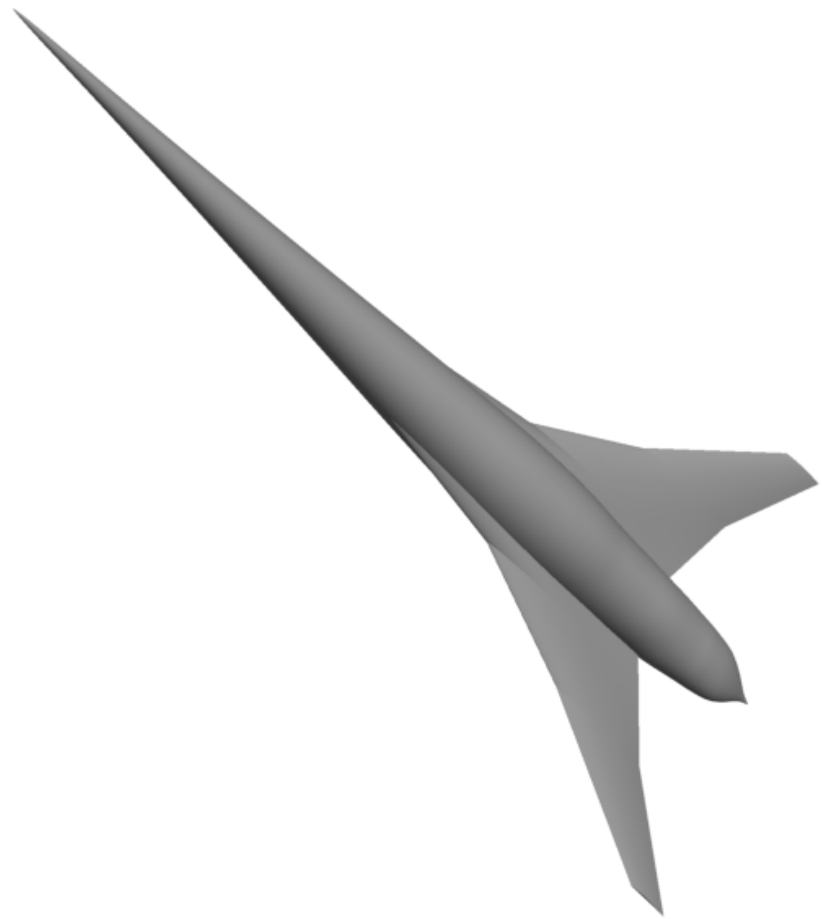
JAXA Wing-Body Configuration



JAXA Wing-Body Configuration

Simulation 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 were a subdivision of the mixed-element grids generated by AFLR3. Grids are in full scale meters and have a uniformly refined spacing.

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

JAXA Wing-Body Configuration

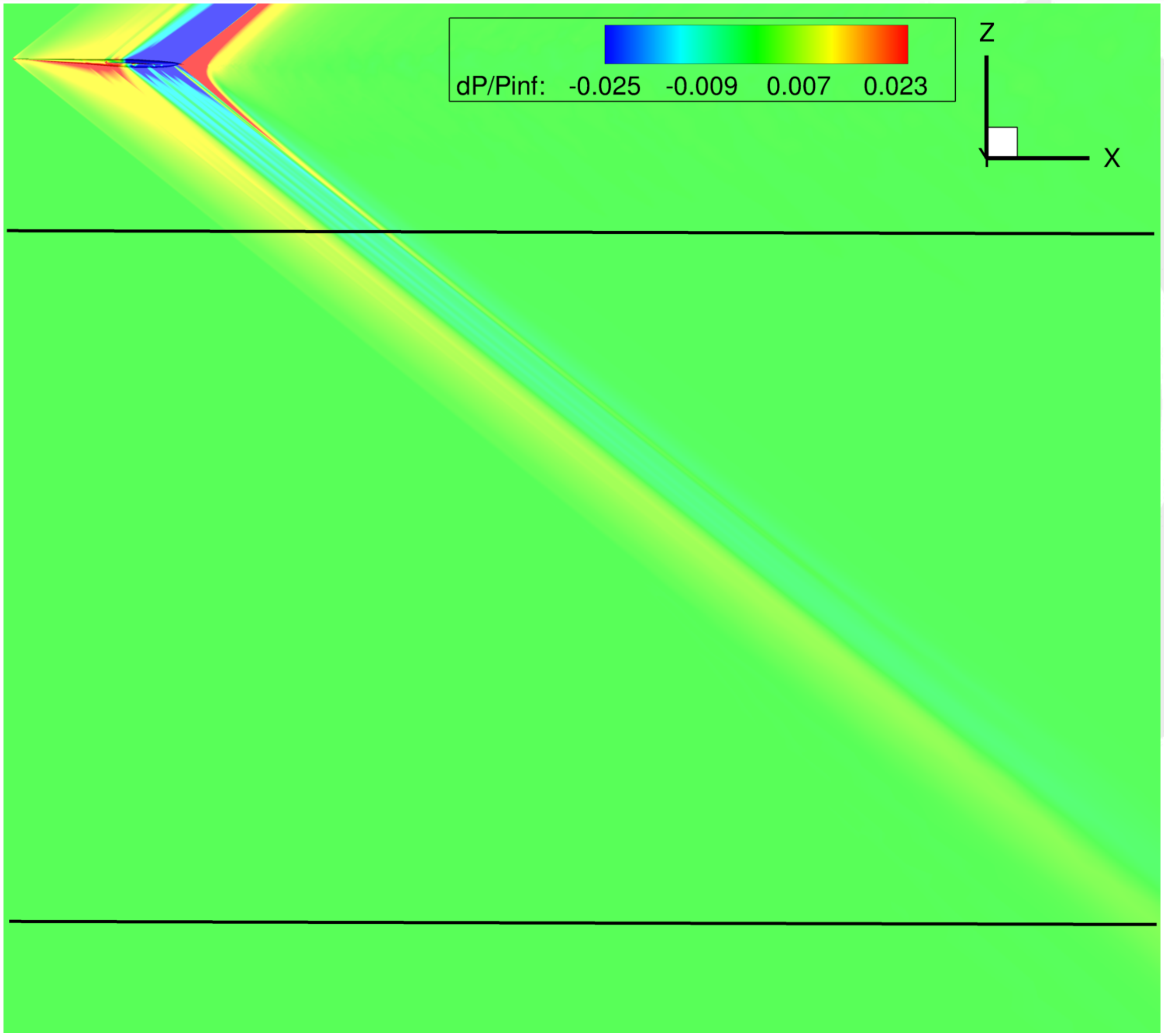
- In-house Pointwise® grids

Grid	Nodes	Tetrahedra
1	1,564,296	9,085,323
2	3,108,124	18,218,984
3	7,532,028	44,485,342

- In-house VGRID grids

Grid	Nodes	Tetrahedra
BG	4,469,805	25,999,618

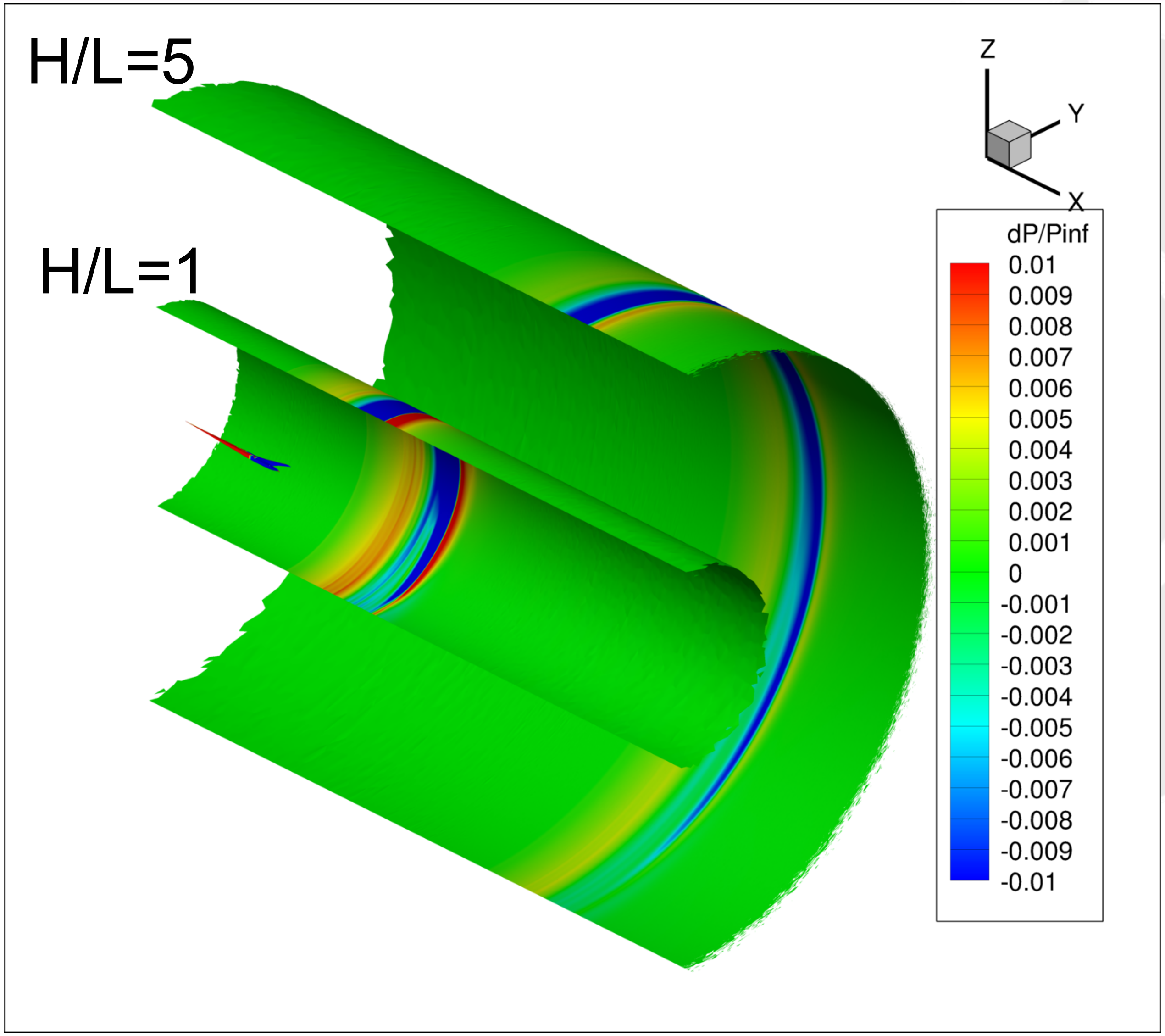
Symmetry Plane Overpressure Contours, Mach=1.6



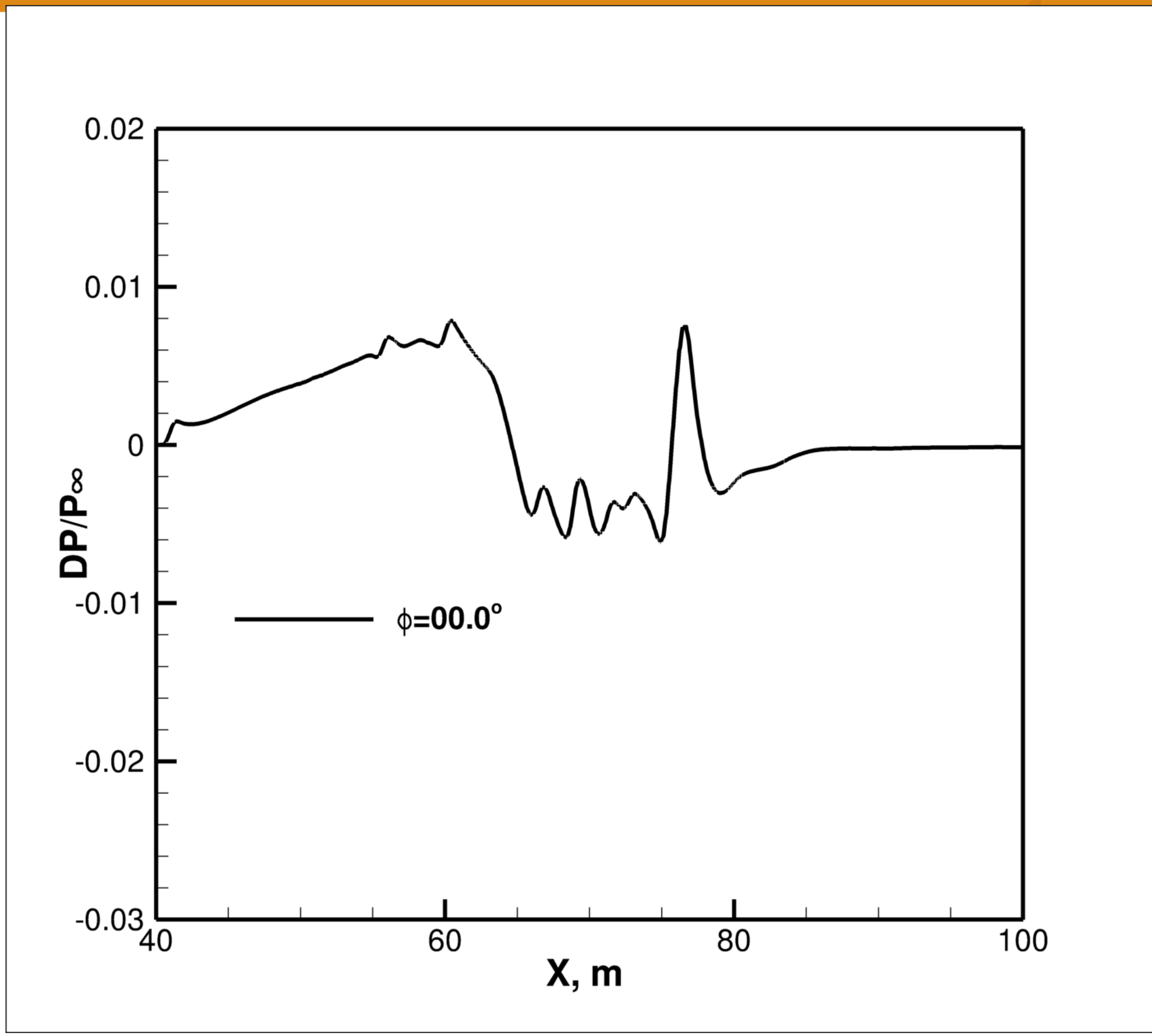
H/L=1

H/L=5

Symmetry Plane Overpressure Contours, Mach=1.6

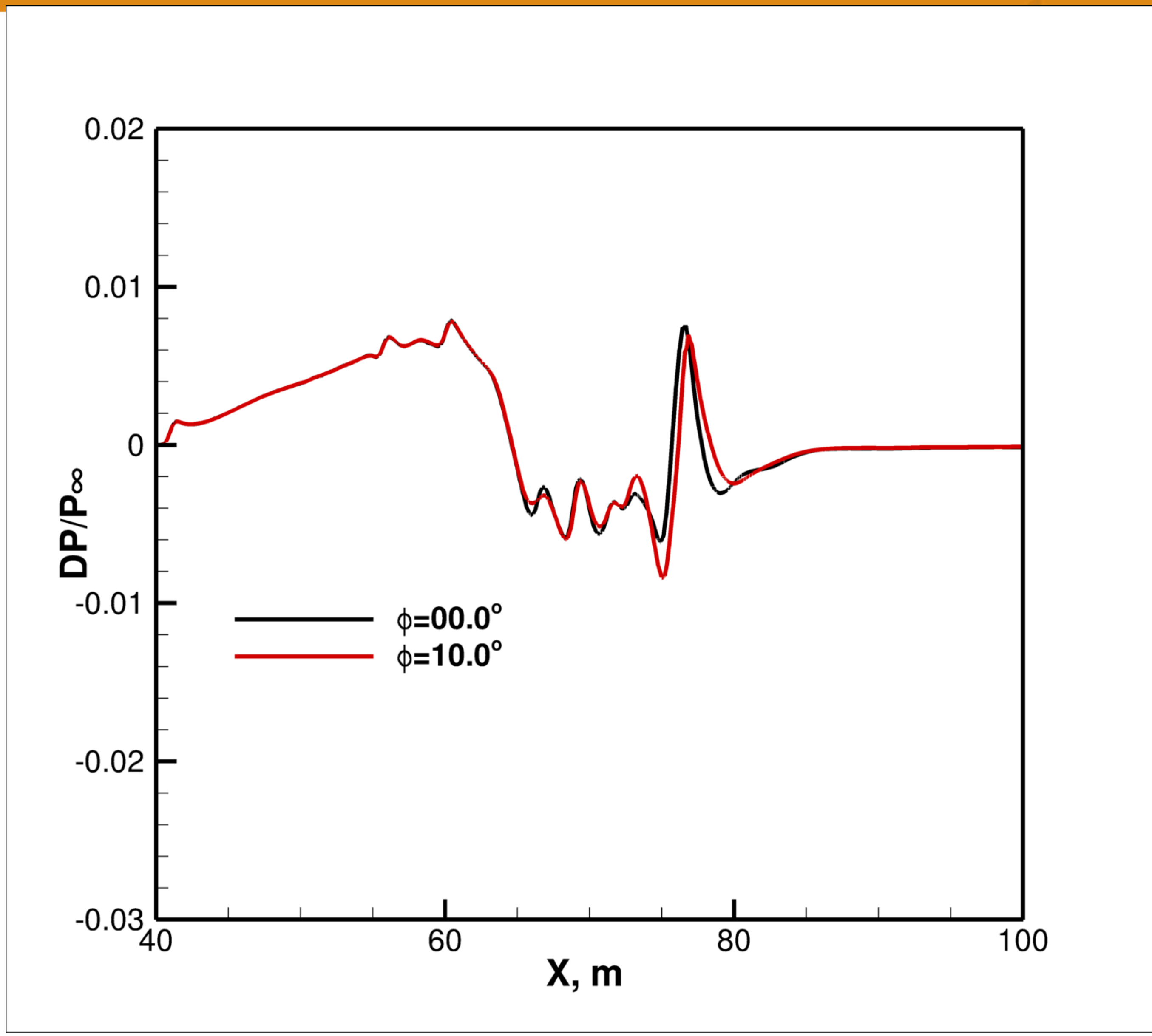


Near Field Pressure Signature, H/L=1



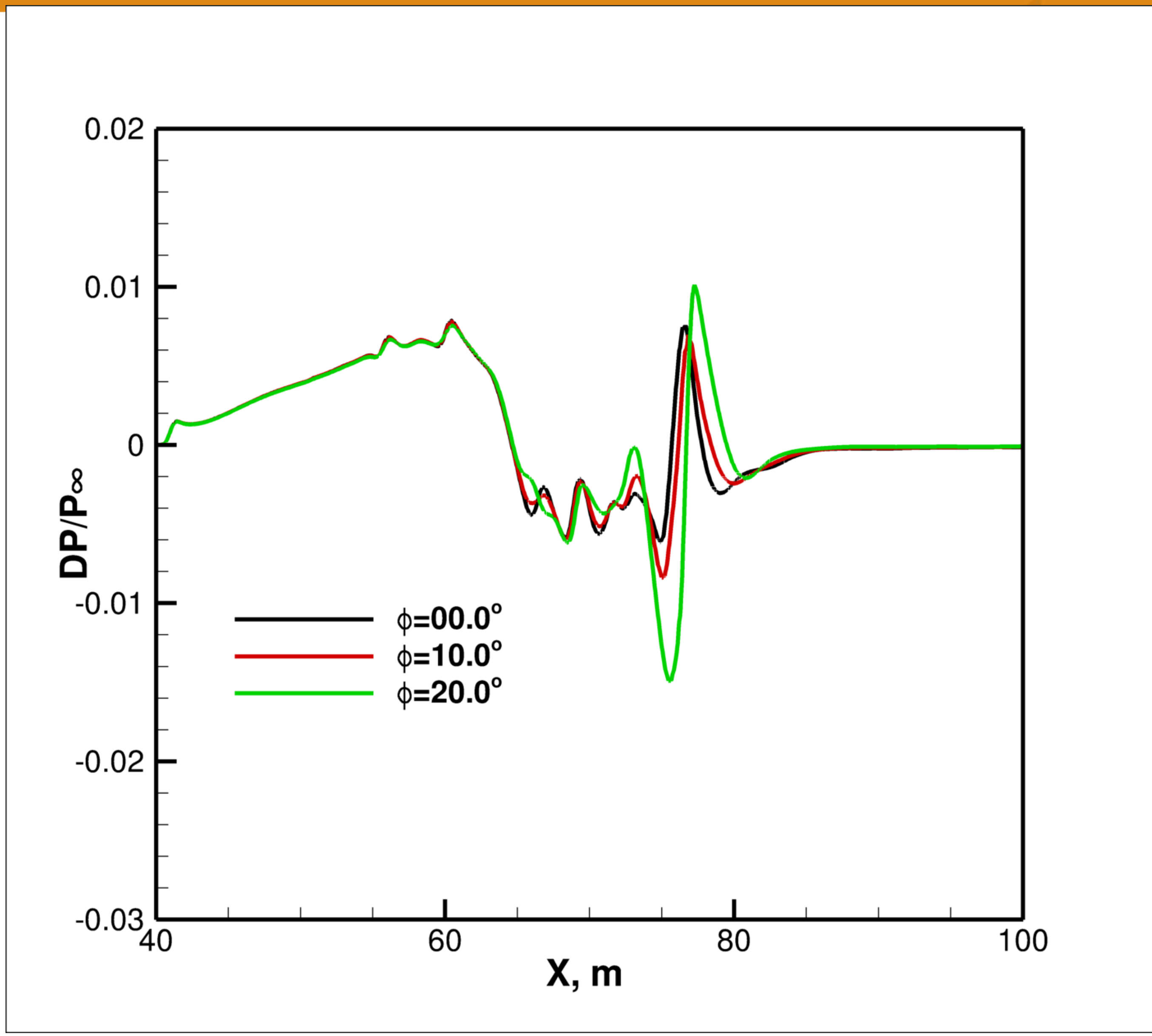
AFRL3
109mil

Near Field Pressure Signature, H/L=1



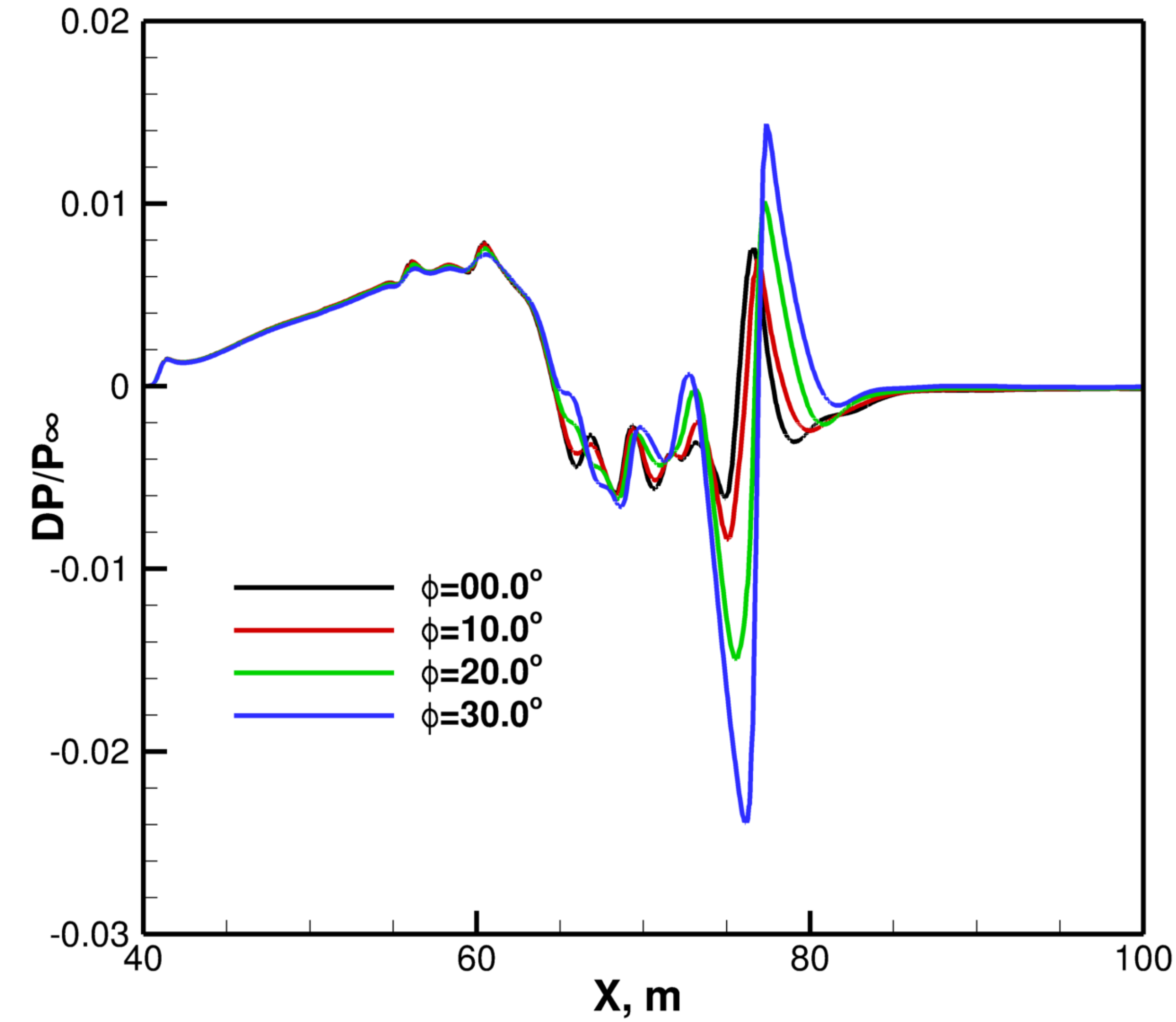
AFRL3
109mil

Near Field Pressure Signature, H/L=1



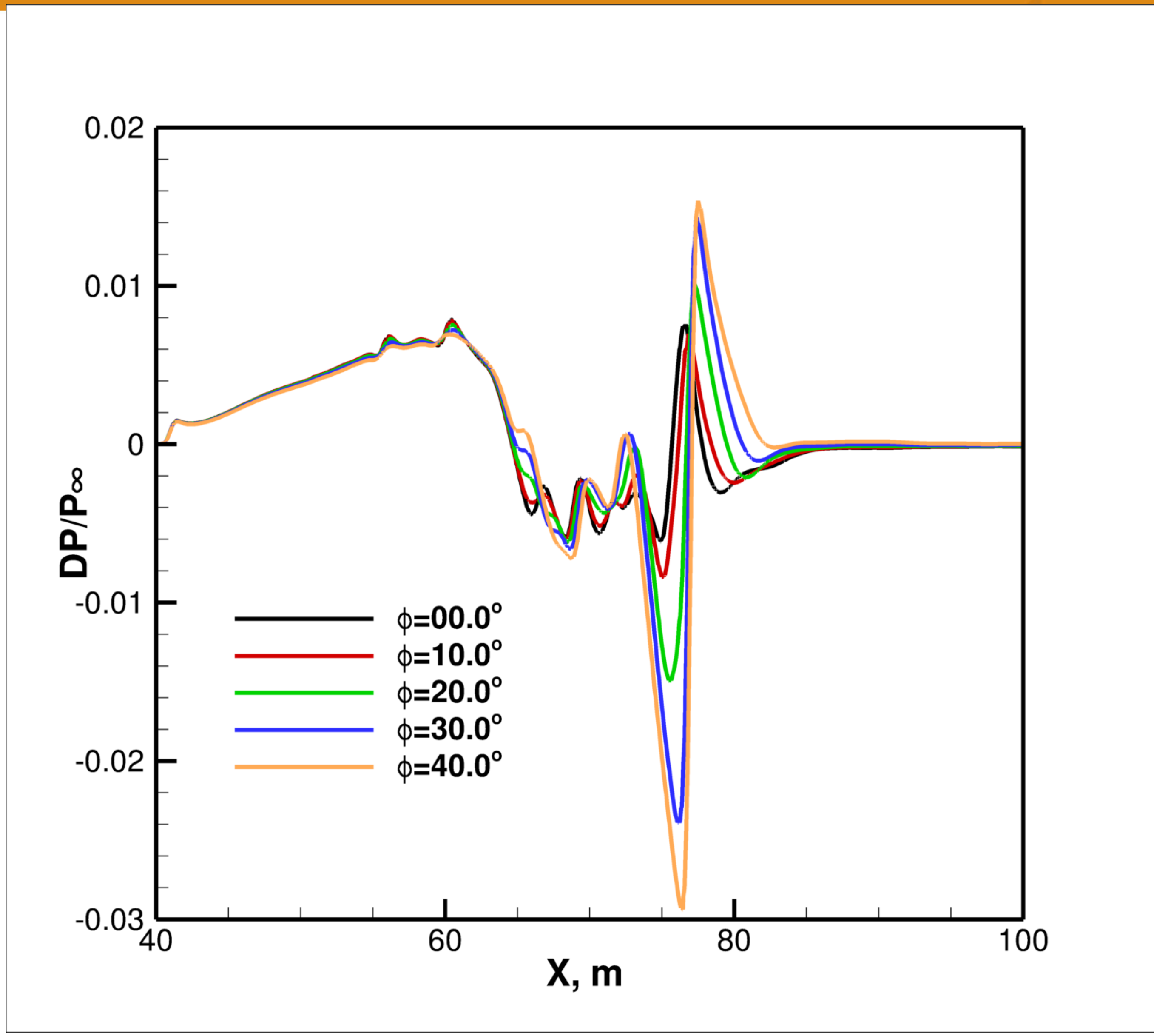
AFRL3
109mil

Near Field Pressure Signature, H/L=1



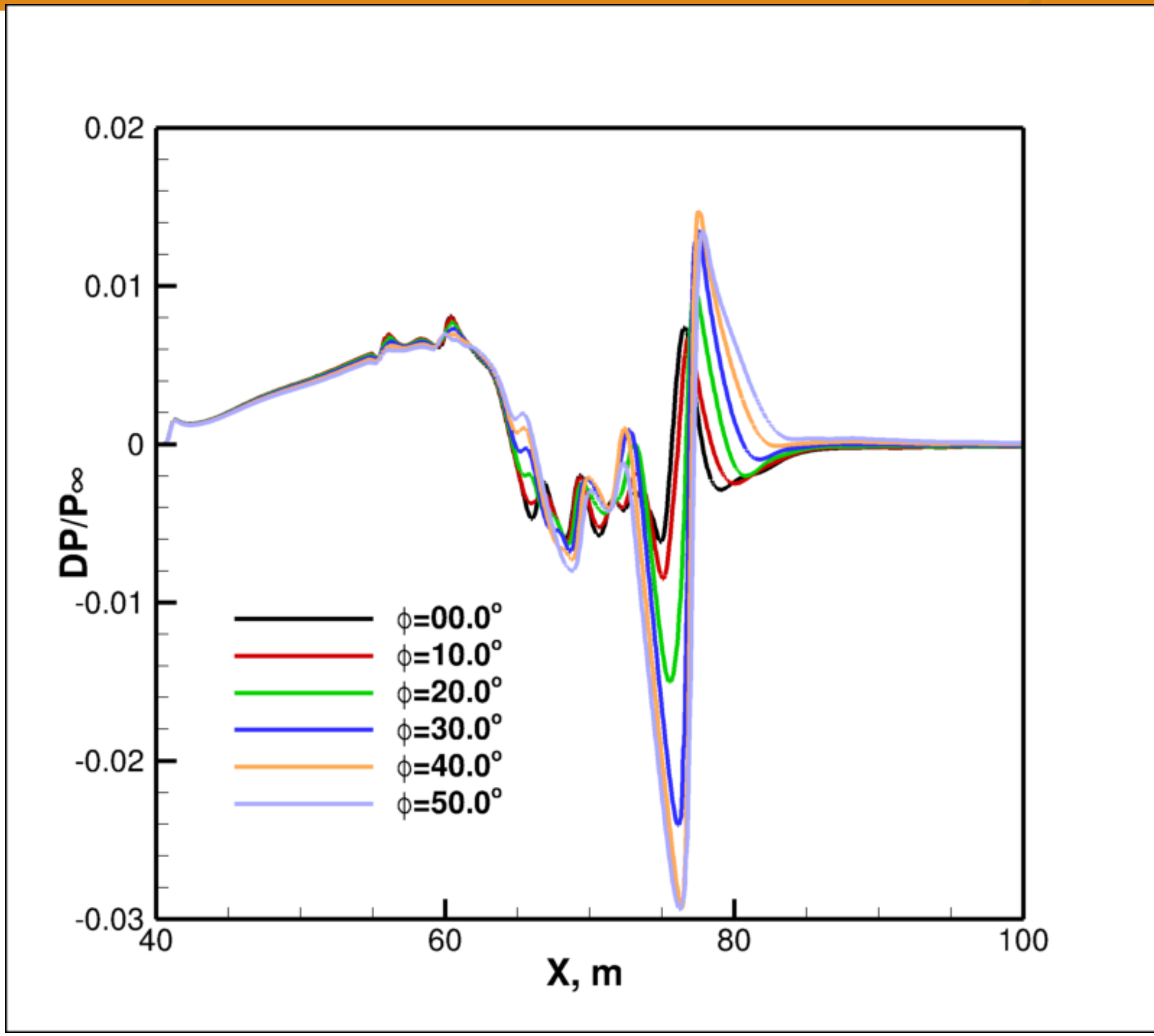
AFRL3
109mil

Near Field Pressure Signature, H/L=1



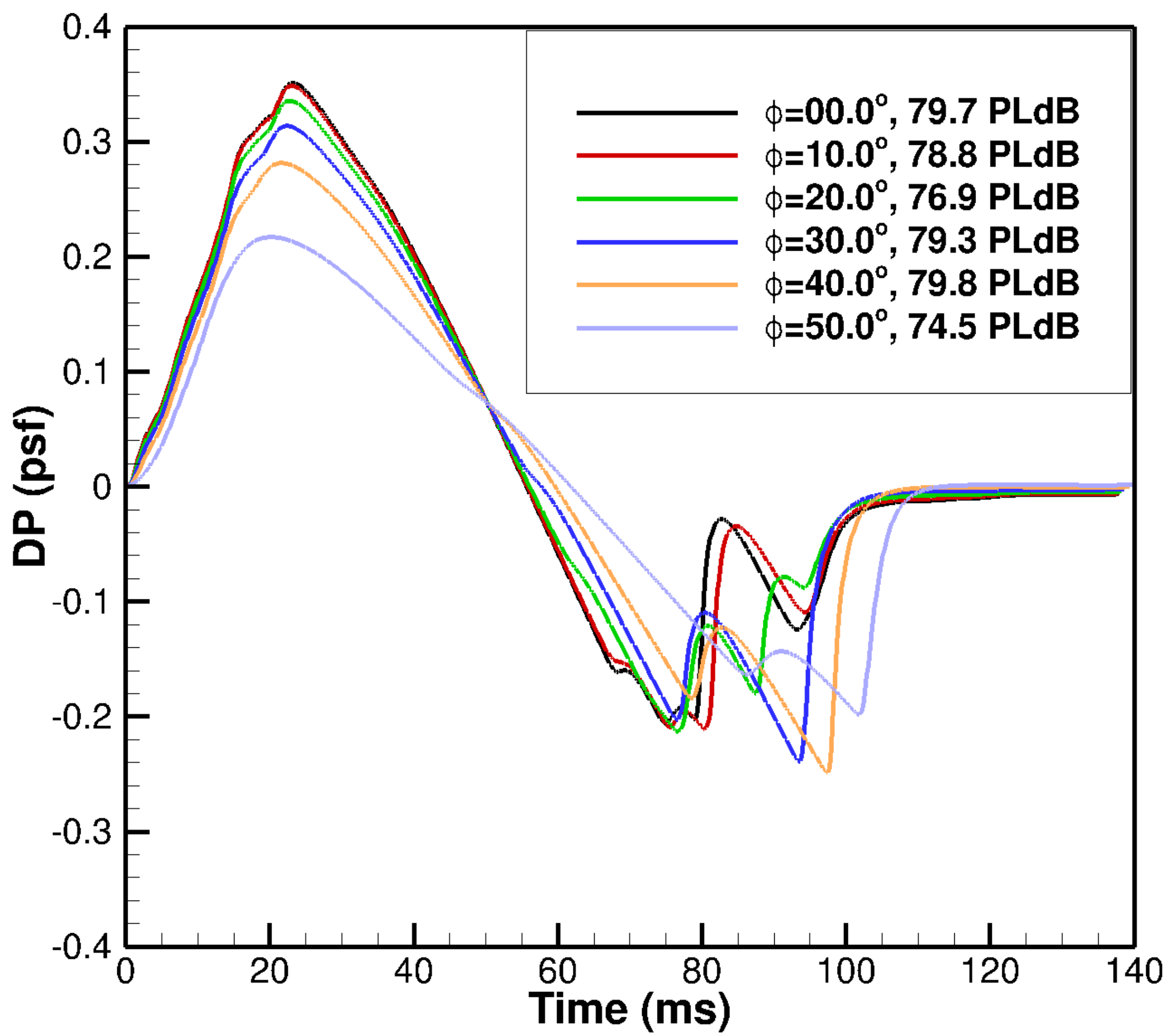
AFRL3
109mil

Near Field Pressure Signature, H/L=1



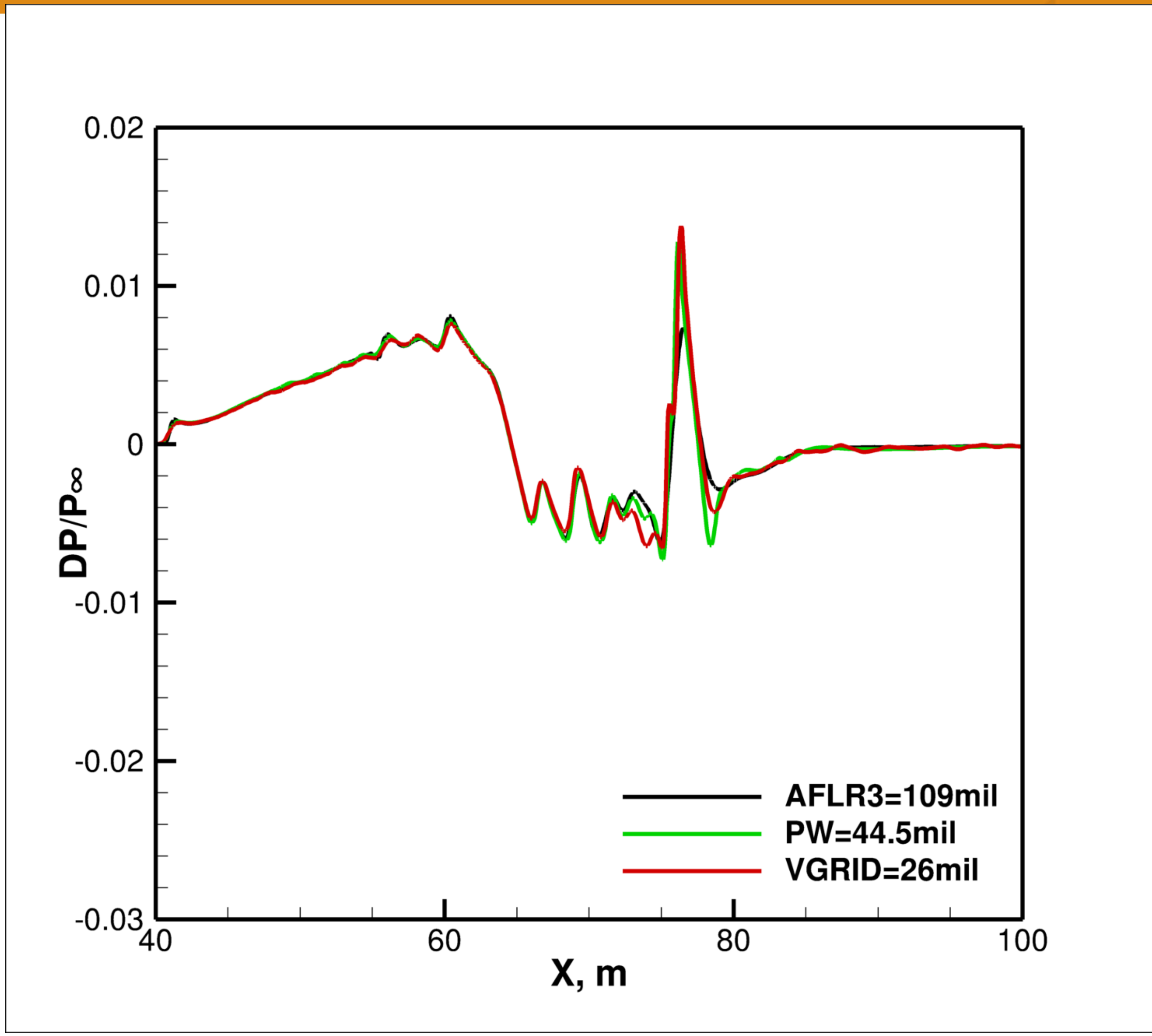
AFRL3
109mil

Ground Signatures Computed from H/L=1

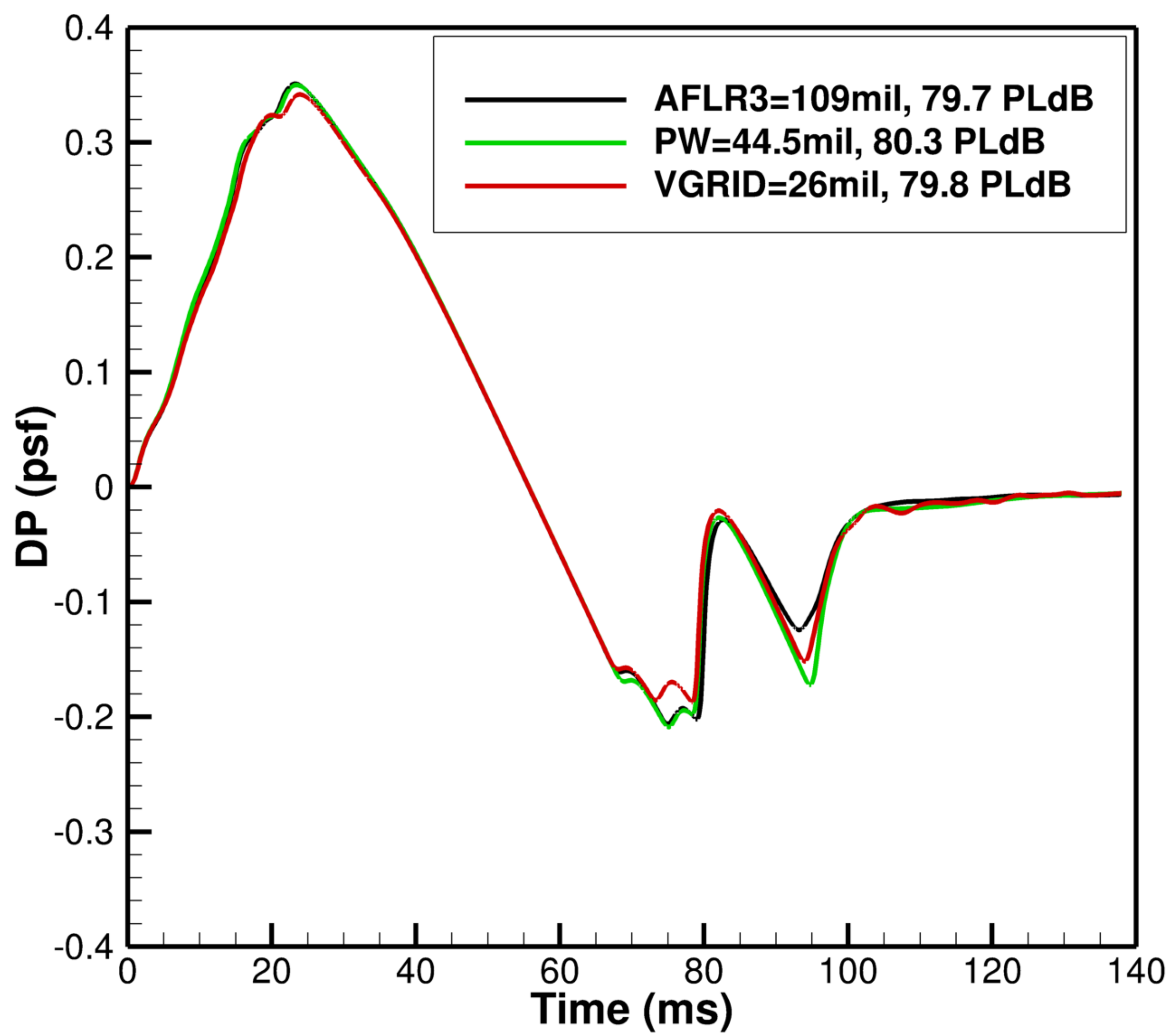


AFRL3
109mil

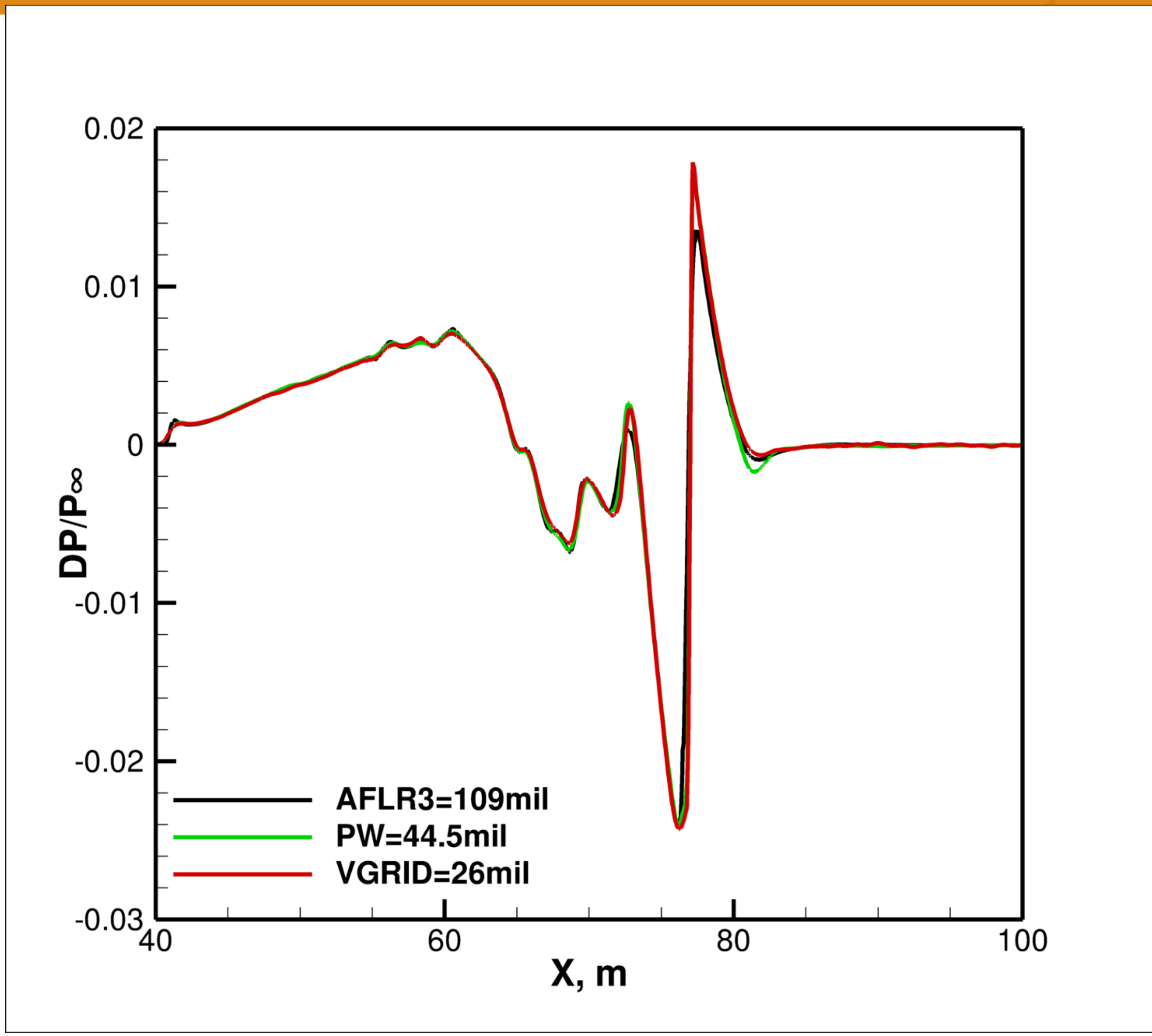
Near Field Pressure Signature, H/L=1, Φ = 0°



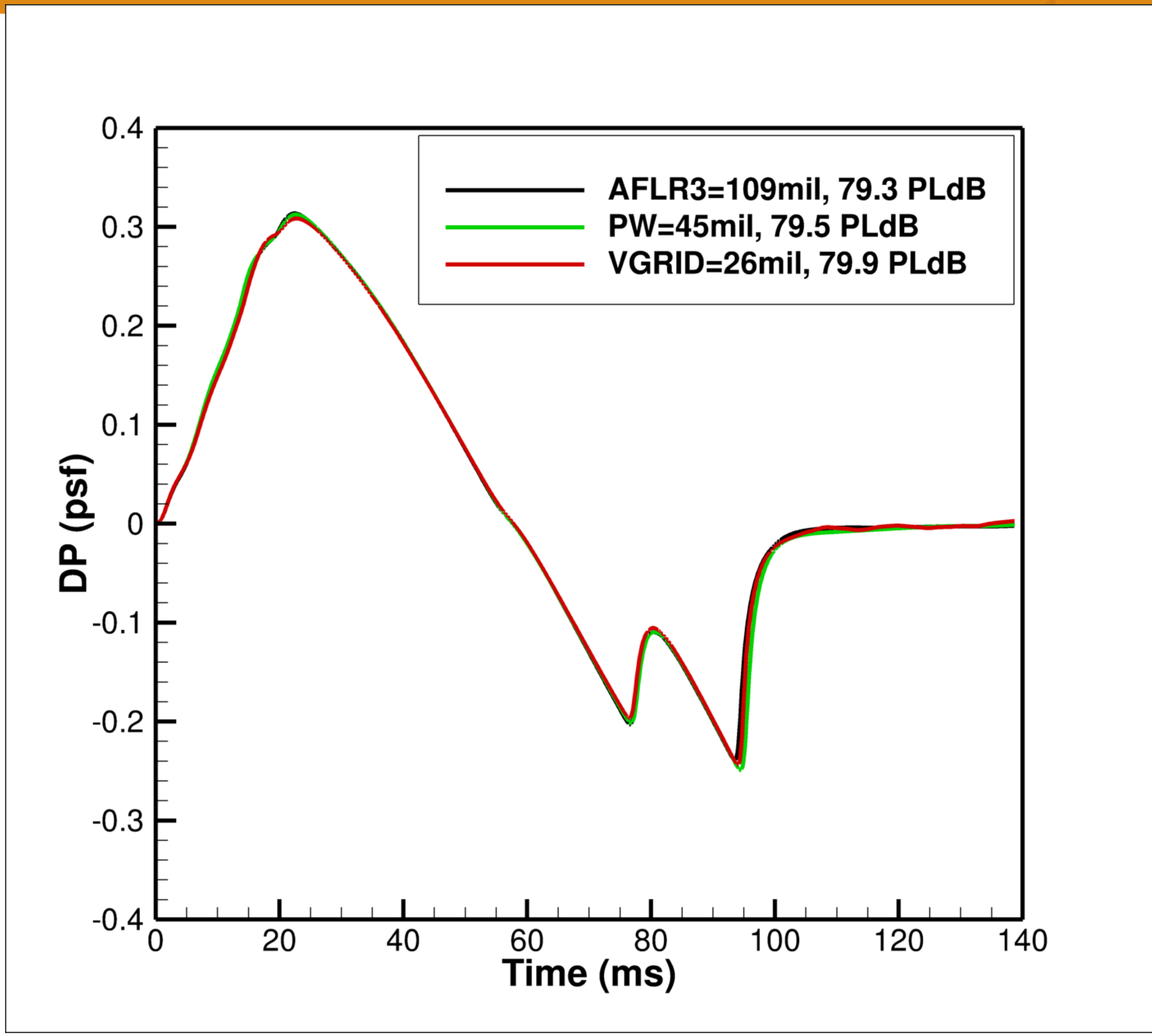
Ground Signatures Computed from H/L=1, Φ=0˚



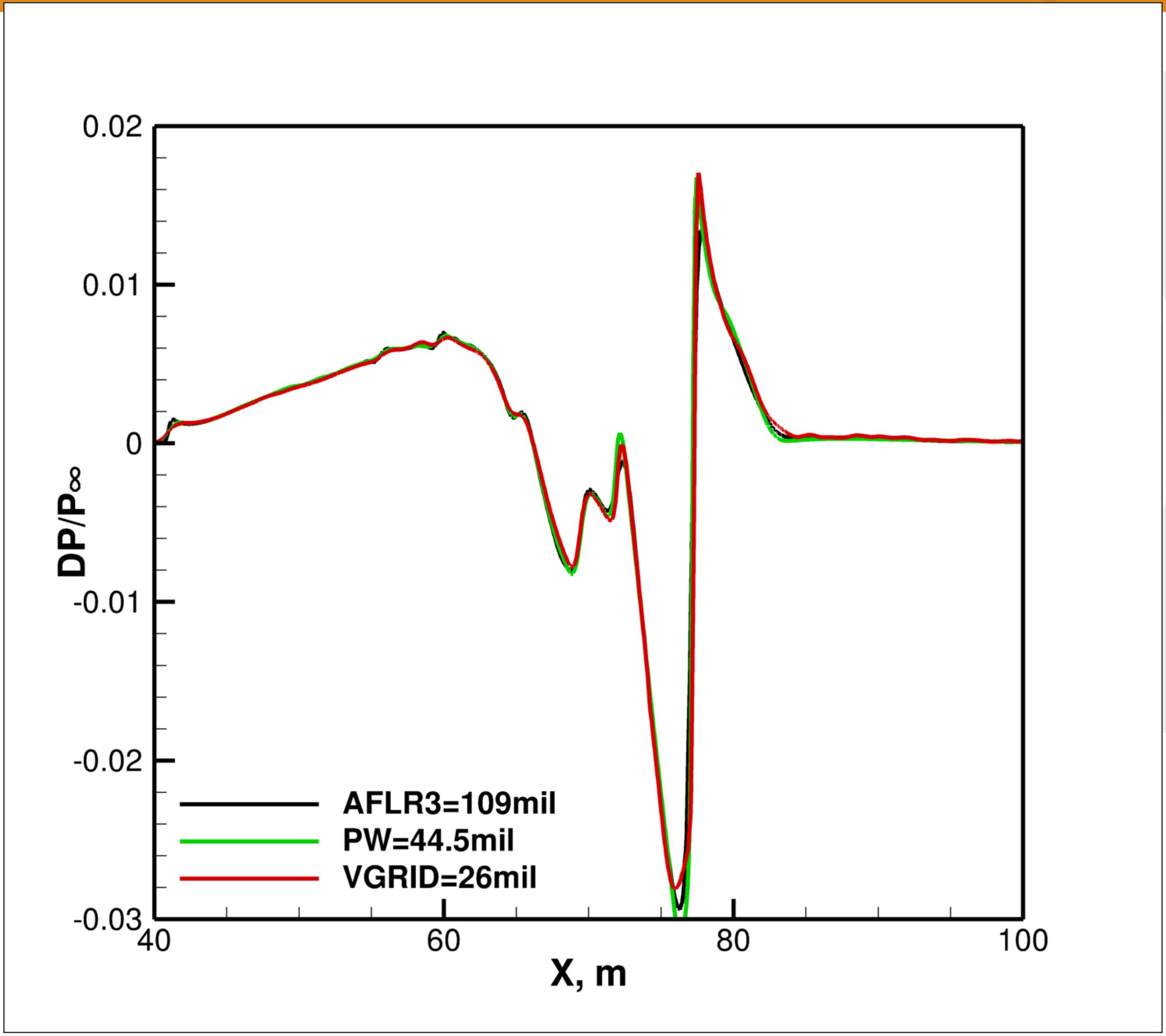
Near Field Pressure Signature, H/L=1, Φ=30˚



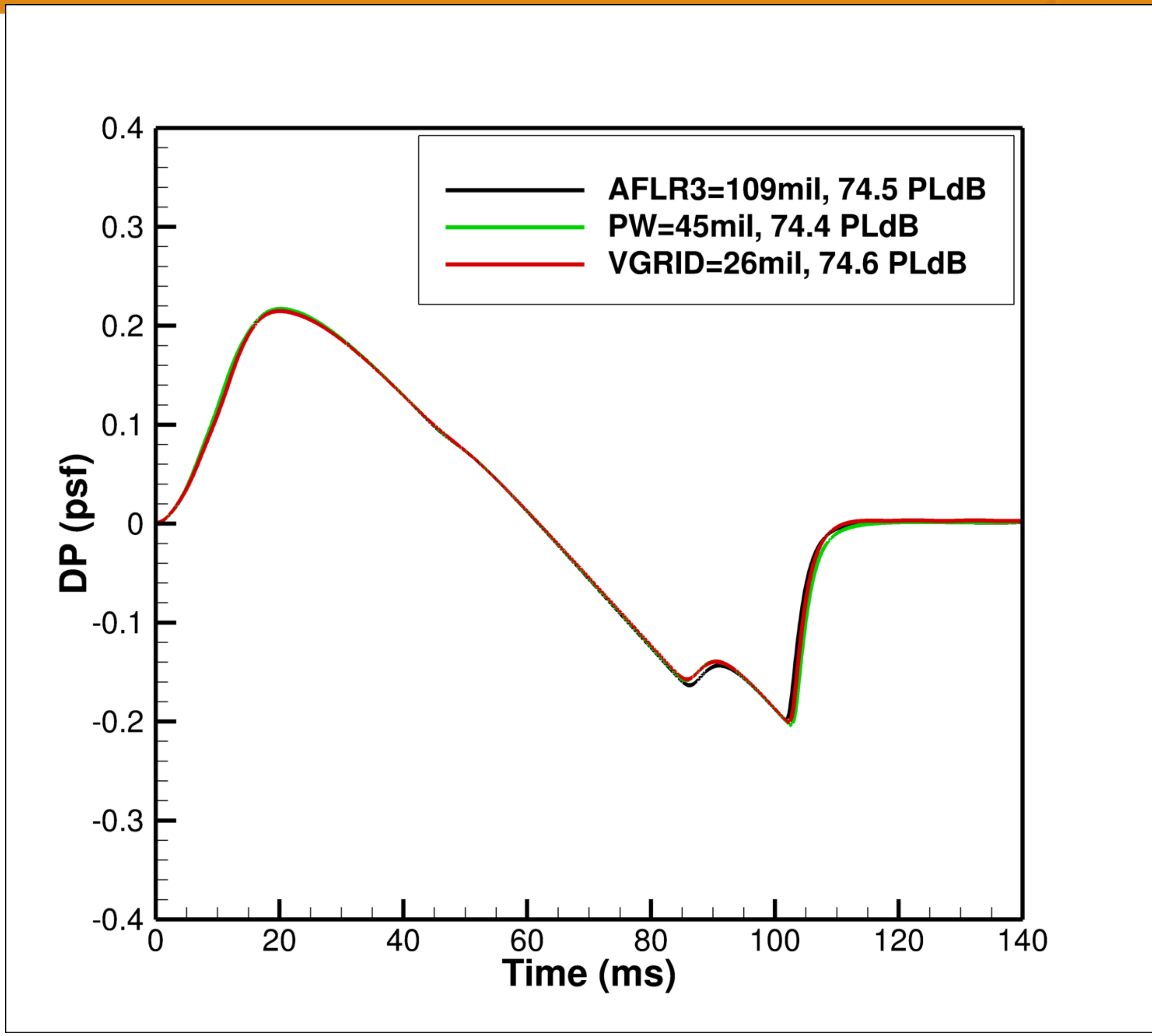
Ground Signatures Computed from H/L=1, Φ=30˚



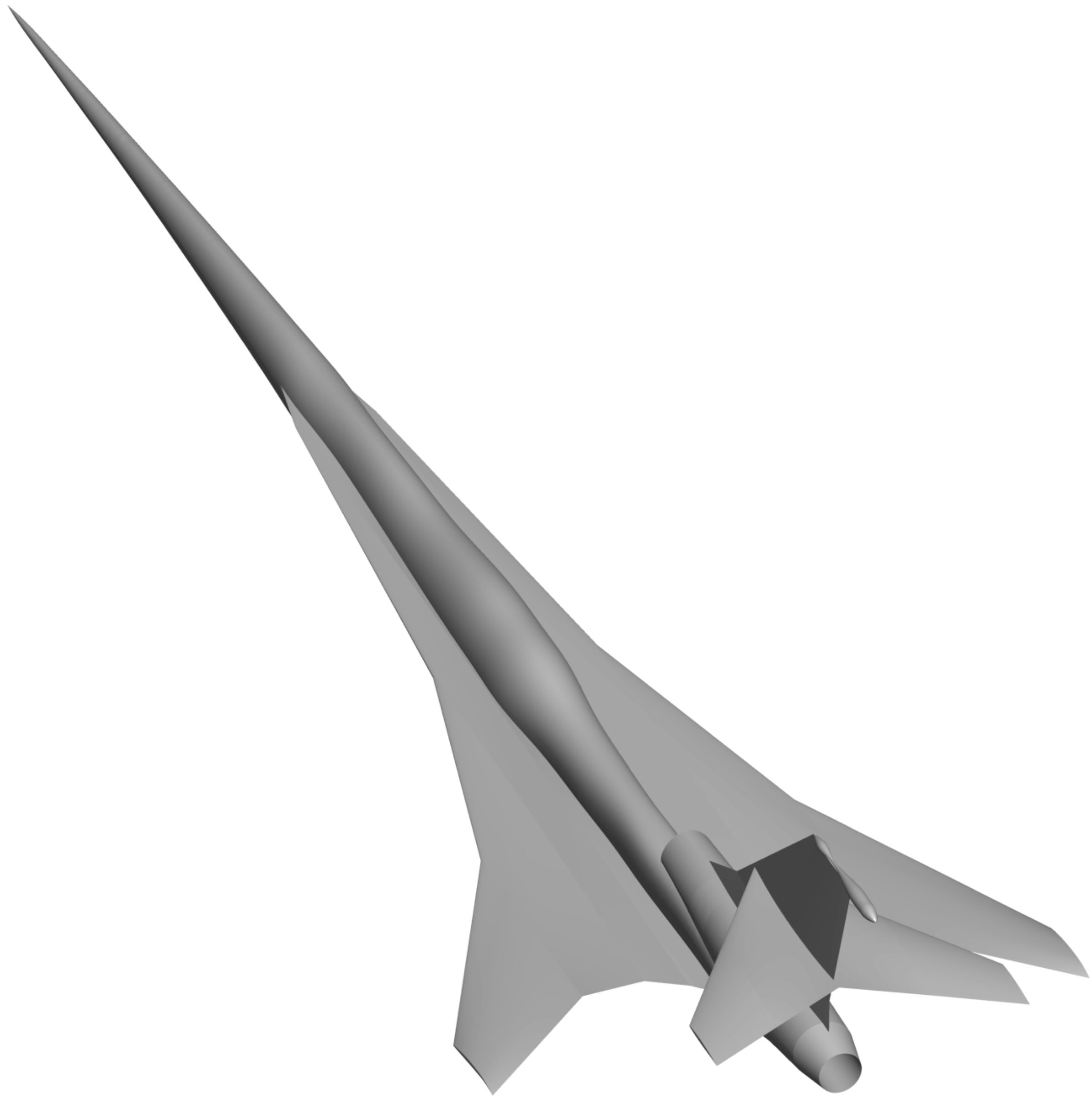
Near Field Pressure Signature, H/L=1, Φ=50˚



Ground Signatures Computed from H/L=1, Φ=50˚



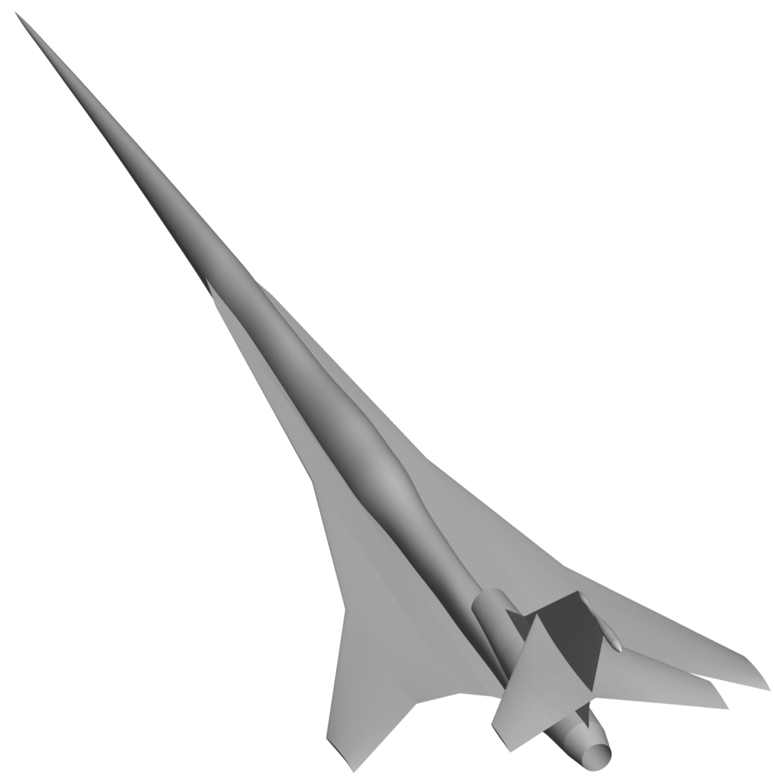
NASA C25D Configuration w/Flow Through Nacelles



NASA C25D Configuration w/Flow Through 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 C25D Configuration w/Flow Through Nacelles

- Workshop provided grids were a subdivision of the mixed-element grids generated by AFLR3. Grids are in full scale meters and have a uniformly refined spacing.

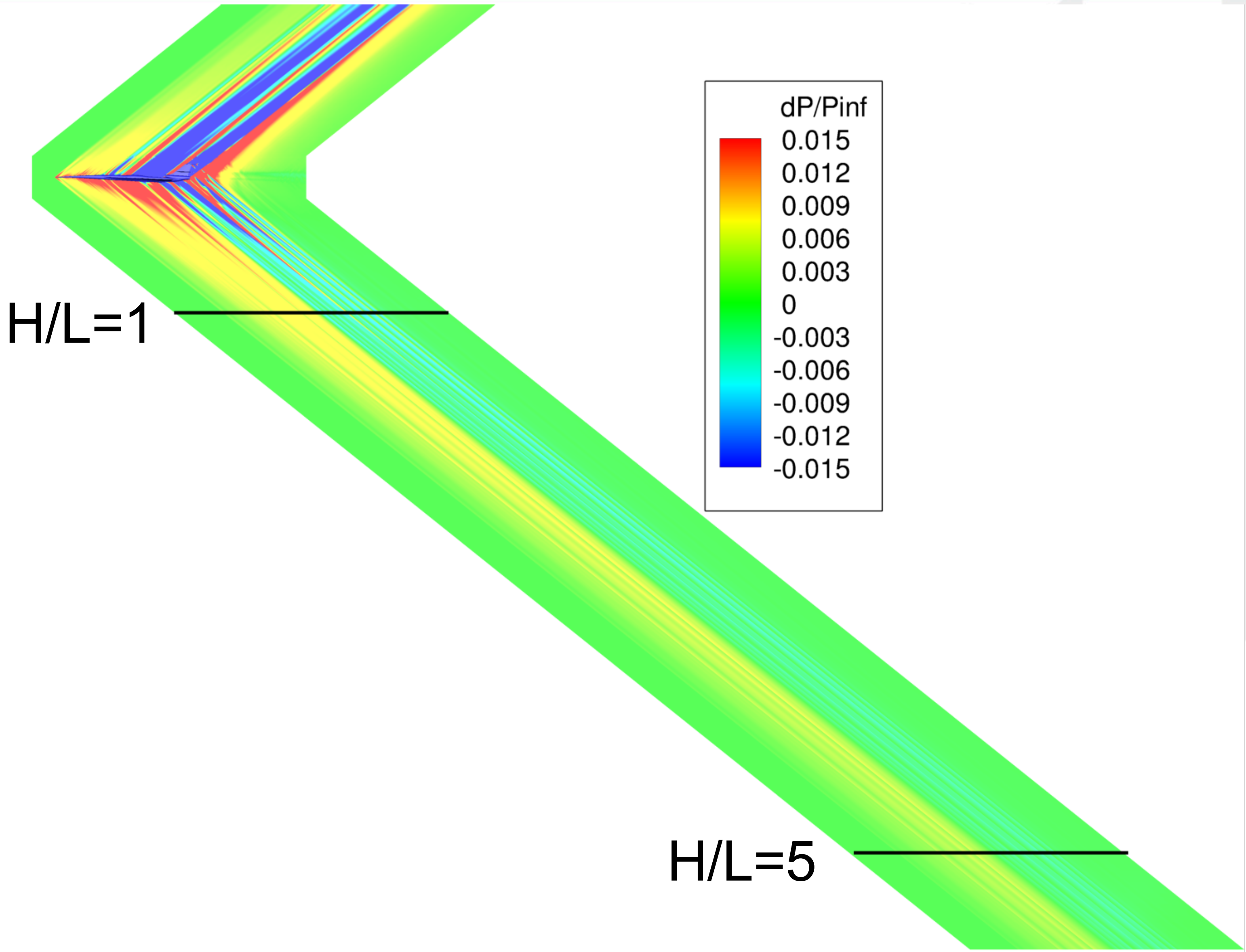
Grid	Nodes	Tetrahedra
1	3,419,776	19,995,530
2	6,323,343	37,082,947
3	13,083,168	77,082,860
4	26,923,206	159,106,053
5	51,542,500	305,204,267
6(v)	4,789,378	28,090,664

NASA C25D Configuration w/Flow Through Nacelles

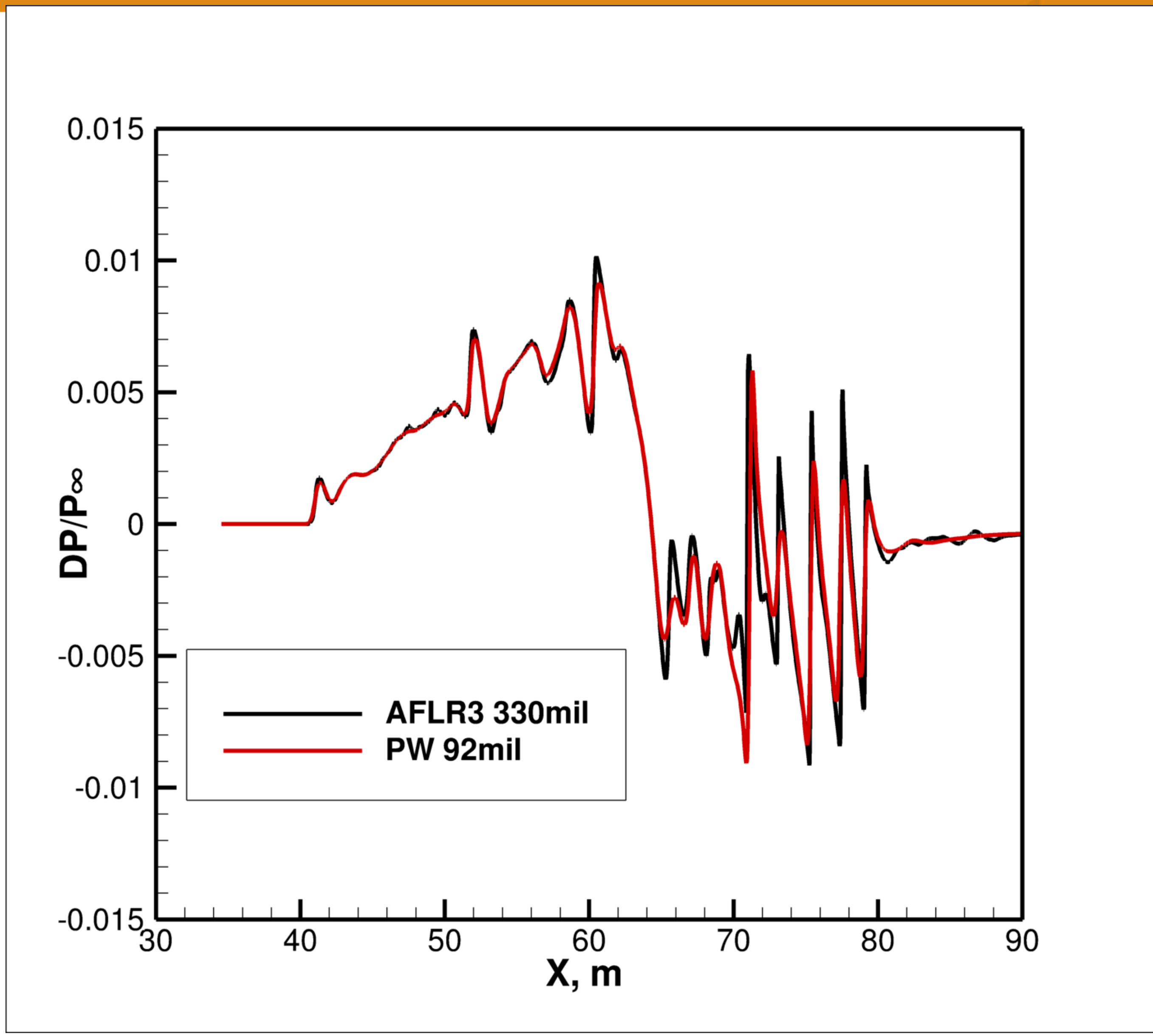
- In-house Pointwise® grids

Grid	Nodes	Tetrahedra
1	9,909,609	58,290,541
2	15,733,466	92,820,860

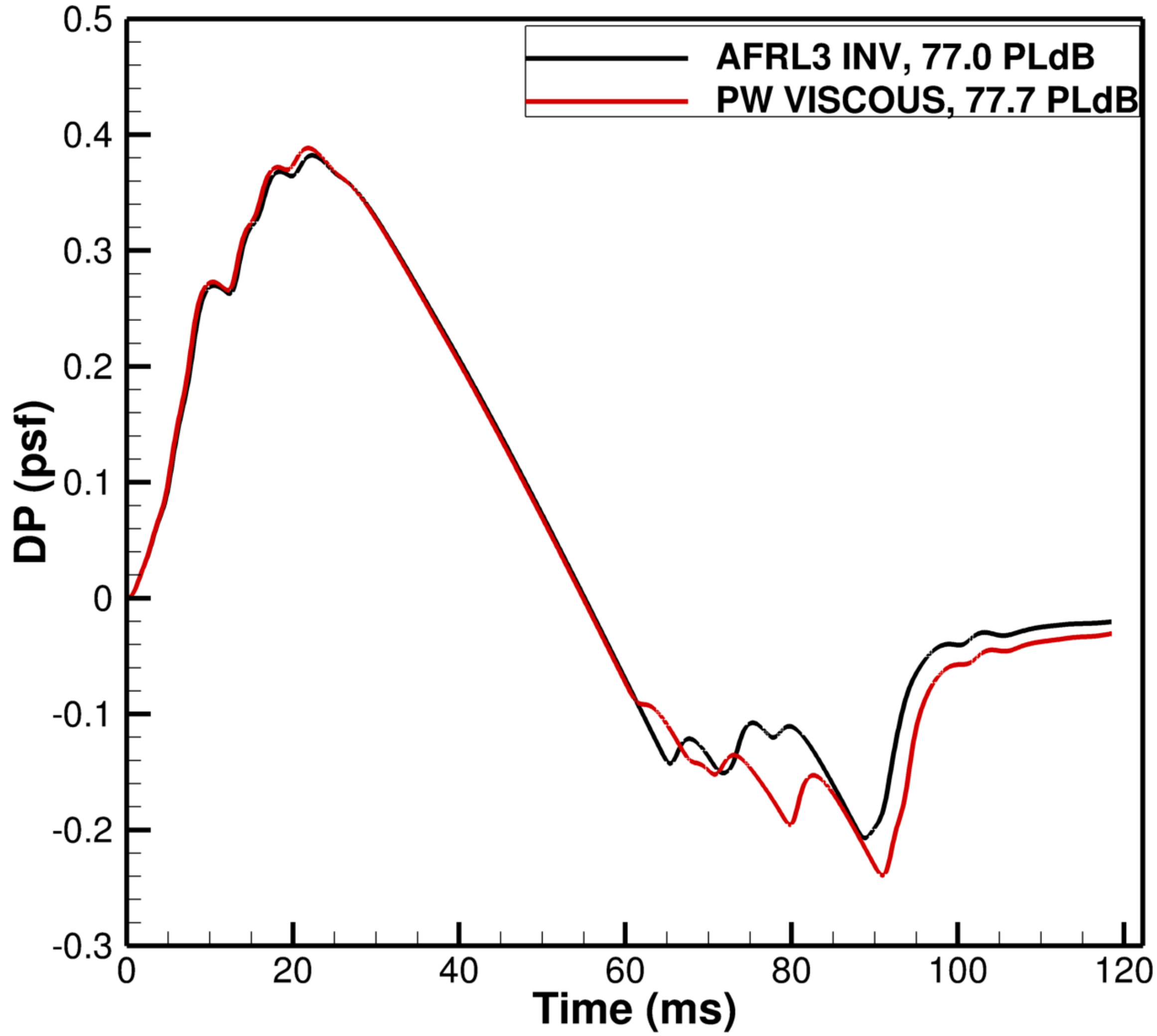
Symmetry Plane Overpressure Contours, Mach=1.6



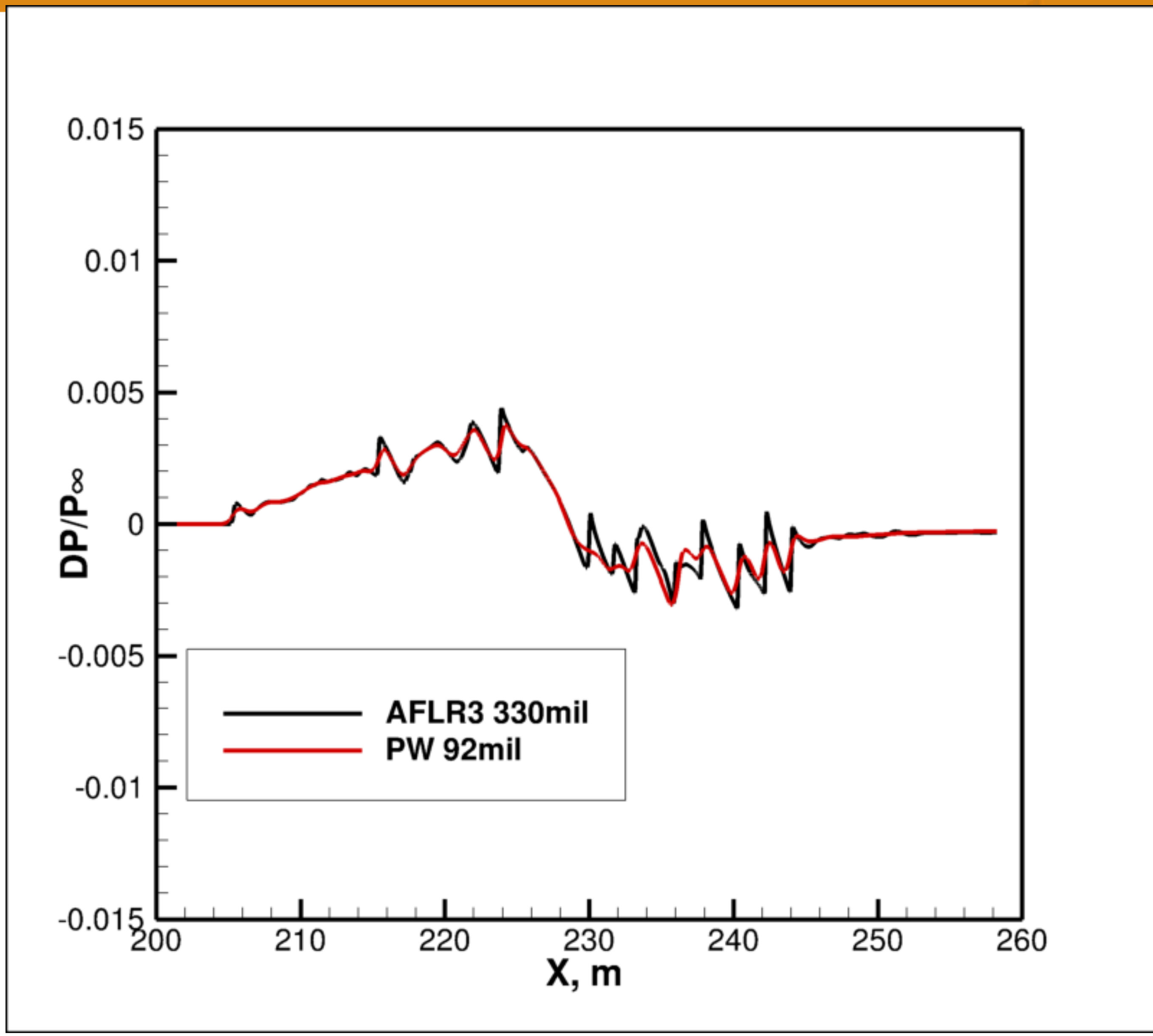
Near Field Pressure Signature, H/L=1



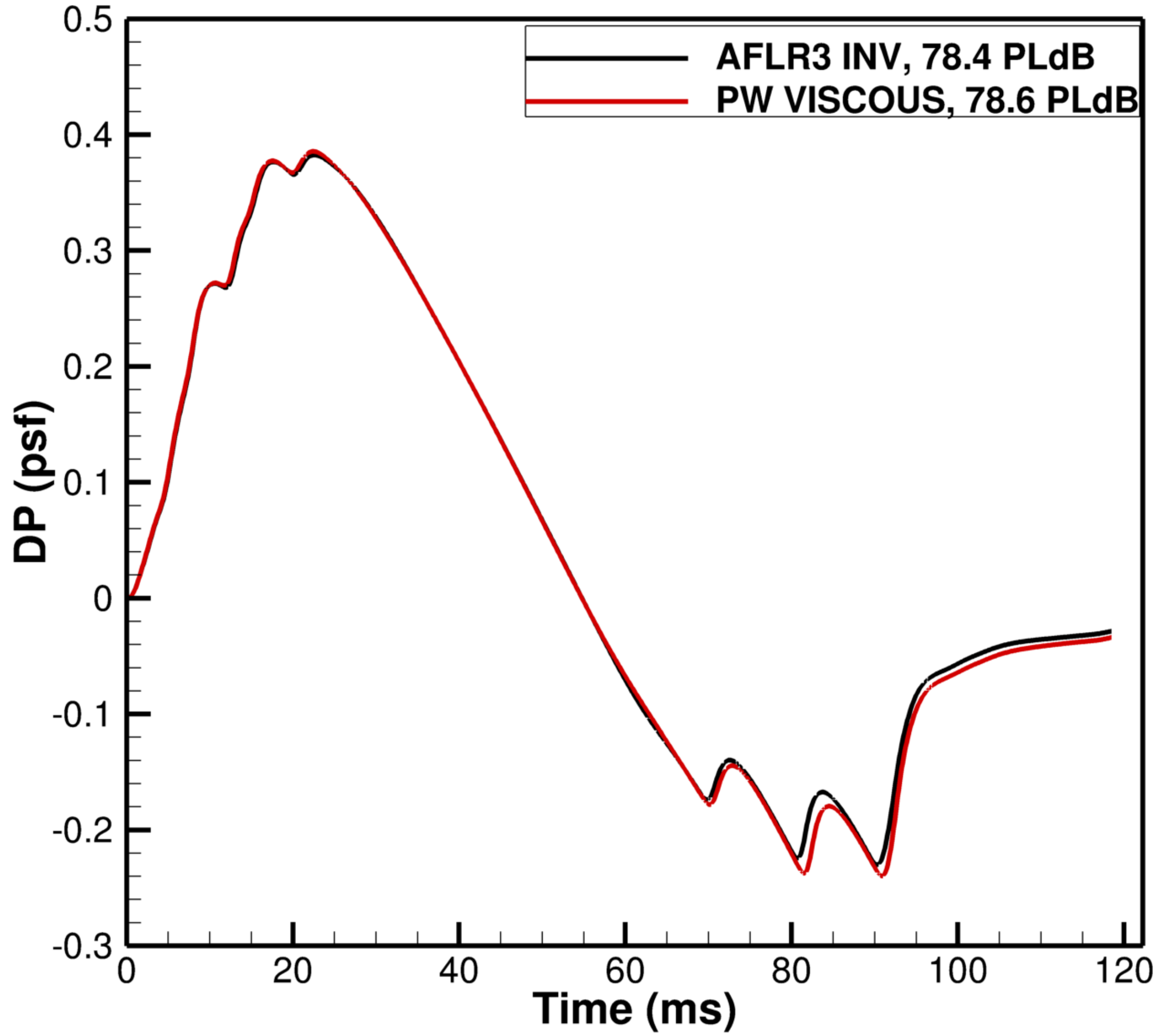
Ground Signatures Computed from H/L=1



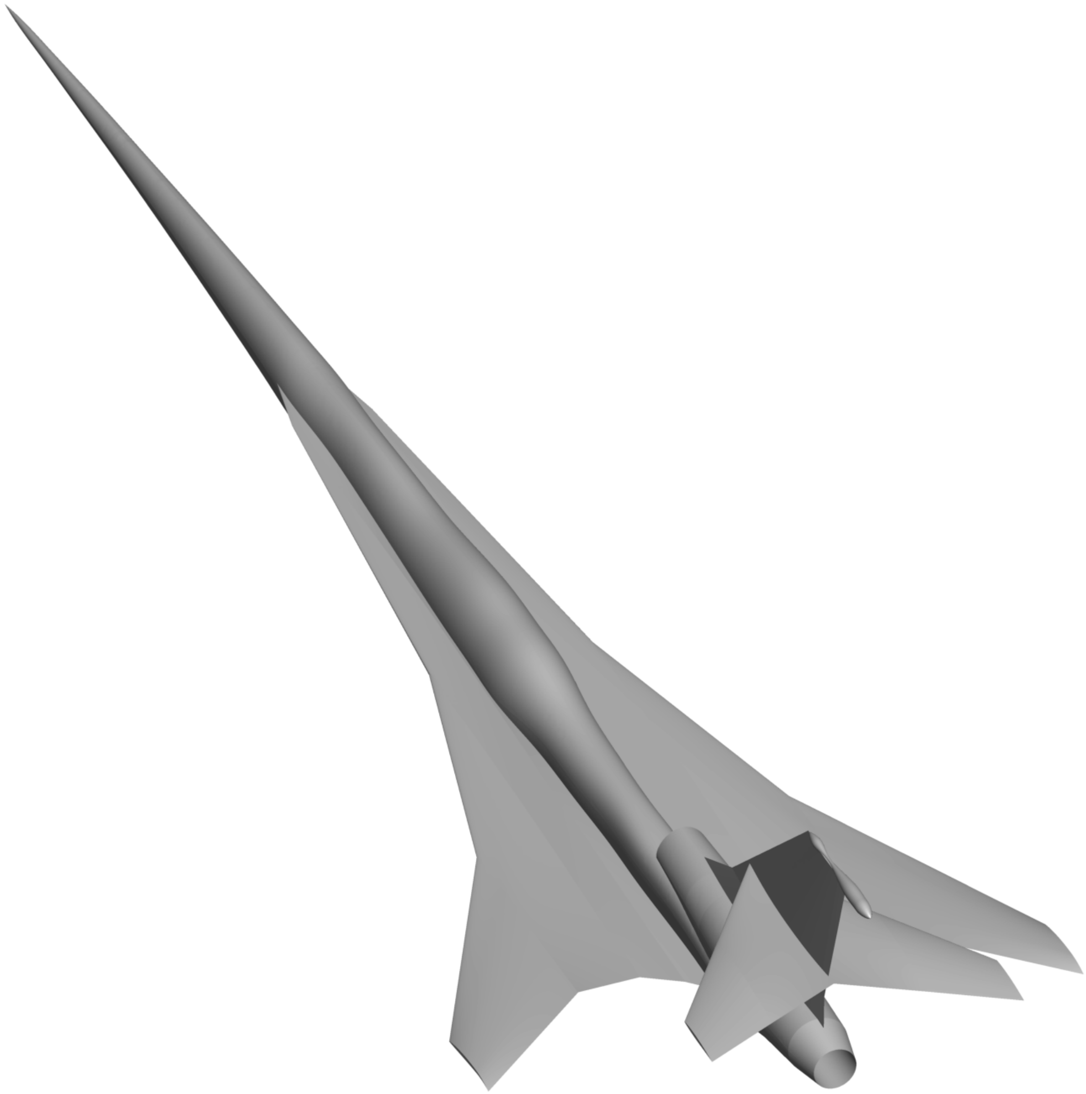
Near Field Pressure Signature, H/L=5



Ground Signatures Computed from H/L=5



NASA C25D Configuration with Powered Nacelles



NASA C25D Configuration with Powered Nacelles

Simulation Conditions:

- Mach 1.6
- Angle of attack 0.0˚
- Reference length 32.92 m
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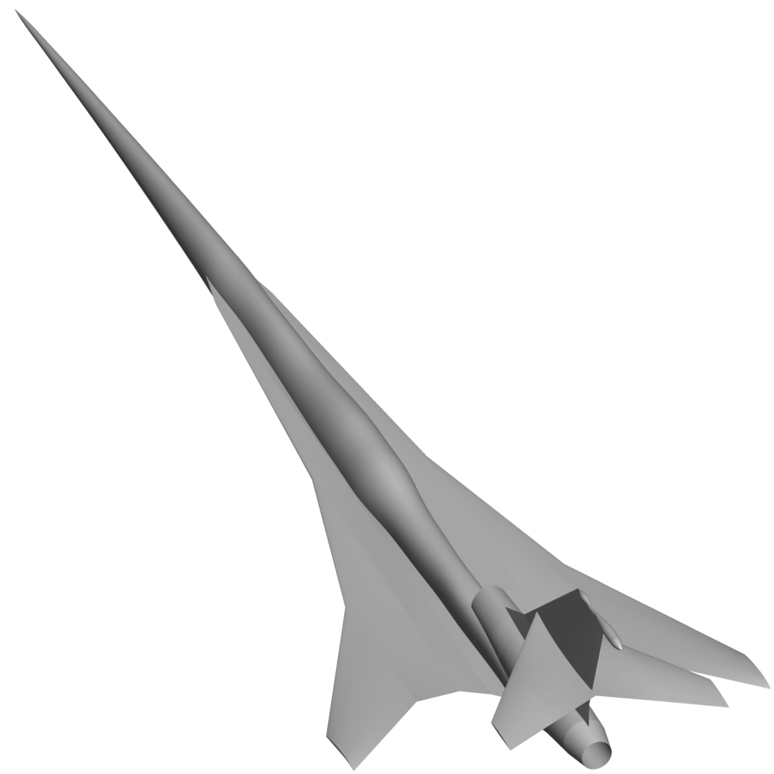


NASA C25D Configuration with Powered Nacelles

- Workshop provided grids were a subdivision of the mixed-element grids generated by AFLR3. Grids are in full scale meters and have a uniformly refined spacing.

Grid	Nodes	Tetrahedra
1	3,421,840	19,987,689
2	6,393,433	37,486,198
3(v)	4,856,211	28,470,874
4(v)	9,052,973	53,267,121

NASA C25D Configuration with Powered Nacelles

- In-house Pointwise® grids

Grid	Nodes	Tetrahedra
1	23,603,132	138,682,615
2	24,647,501	145,058,957

- In-house VGRID grid

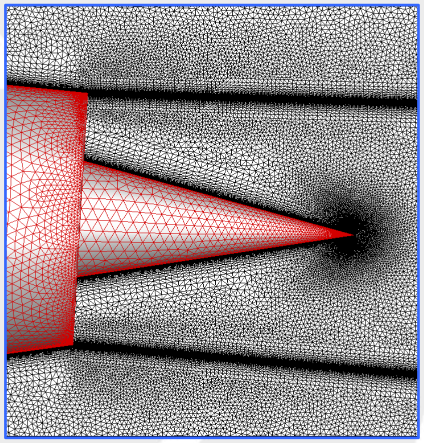
Grid	Nodes	Tetrahedra
BG	9,616,415	56,048,830

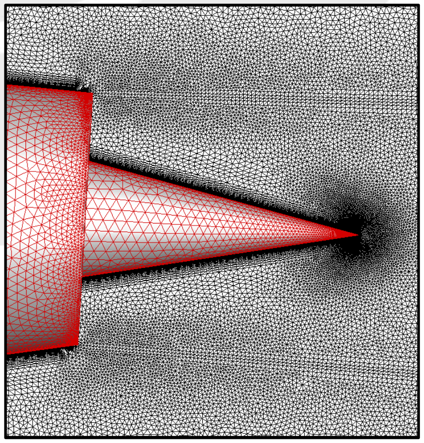
25D Plume Mesh Study (Pointwise® Software)

Two High-quality meshes with same surface and volume except in the plume region

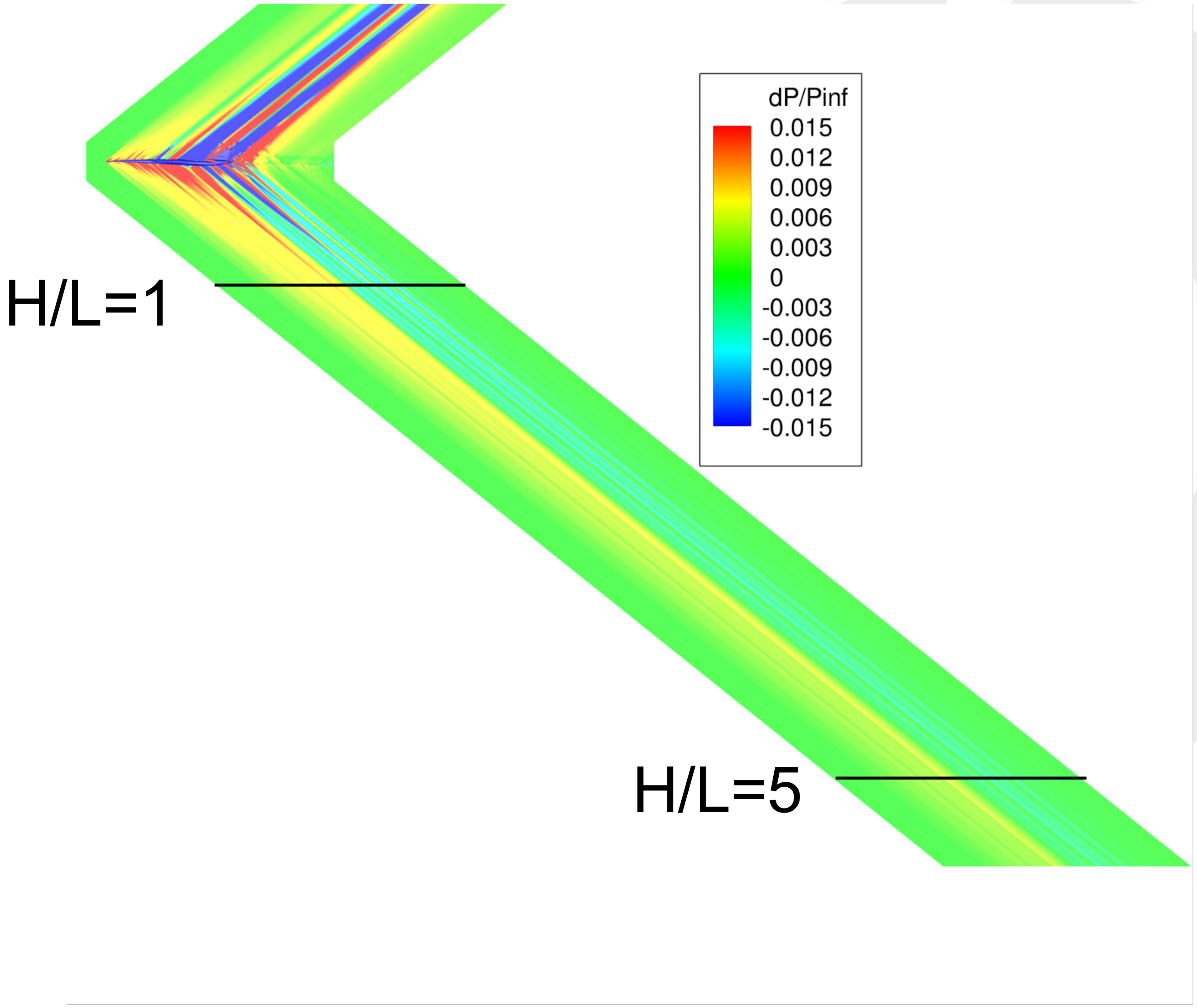
- Mesh 1 carries anisotropic boundary layer refinement into plume (.00001 m spacing)

- Mesh 2 coarsens 4 orders of magnitude in plume (.01 m spacing)

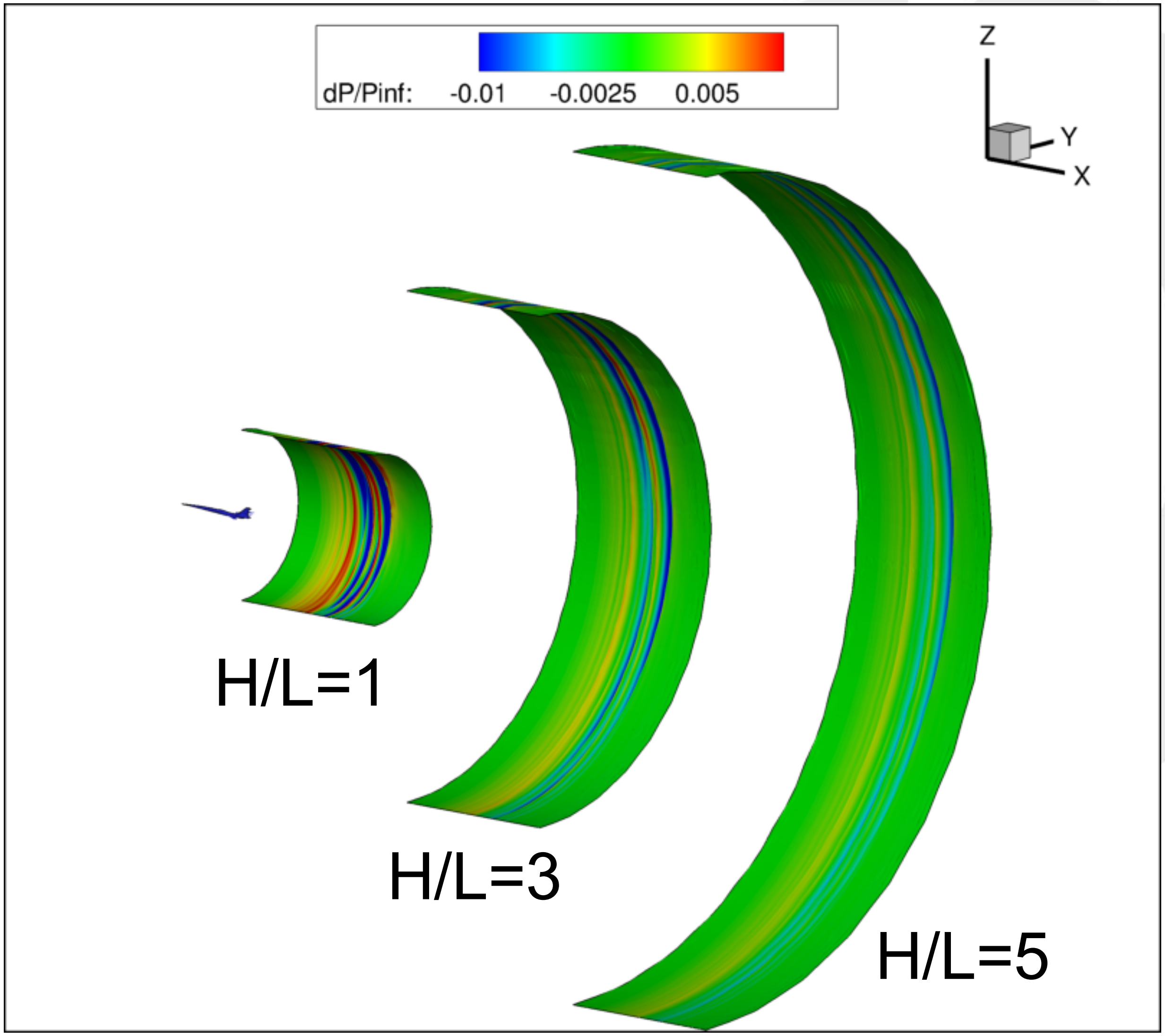




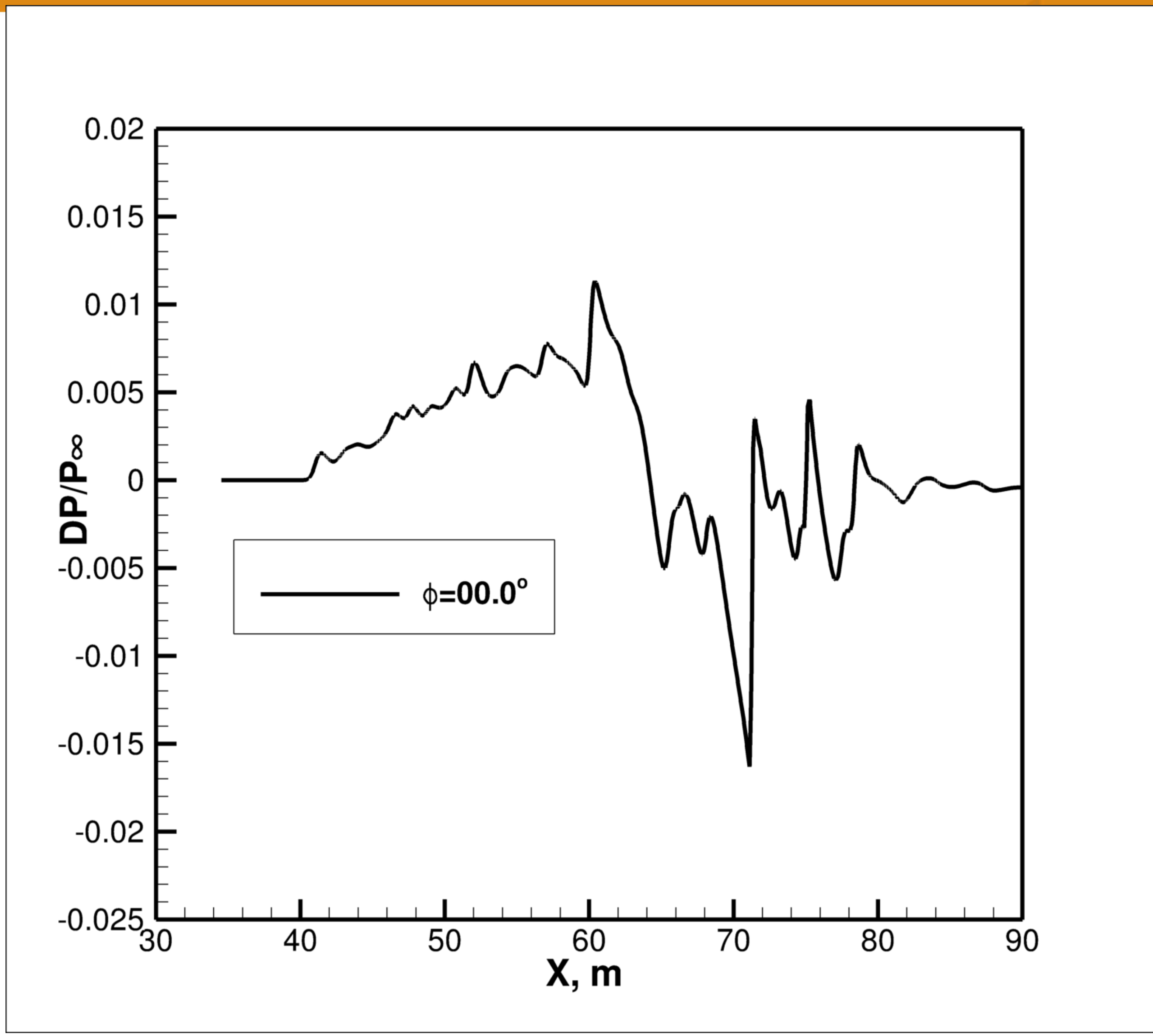
Symmetry Plane Overpressure Contours, Mach=1.6



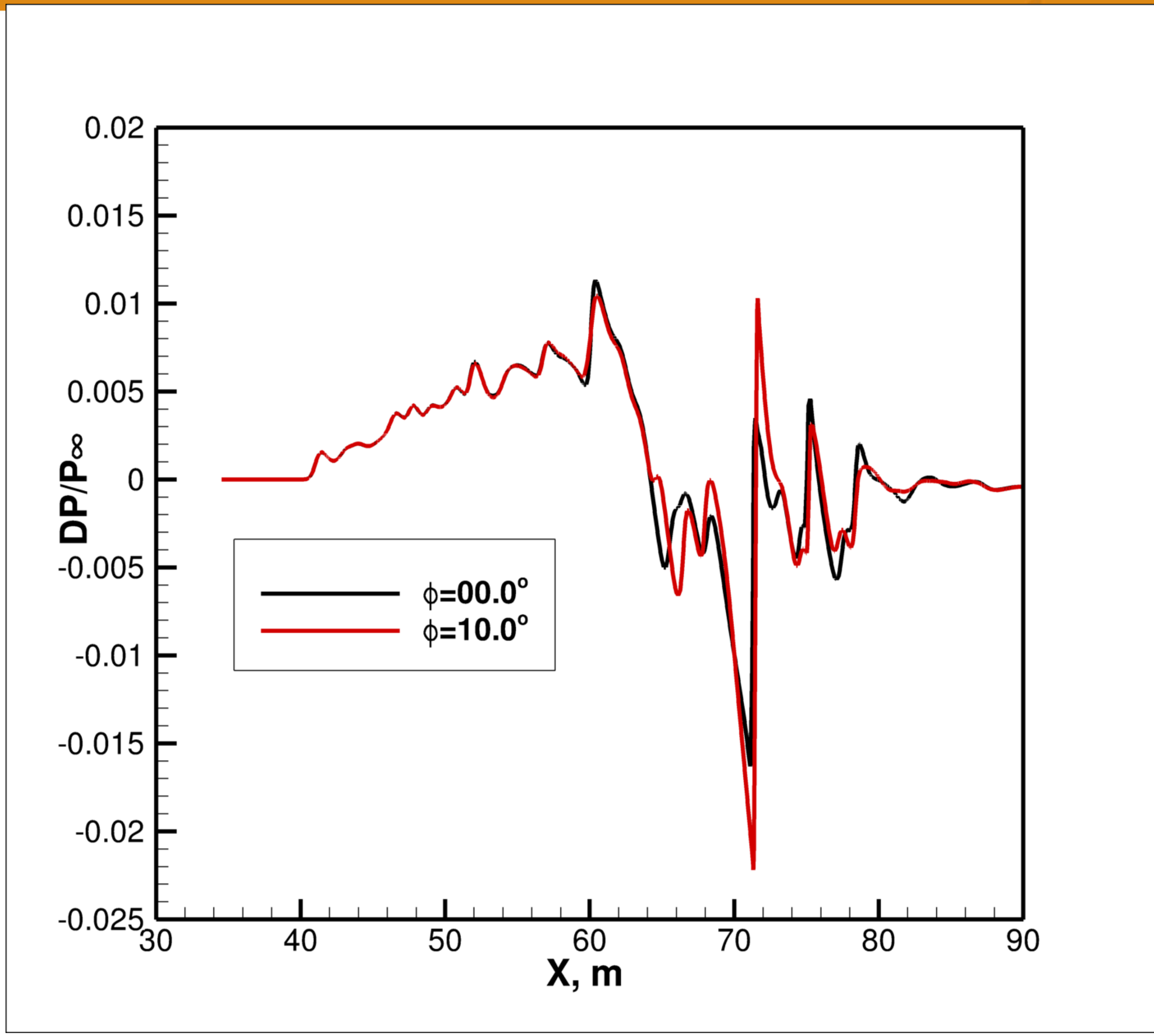
Symmetry Plane Overpressure Contours, Mach=1.6



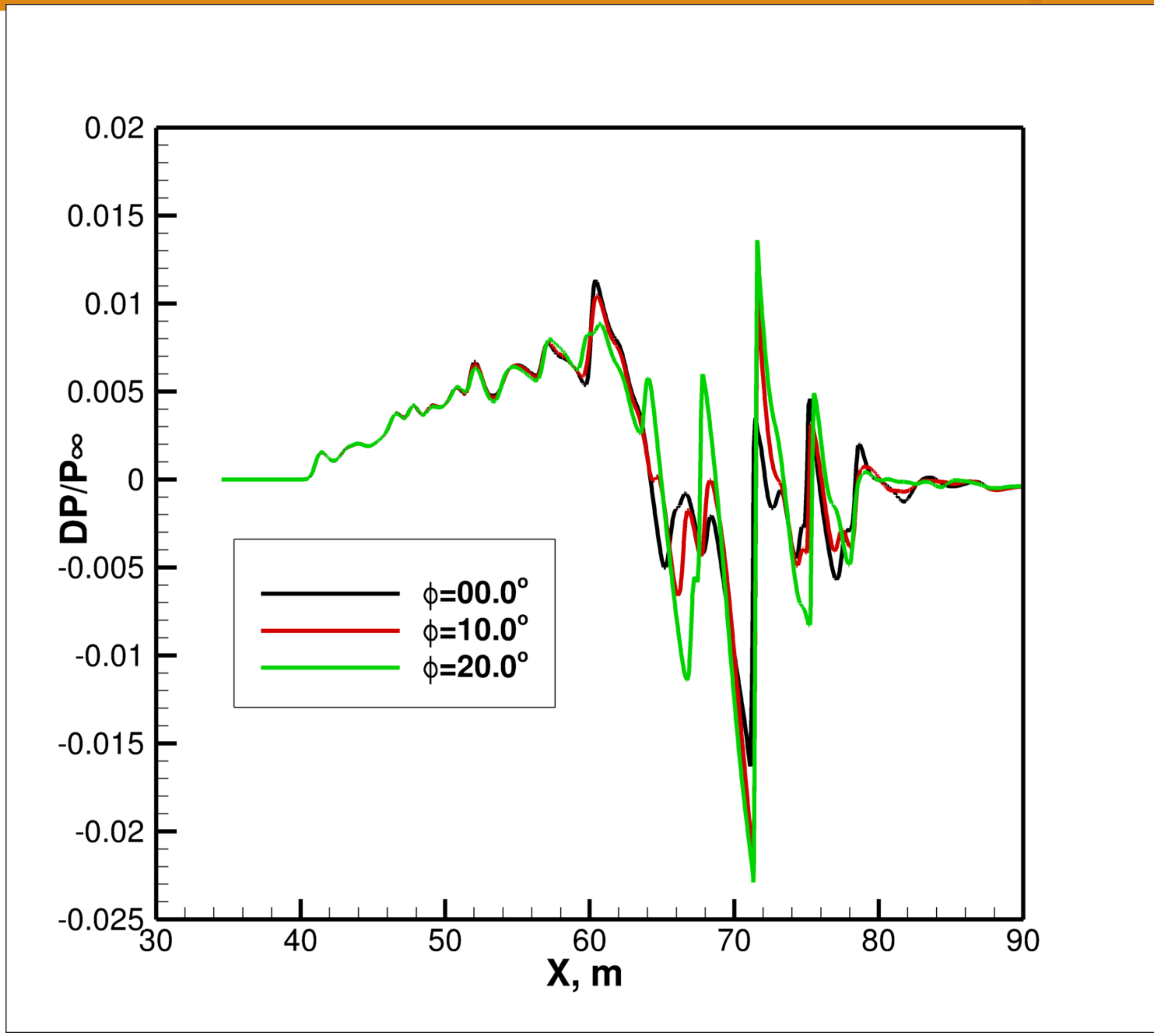
Near Field Pressure Signature, AFLR3 160, H/L=1



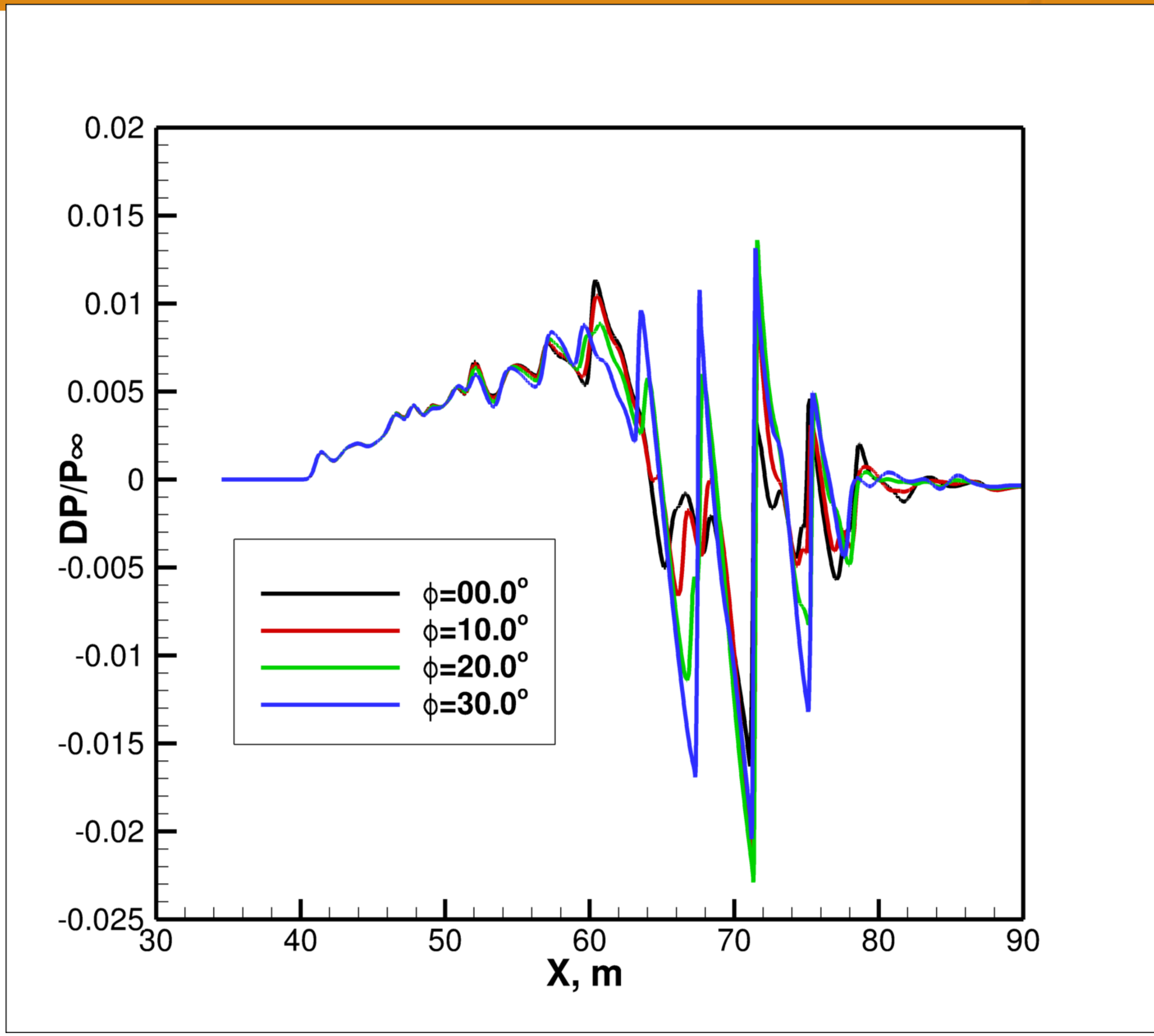
Near Field Pressure Signature, AFLR3 160, H/L=1



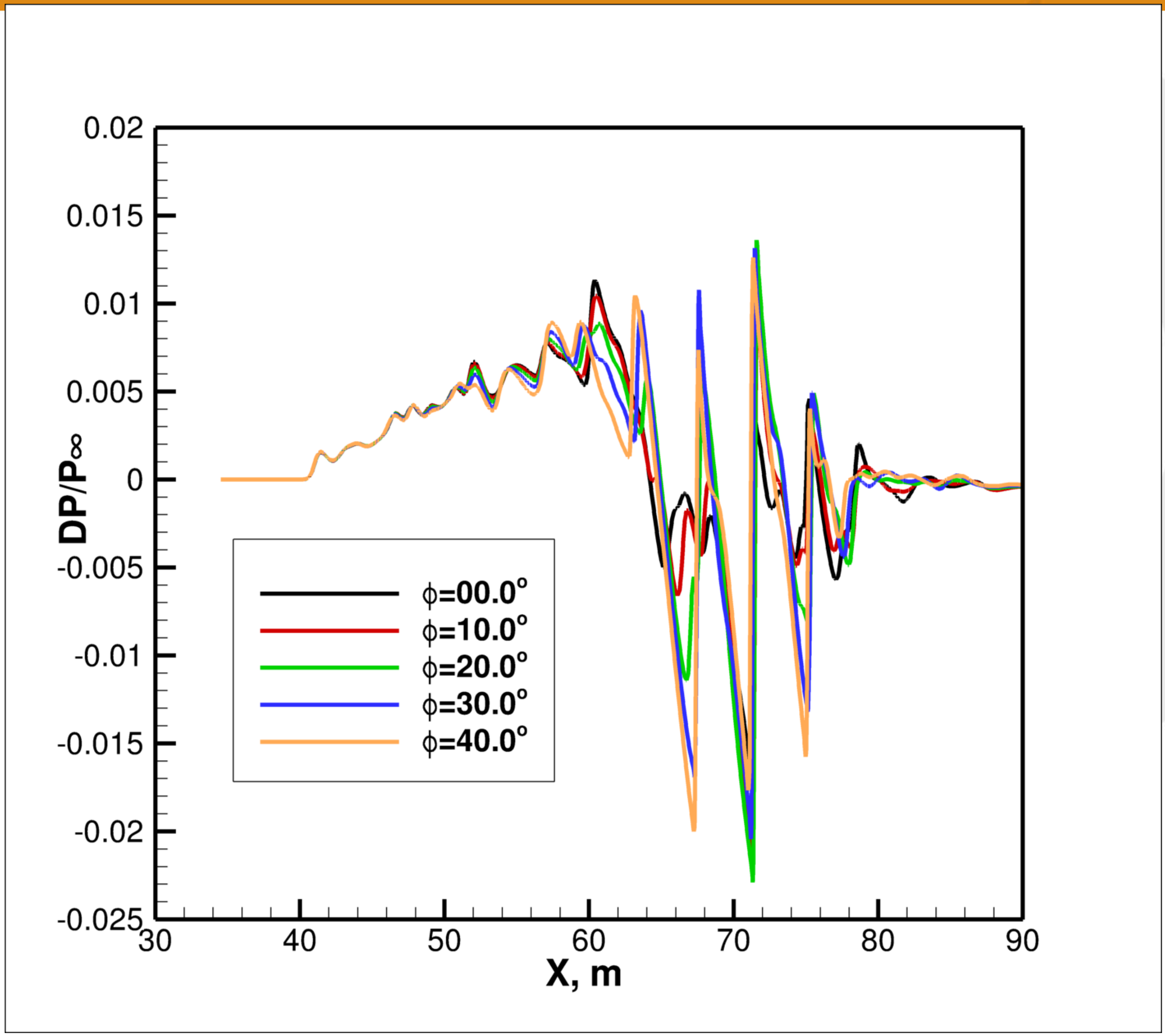
Near Field Pressure Signature, AFLR3 160, H/L=1



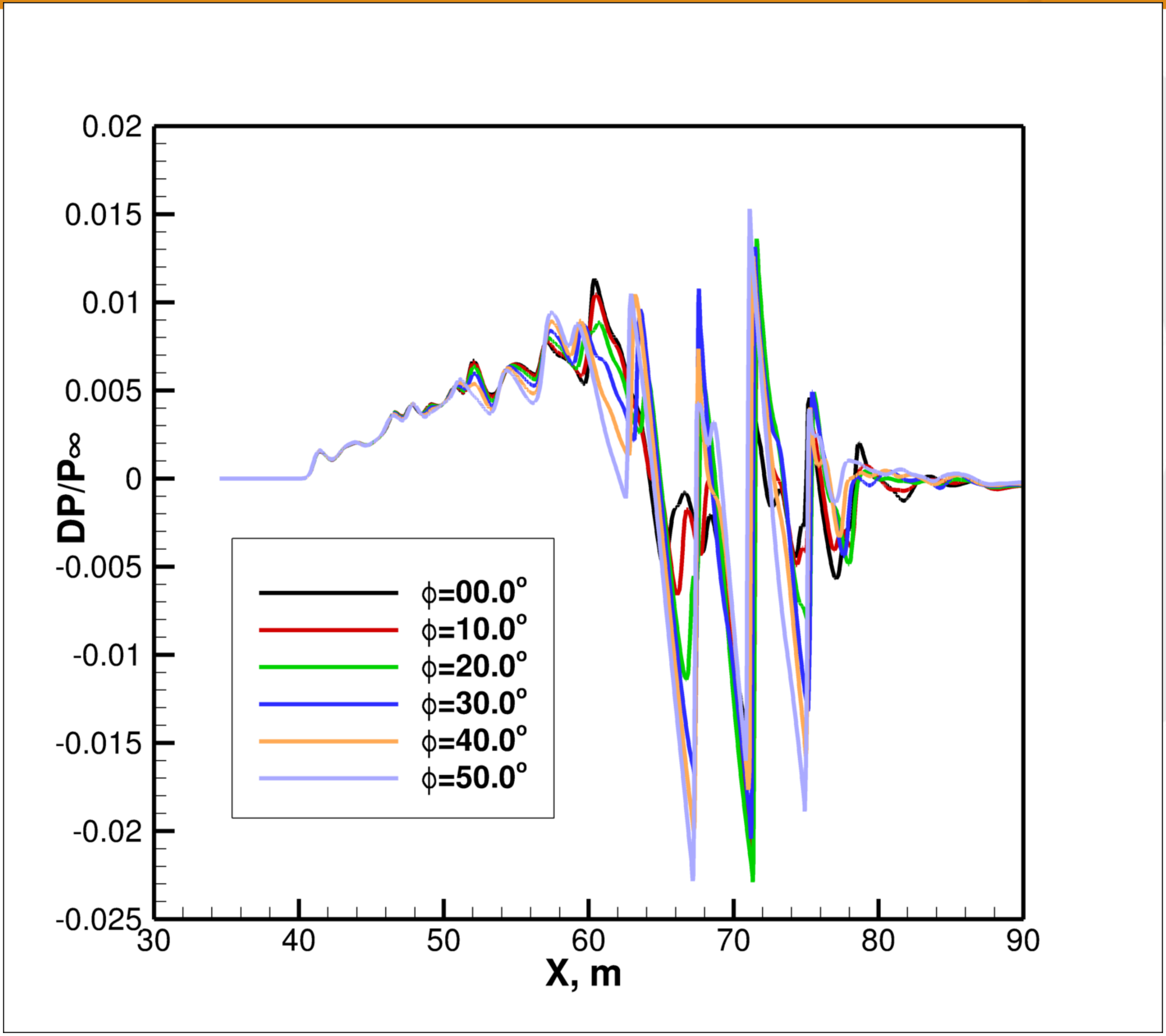
Near Field Pressure Signature, AFLR3 160, H/L=1



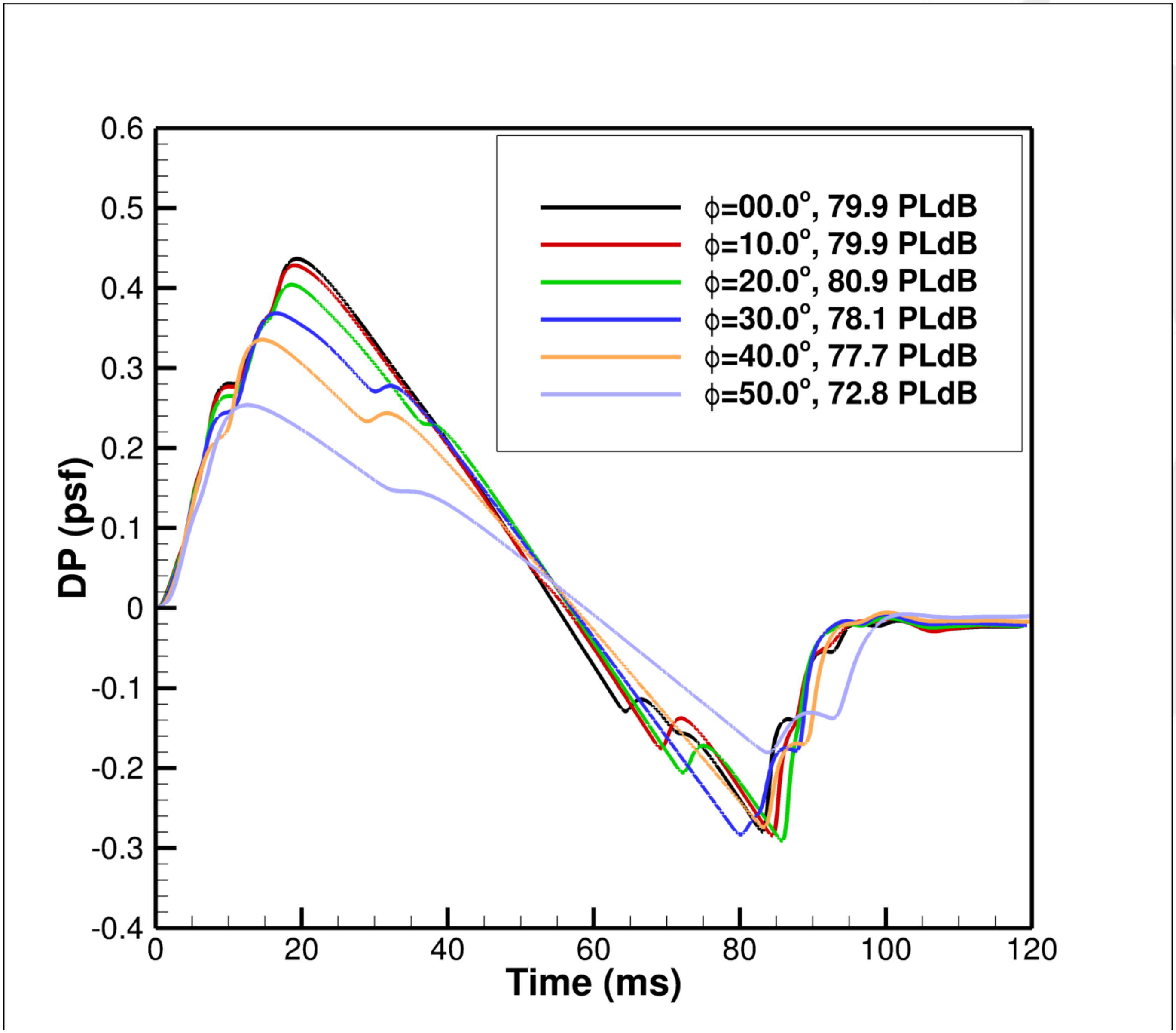
Near Field Pressure Signature, AFLR3 160, H/L=1



Near Field Pressure Signature, AFLR3 160, H/L=1

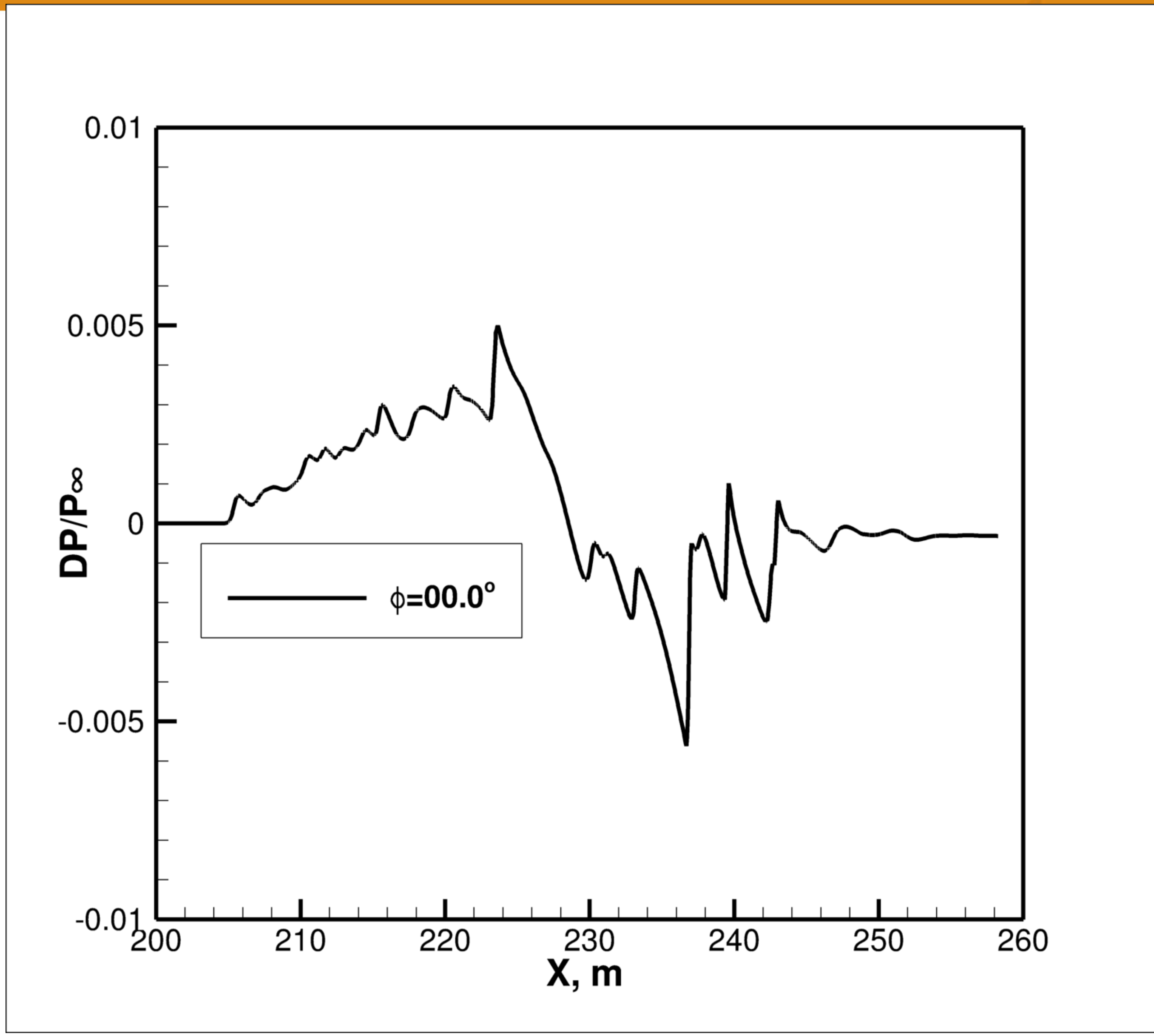


Ground Signatures Computed from H/L=1

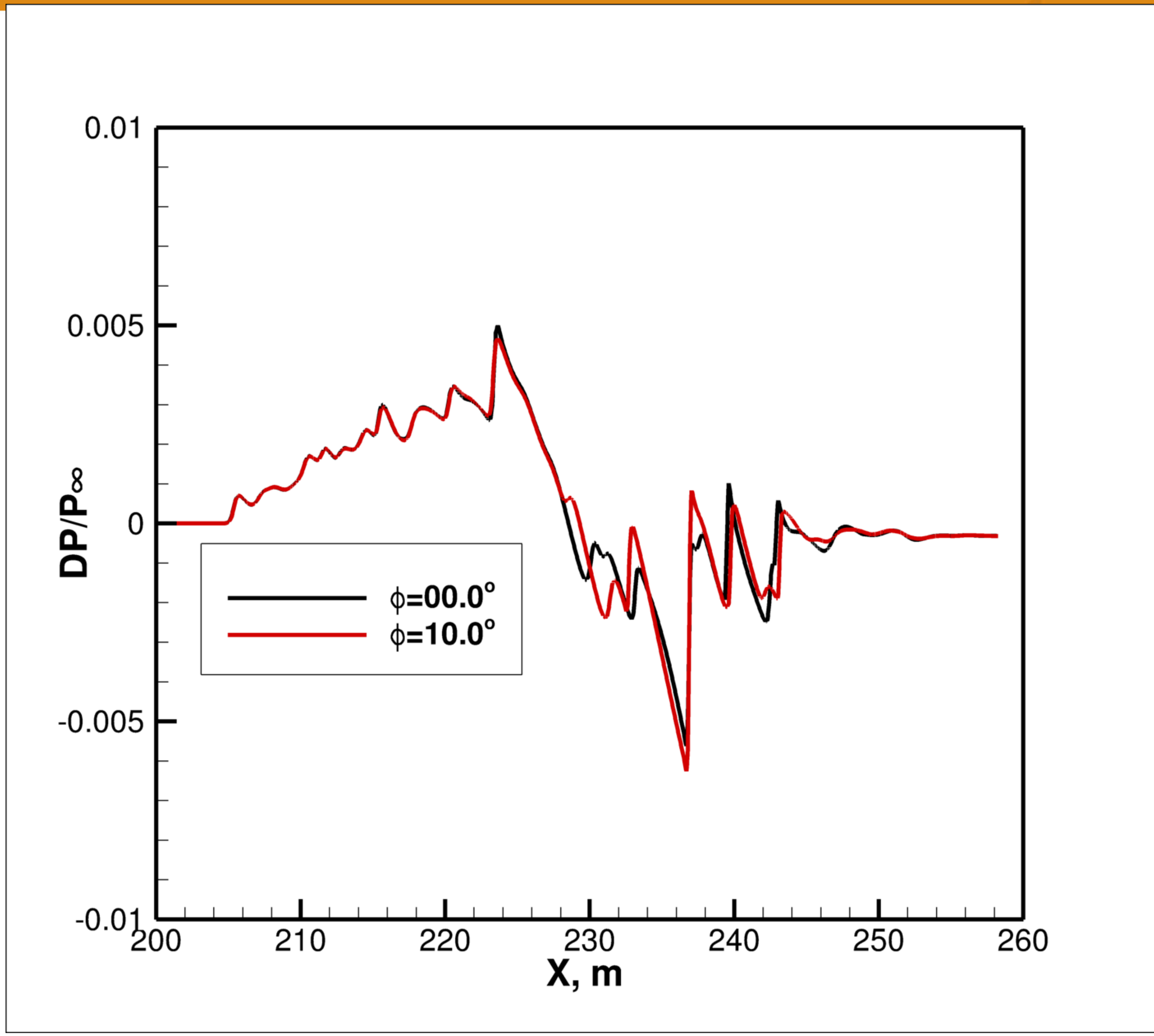


AFLR3
160

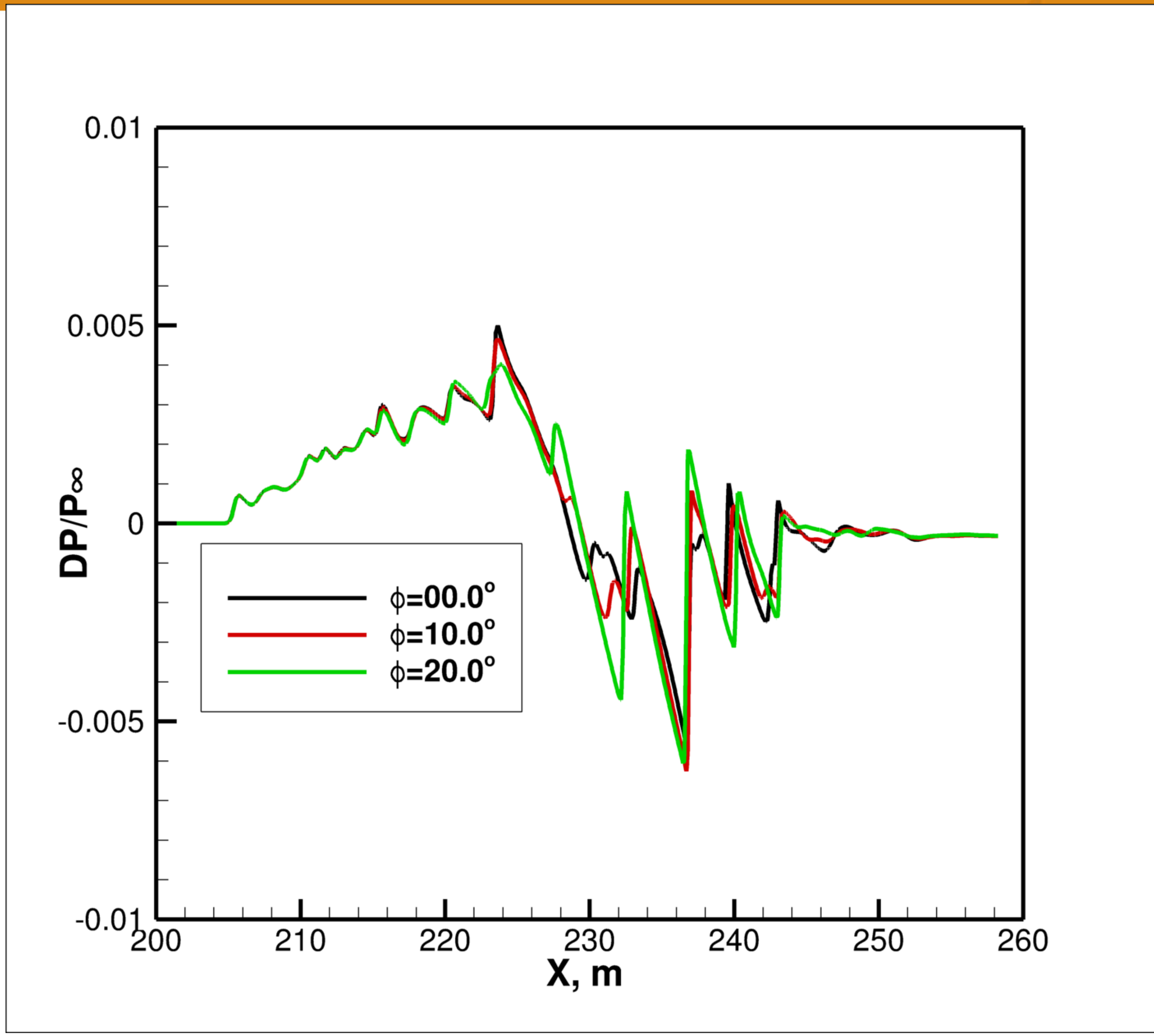
Near Field Pressure Signature, AFLR3 160, H/L=5



Near Field Pressure Signature, AFLR3 160, H/L=5



Near Field Pressure Signature, AFLR3 160, H/L=5



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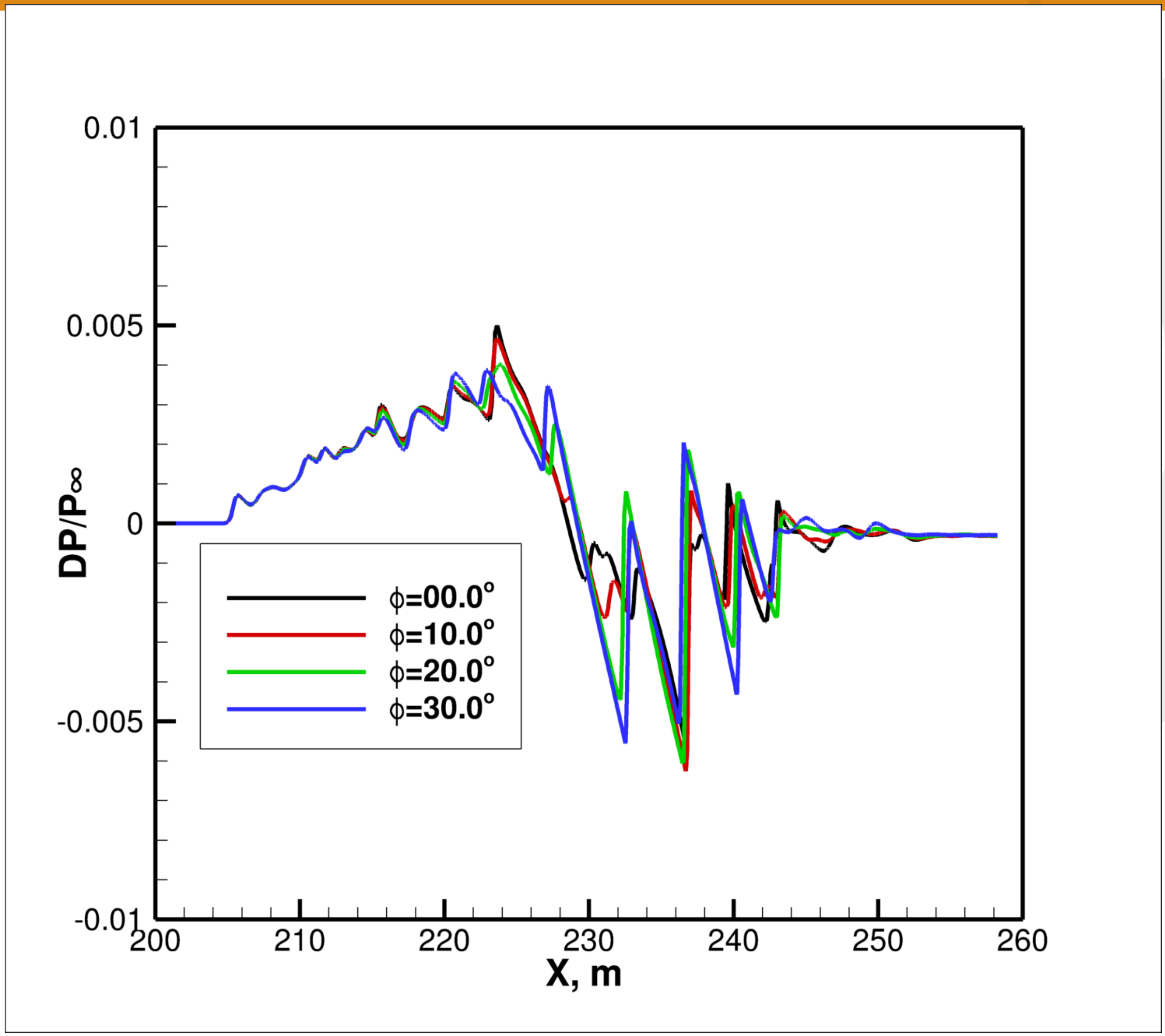
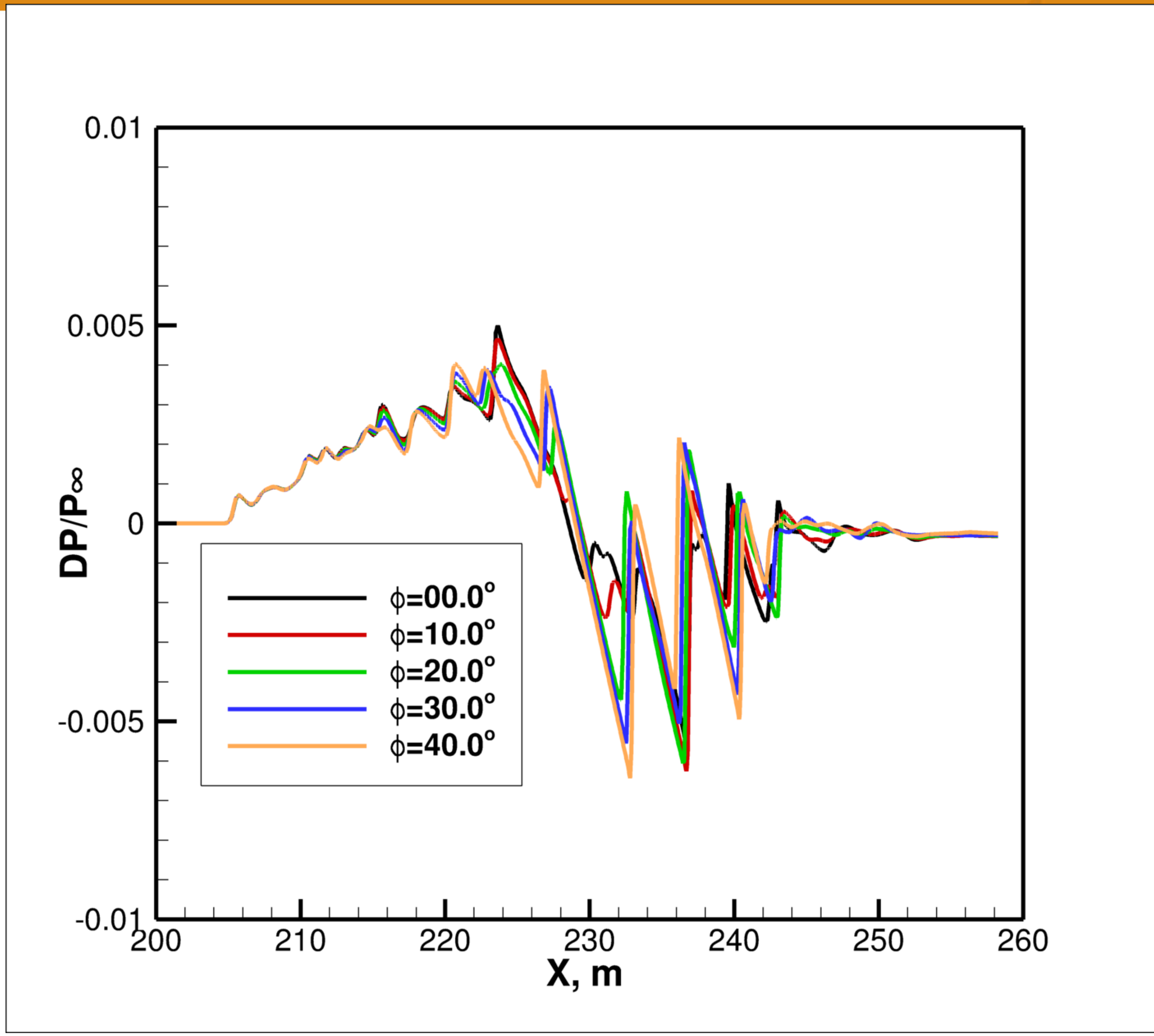
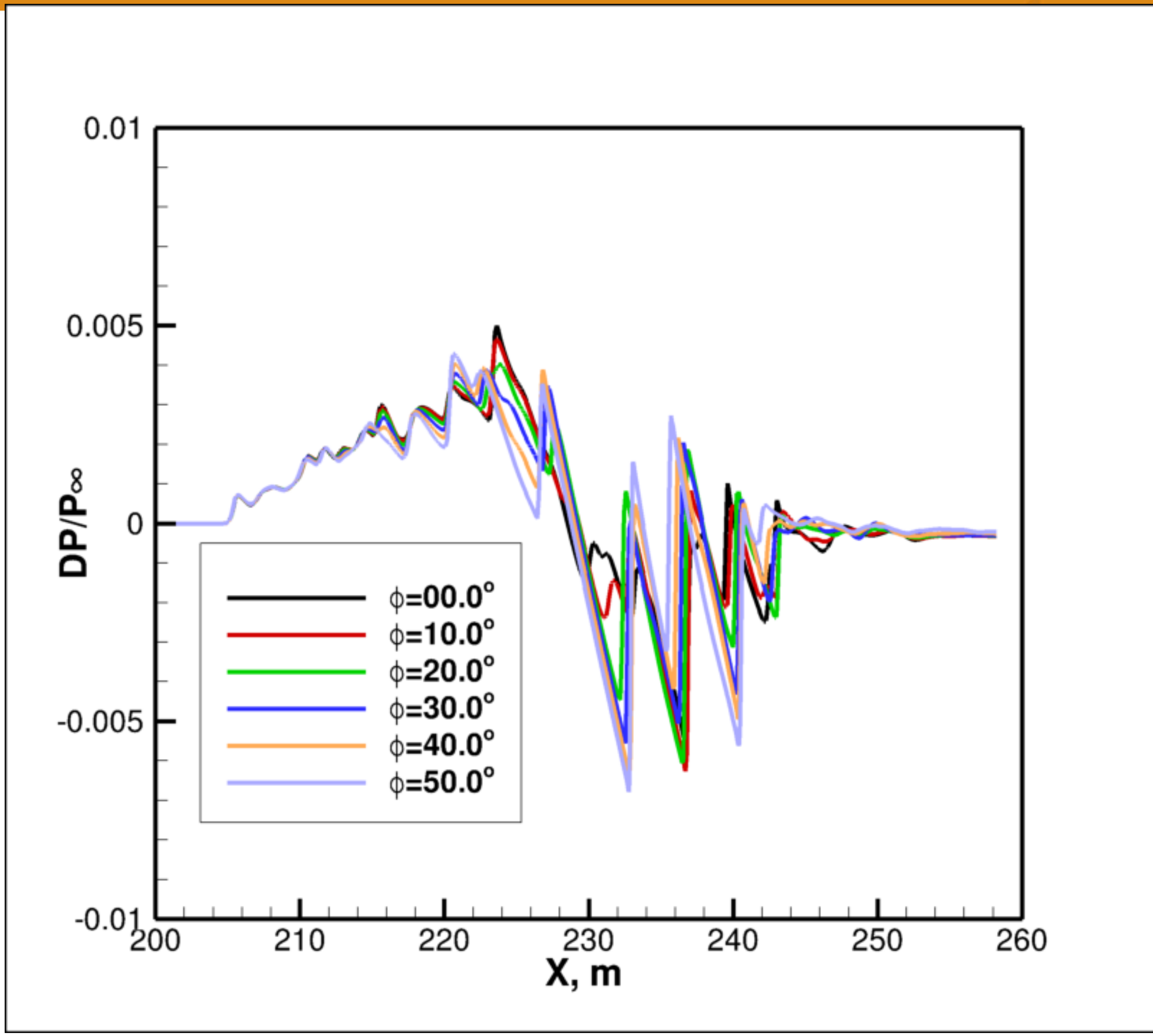


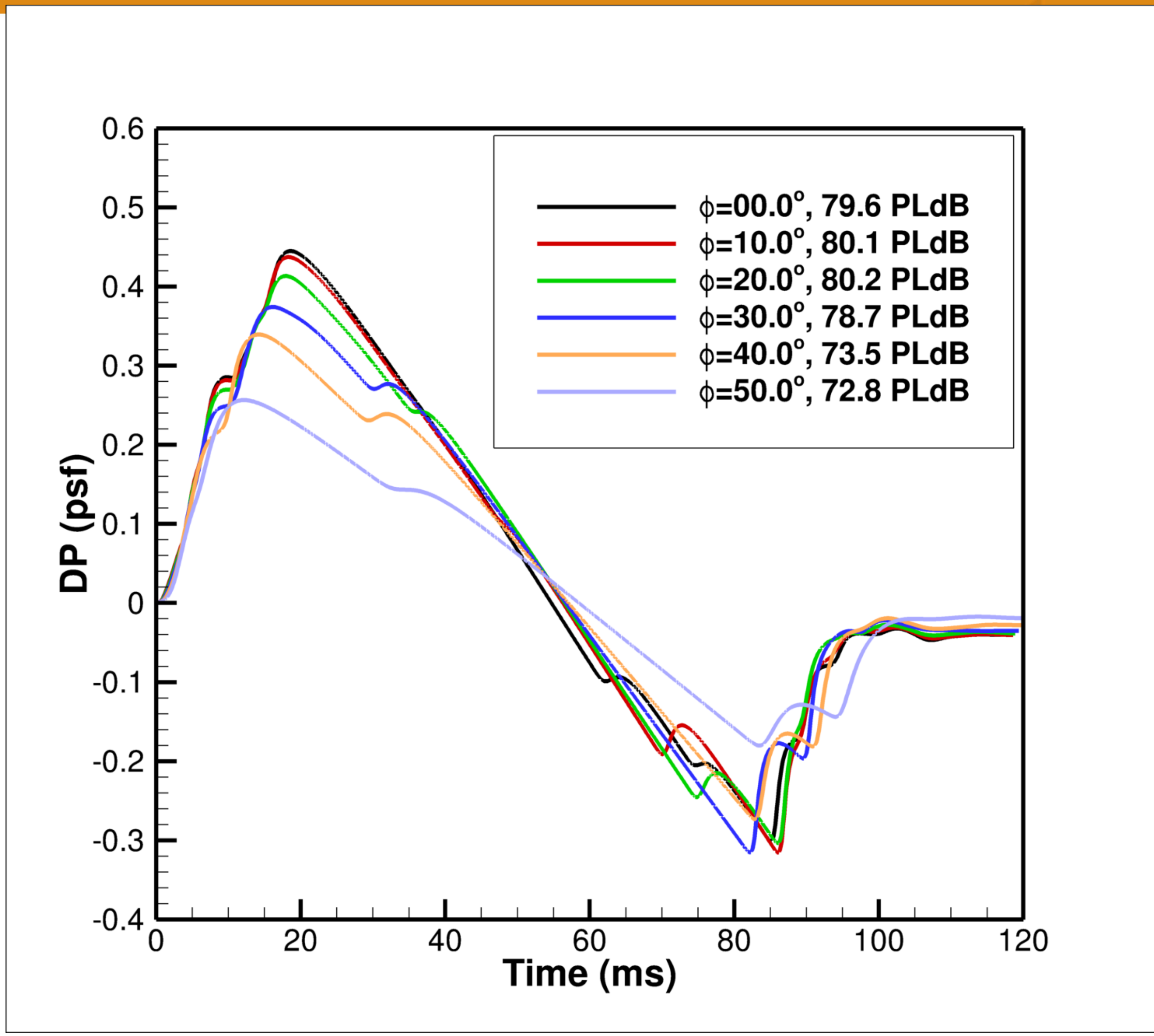
Near Field Pressure Signature, AFLR3 160, H/L=5



Near Field Pressure Signature, AFLR3 160, H/L=5

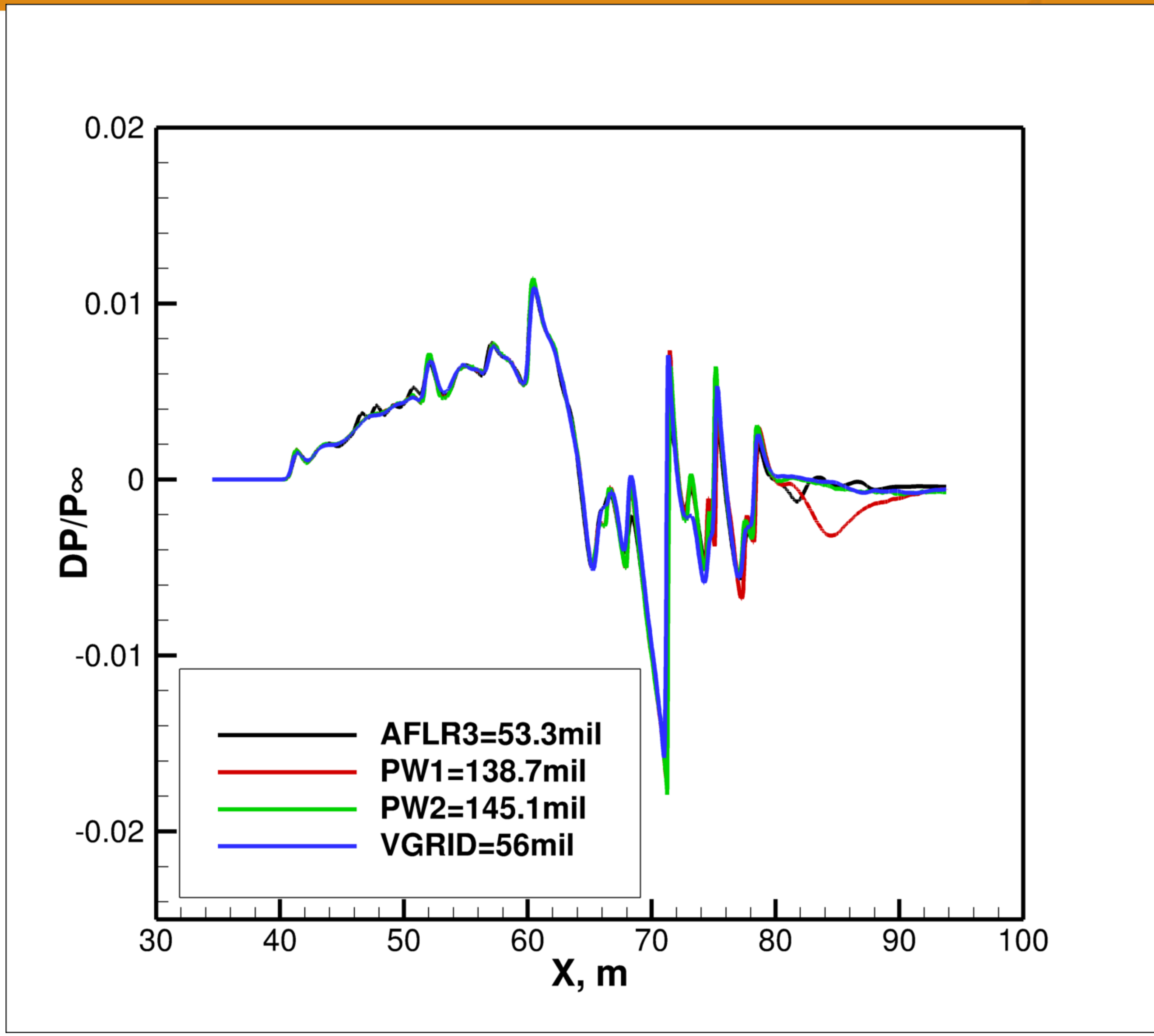


Ground Signatures Computed from H/L=5

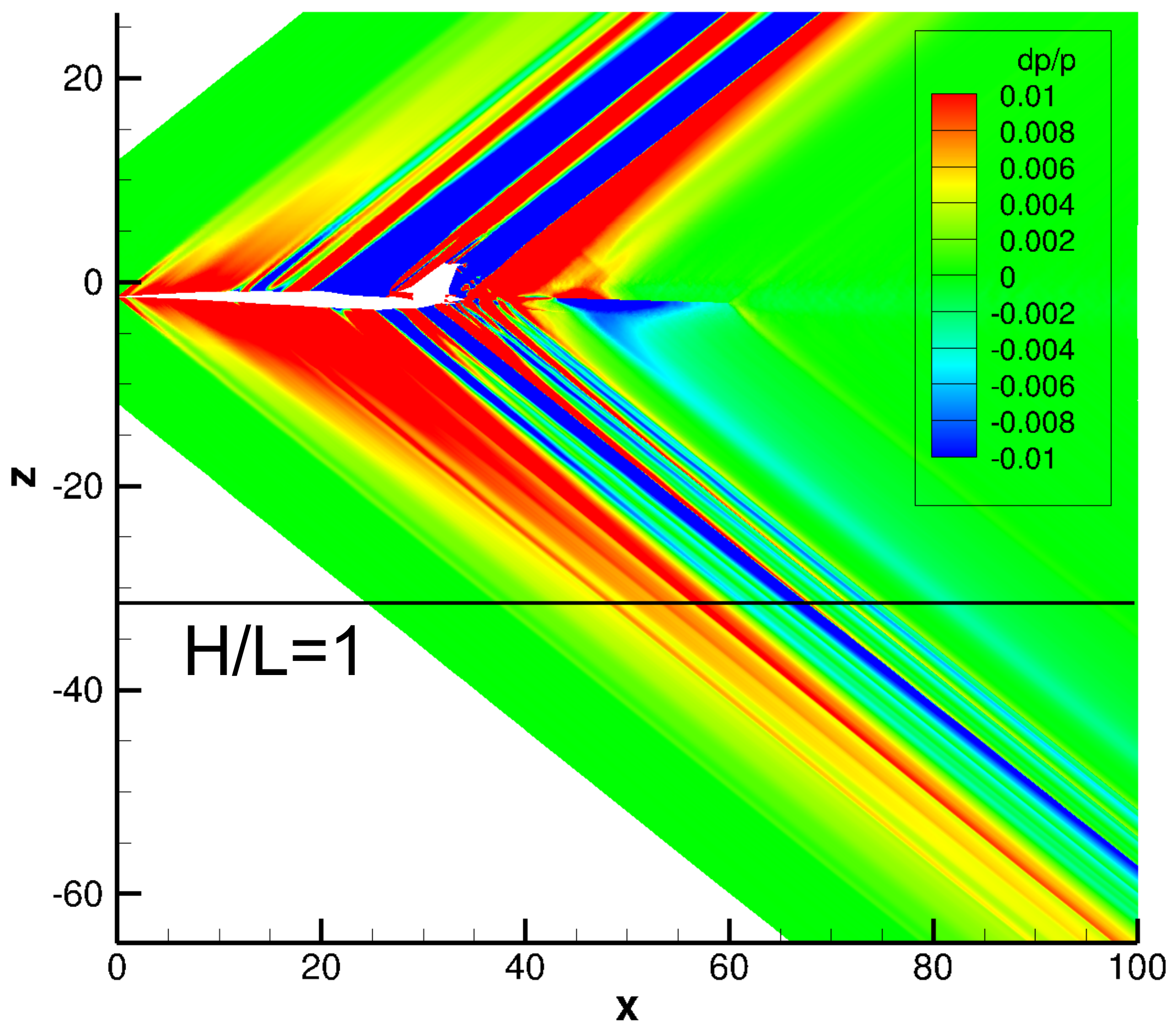


AFLR3
160

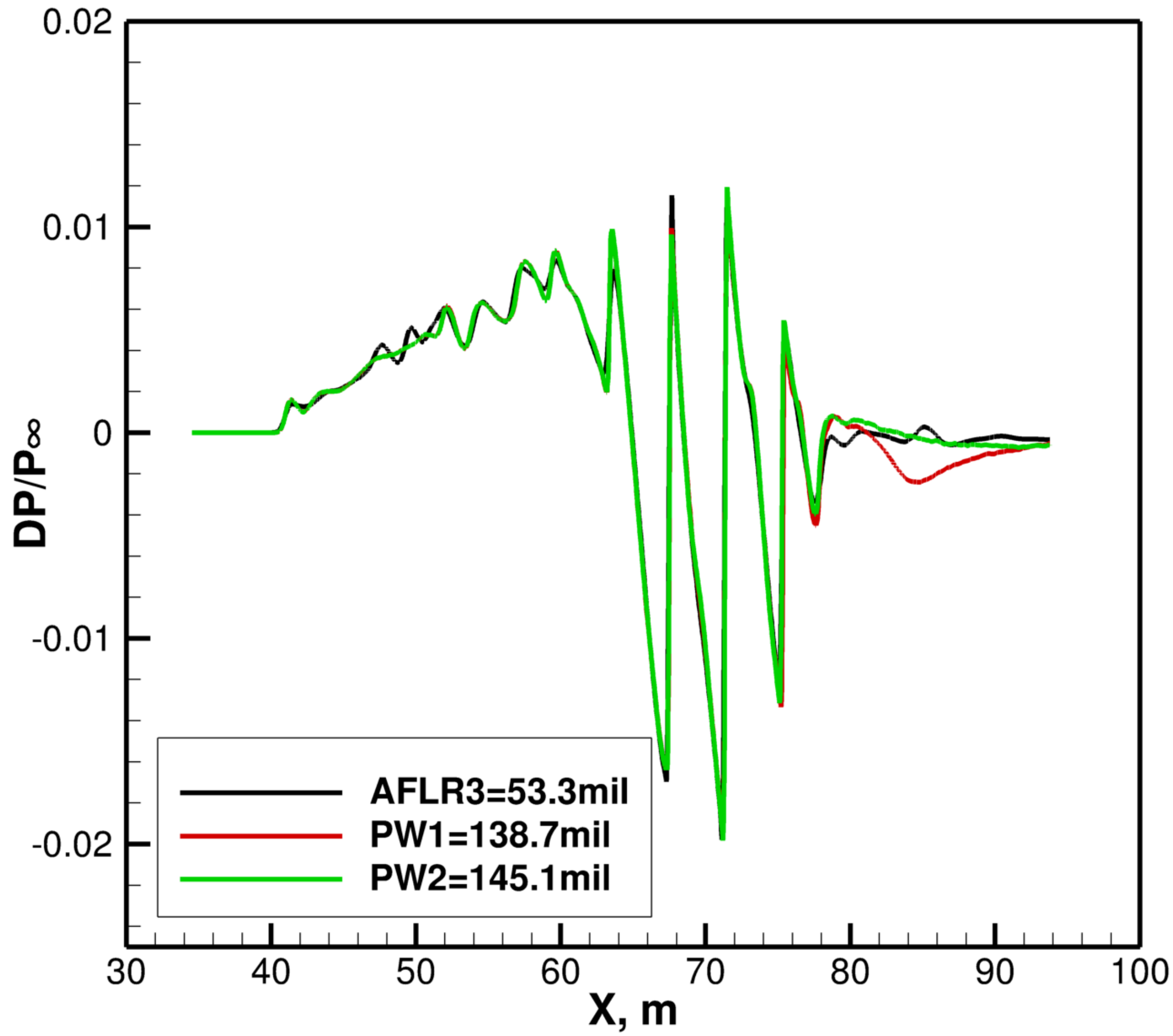
Near Field Pressure Signature, H/L=1, Φ=0˚



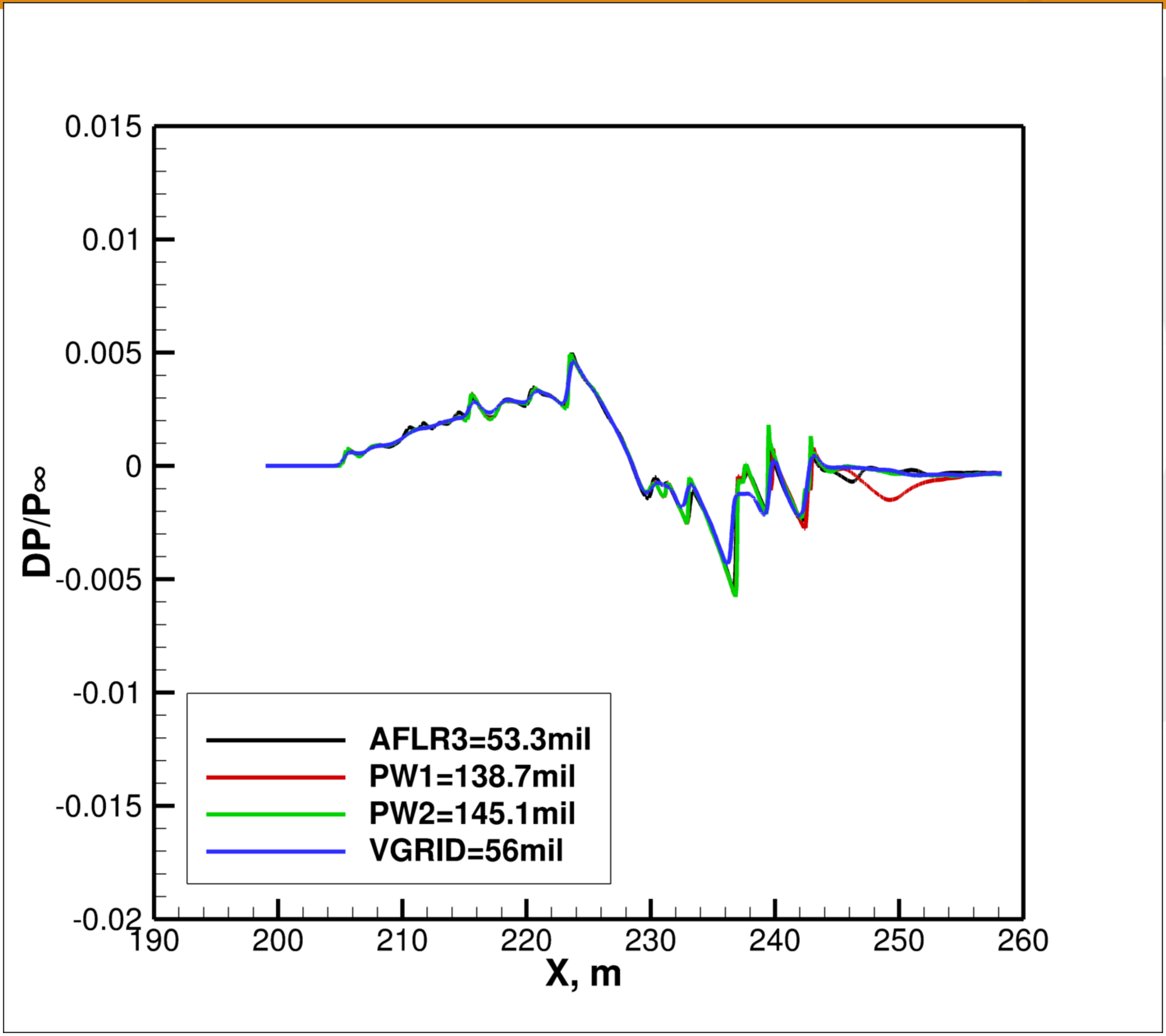
PW1 Grid Aft Difference



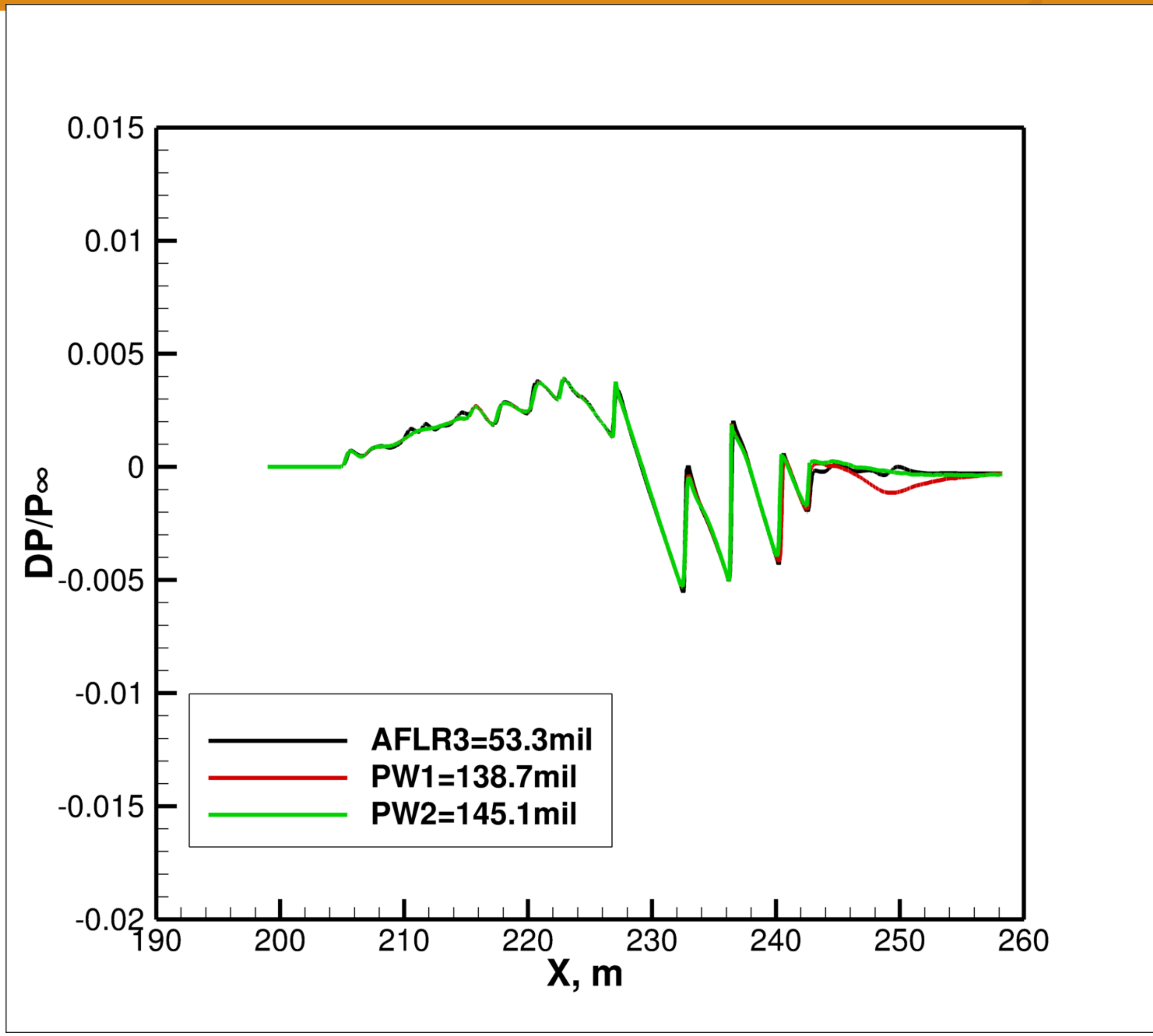
Near Field Pressure Signature, H/L=1, Φ=30°



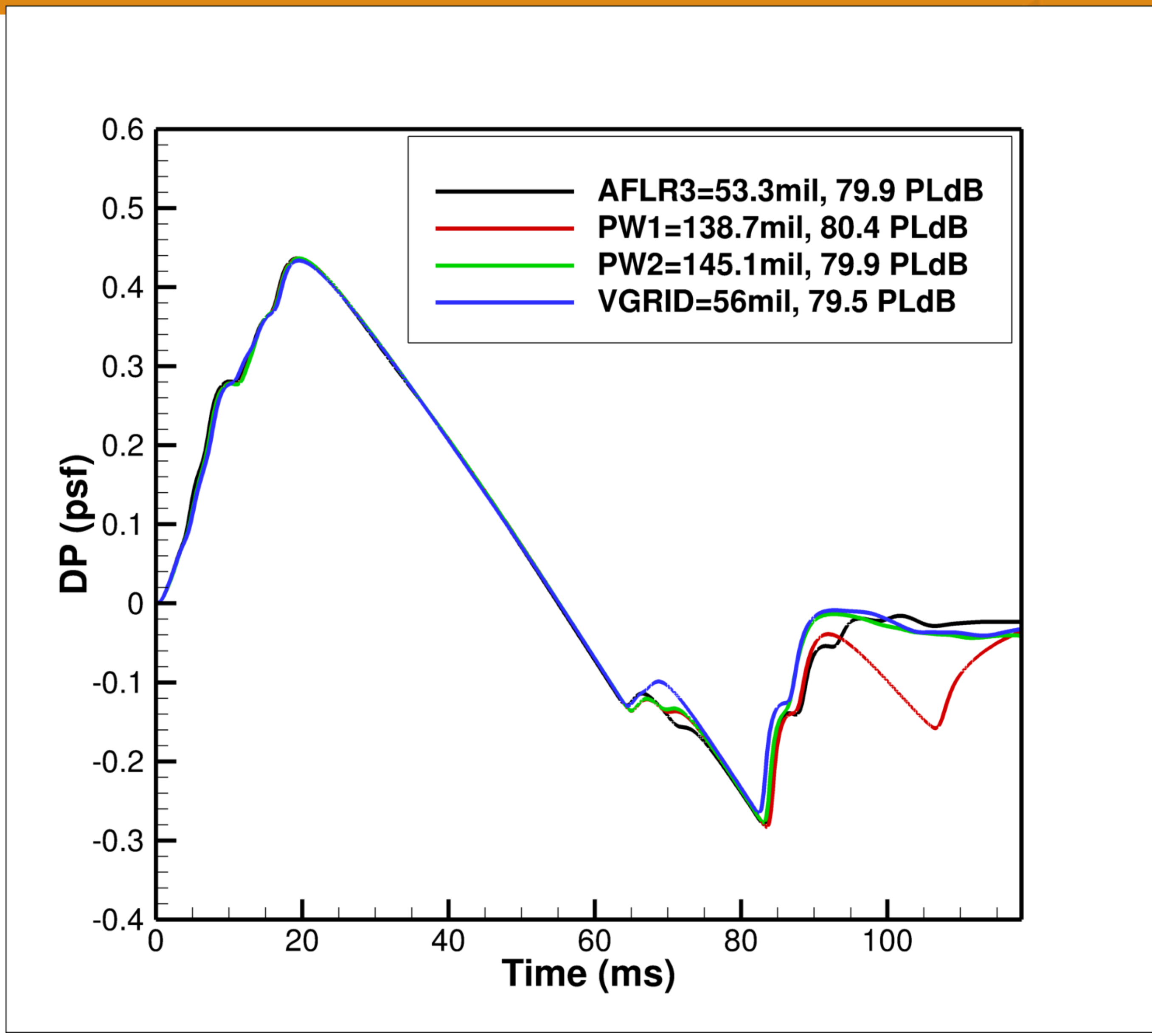
Near Field Pressure Signature, H/L=5, Φ=0˚



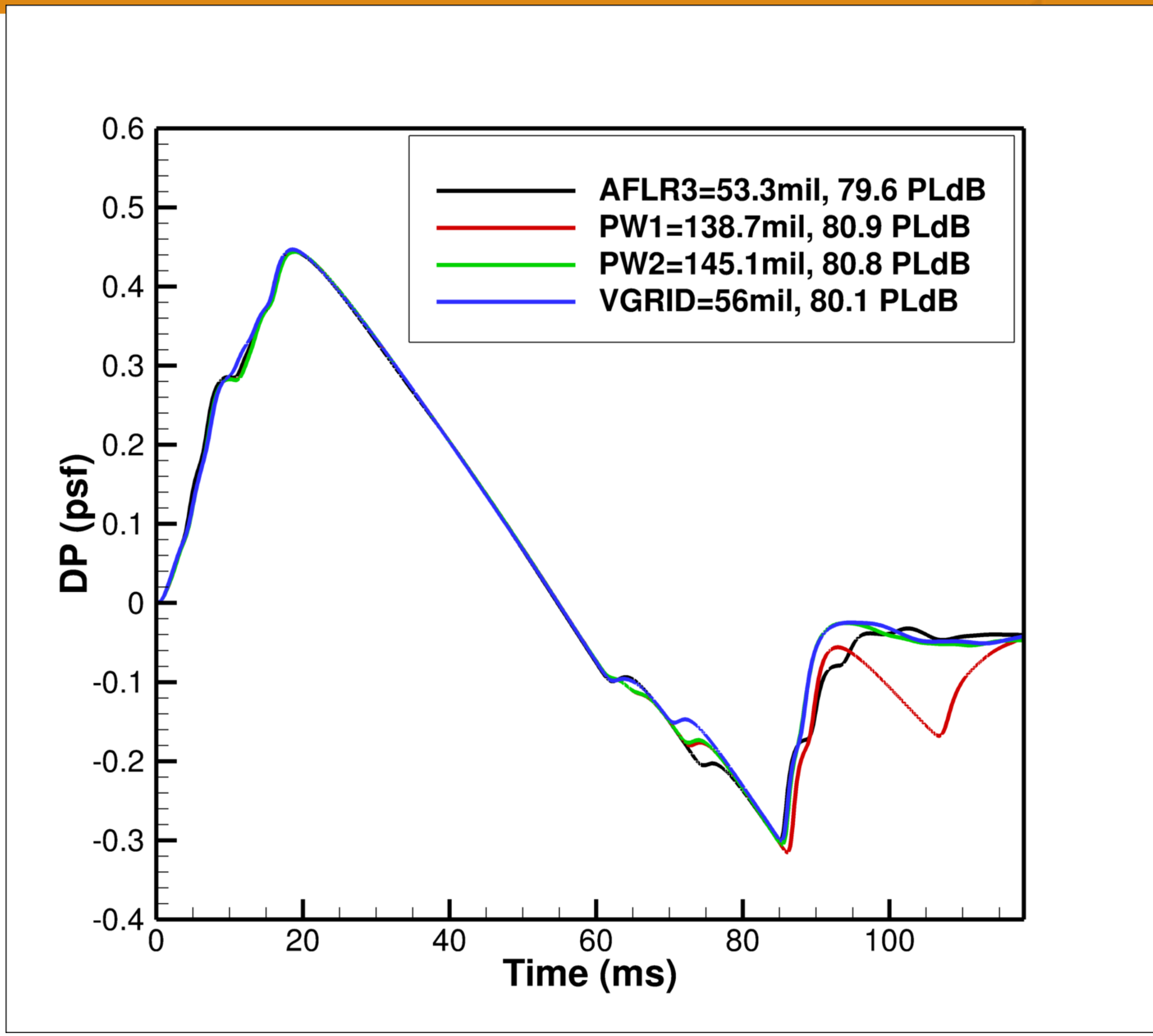
Near Field Pressure Signature, H/L=5, Φ=30˚



Ground Signatures Computed from H/L=1, Φ=0˚



Ground Signatures Computed from H/L=5, Φ=0˚



Summary

- USM3D simulations were conducted on all four configurations provided by the sonic boom workshop
- Simulations were conducted on workshop provided grids as well as in house grids
- SBOOM used to propagate the nearfield signature to the ground
- Loudness code used to compute the loudness at the ground

References

- USM3D: https://tetruss.larc.nasa.gov/usm3d/
- Sboom: Sriram K. Rallabhandi. "Advanced Sonic Boom Prediction Using the Augmented Burgers Equation", Journal of Aircraft, Vol. 48, No. 4 (2011), pp. 1245-1253.
- Loudness: K.P. Shepherd and B.M. Sullivan. “A loudness calculation procedure applied to shaped sonic booms”, NASA-TP-3134, 1991.

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