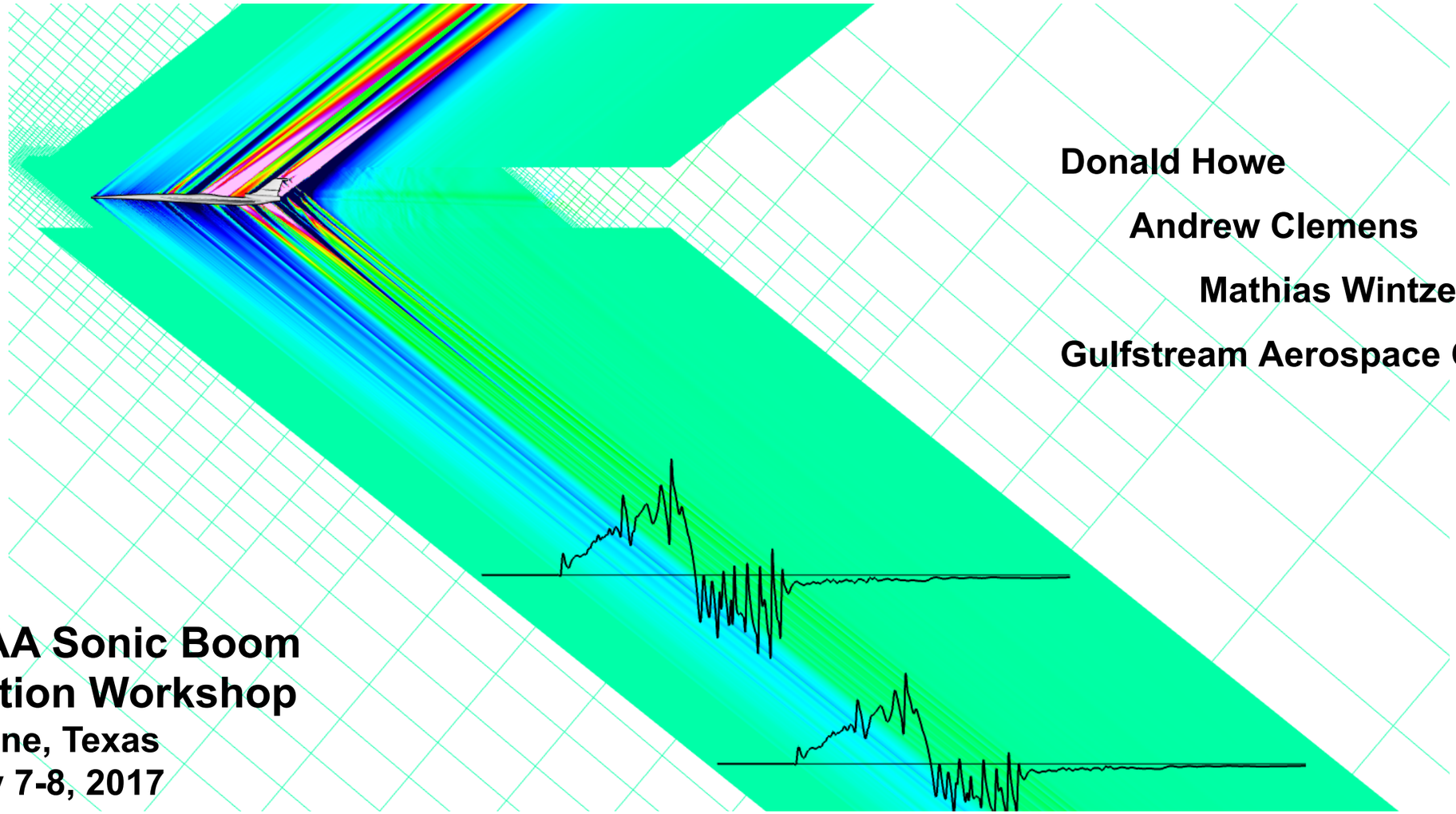
Hybrid CART3D/OVERFLOW and FUN3D Near Field Analysis for Sonic Boom Prediction



Donald Howe

Andrew Clemens

Mathias Wintzer

Gulfstream Aerospace Corporation

2nd AIAA Sonic Boom Prediction Workshop

Grapevine, Texas

January 7-8, 2017

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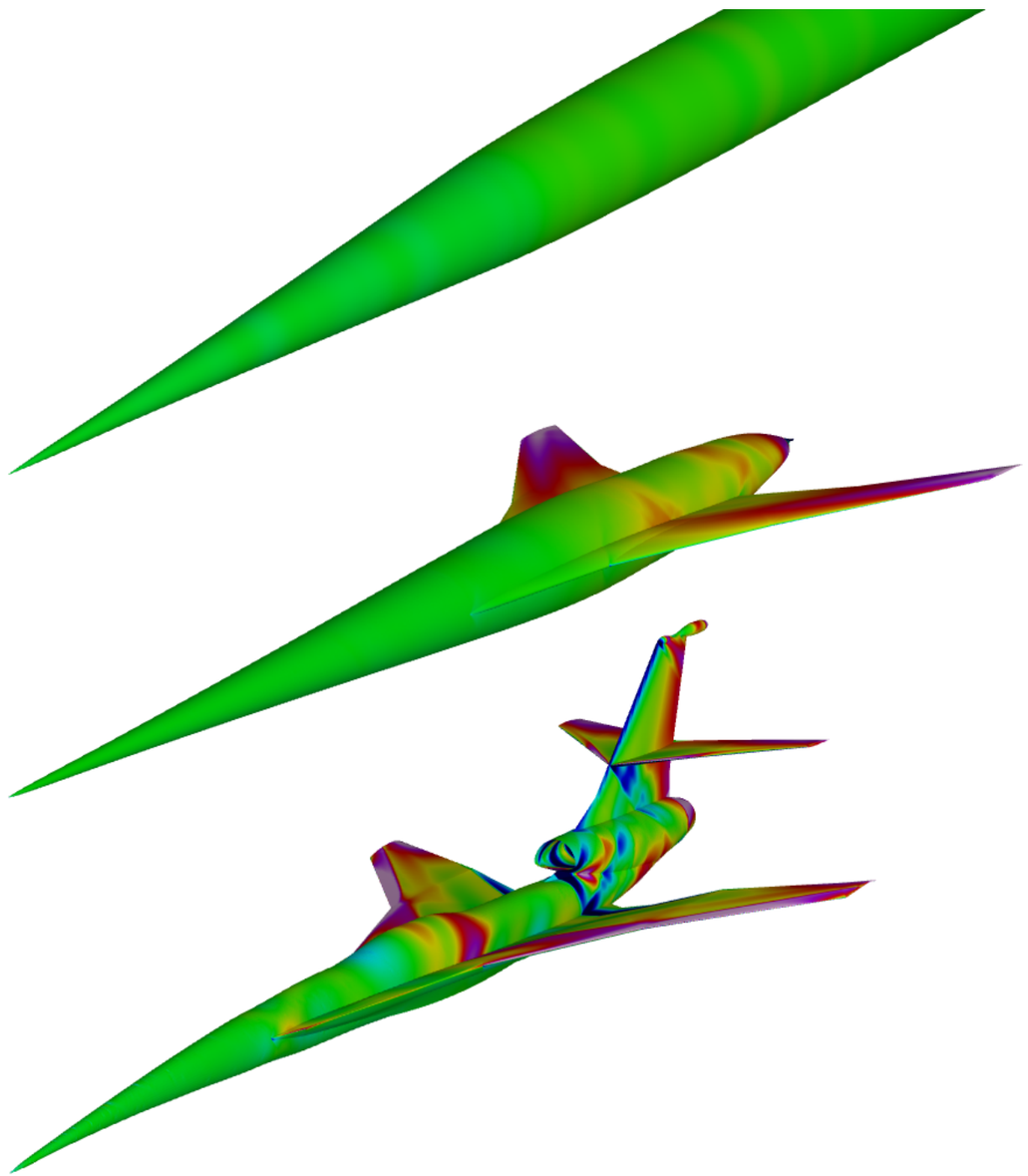
Second Sonic Boom Prediction Workshop



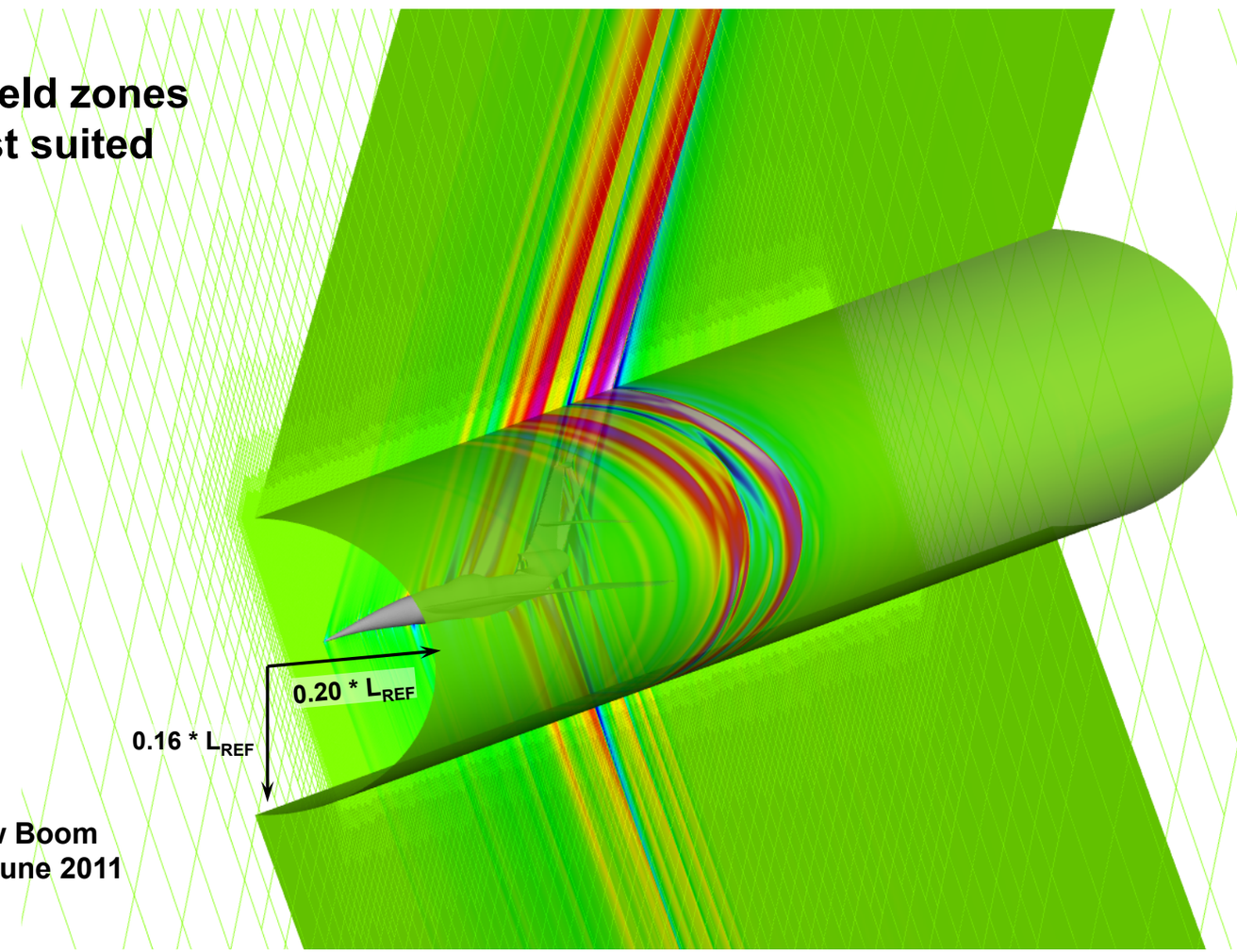
- **Axisymmetric Body Based on NASA C25D**
  - **Hybrid Cart3D/Overflow**
    - **6 cases with Uniform Refinement**
    - **9.9 to 240.8 million cells total**

- **JAXA Wing/Body**
  - **Hybrid Cart3D/Overflow**
    - **6 cases with Uniform Refinement**
    - **10.9 to 233.7 million cells total**
  - **Fun3D Unstructured**
    - **Workshop tet meshes**
    - **3 meshes, 62 to 129 million cells**
    - **Inviscid analysis**

- **NASA 25D Flow Through**
  - **Hybrid Cart3D/Overflow**
    - **6 cases with Uniform Refinement**
    - **12.8 to 225.8 million cells total**
  - **Cart3D Adjoint / Fixed Overflow**
    - **3 cases (last 3 steps of adjoint adaptation)**
    - **65.9 to 207.6 million cells total**

Hybrid Cart3D/Overflow Near Field Sonic Boom Analysis

- Hybrid Near-/Mid-Field method originally developed in the following context:
  - Implement existing analysis codes in a design setting
  - Complete complex configurations including propulsion integration
  - Adequate mid-field distance for propagation (4 to 5 body lengths)
  - Simultaneous on- and off-track analysis
- Flow field split into separate near-field and mid-field zones using different codes where each topology is best suited
  - Near-Field
    - Cart3D Cartesian cut-cell Euler
    - Grid focused within h/l = ¼
  - Mid-Field
    - Overflow structured mesh (Euler)
    - Mach aligned grid
    - Single annular block



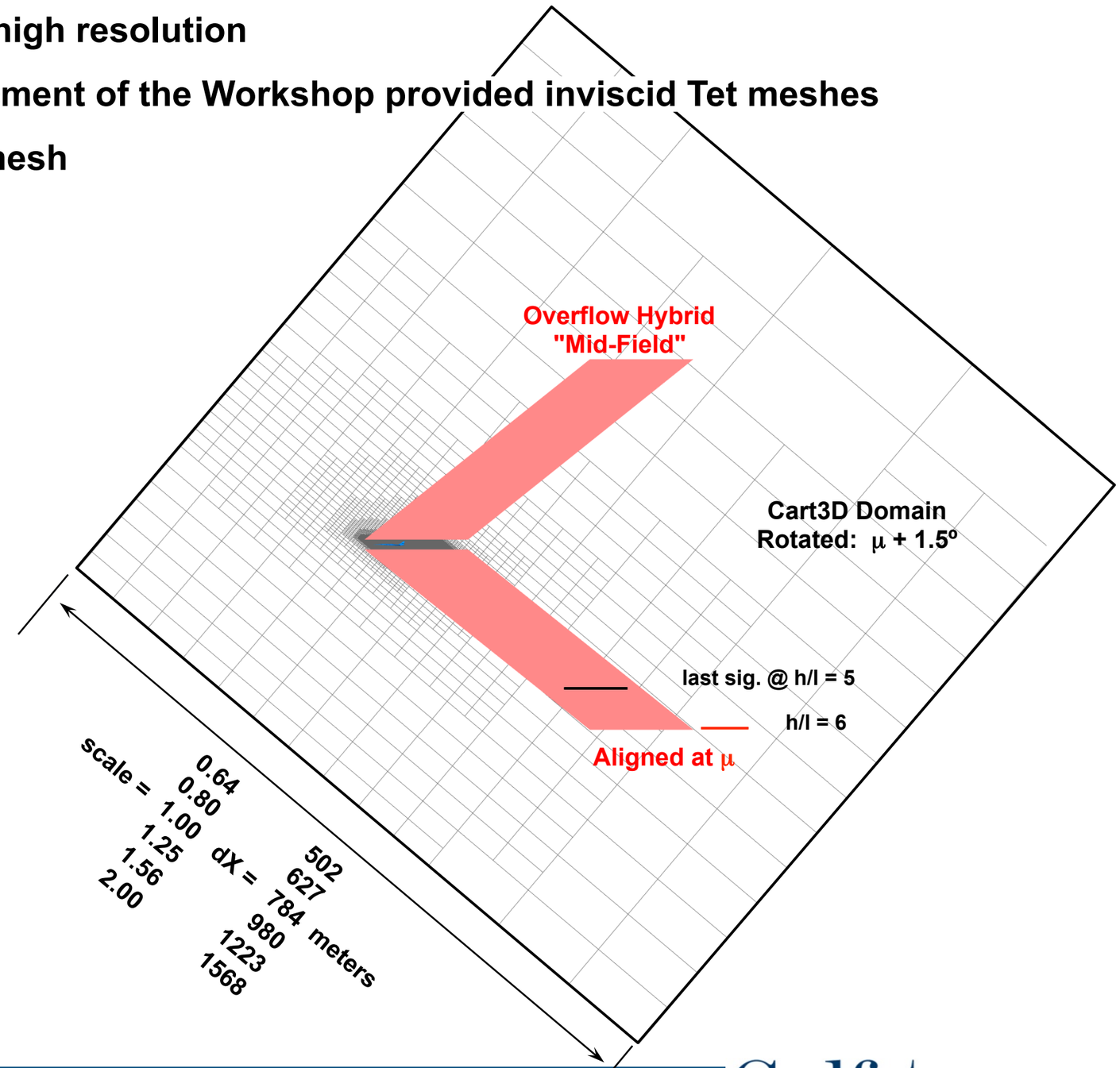
Previously Published:

AIAA-2011-3336, Hybrid CART3D/OVERFLOW Near-Field Analysis of a Low Boom Configuration with Wind Tunnel Comparisons, D. Howe, June 2011

1st AIAA Sonic Boom Prediction Workshop, January 2014

C25D Flow Through Uniform Refinement

- First Workshop (2014): Single grid with very high resolution
- This Workshop: Emulating the uniform refinement of the Workshop provided inviscid Tet meshes
- Scale 1.00 mesh patterned after inviscid Tet mesh
- For Cart3D uniform refinement the entire domain is scaled and the levels of refinement are fixed
- Overflow mesh dimensions are fixed, number of grid points scaled accordingly in all three dimensions: J, K, L
- This includes varying the number of line sensors which make up the hybrid "cutting cylinder"
- Surface triangulation from Scale 0.80 inviscid Tet mesh used for all Cart3D analyses



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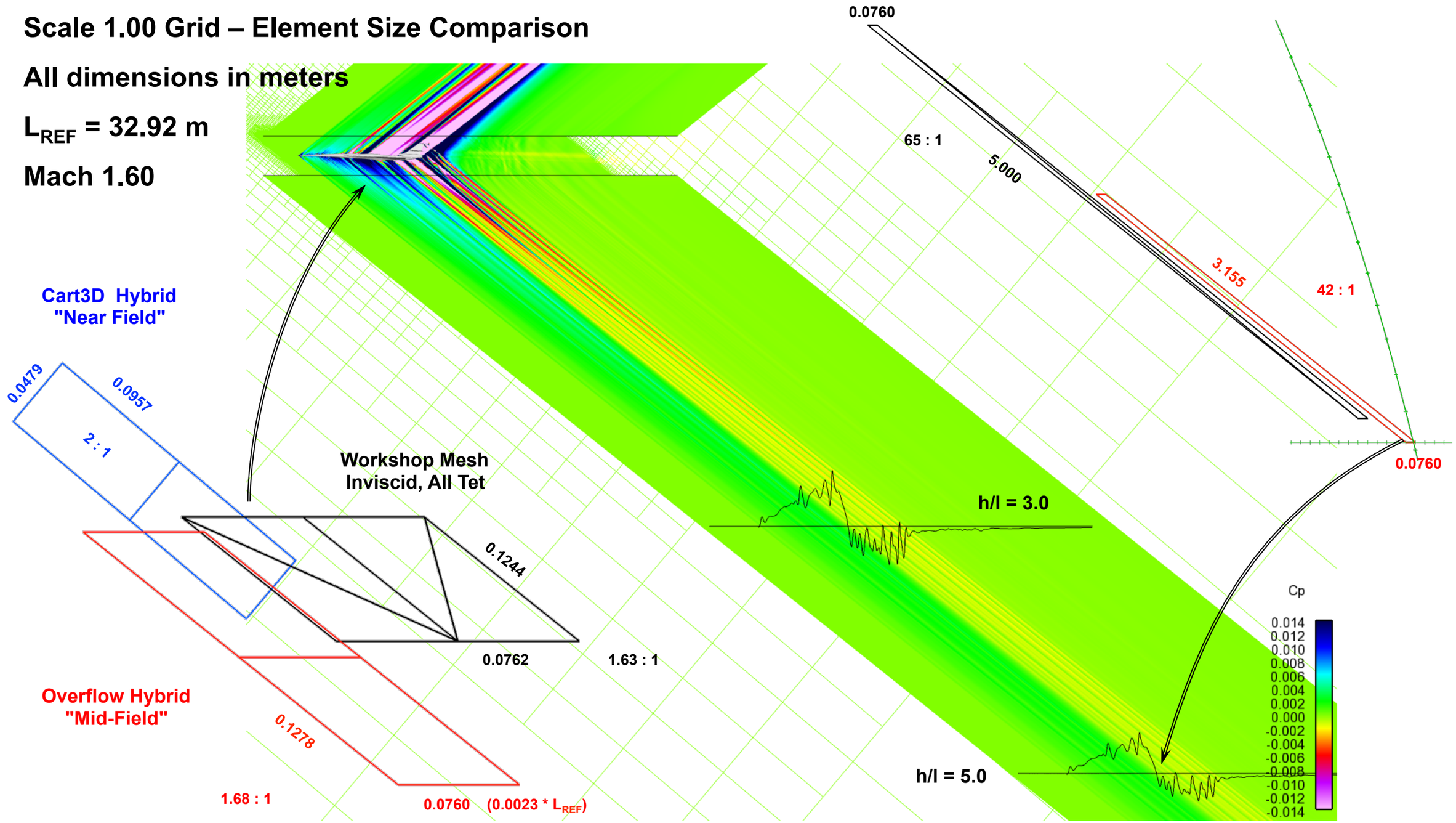
C25D Flow Through Uniform Refinement

- Scale 1.00 Grid – Element Size Comparison
- All dimensions in meters
- L_{REF} = 32.92 m
- Mach 1.60



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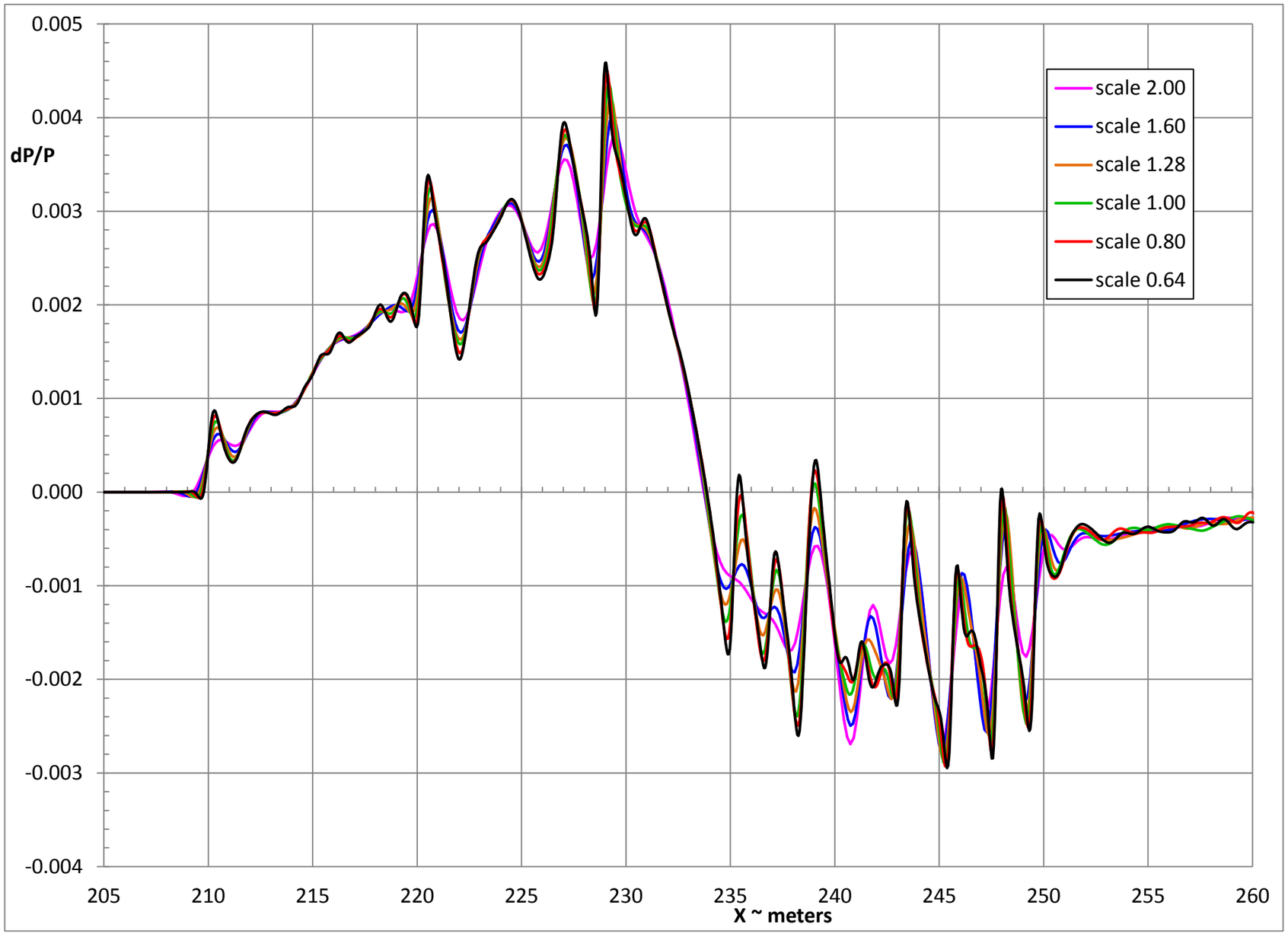
C25D Flow Through Uniform Refinement – Grid Summary

		Cart3D			Overflow				Total	Cart3D		Overflow	
Case	Scale	ds-mid	ds/Lref	nCvol	J	K	L	cells	Cells	cores	min.	cores	min.
c25ft200	2.000	0.1520	0.00462	9,740,005	564	51	111	3,096,500	12,836,505	32	12	28	6
c25ft160	1.560	0.1186	0.00360	16,056,452	702	65	142	6,325,824	22,382,276	32	18	28	11
c25ft128	1.250	0.0950	0.00289	26,128,996	852	81	177	11,982,080	38,111,076	32	27	28	19
c25ft100	1.000	0.0760	0.00231	44,690,867	1036	101	220	22,666,500	67,357,367	32	43	28	36
c25ft080	0.800	0.0608	0.00185	78,500,402	1261	127	275	43,500,240	122,000,642	32	73	28	77
c25ft064	0.640	0.0486	0.00148	142,677,053	1536	159	344	83,187,790	225,864,843	32	140	84	95

Note: 28 core nodes are Haswell processors
32 core nodes are Broadwell processors

C25D Flow Through Uniform Refinement – h/l = 5 Signatures

- **h/l = 5 Signatures -- Uniform Refinement**



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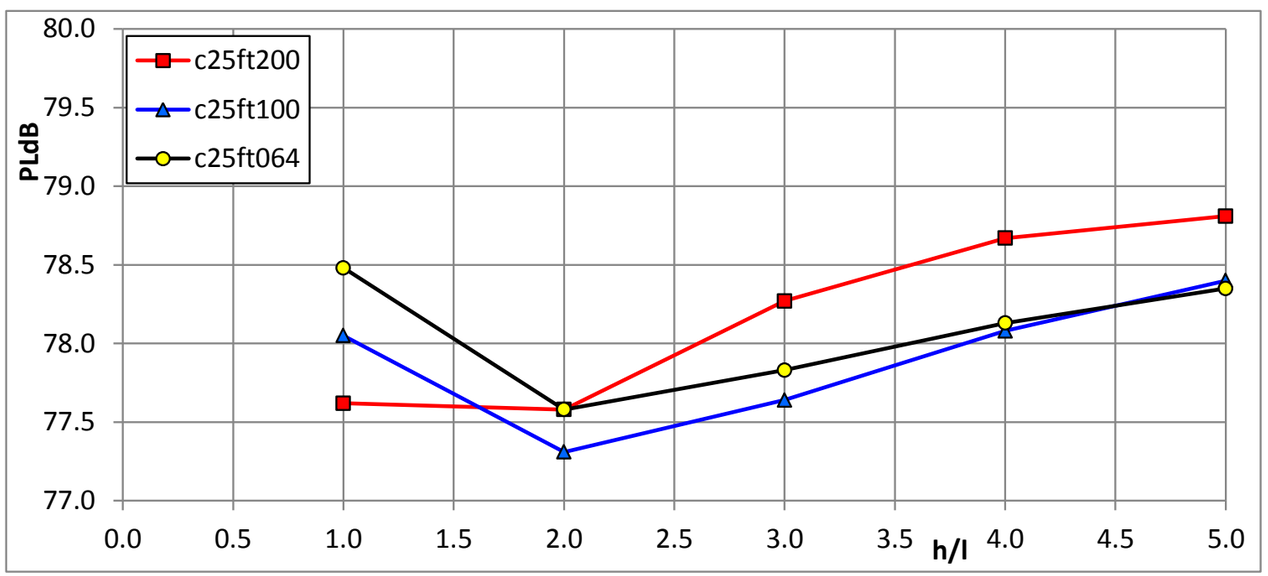
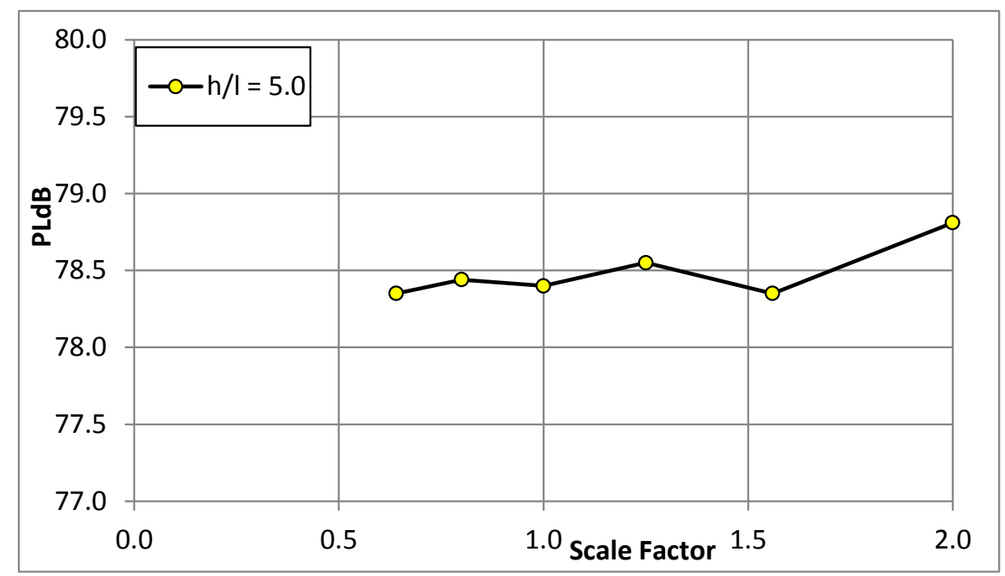
C25D Flow Through Uniform Refinement – Signature Convergence

- **Propagated signatures were not submitted to the workshop**
- **But, showing GACBoom propagated PLdB to assess convergence**

h/l Convergence



Grid Refinement Convergence



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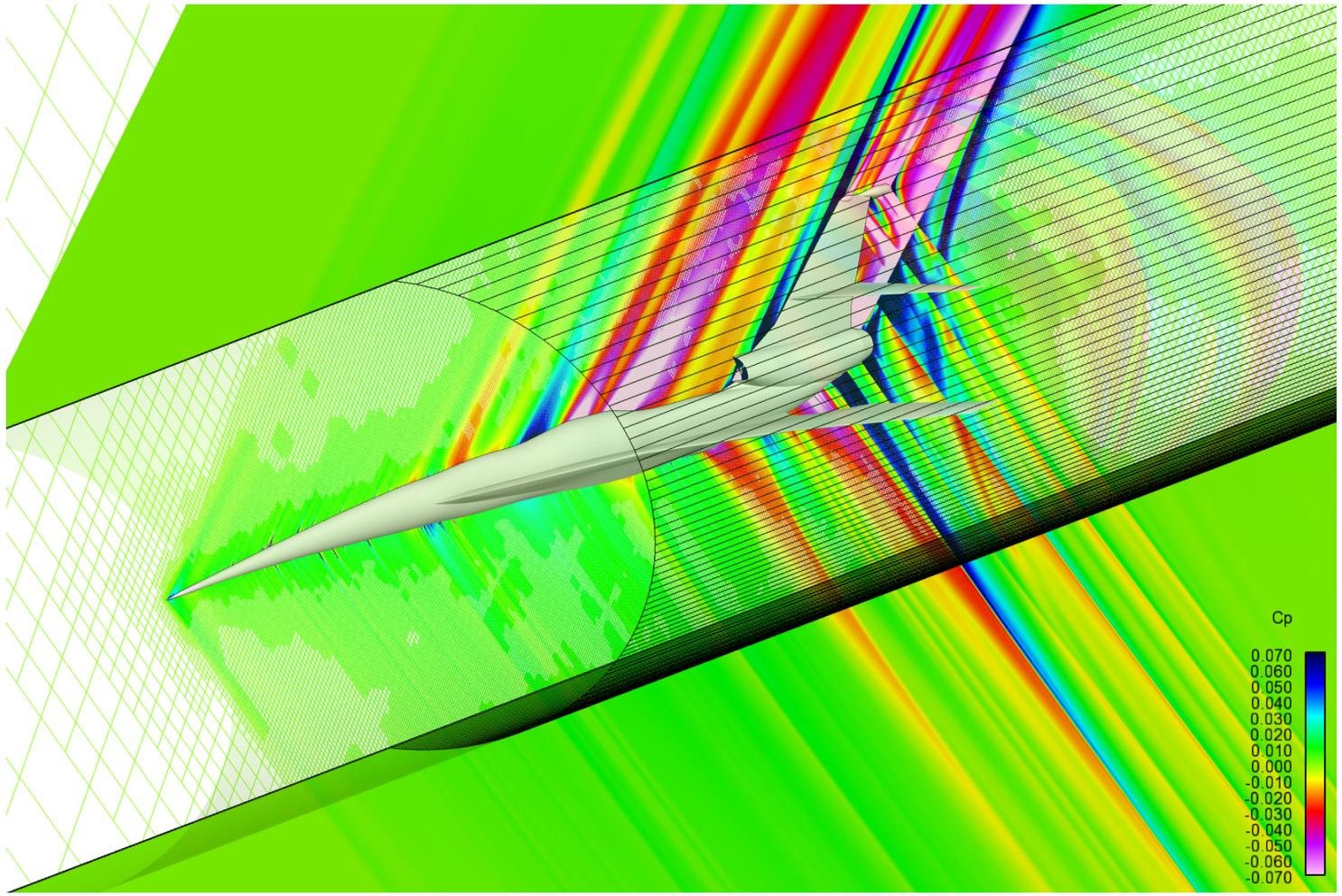
C25D Flow Through – Hybrid / Adjoint

Cart3D Adjoint Near-Field

- **Grid rotated to μ + 1.5º to avoid "sonic glitch"**
- **AR = 2 cell stretching**
  - **Cells square in the Mach plane**
  - **Rotation of grid favors undertrack ϕ**
- **Mesh adaptation**
  - **Targets all 101 sensors,**
  - **Evenly weighted**
  - **Squared functional form**
- **Initial mesh contains 55k cells**
- **8 refinement cycles**
- **Cart3D "auto growth" feature**
- **Terminal mesh contains 155M cells**

Overflow Midfield:

- **Fixed number of cutting cylinders**
- **Therefore, fixed Overflow block**



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C25D Flow Through – Hybrid / Adjoint Mesh Summary

Uniform Refinement

		Cart3D			Overflow				Total	Cart3D		Overflow	
Case	Scale	ds-mid	ds/Lref	nCvol	J	K	L	cells	Cells	cores	min.	cores	min.
c25ft200	2.000	0.1520	0.00462	9,740,005	564	51	111	3,096,500	12,836,505	32	12	28	6
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c25ft080	0.800	0.0608	0.00185	78,500,402	1261	127	275	43,500,240	122,000,642	32	73	28	77
c25ft064	0.640	0.0486	0.00148	142,677,053	1536	159	344	83,187,790	225,864,843	32	140	84	95

Adjoint Refinement

Fixed Midfield Block

		Cart3D			Overflow				Total	Cart3D		Overflow	
Case	Scale	ds-mid	ds/Lref	nCvol	J	K	L	cells	Cells	cores	min.	cores	min.
c25adj174	1.740			13,281,922	1536	101	344	52,650,500	65,932,422			56	46
c25adj115	1.150			38,848,872	1536	101	344	52,650,500	91,499,372			56	46
c25adj060	0.600			154,919,685	1536	101	344	52,650,500	207,570,185	256	174	56	46

"scale factors" backed out based on number of nodes

SGI Altix – Sandy Bridge cores

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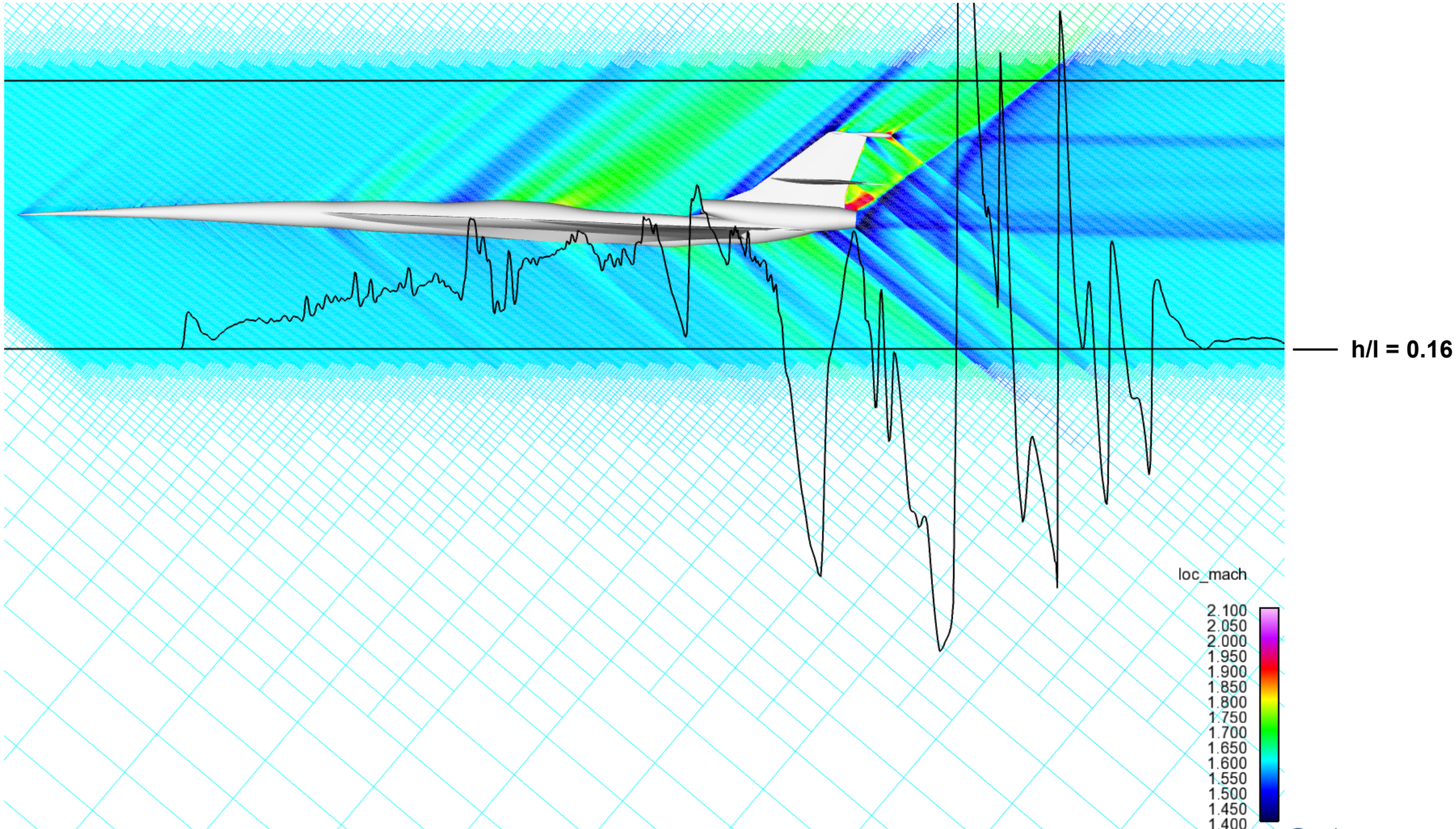
C25D – Comparison at the Cutting Cylinder

- **preSpec Refinement, finest mesh**



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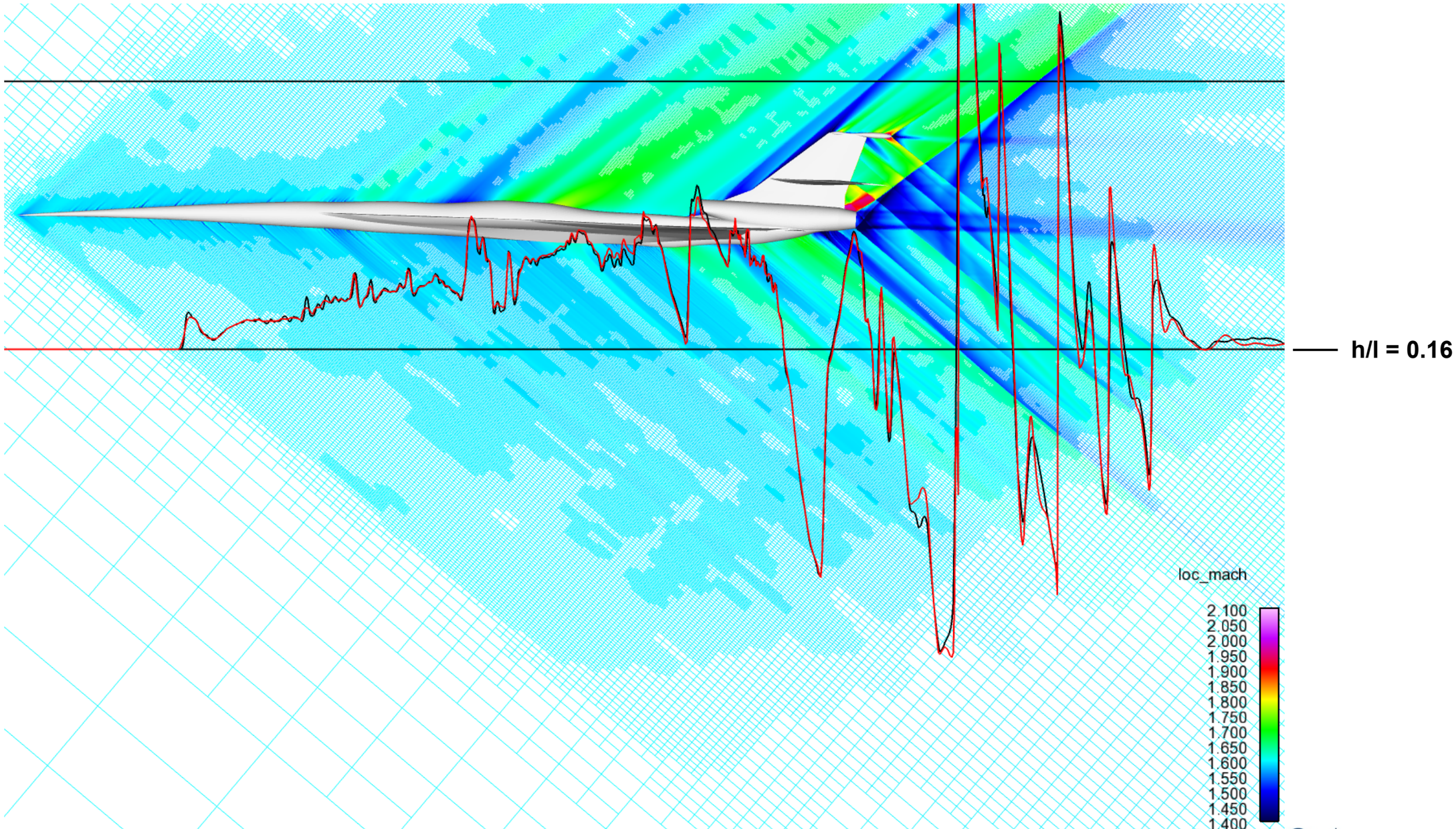
C25D – Comparison at the Cutting Cylinder

- **Adjoint Refinement, finest mesh**



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C25D – Comparison at the Cutting Cylinder

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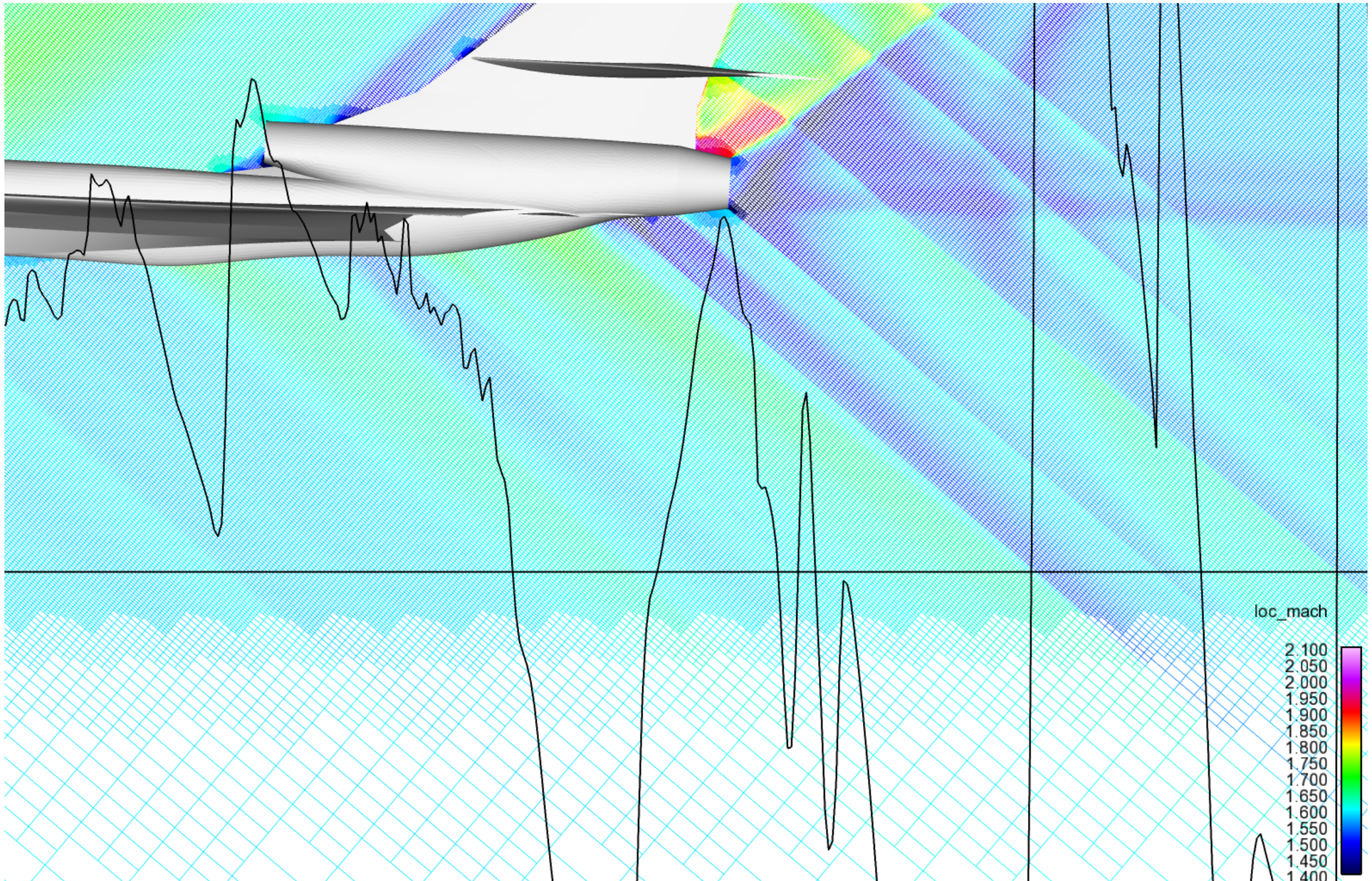

h/l = 0.16

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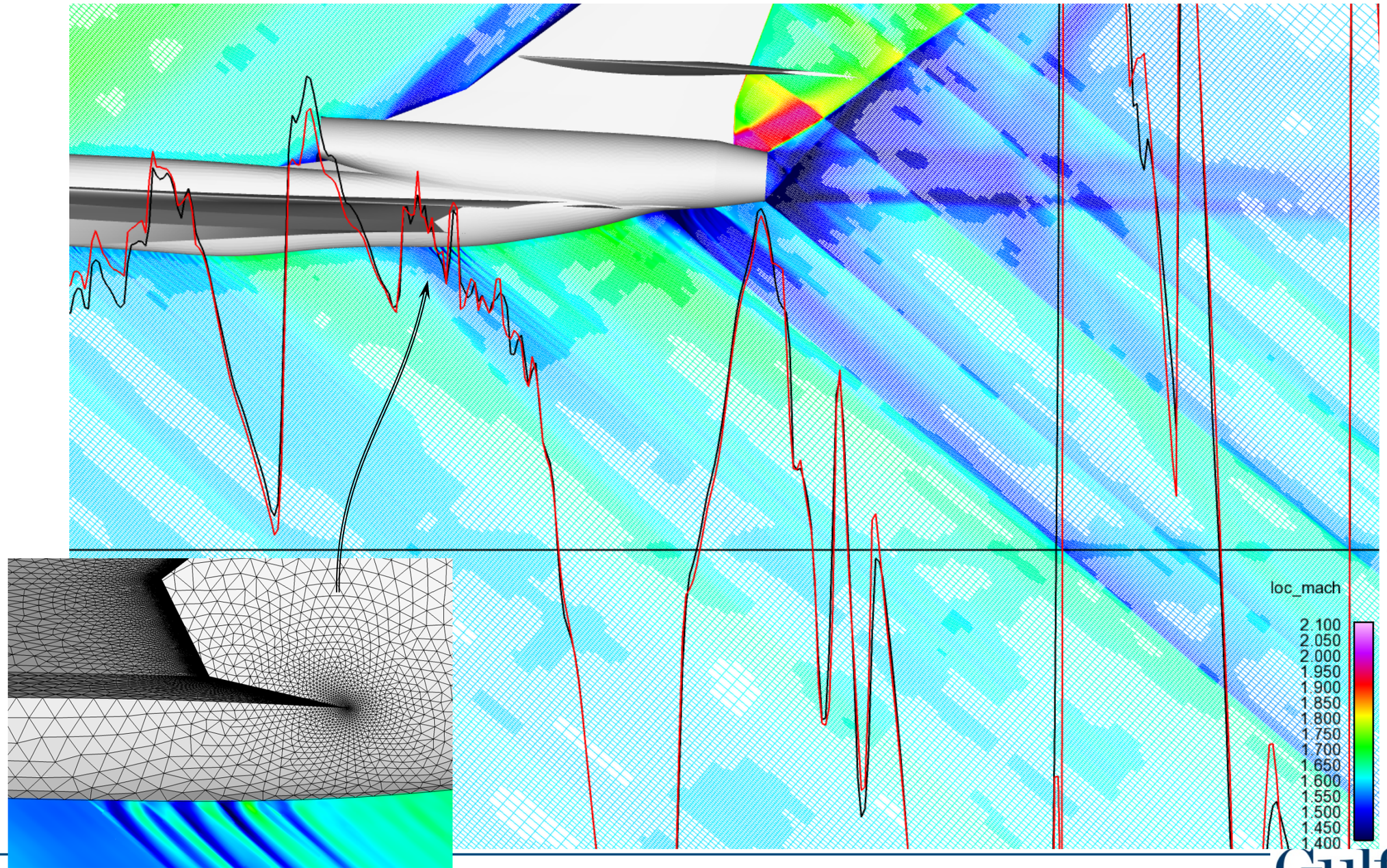
C25D – Comparison at the Cutting Cylinder

- **Adjoint Refinement, finest mesh**



h/l = 0.16

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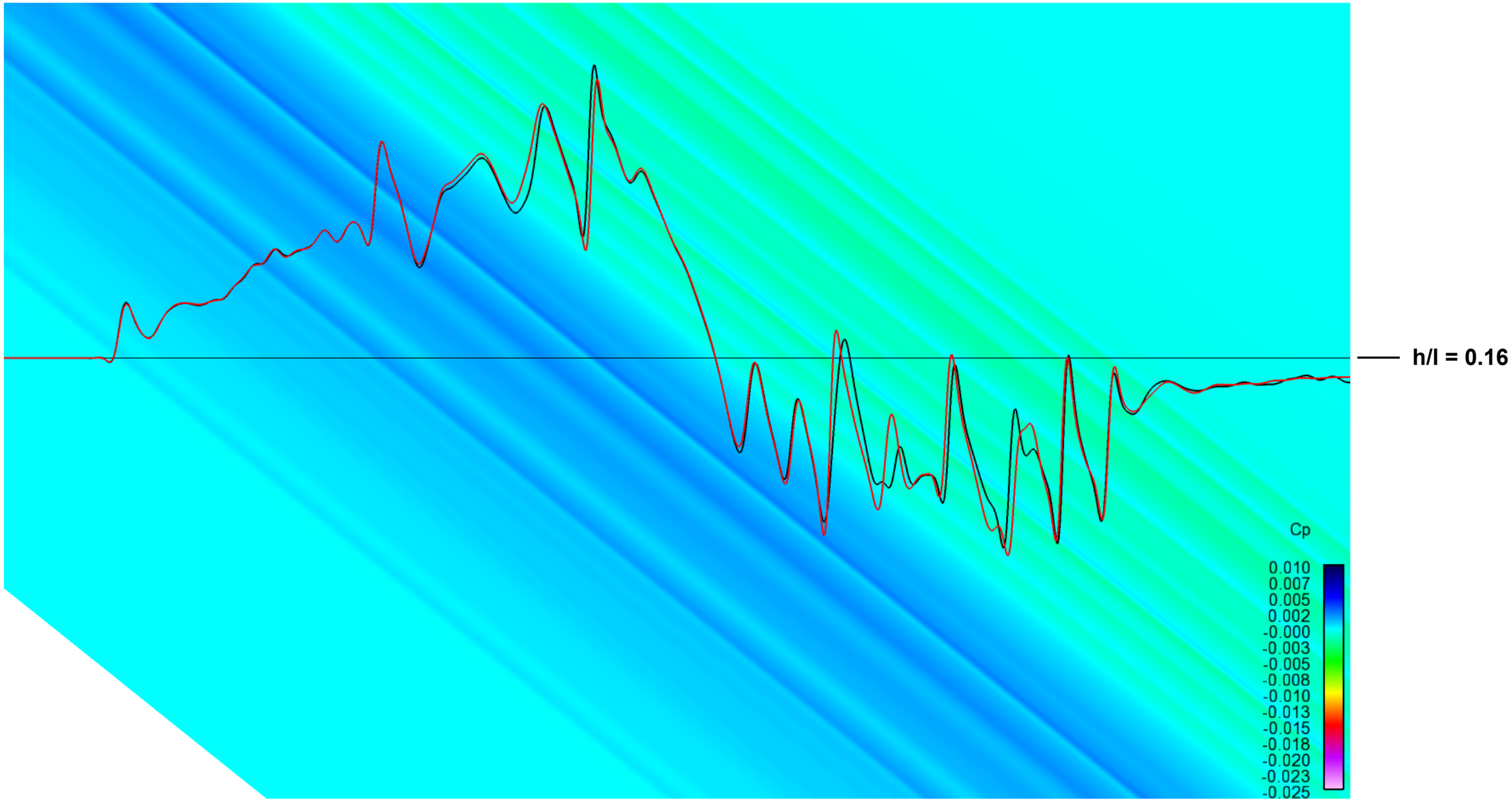
C25D – Signature Comparison at h/l = 5.0

- h/l = 5 Signature Comparison (preSpec Refinement, Adjoint Refinement)



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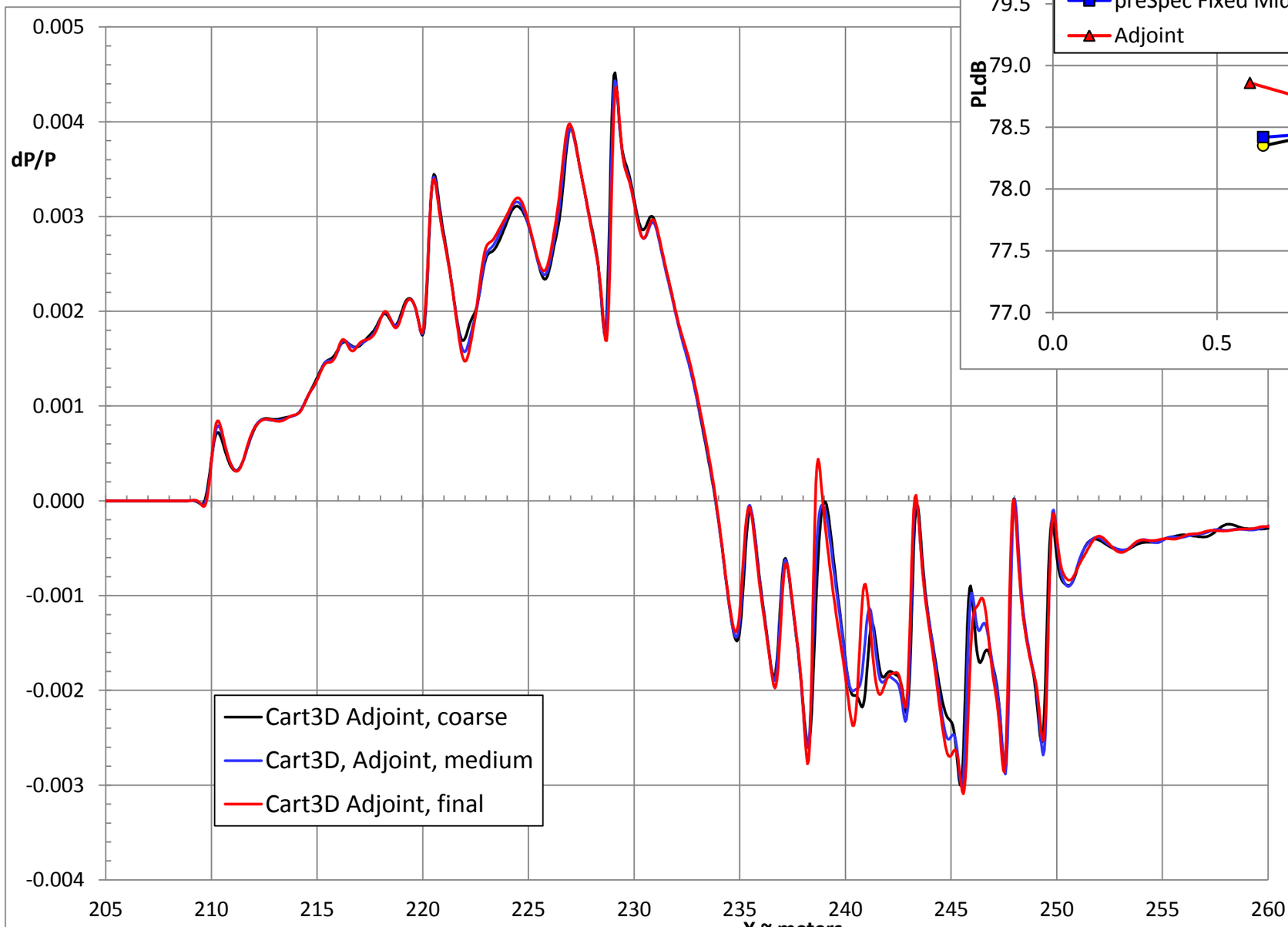
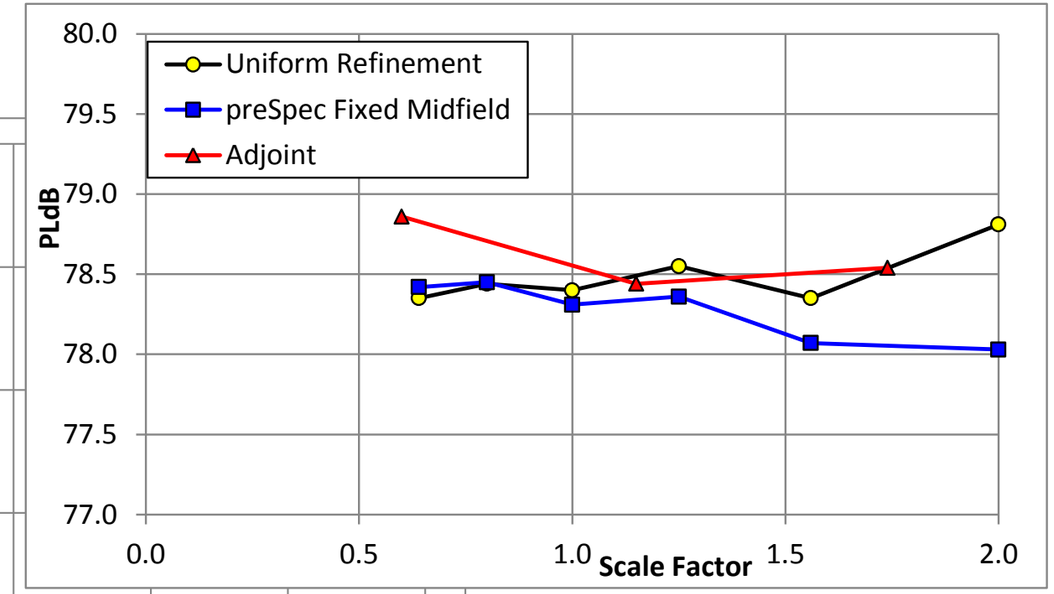
C25D Flow Through – Final Signature Comparison

- **h/l = 5.0 Signature Comparison, All at Finest Mesh**





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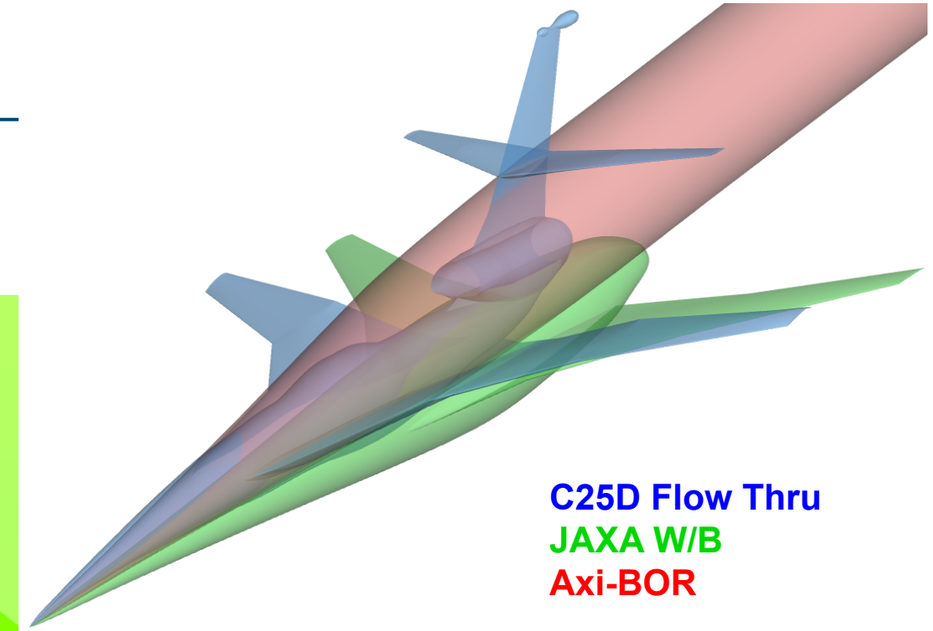
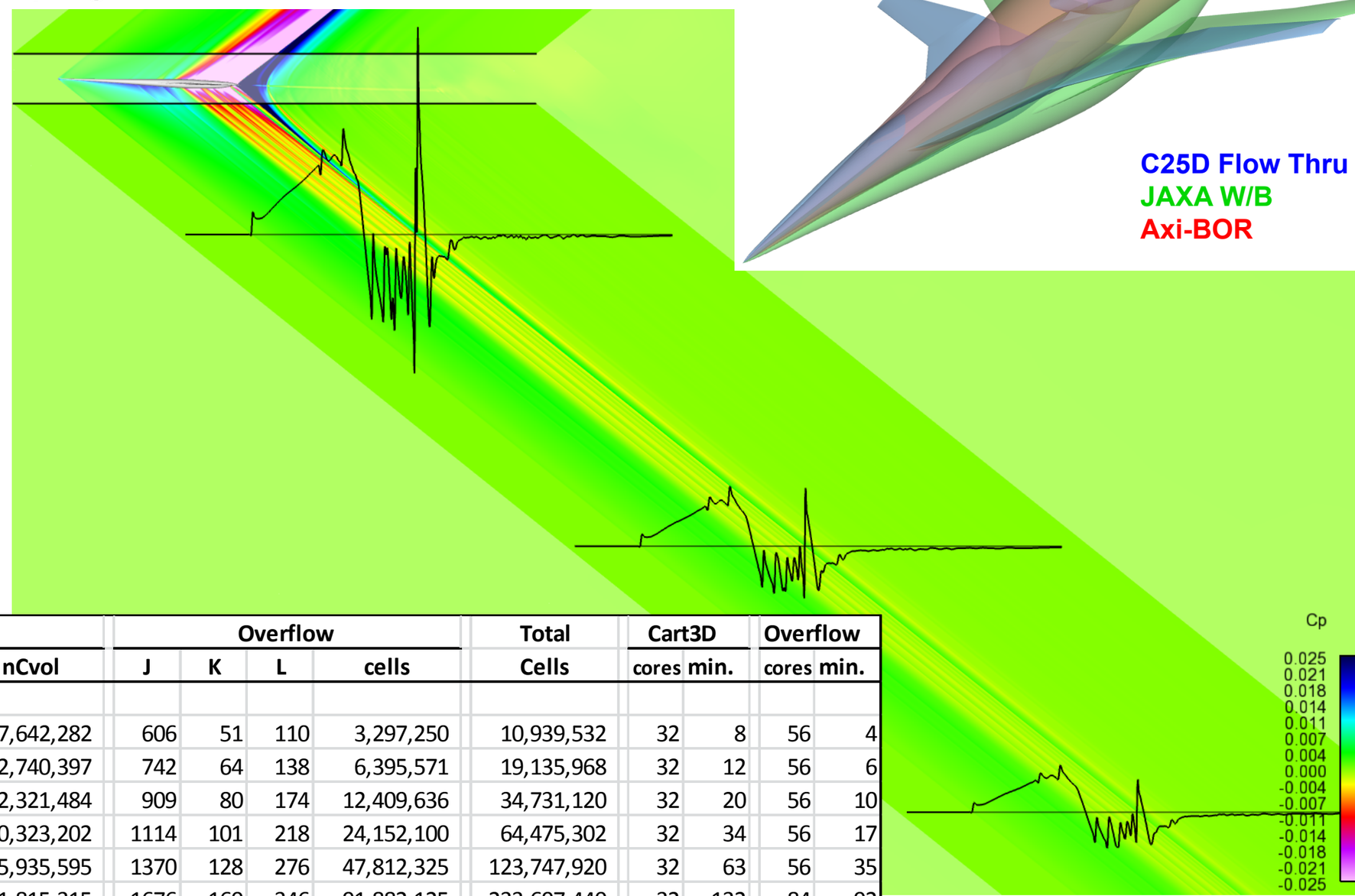
JAXA Wing/Body – Hybrid Analysis

- JAXA Wing/Body essentially the same size as C25D
- Run with the same mesh progression





		Cart3D			Overflow				Total	Cart3D		Overflow	
Case	Scale	ds-mid	ds/Lref	nCvol	J	K	L	cells	Cells	cores	min.	cores	min.
c25ft200	2.000	0.1400	0.00362	7,642,282	606	51	110	3,297,250	10,939,532	32	8	56	4
c25ft160	1.590	0.1113	0.00288	12,740,397	742	64	138	6,395,571	19,135,968	32	12	56	6
c25ft128	1.260	0.0882	0.00228	22,321,484	909	80	174	12,409,636	34,731,120	32	20	56	10
c25ft100	1.000	0.0700	0.00181	40,323,202	1114	101	218	24,152,100	64,475,302	32	34	56	17
c25ft080	0.790	0.0553	0.00143	75,935,595	1370	128	276	47,812,325	123,747,920	32	63	56	35
c25ft064	0.630	0.0441	0.00114	141,815,315	1676	160	346	91,882,125	233,697,440	32	132	84	92

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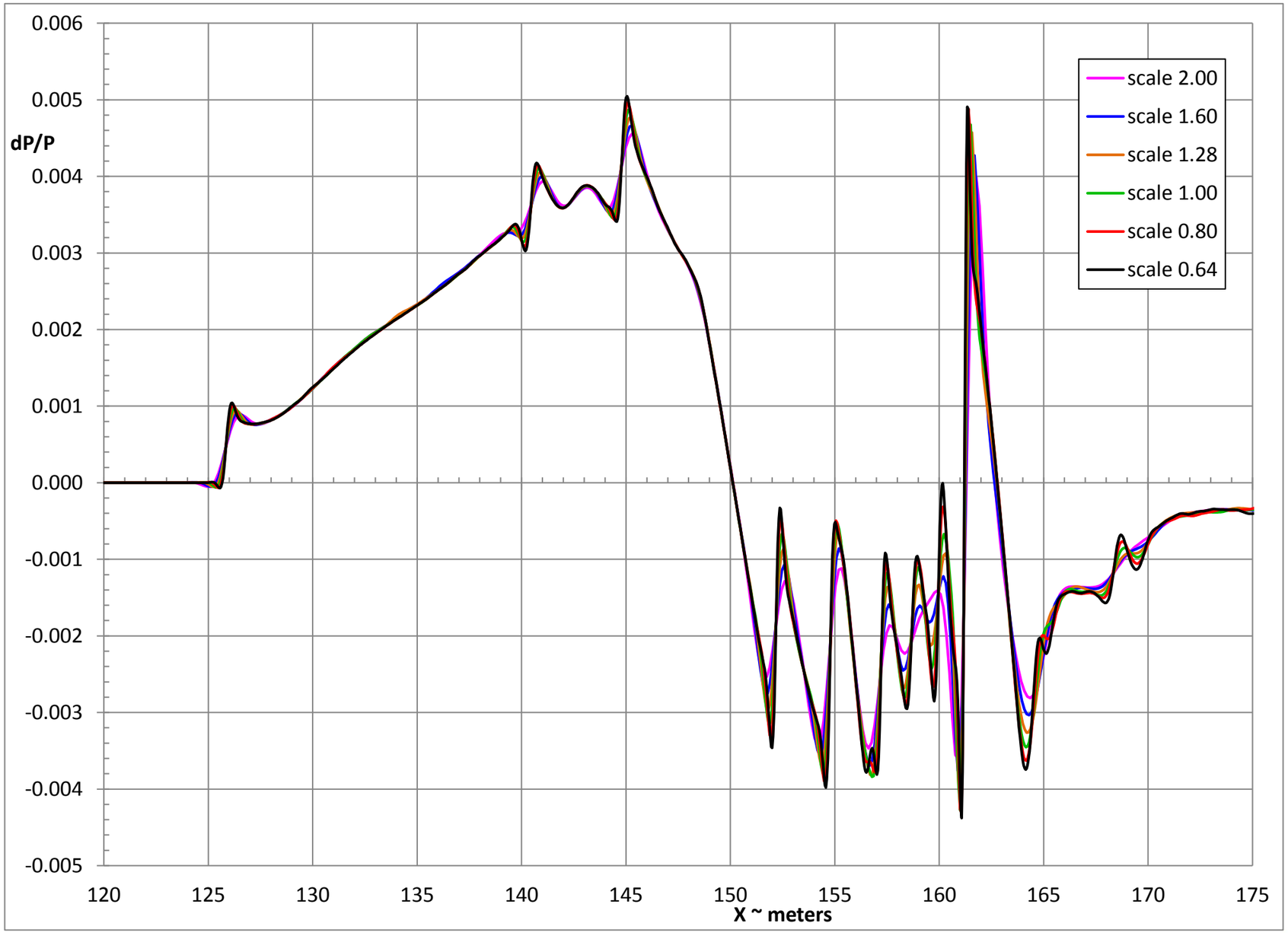
JAXA Wing/Body – Hybrid Uniform Refinement at h/l = 2.55

- **Signature Comparisons h/l = 2.55**



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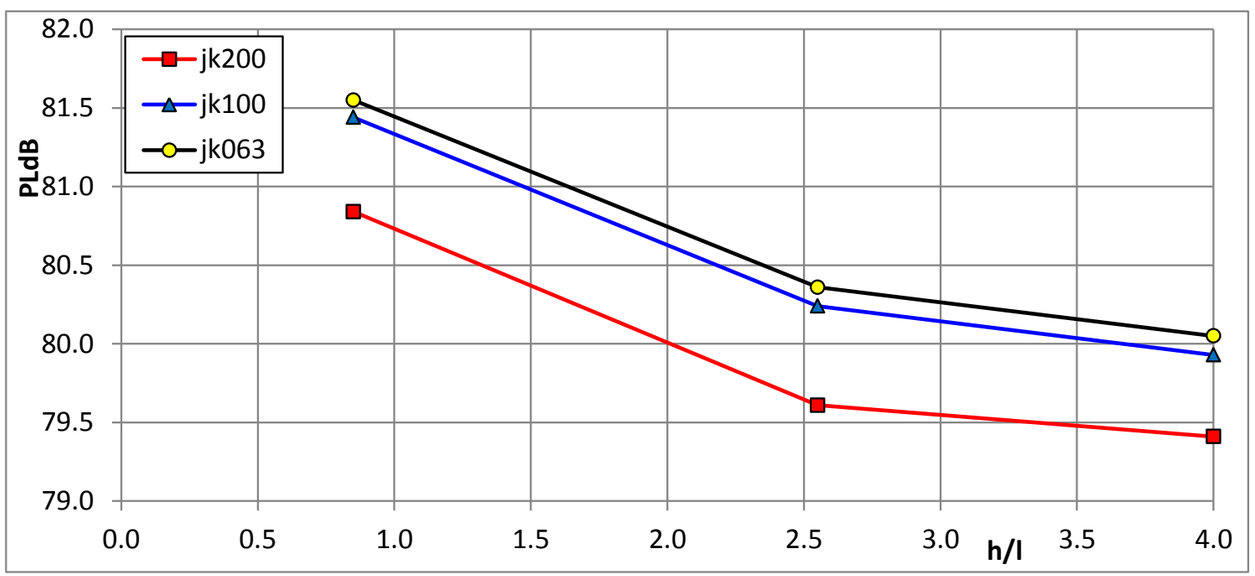
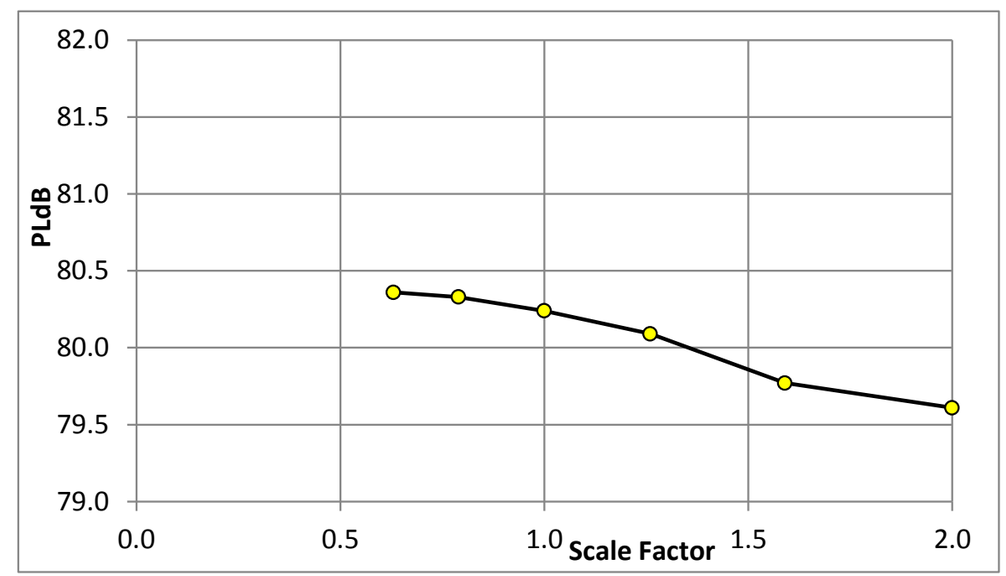
JAXA Wing/Body – Hybrid Analysis Signature Convergence

- **Propagated signatures were not submitted to the workshop**
- **But, showing GACBoom propagated PLdB to assess convergence**





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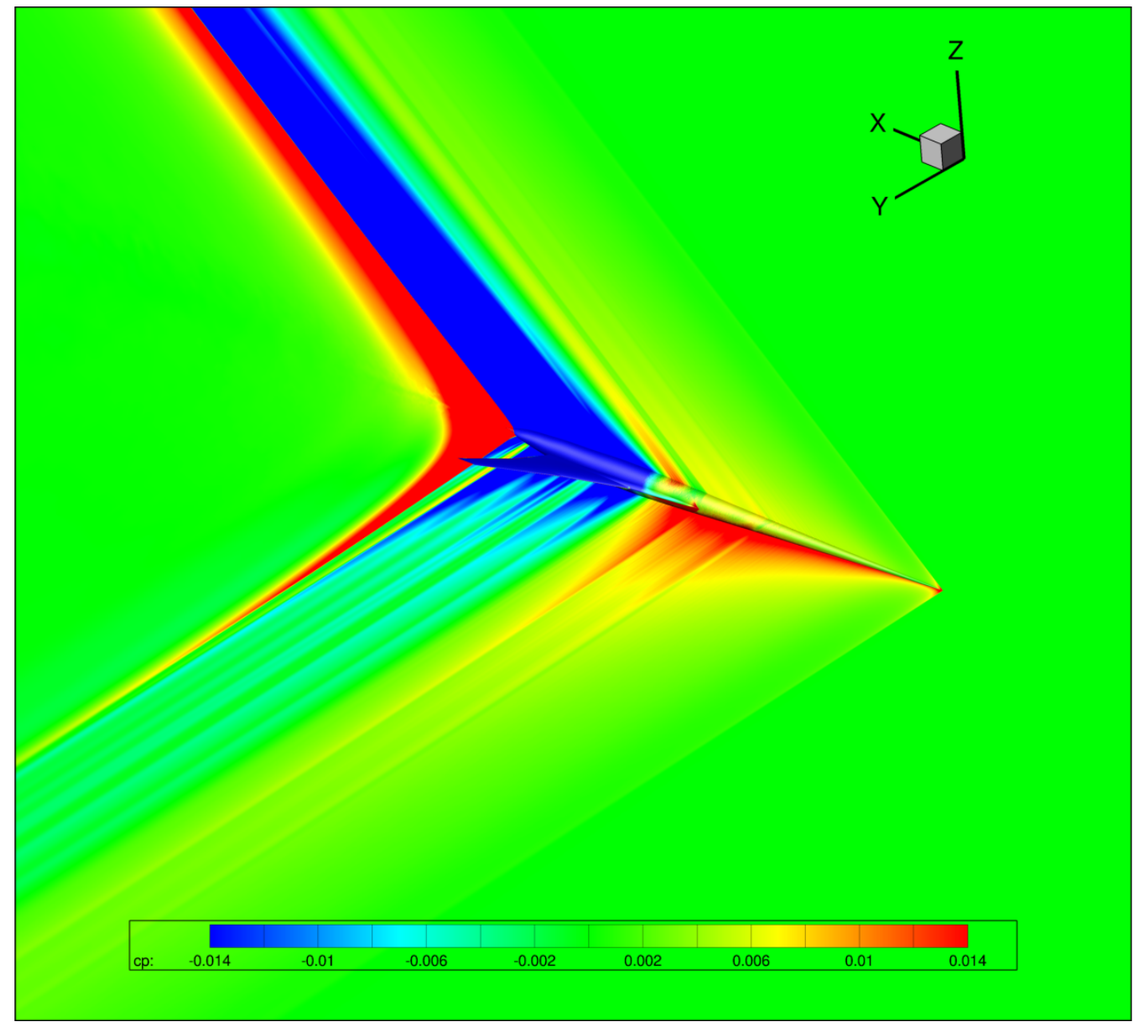
JAXA Wing/Body – Unstructured Tet mesh Generation

- **Grids**
  - **Generated with HeldenMesh**
    - **Auto-patch and auto-source features**
    - **Global source scaling factor applied to generate grid families**
  - **Solutions with Fun3D**
    - **Inviscid**

Dense: 128.8 million cells
Intermediate: 96.6 million cells
Coarse: 62.4 million cells

HeldenMesh Input File

```
JAXA_wb.rst
-----------------------------------------------------------
GRID_TYPE    SMOOTH_ITER REFINE_FAC  SRC_GROWTH
-2           5           -0.9        0.1
-----------------------------------------------------------
SRC_PATCH: wing_cap
STRENGTH     WIDTH_RATIO STRETCH_MAX EDGE_ANGLE
1            2           1           30
S_MIN        S_BASE      CURVANGLE   S_EDGE
0.001        0.3         3           0.01
-----------------------------------------------------------
SRC_PATCH: wing
STRENGTH     WIDTH_RATIO STRETCH_MAX EDGE_ANGLE
1            2           10          30
S_MIN        S_BASE      CURVANGLE   S_EDGE
0.001        0.3         3           0.01
-----------------------------------------------------------
SRC_PATCH: fuselage
STRENGTH     WIDTH_RATIO STRETCH_MAX EDGE_ANGLE
1            2           10          30
S_MIN        S_BASE      CURVANGLE   S_EDGE
0.005        0.5         3           0.02
-----------------------------------------------------------
SRC_SHOCK: Shock
STRENGTH     RADIUS      STRETCH_MAX CURV_ANGLE  ANG1  ANG2
3            2000        50          10          -1.6  -1.6
X1           Y1          Z1          S1_Inner    S1_Outer
0            0           0           0.01        3
X2           Y2          Z2          S2_Inner    S2_Outer
38.6505      0           -1.4        0.02        3
-----------------------------------------------------------
-----------------------------------------------------------
```



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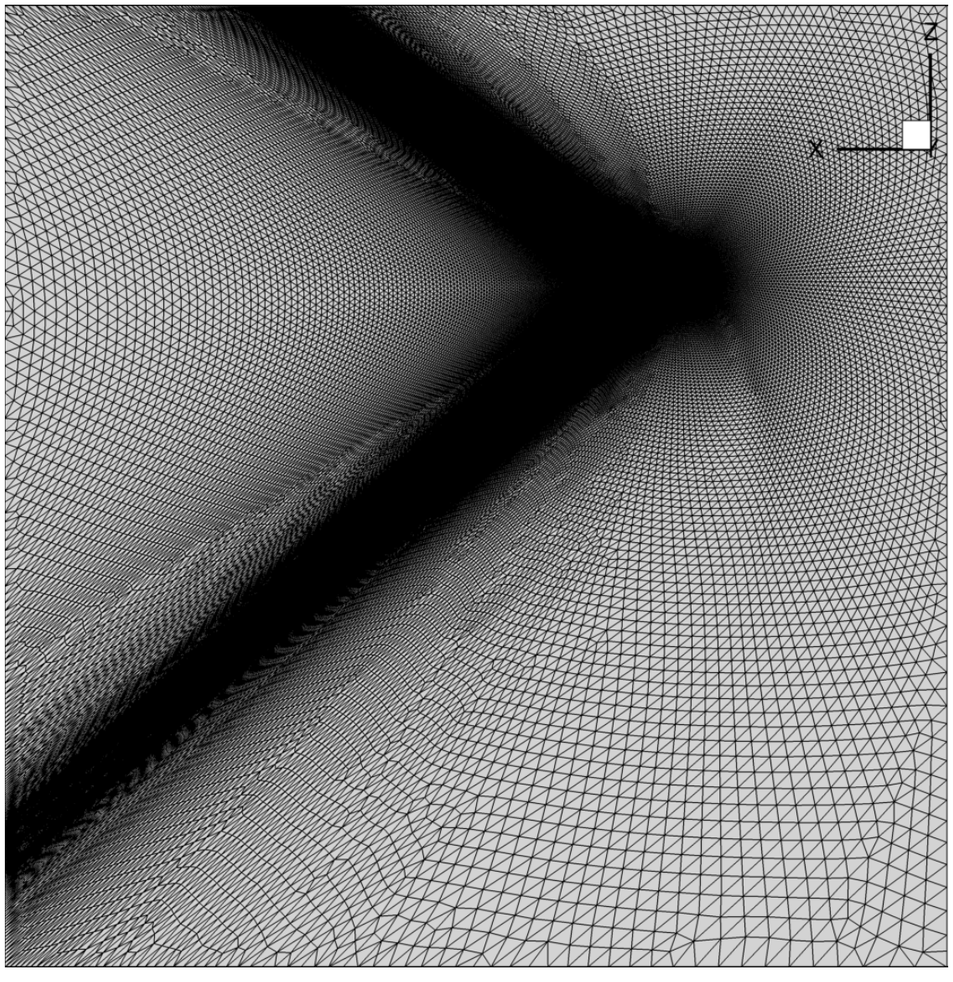
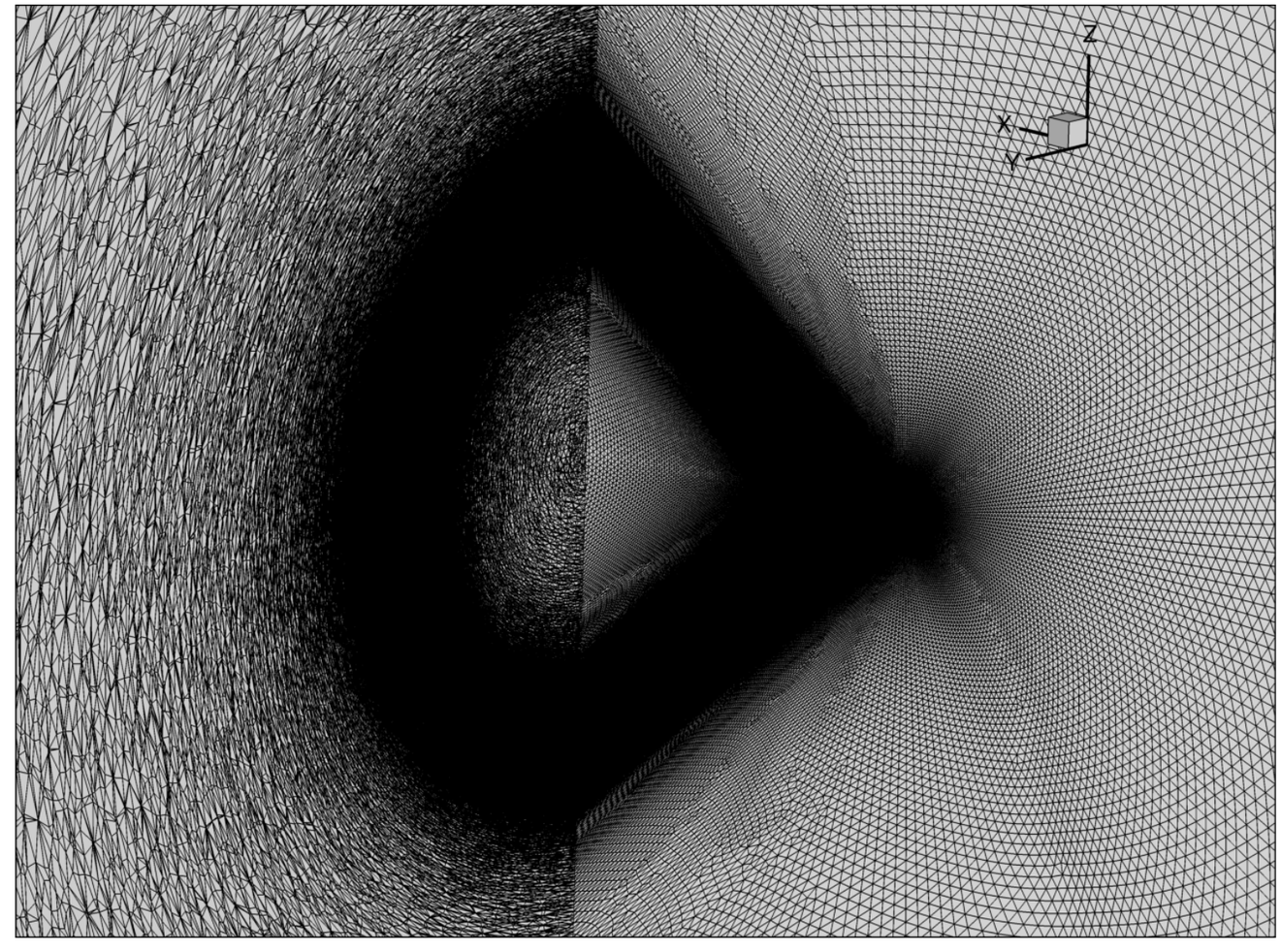
JAXA Wing/Body – Unstructured Tet mesh Generation

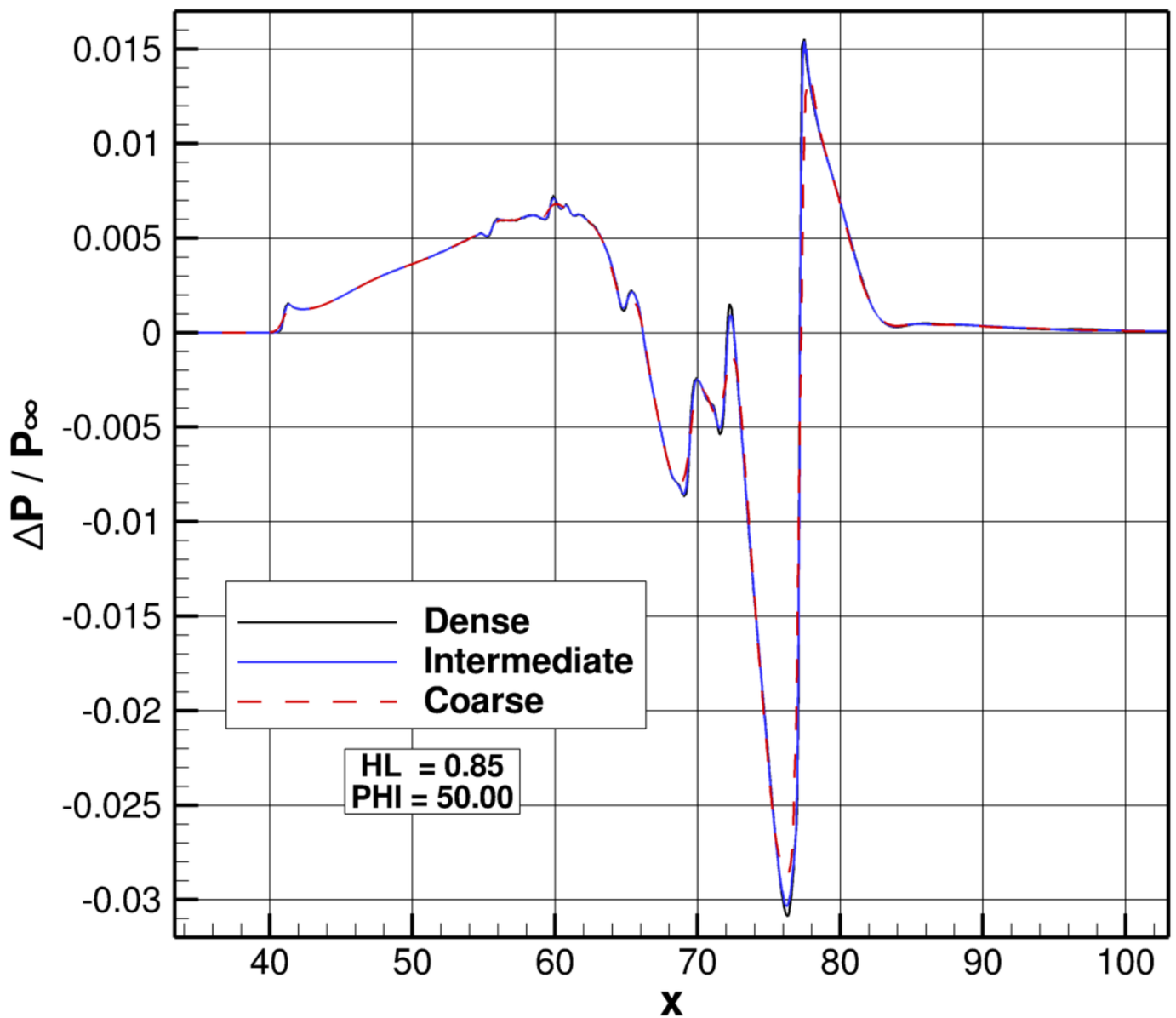
- **Grids**
  - **Shock sourcing auto-built after definition**





JAXA Wing/Body – Fun3D Inviscid Analysis at h/l = 0.85

- **Inviscid – H/L 0.85**



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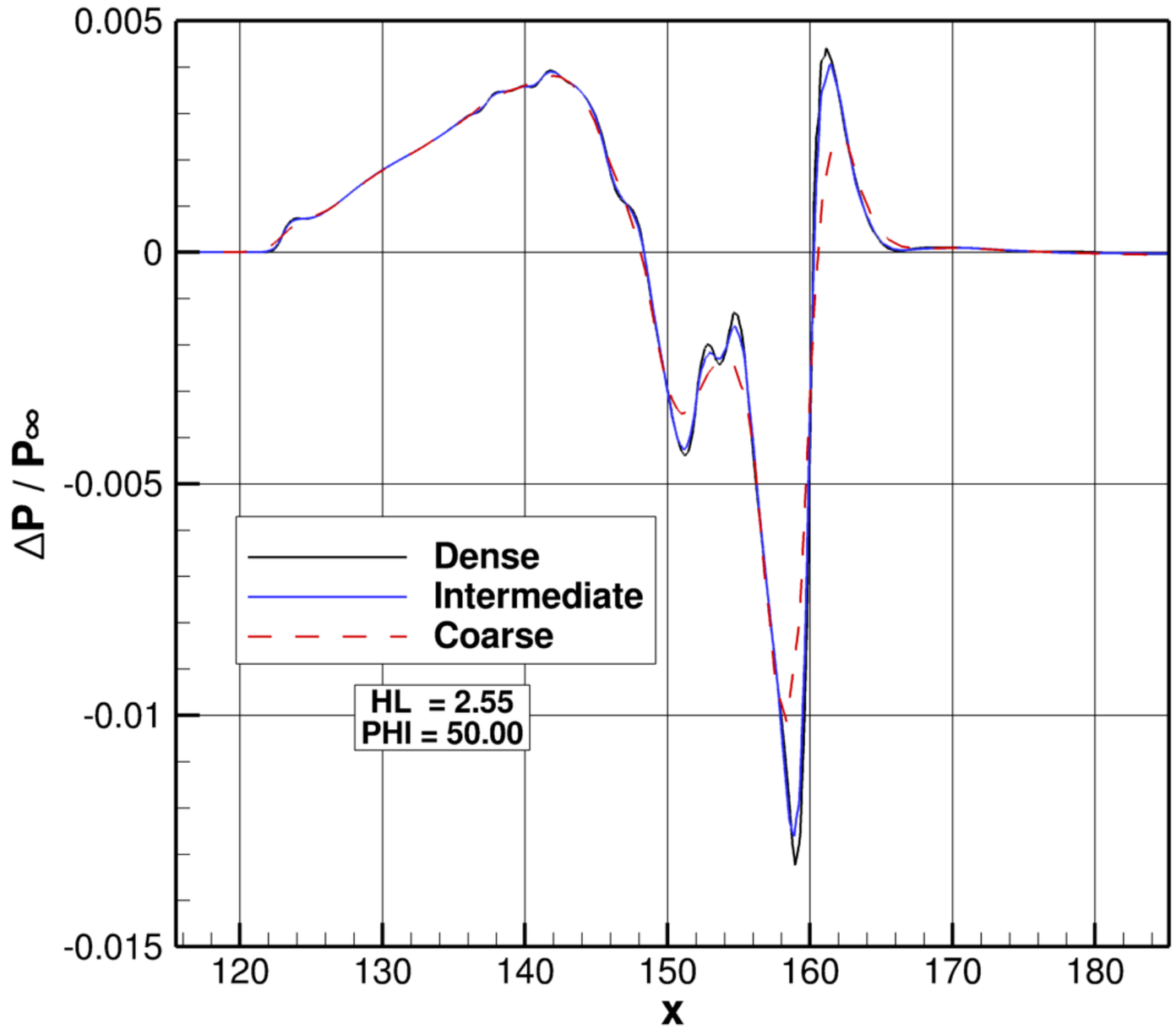
JAXA Wing/Body – Fun3D Inviscid Analysis at h/l = 2.55

- **Inviscid – H/L 2.55**



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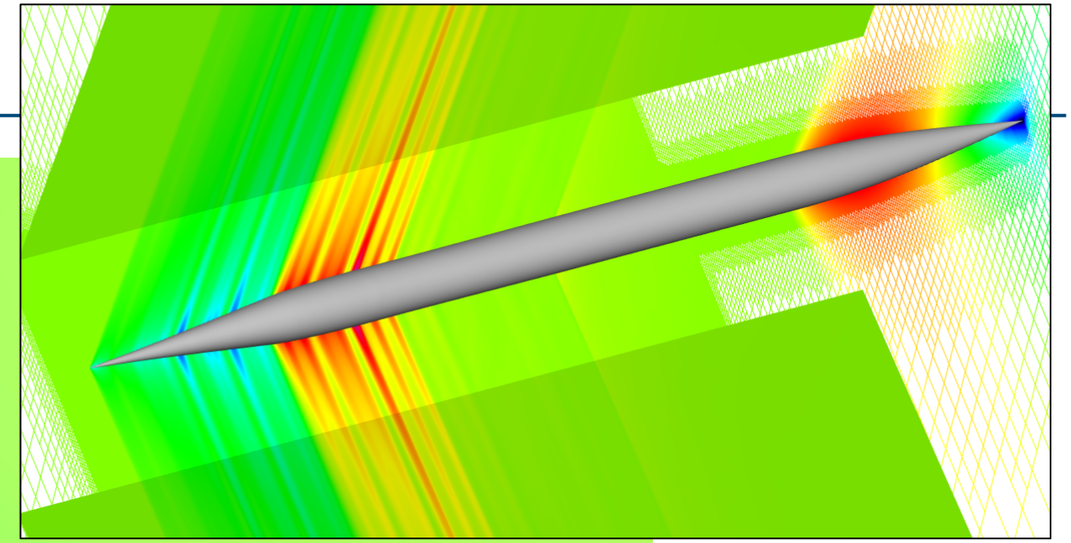
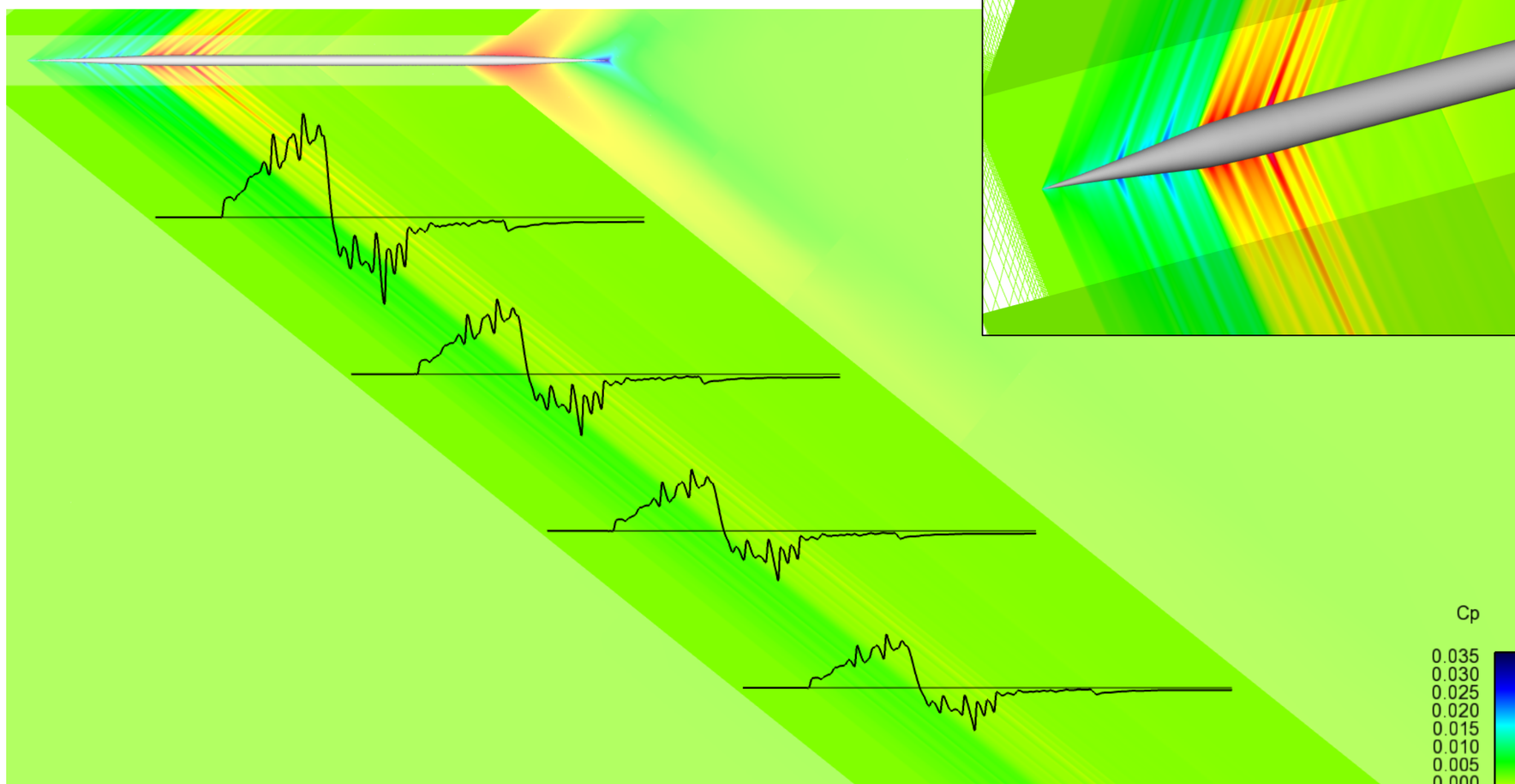
Axi- Body of Revolution





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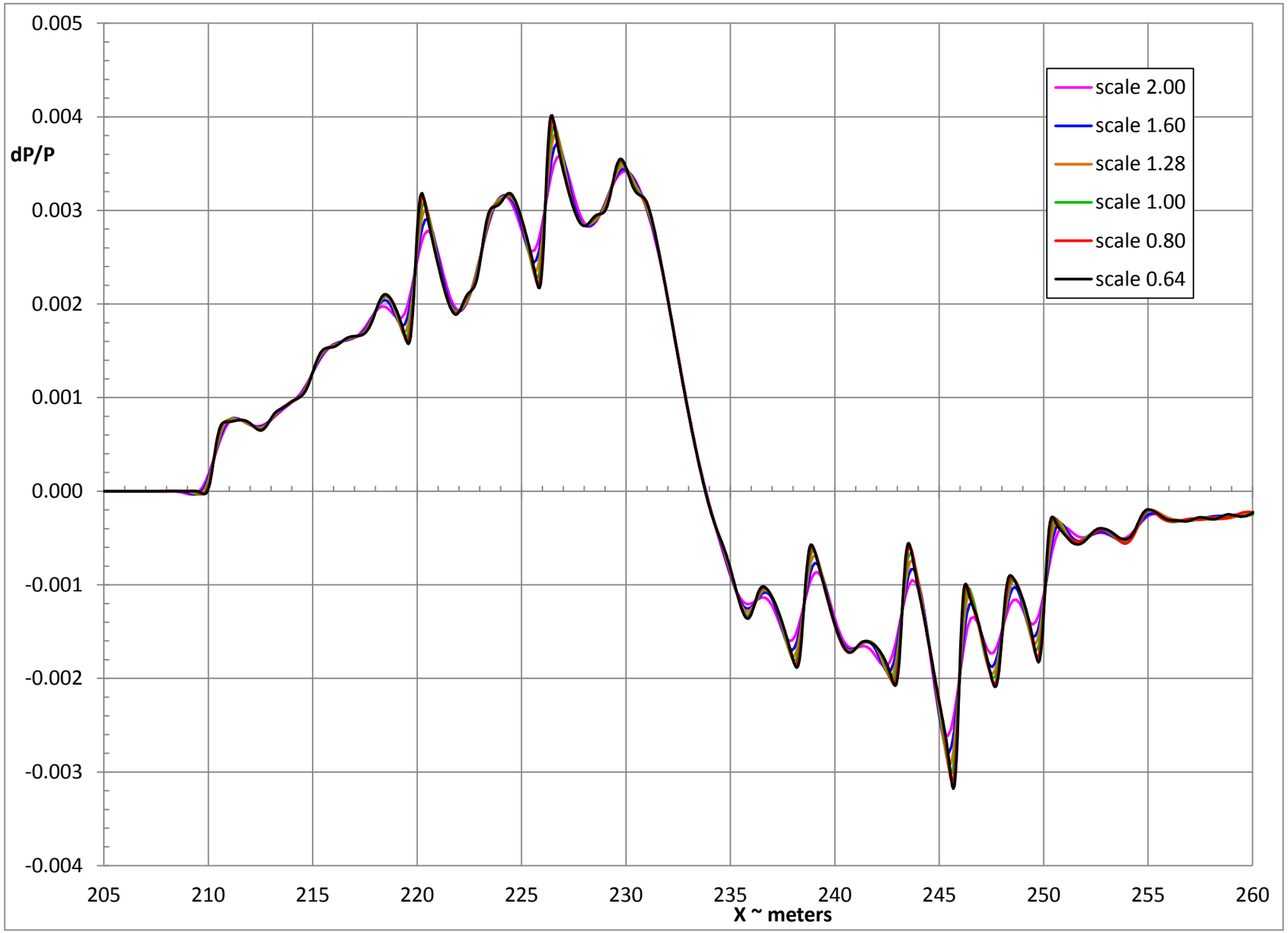
Axi-BOR Hybrid Uniform Refinement at h/l = 5

- **h/l = 5 Signature Comparisons**



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Axi- Body of Revolution Signature Convergence

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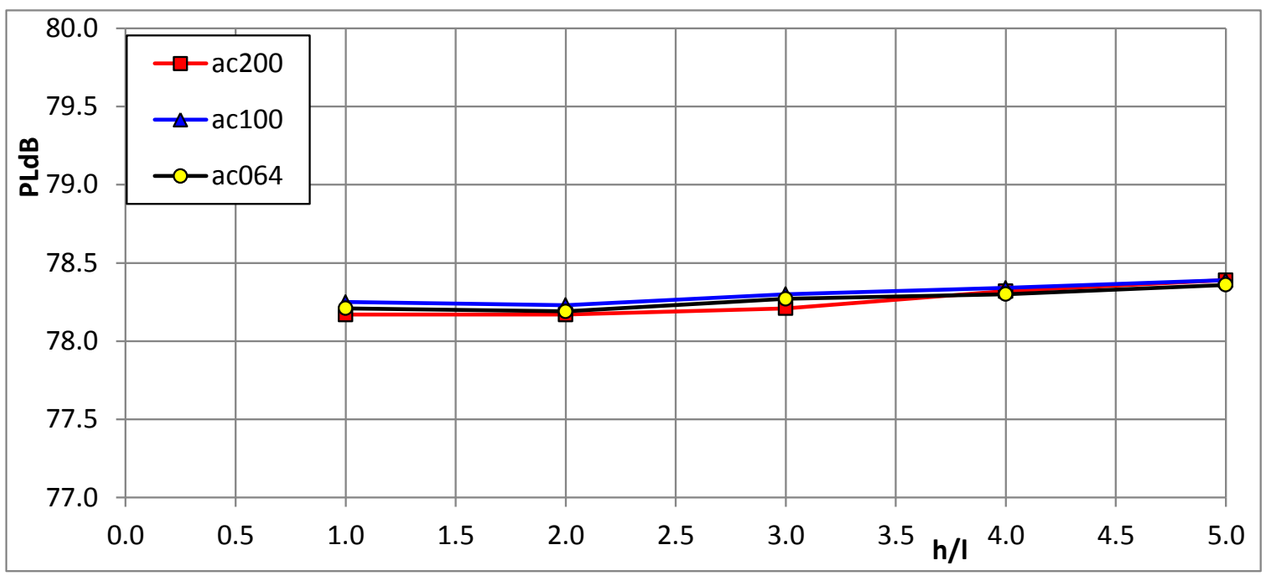
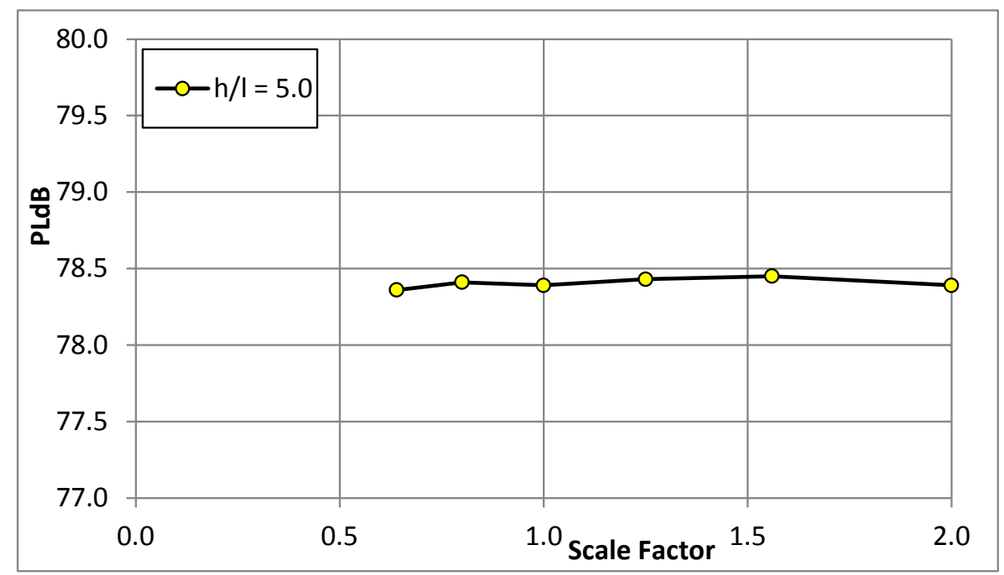
h/l Convergence



Grid Refinement Convergence



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Summary / Conclusions

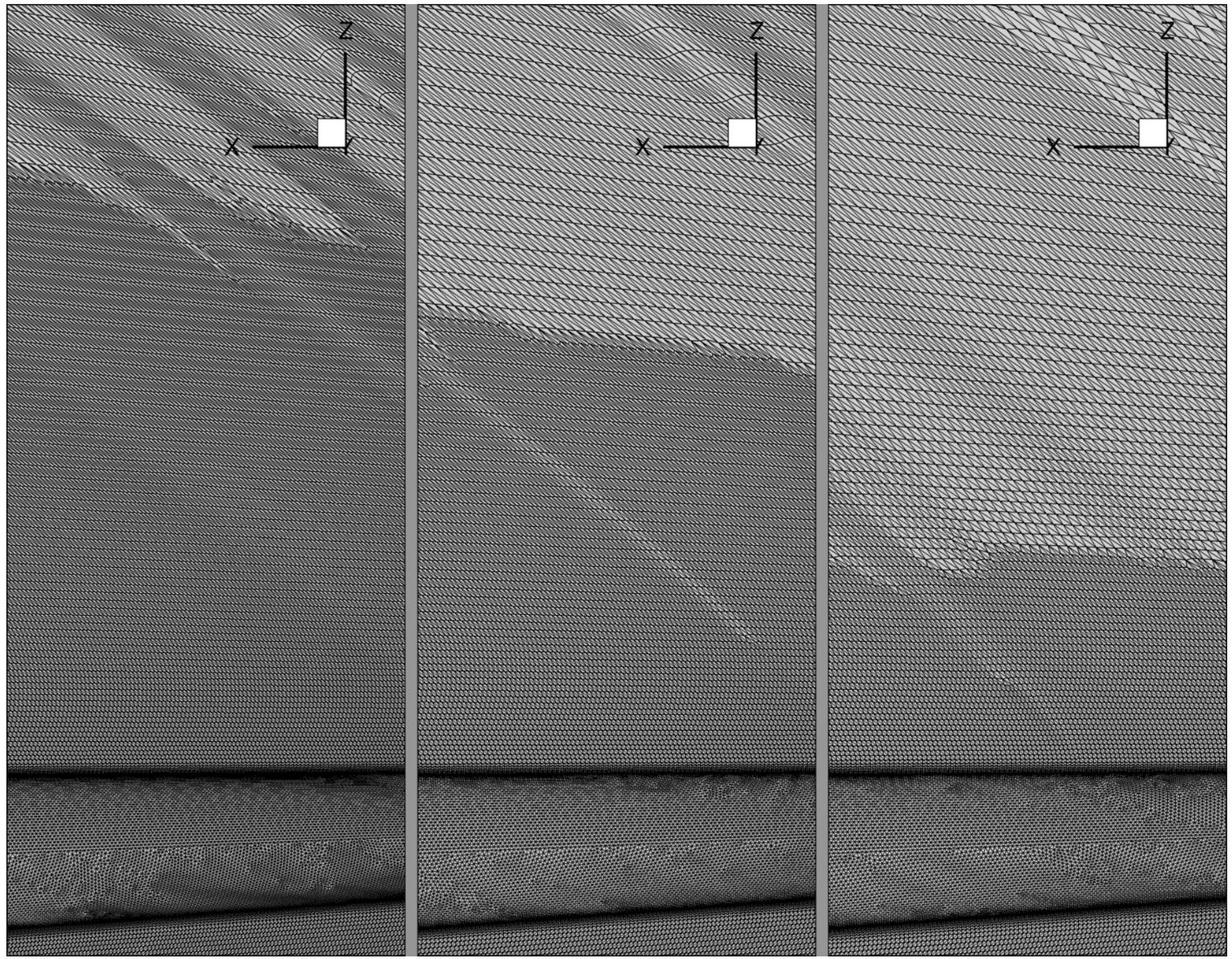
- **Submitted analyses include:**
  - **Inviscid Hybrid Cart3D/Overflow analysis on the Axi-BOR, JAXA W/B and C25D Flow Through**
  - **"Hybrid/Adjoint" on the C25D Flow Through only**
  - **Fun3D inviscid analysis on the JAXA Wing/Body**
- **With Hybrid midfield the Cart3D preSpecified refinement vs. Adjoint refinement show similar signatures at h/l = 5, though some differences remain**
- **Strong shock/expansion cancellation feature in the C25D signature appears to be more sensitive to grid resolution than are "isolated" features**
- **While the Cart3D volume mesh is "uncoupled" from the surface triangulation, the C25D solutions illustrate the importance of properly matched resolution between the surface triangulation and volume mesh – *particularly important with Adjoint mesh refinement***
- **JAXA Wing/Body inviscid Fun3D solutions capture the same features but less crisply**

- **Signatures in the 77 to 80 PLdB range on these configurations are much more meaningful than the ~95 PLdB signatures of the first workshop**
- **But, differences in the "qualitative convergence" of the near field signatures and the "quantitative convergence" of the propagated PLdB levels leave lingering questions … How closely does the nearfield really need to be resolved?**

BACK UP SLIDES FOLLOW

JAXA Wing/Body – Andrew

- **BACK UP SLIDES**



Gulfstream

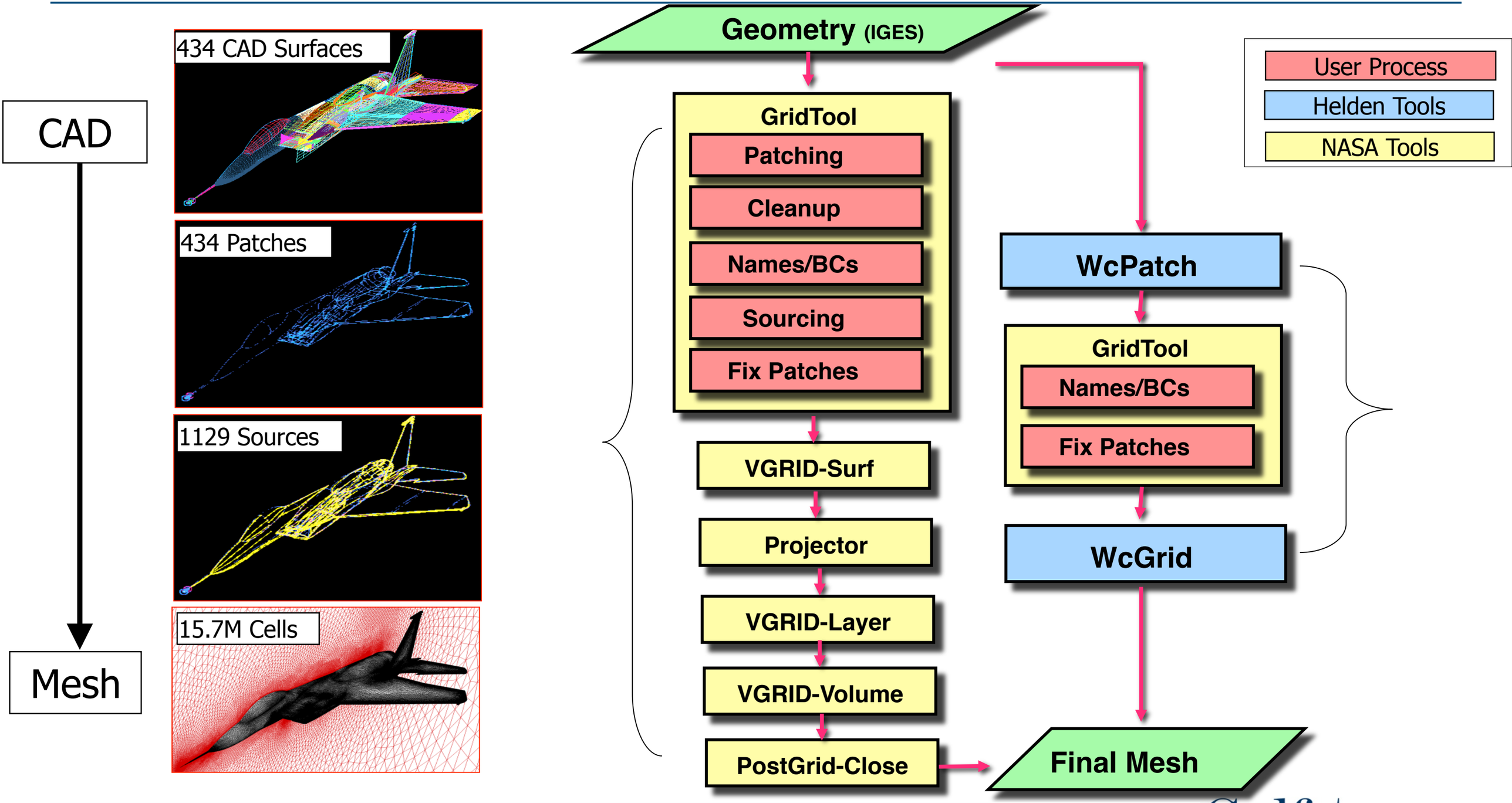
Helden Aerospace

Grid Generation Overview

June 23, 2015

HELDEN AEROSPACE PROPRIETARY INFORMATION

Grid Generation Process

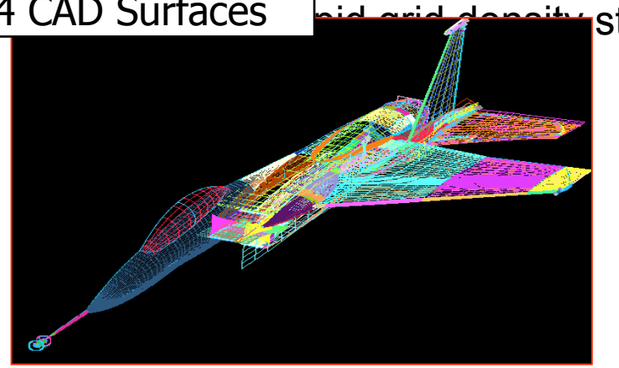


Process Overview

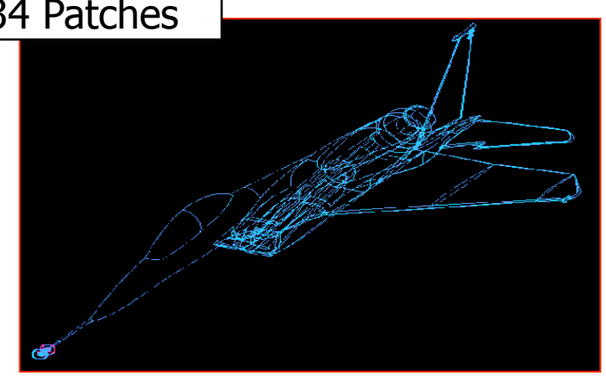
- Streamline the mesh generation process
  - Automate the labor intensive portions of the current process
  - Automatically convert trimmed IGES NURBS surfaces to water-tight patch definition
    - Performs 99% of the patching process
  - Curvature based auto-sourcing defines scientific standards for mesh consistency
    - Transforms “Art” of gridding to a “Science”

studies

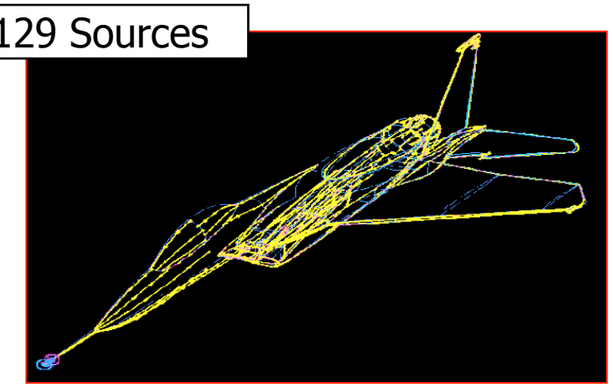
434 CAD Surfaces



434 Patches

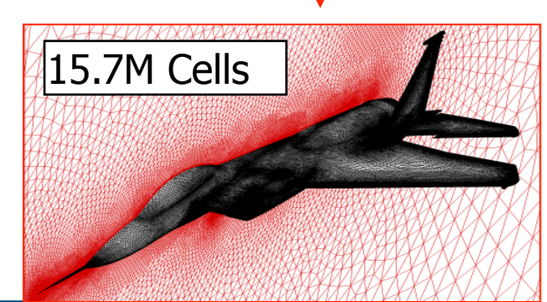


1129 Sources



From CAD to CFD in hours instead of months

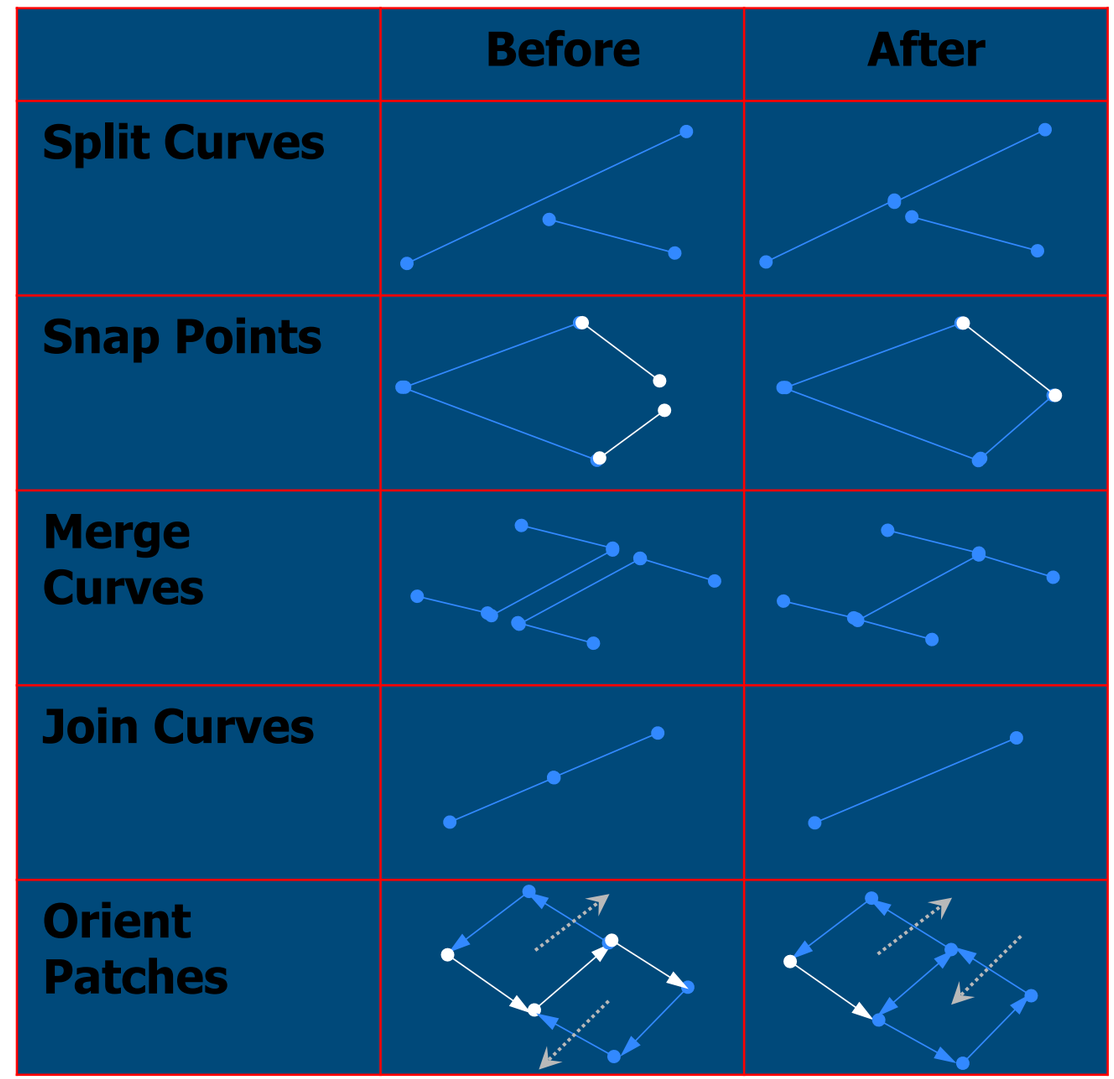
15.7M Cells



Geometry Preprocessing

Auto-Patch and Model Cleanup

- CAD Surfaces are Auto-patched upon initial read
  - Converts trimmed surfaces to patches
  - Create boundary curves for untrimmed surfaces and convert to patches
  - Each patch is initially unconnected to its neighbor patches
  - Cleanup operations connect patches together by tolerance
- Split curves by other nearby end points
- Snap curve end points together
- Merge overlapping curves into a single curve
- Join continuous curves into a single curve
- Automatically orient patches into a consistent direction
  - Properly accounts for multiple trim loops
  - Keeps outer loop the first loop



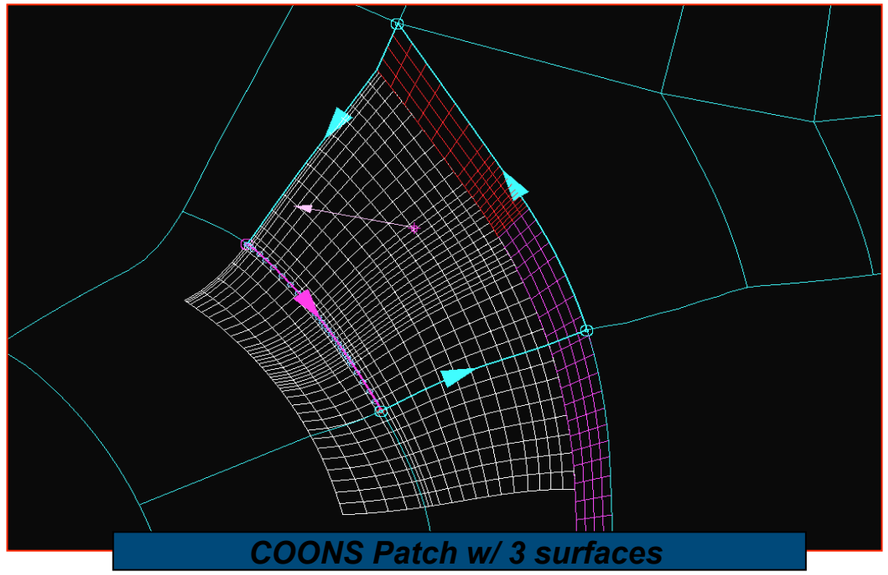
Geometry Preprocessing

Geometry Simplification Functions

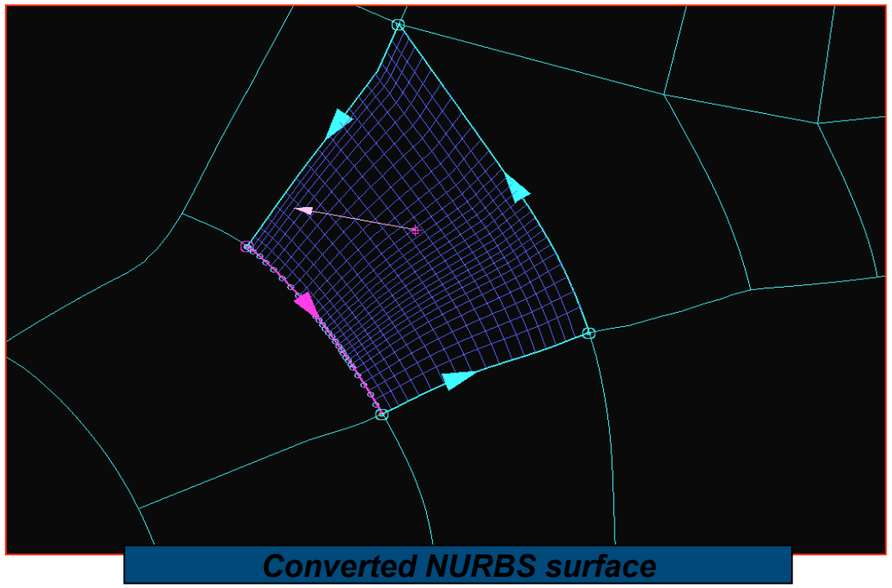
- Delete all curves with an arc-length less than a specified value
- Convert all COONS patches to NURBS definition

Geometry Management Functions

- Delete unused curves
- Delete unused surfaces
- Rename all surfaces to their respective patch names
- Delete specific patch families
- Keep only specific patch families
- Delete all patches
- Delete all patches within a given box
- Delete specific source families
- Keep only specific source families
- Delete all sources
- Delete all sources within a given box
- Rescale all source sizes by a given scale factor



COONS Patch w/ 3 surfaces



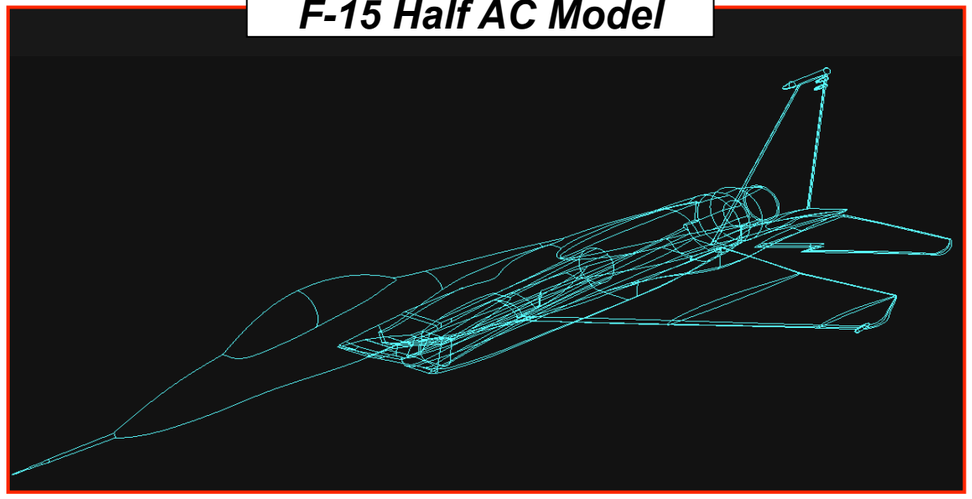
Converted NURBS surface

Geometry Preprocessing

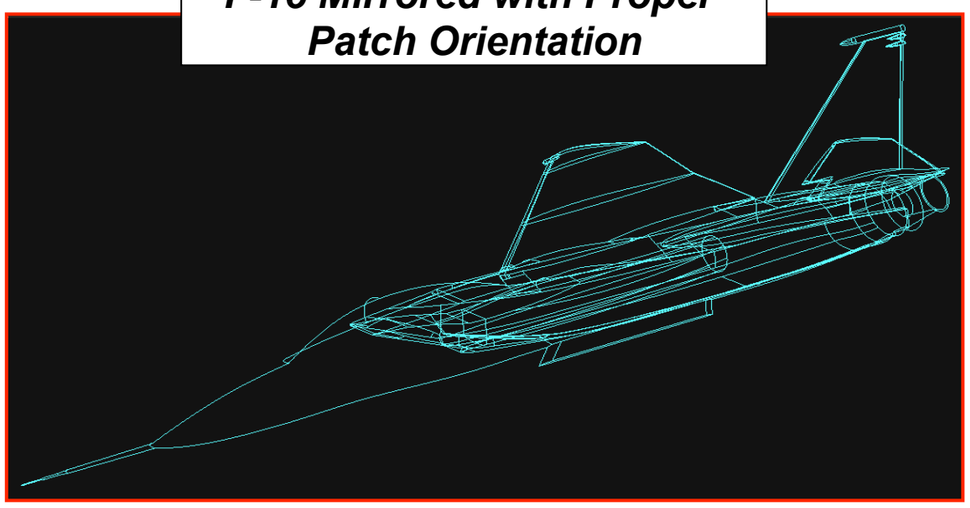
Geometric Transforms

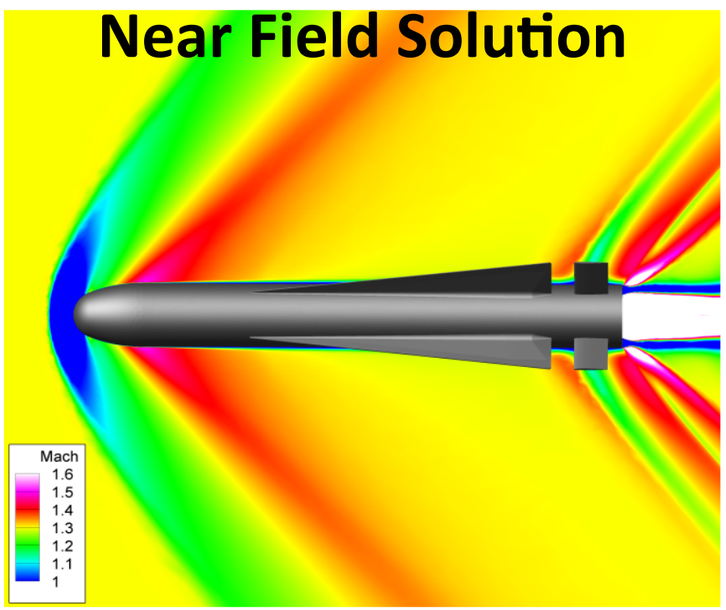
- Translate geometry by dx, dy, dz
- Translate geometry from point 1 to point 2
- Rotate x-axis about a point by a given angle
- Rotate y-axis about a point by a given angle
- Rotate z-axis about a point by a given angle
- Rotate about a vector defined by two points
- Mirror the geometry in x, y, or z and reverse the patch orientation
  - Properly accounts for multiple patch loops
- Scale the geometry / sources by a given scale factor

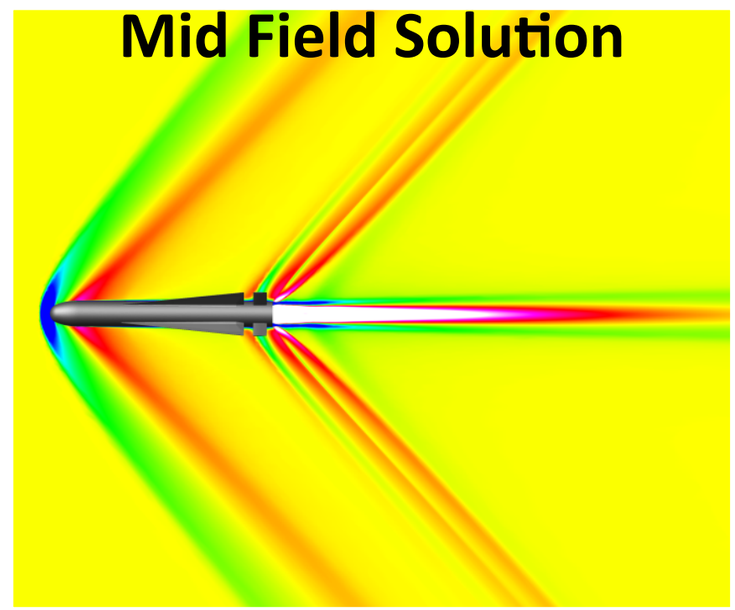
F-15 Half AC Model

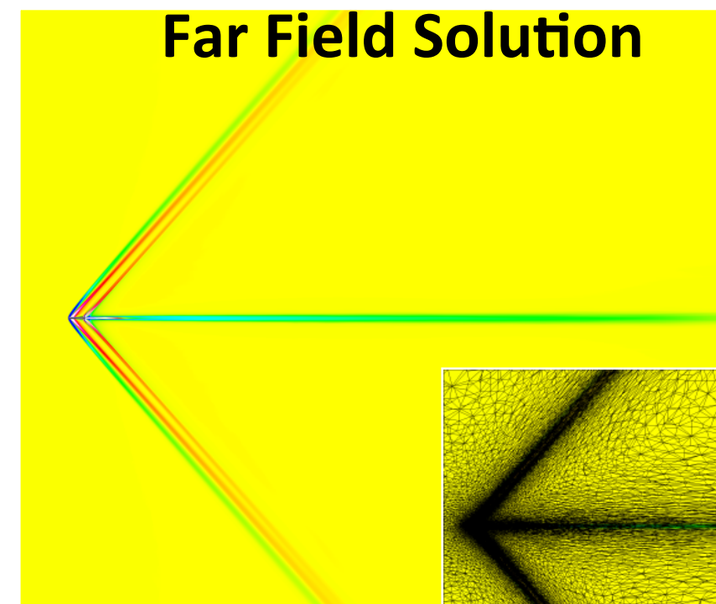


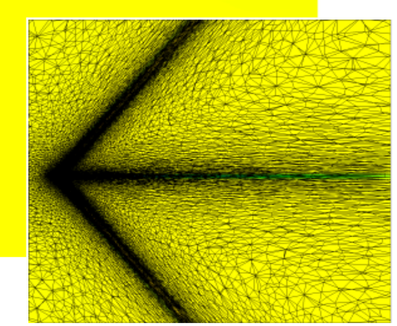
F-15 Mirrored with Proper Patch Orientation







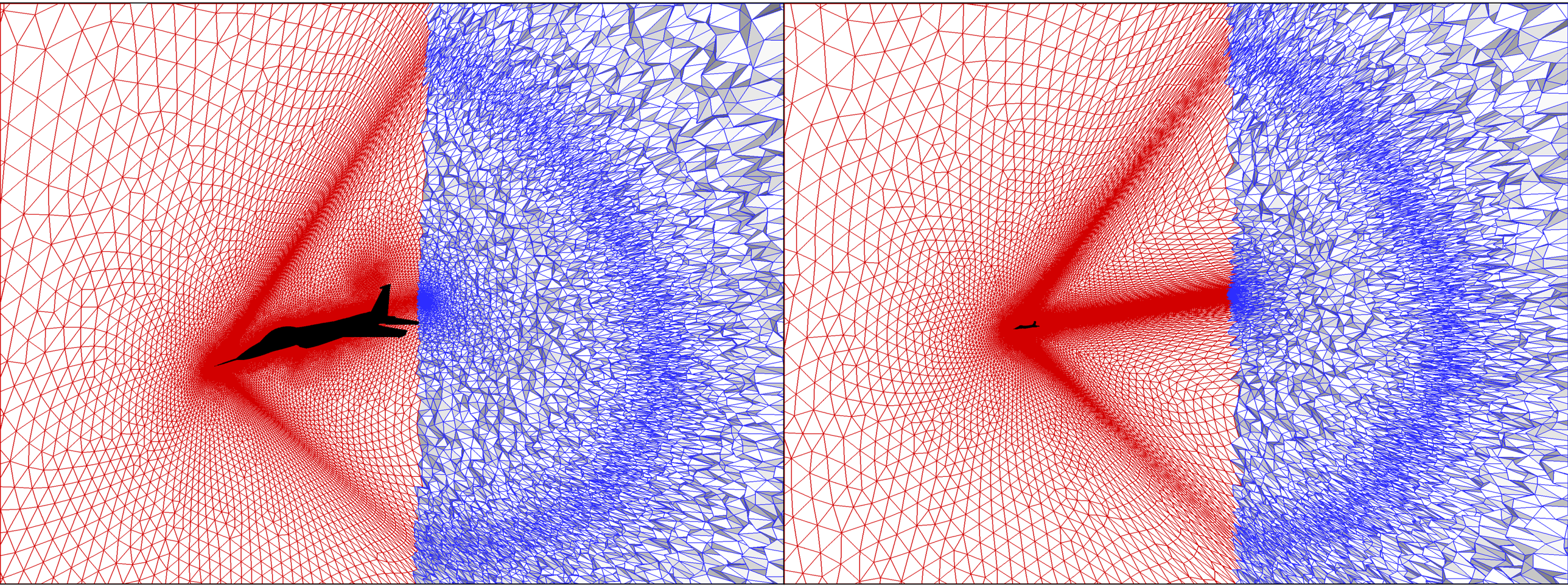




Mesh stretching enables far-field CFD analysis w/ no extra cost

Efficient Mesh Generation

Examples

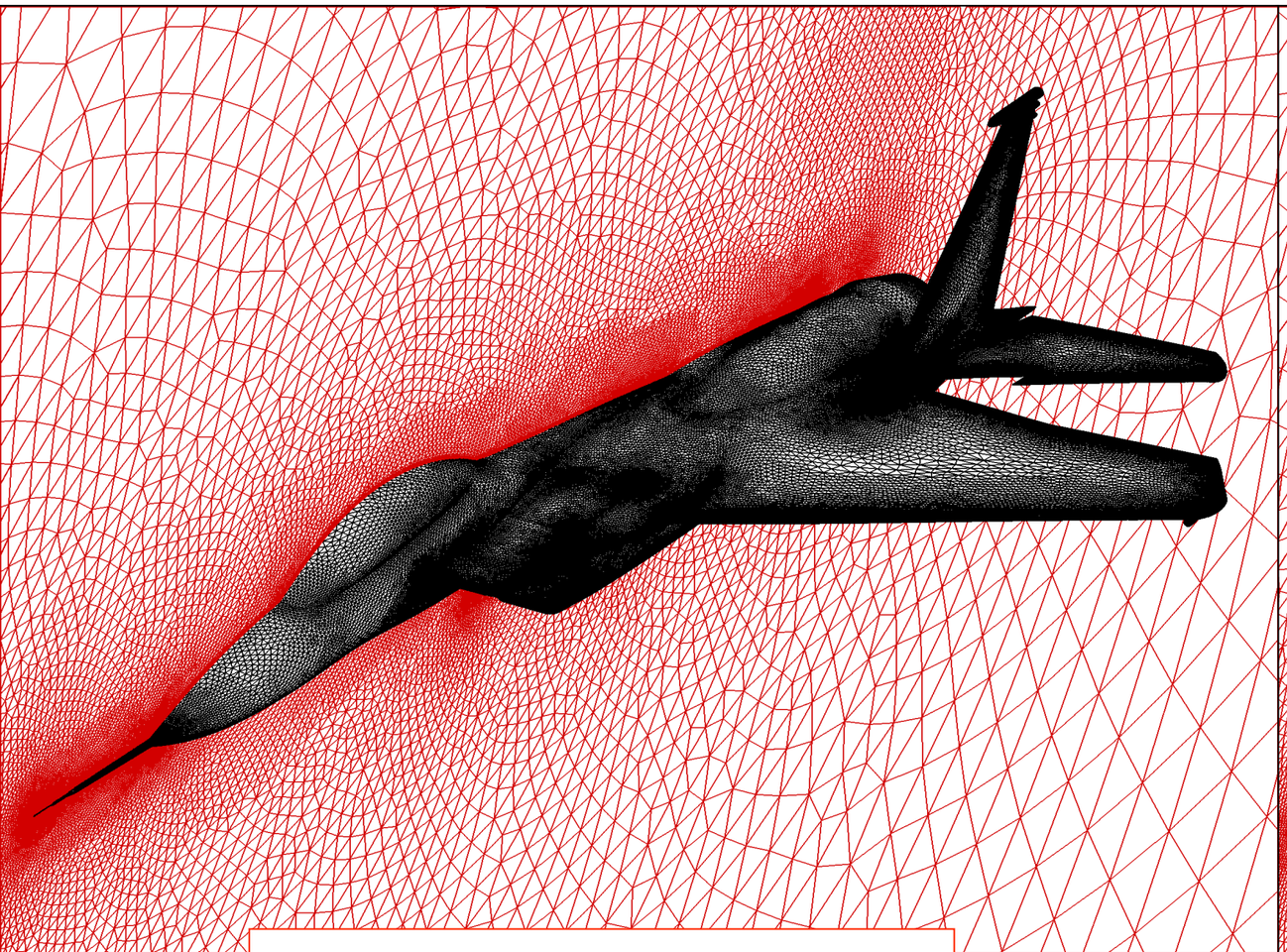


Shock Cone and Wake is Resolved by Stretched Sources in Volume

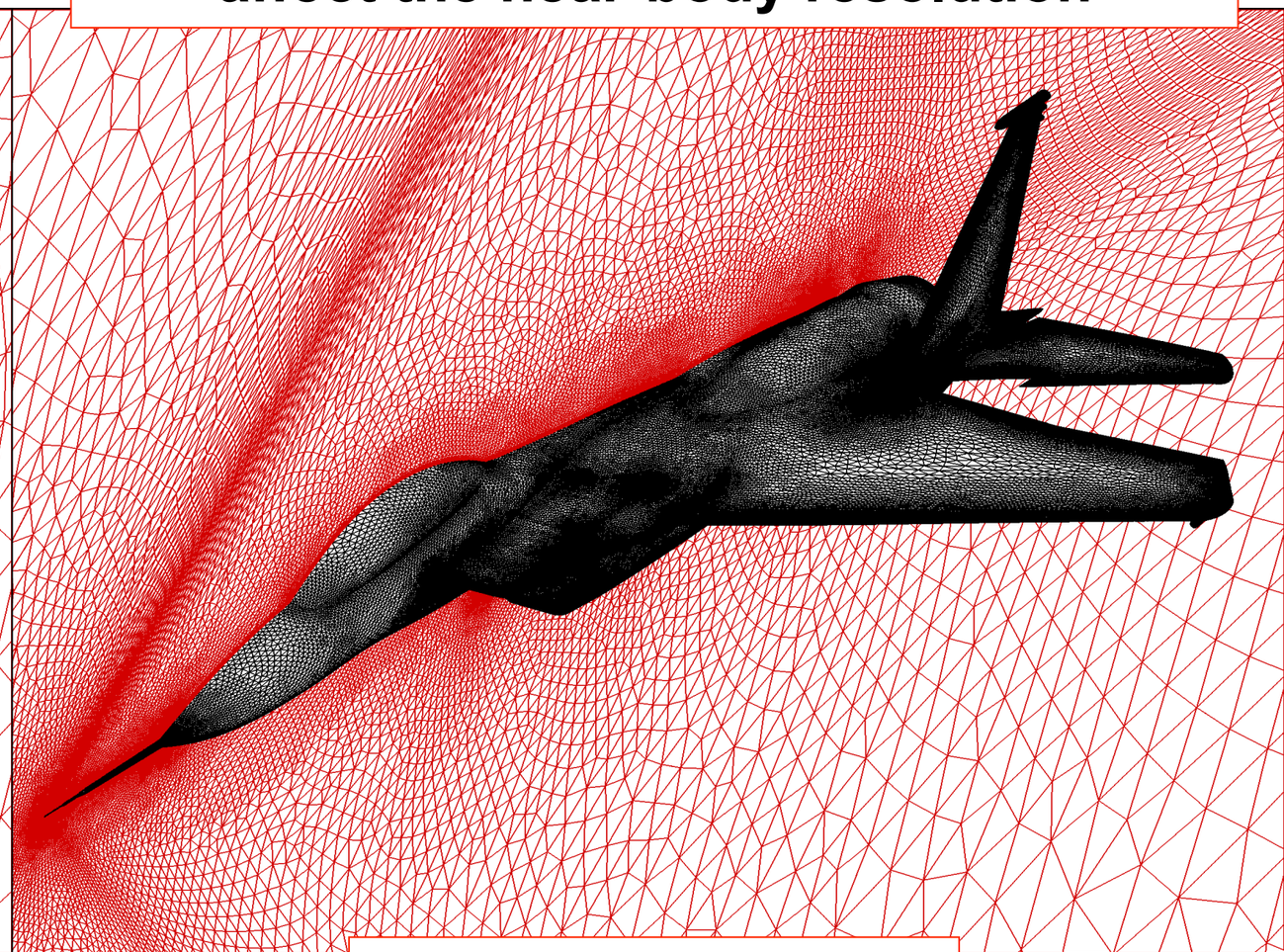
Efficient Mesh Generation

Examples

Stretched Cone/Wake cells do not affect the near-body resolution

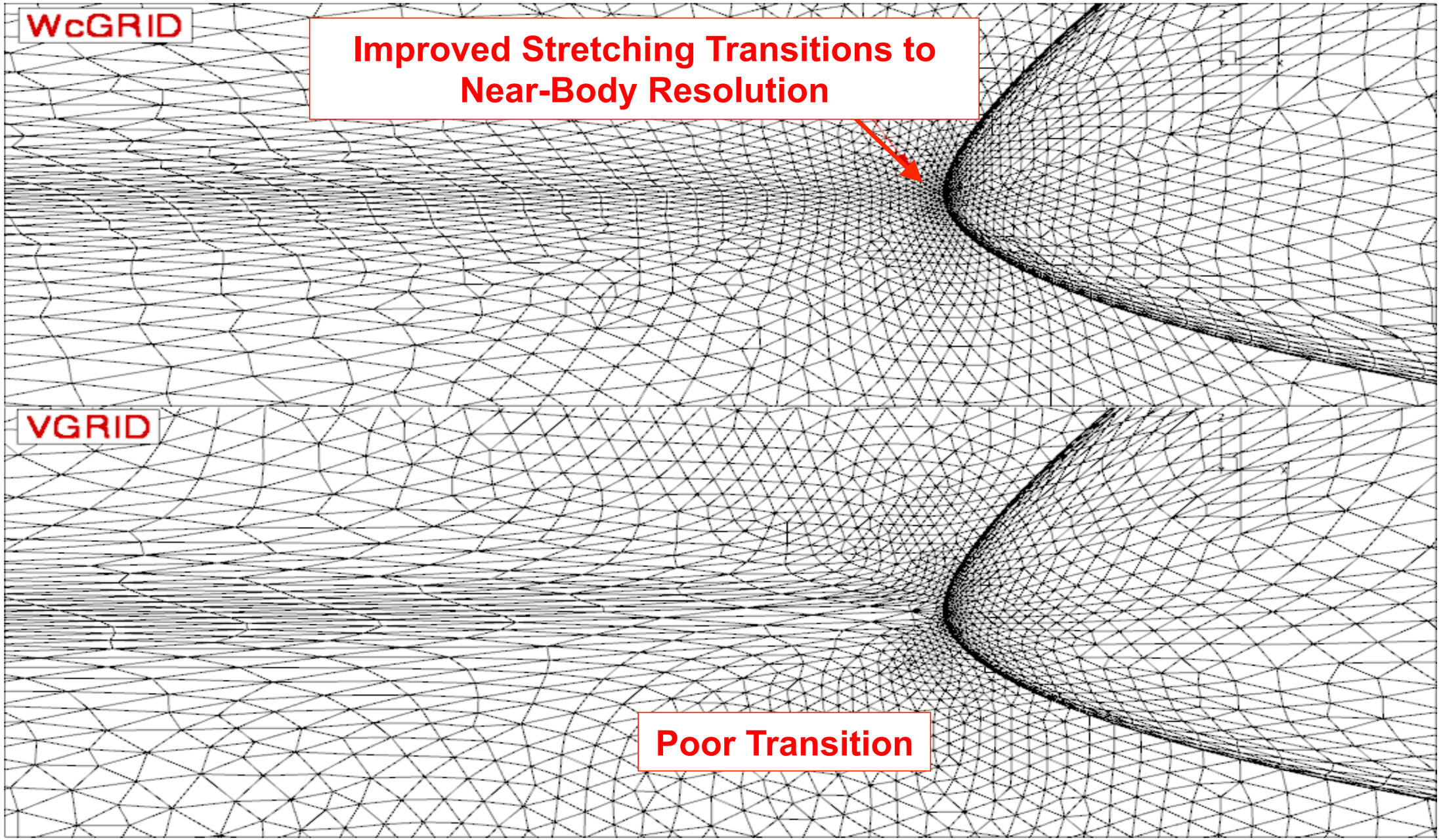


No Volume Refinement
15.7 Million Cells



Farfield Refinement
19.3 Million Cells

Efficient Mesh Generation



Efficient Mesh Generation

Results

- How does it handle complicated geometries?
  - WcGRID was successfully applied to a proprietary “Grid Challenge” problem containing over 19,000 patches and over 9,000 sources with many tight gaps and cracks
  - WcGRID successfully closed the mesh on the first try with no difficulties, even in complicated areas and tight gaps
    - VGRID required attempts with Postgrid and fiddling with the inputs
  - Details on RAM usage and Time-to-Mesh given below…
    - WcGRID generated the mesh in 1/6th with half the RAM

VGRID 9.1 Hours

VGRID	Surface	Layers	Volume	Postgrid
Cell Sizes	2 million tri	76 million tet	22 million tet	98 million tet
Memory	2.9 GB	5.2 GB	2.1 GB	2.0 GB
Time	213 min	103 min	201 min	~30 min

WcGRID 1.5 Hours

WcGRID	Surface	Layers	Volume	Post
Cell Sizes	2.3 million tri	80 million tet	47 million tet	127 million tet
Memory	1.1 GB	882mb	660mb	2.5 GB
Time	12 min	30 min	28 min	20 min