Engineering, Operations & Technology
Boeing Research & Technology

Boeing Sonic Boom Prediction Workshop Results

2nd AIAA Sonic Boom Prediction Workshop - Sci Tech 2017 - Grapevine, Texas

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Outline

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  - Method/Approach
  - Convergence
  - Nearfield Results for Required Grids
  - Comparison of Inviscid Flux/Limiter Methods
- Cart3D Results
  - Summary of Cases
  - General Cart3D Setup
  - Space-Marching Setup
  - Nearfield Results for Required Geometries and Adapted Grids
- Conclusions
- Questions

FUN3D Results

FUN3D Method / Approach

FUN3D flow solver Version-12.9-0555546

- Euler Equations
- Conducted a flux methods and limiters trade for the NASA 25D with FTN
- HLLC inviscid flux method with Van Leer limiter for all required cases
  - This method has worked well for our preferred OVERFLOW method, so we wanted to see how the FUN3D implementation did for the required cases
- Initialized flow by running all cases 1st order

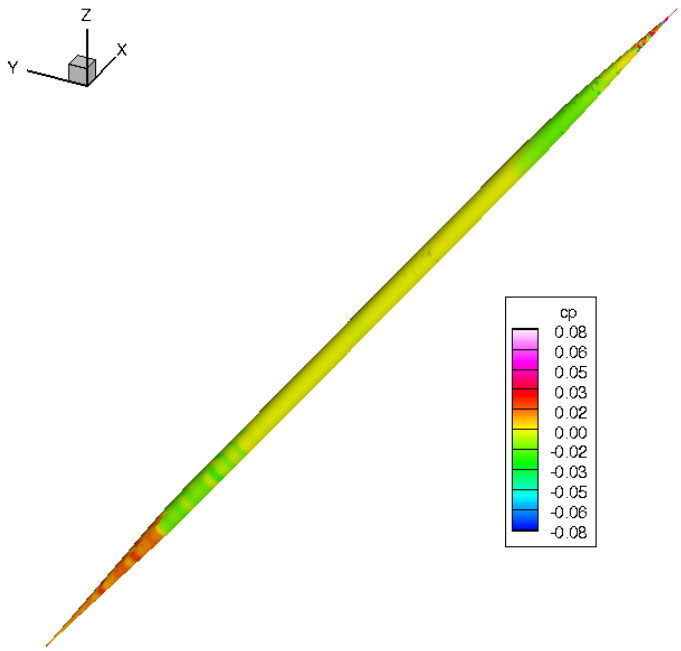
Utilized top three refined grids for each required case

- Mixed grid for Axisymmetric body (1.00, 1.28, and 1.60)
- Tetrahedra grid for JAXA WB (0.70, 0.83, and 1.00)
- Mixed grid for NASA 25D with FTN (0.64, 0.80, 1.00)

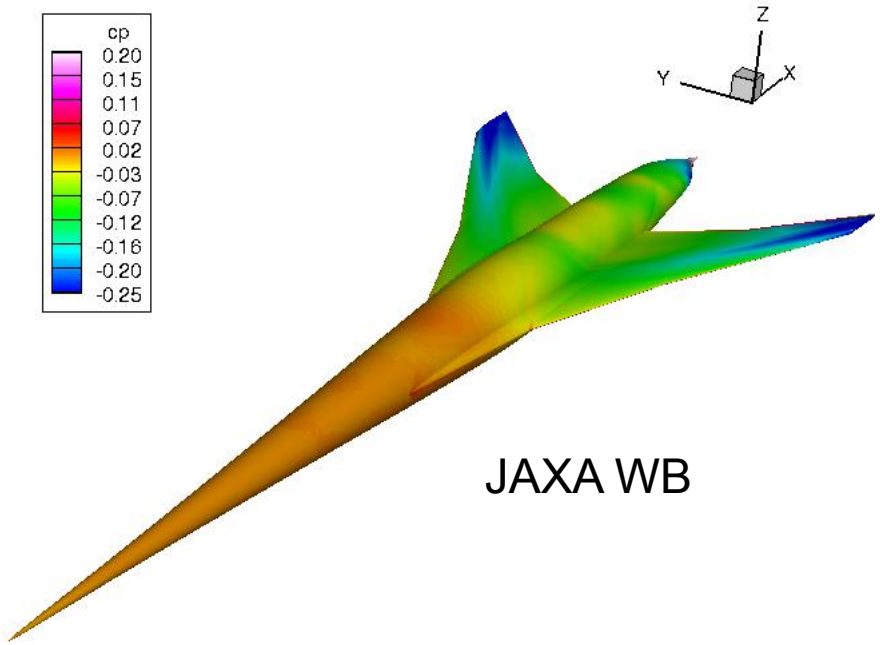
Dual Intel Haswell 64-bit 14-core processors

- NASA 25D Axisymmetric Body – 420 cores
- JAXA WB – 420 cores
- NASA 25D with FTN – 840 cores

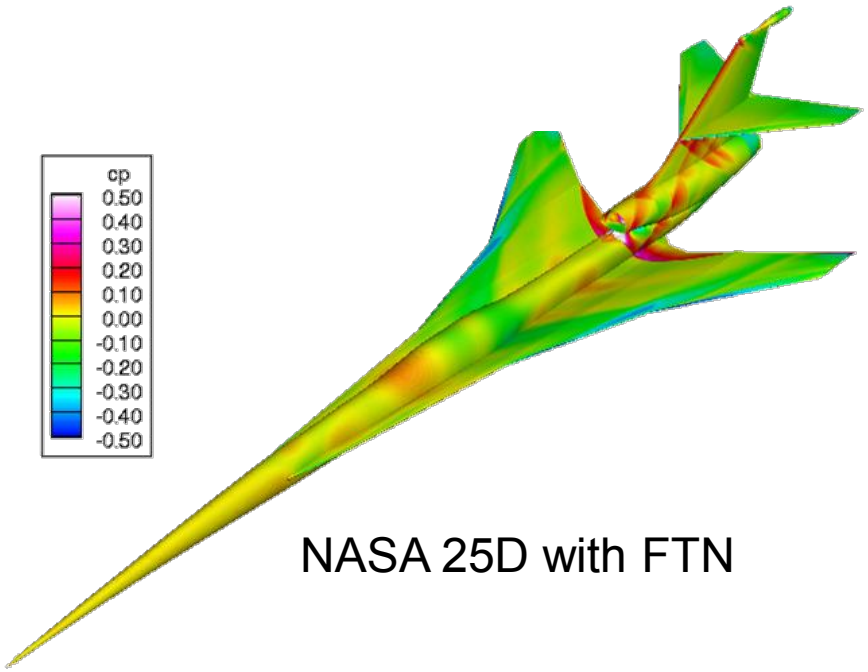
FUN3D was Utilized for all Required Cases



NASA 25D Axisymmetric Body Equivalent Area

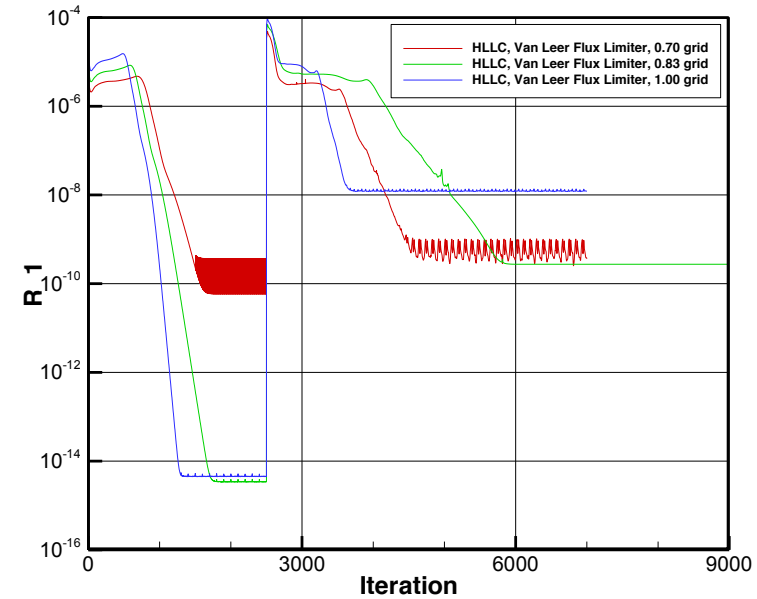


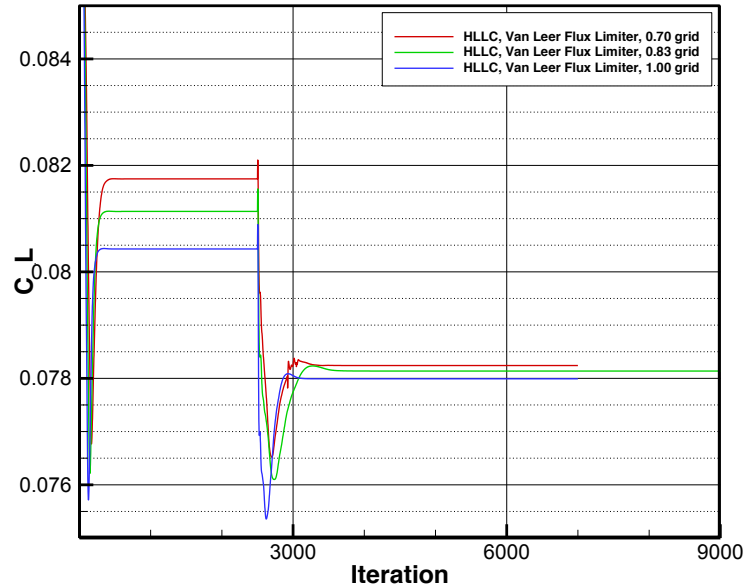
JAXA WB

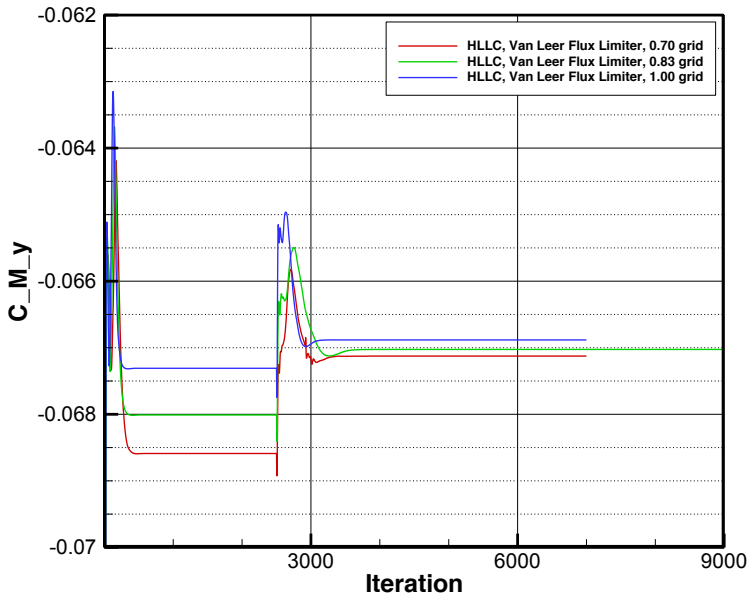


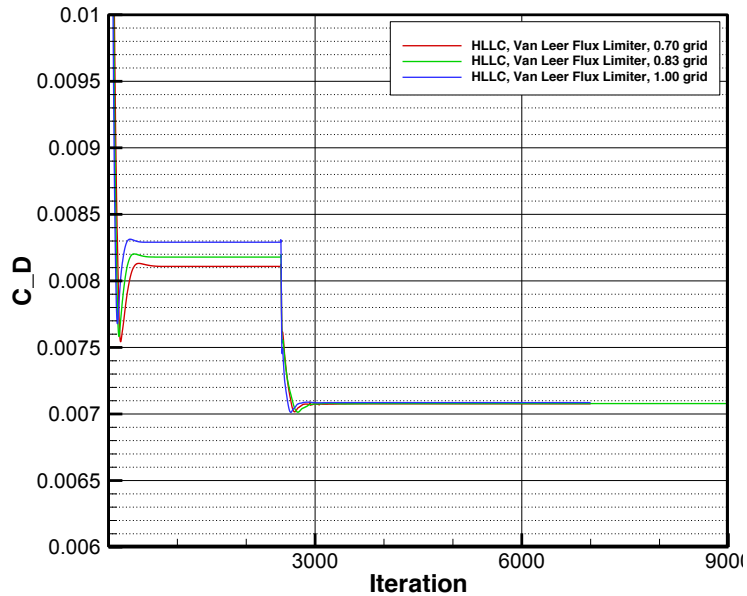
NASA 25D with FTN

JAXA W/B Convergence History

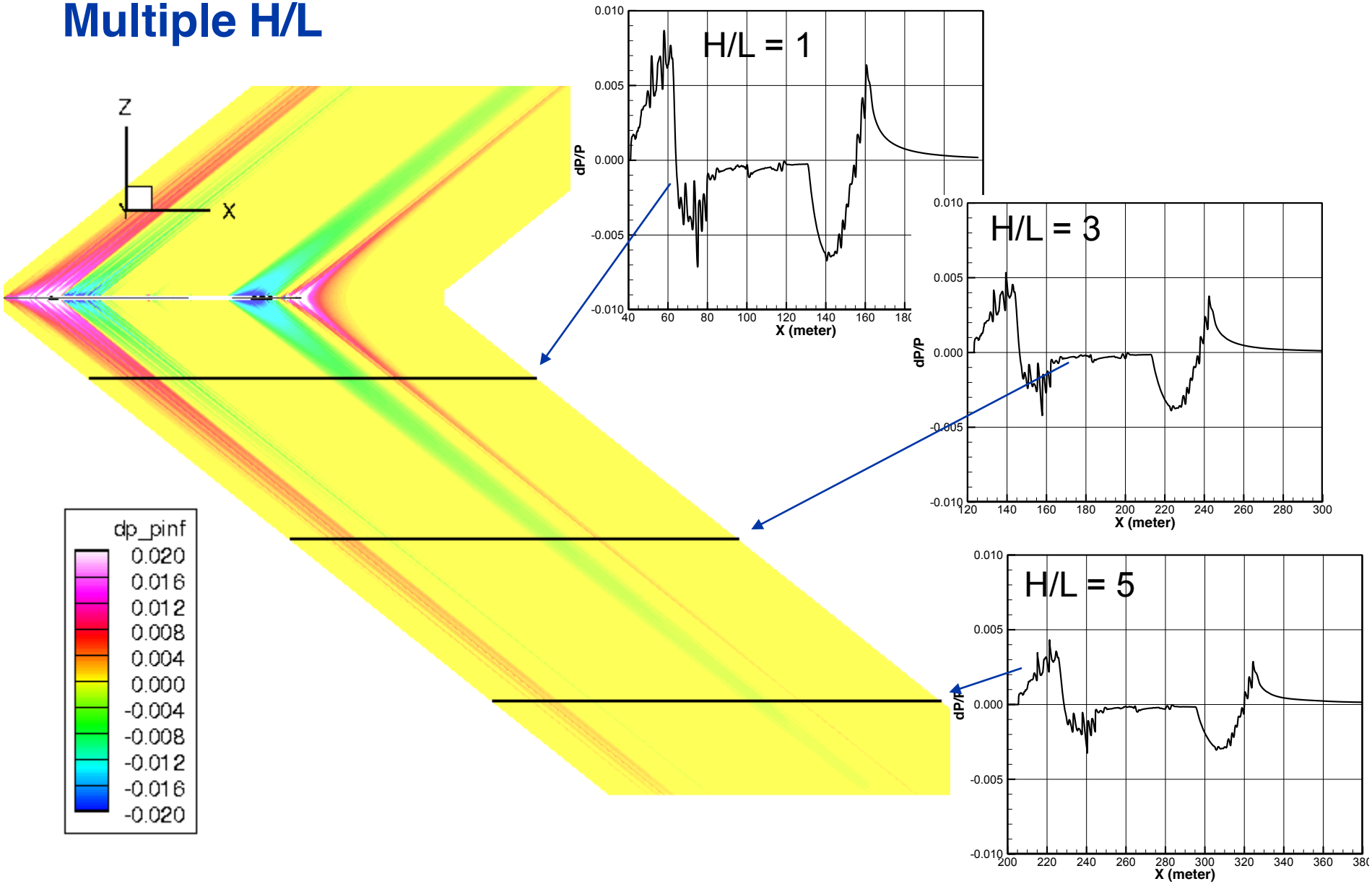




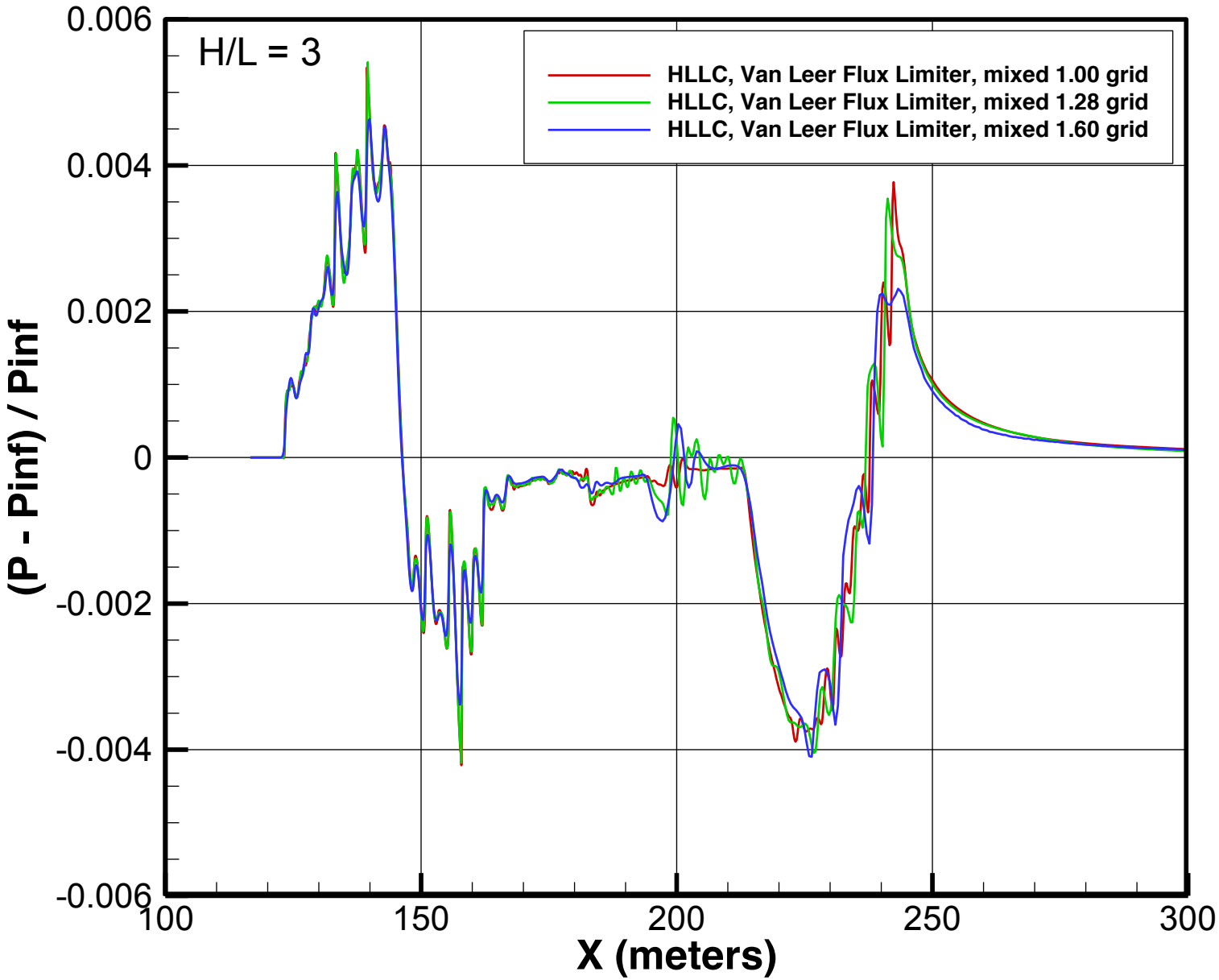




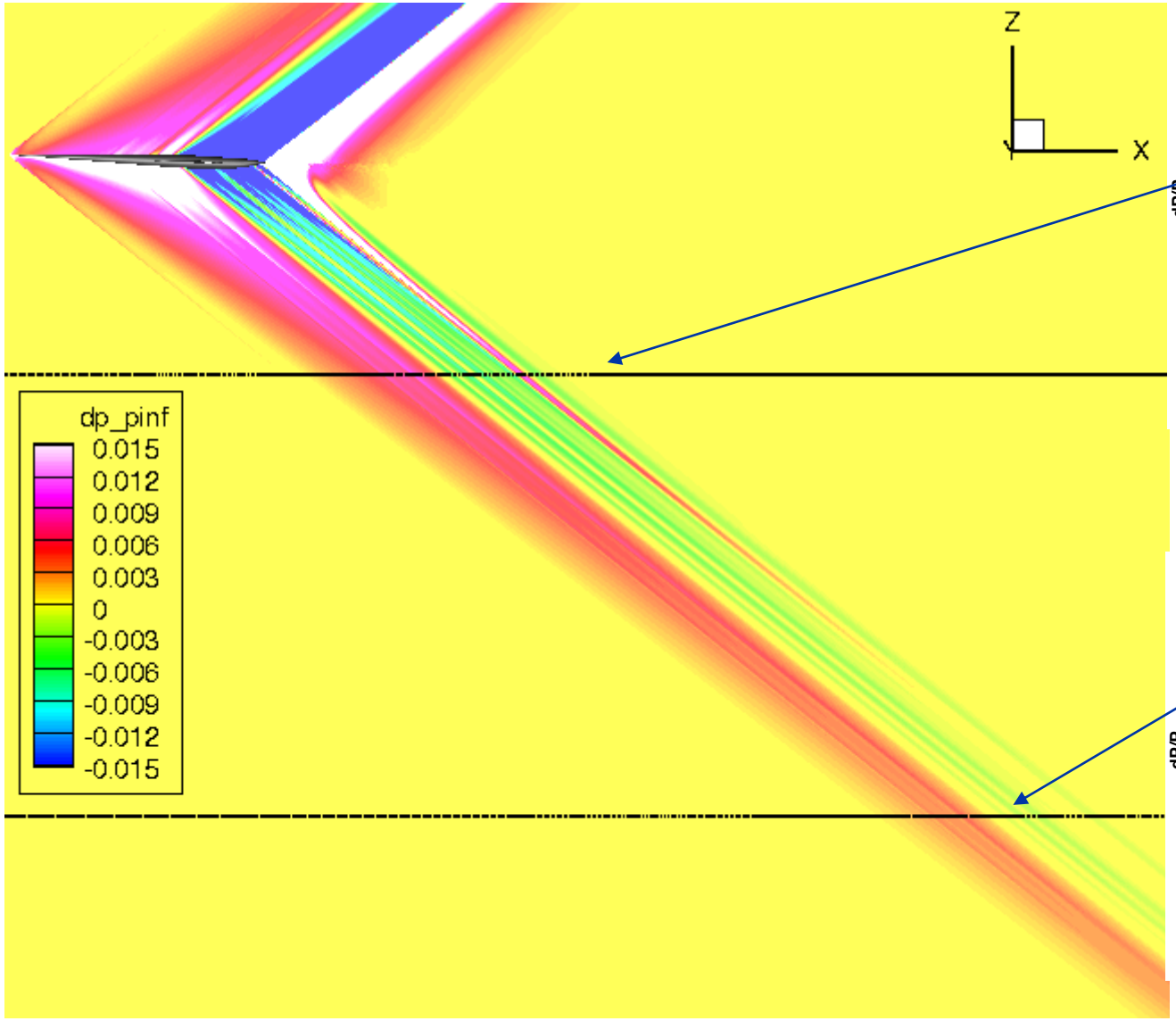
Undertrack Nearfield Results for NASA 25D Axi-Body At Multiple H/L

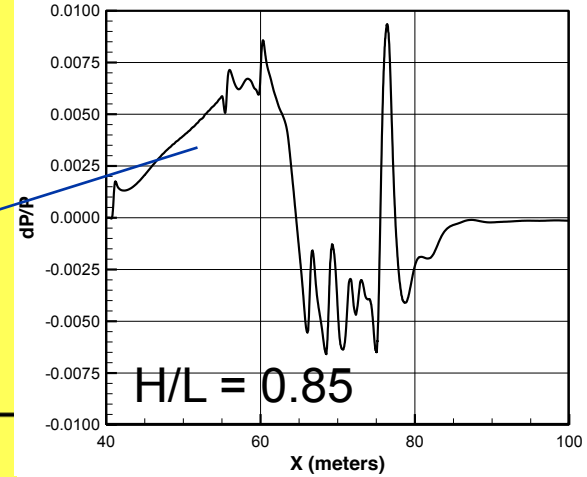


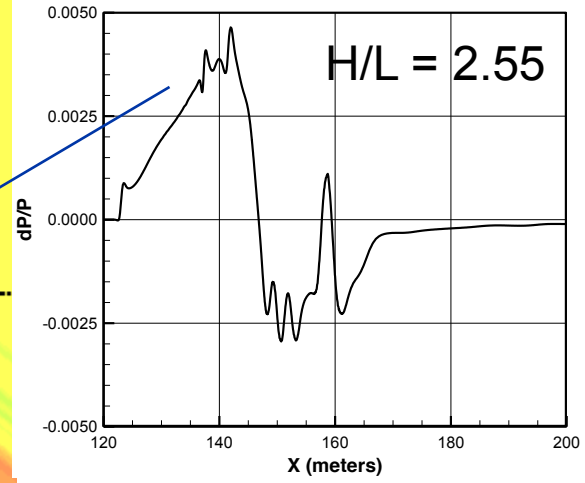
Undertrack Nearfield Results for NASA 25D Axi-Body



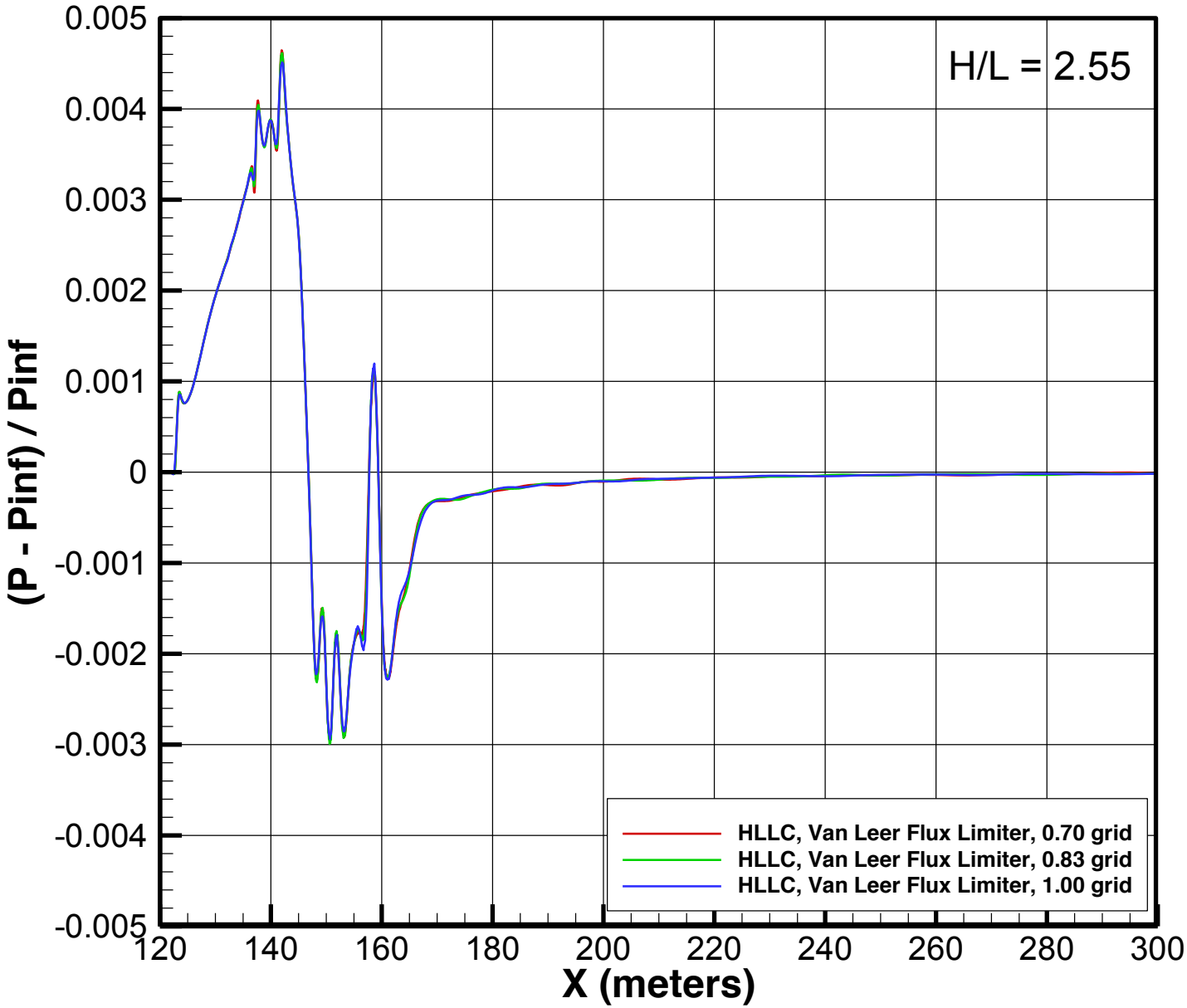
Undertrack Nearfield Results for JAXA WB at Multiple H/L



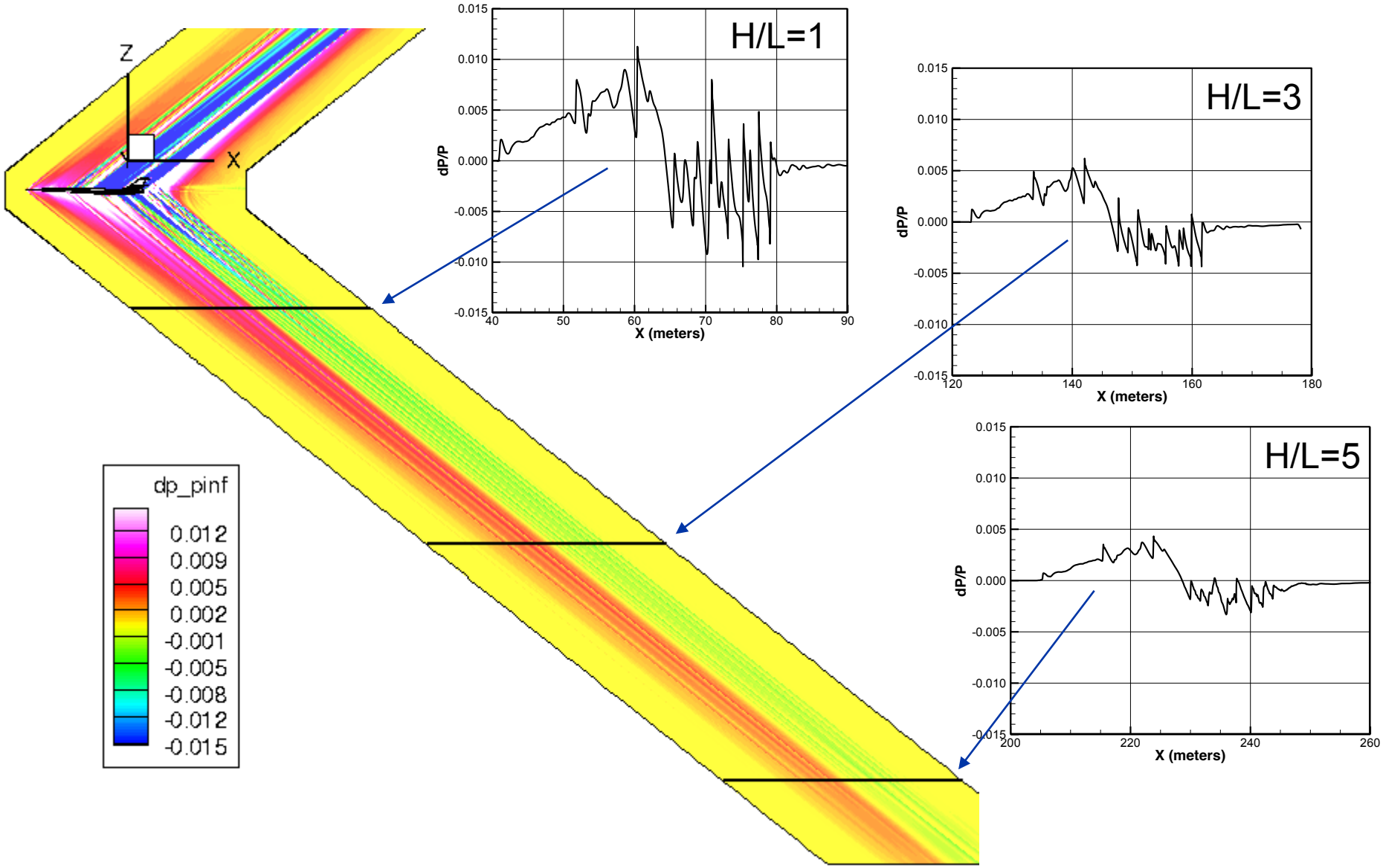




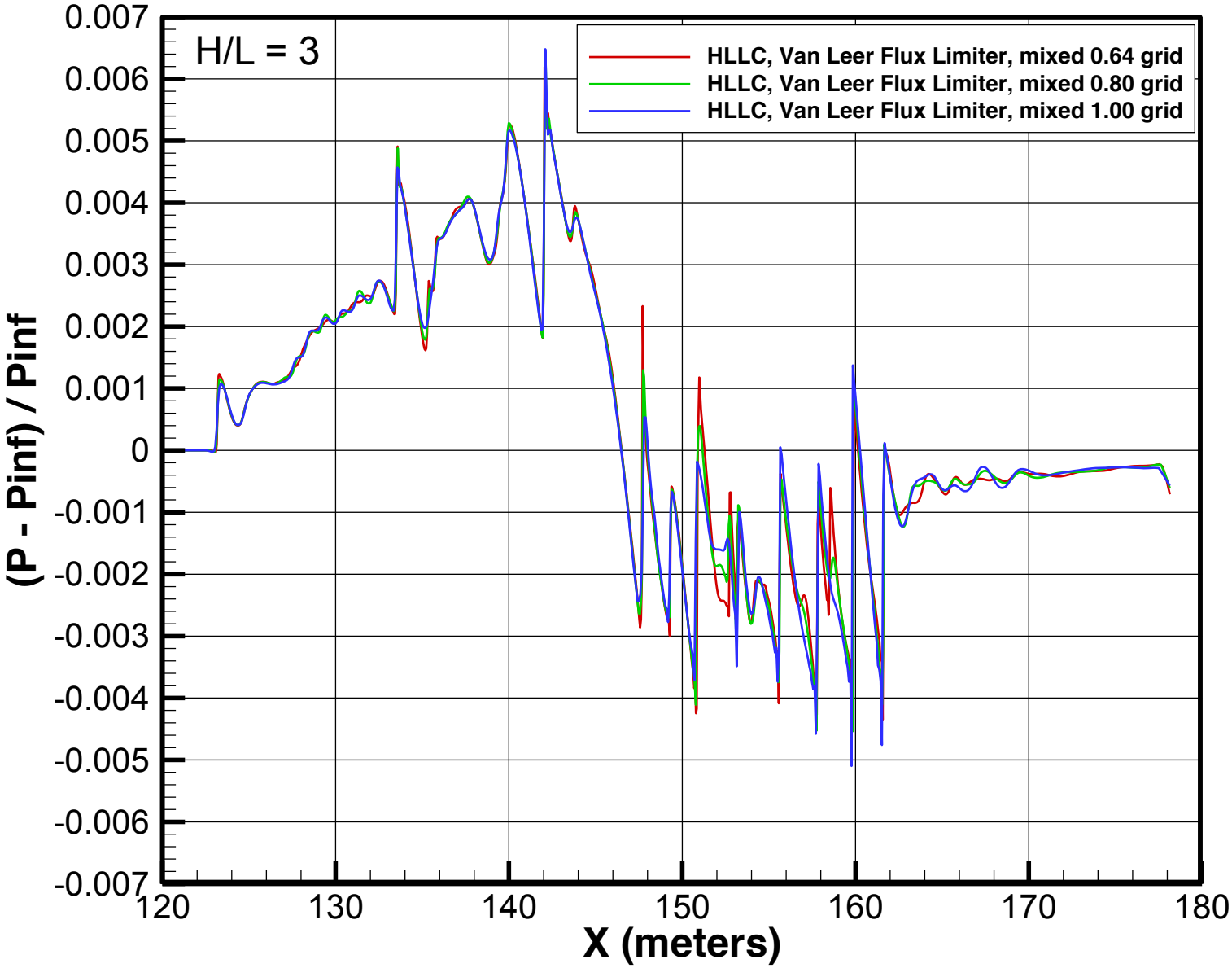
Undertrack Nearfield Results for JAXA WB

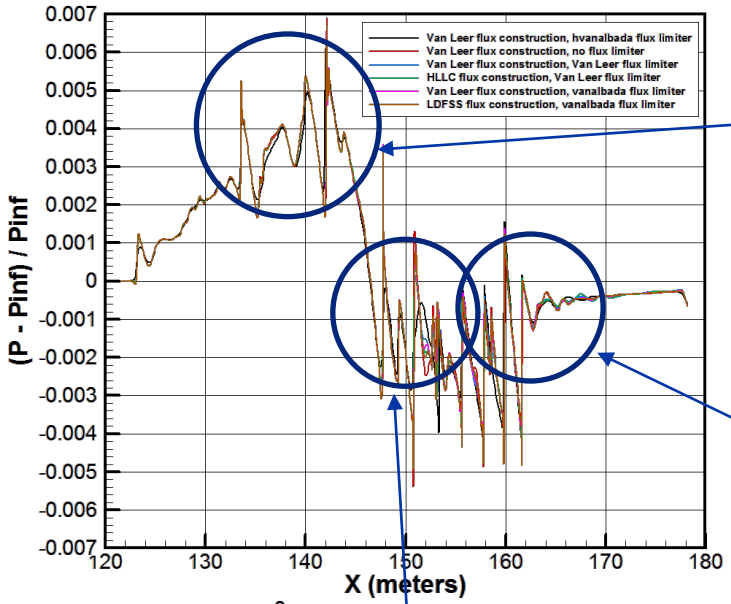


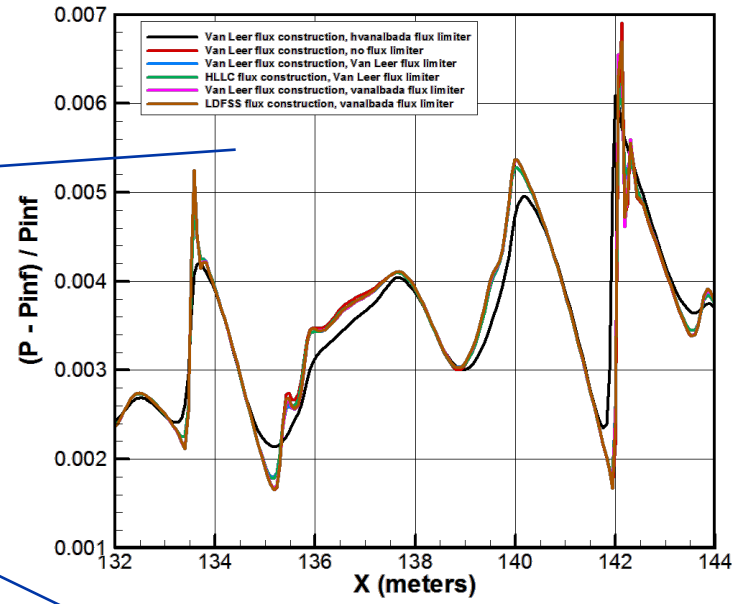
FUN3D Undertrack Nearfield Results for NASA 25D FTN

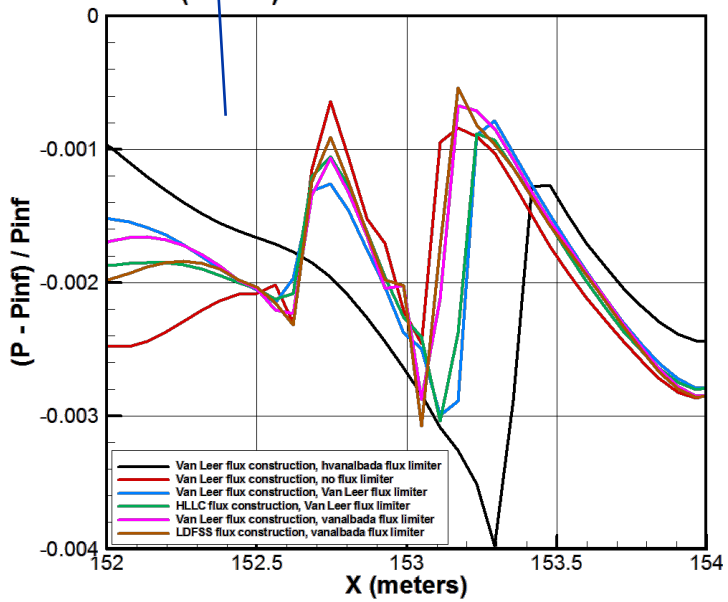


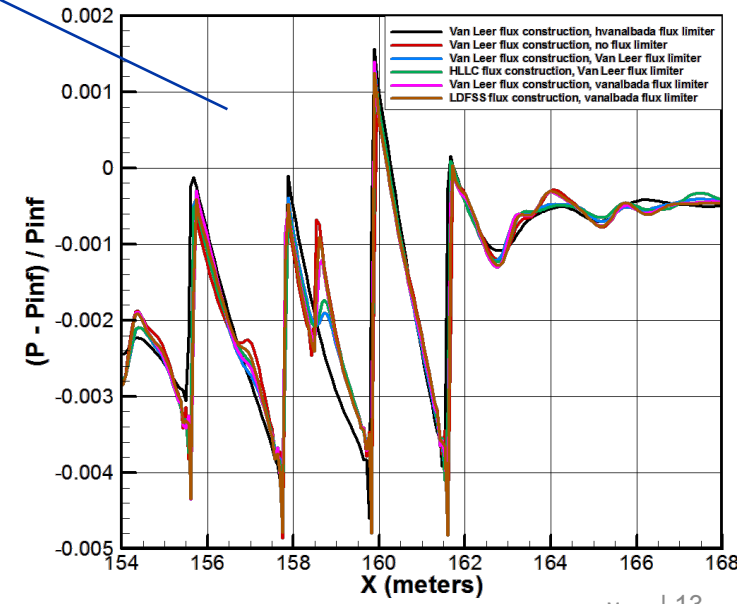
FUN3D Undertrack Nearfield Results for NASA 25D FTN





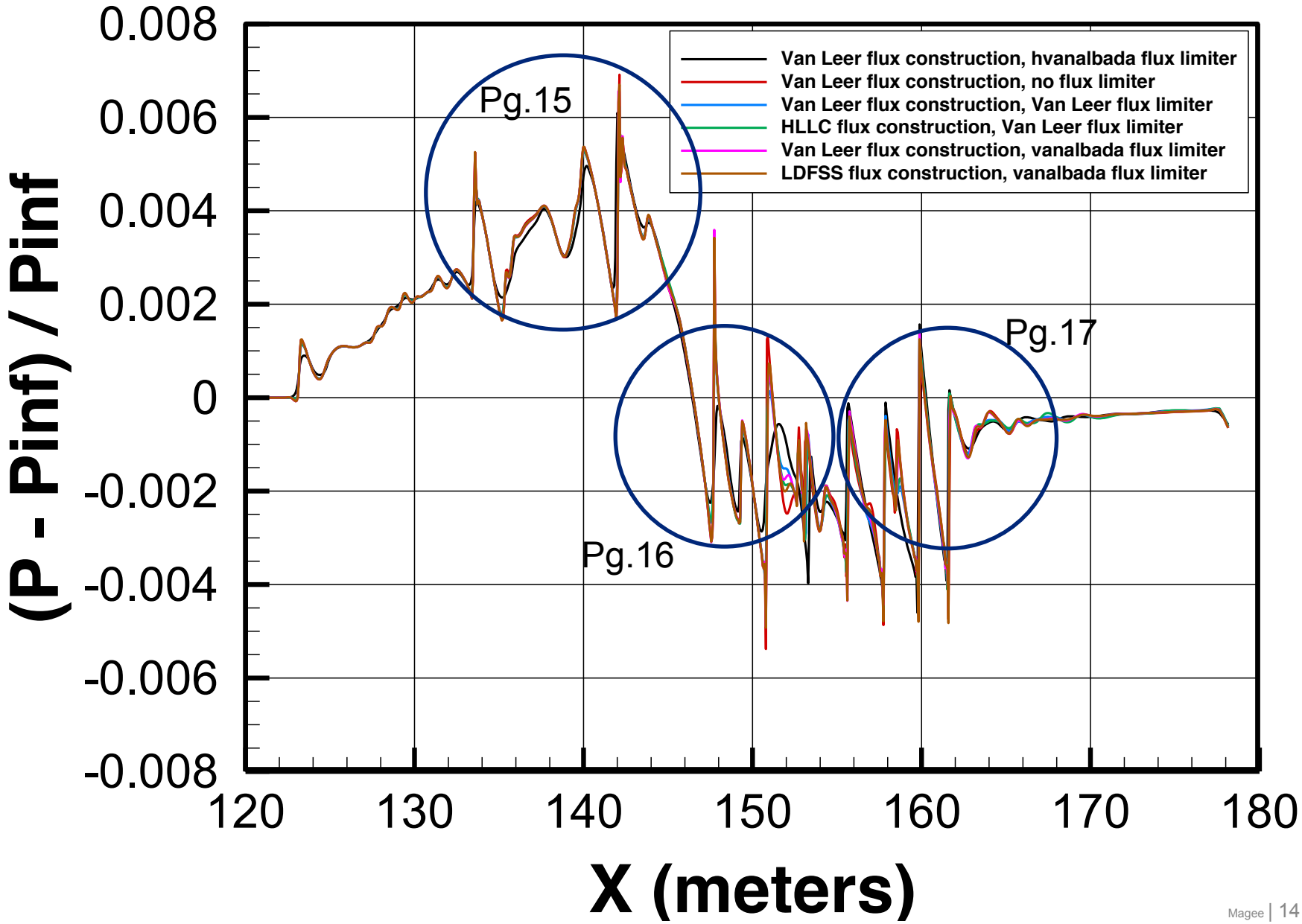




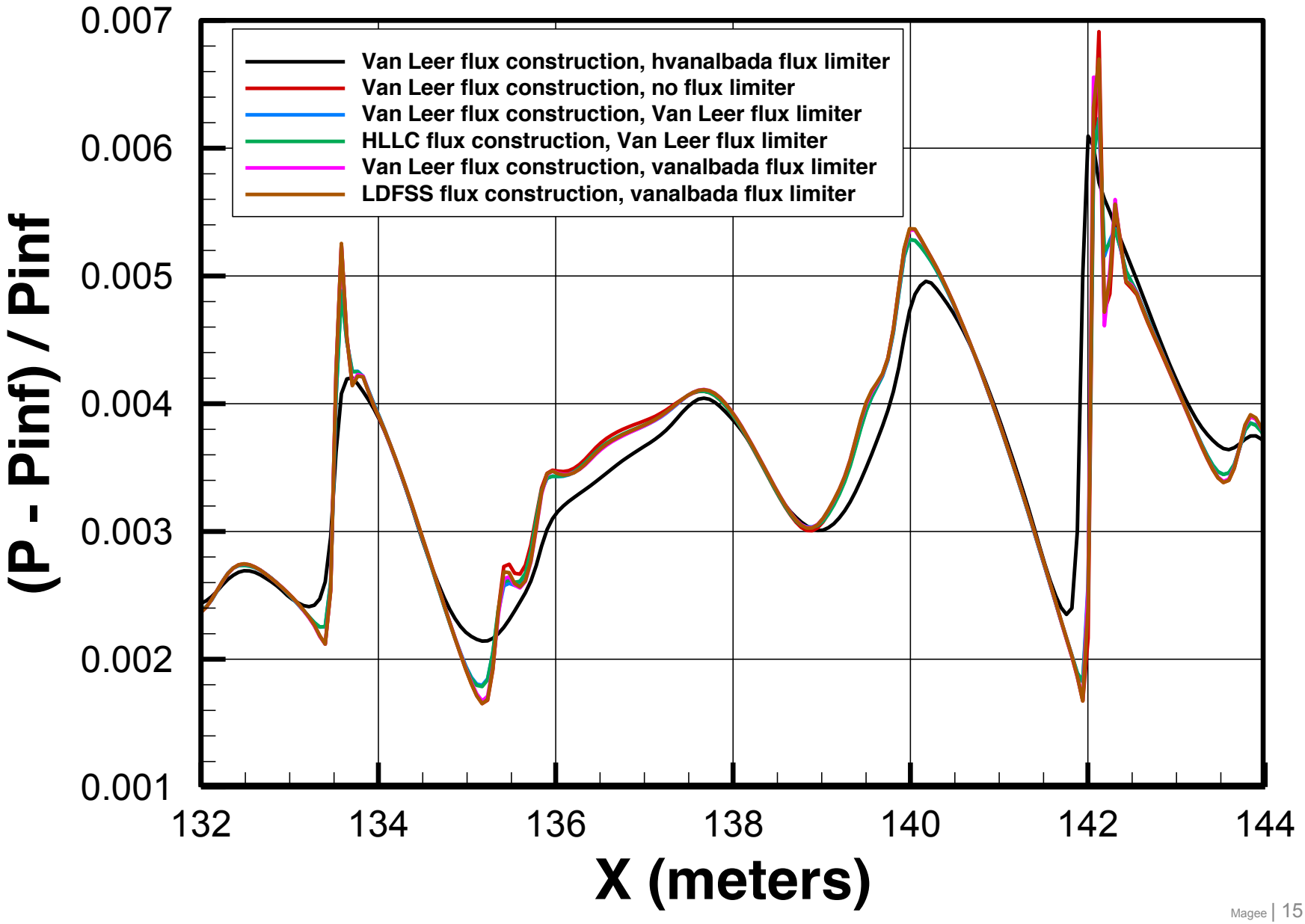


Comparison of Several Inviscid Flux/limiter Methods for NASA 25D with FTN

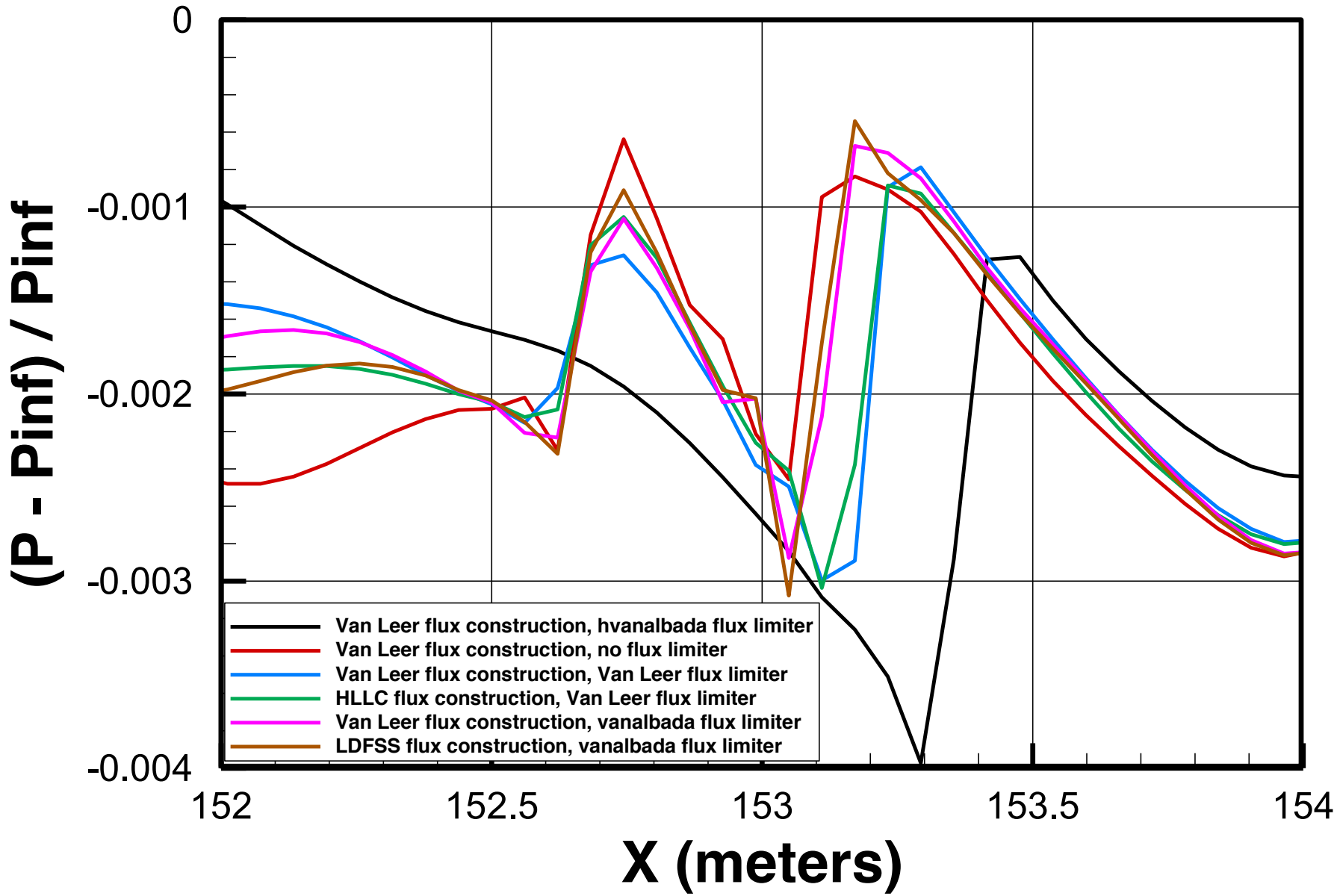
Comparison of Inviscid Flux/limiter Methods - NASA 25DFTN



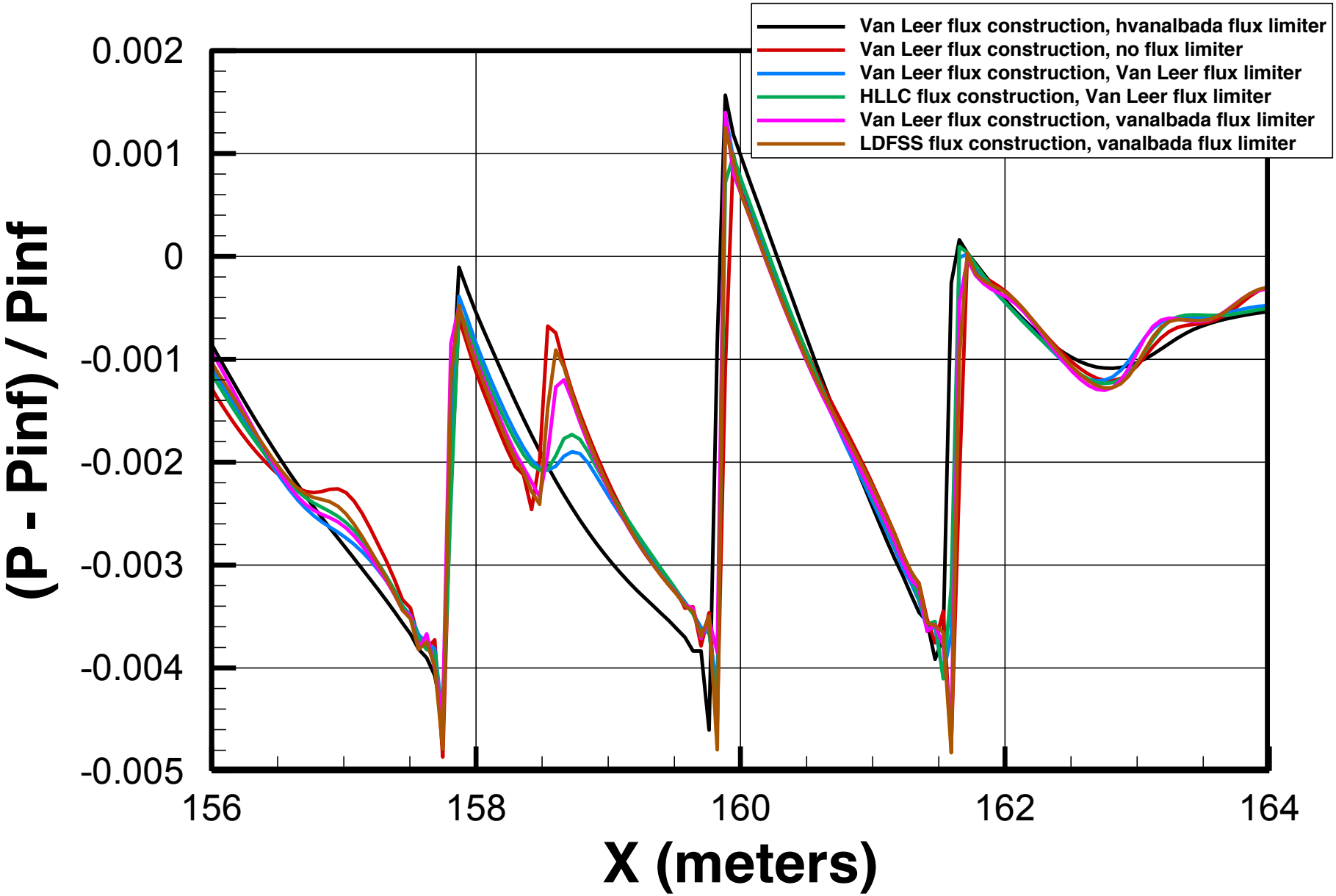
Comparison of Inviscid Flux/limiter Methods - NASA 25DFTN



Comparison of Inviscid Flux/limiter Methods - NASA 25DFTN



Comparison of Inviscid Flux/limiter Methods - NASA 25DFTN



Cart3d Results

Summary of Cases

Non-adapted and adapted grids used for each case

- Axisymmetric Equivalent Area case
- JAXA Wing Body case
- NASA 25D with flow-through nacelle case

CART3D flow-solver

- Finite volume, inviscid Euler solver, Cartesian Euler grid, with minor vertical stretching
- Grid-aligned shock, along with a small radius cylinder around the model for extraction of flow state variables along linear sensors
- Parallel execution on single compute node
  - Non-adapted cases: 20 core, 128 GB RAM nodes
  - Adapted cases: 20 core, 512 GB RAM nodes

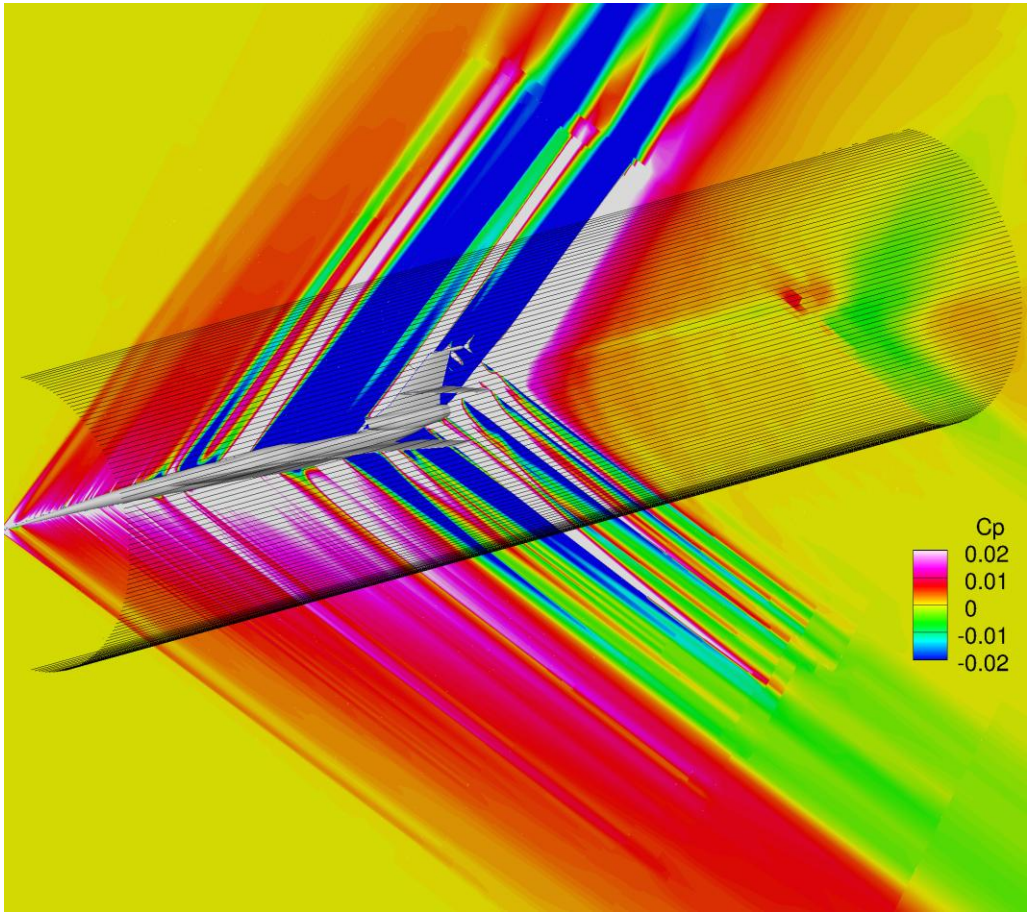
Space-marching solver

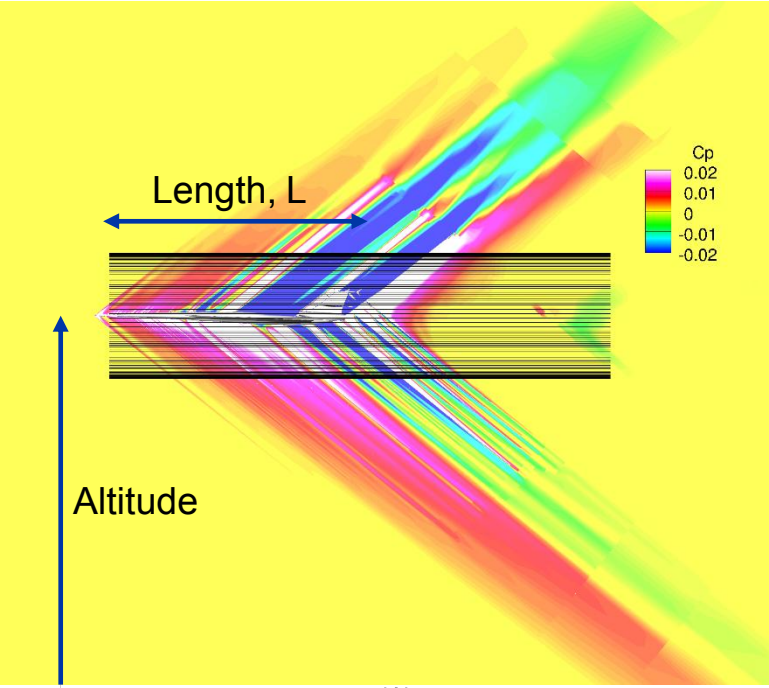
- High-order finite difference Euler solver
- Propagates flow state variables from an inner cylinder boundary to an outer cylinder
- High density structured grid
- Parallel execution on a single compute node: 20 core, 128 GB RAM

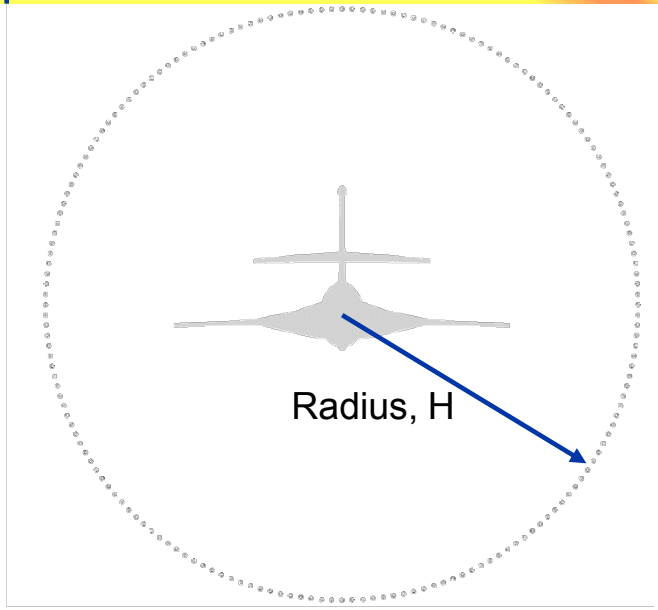
General Cart3D Setup

Full Cylinder State Variable Extraction

- Full model geometry, cylinder H/L = 0.25, 2 deg spacing (Axisymmetric case used half-model)
- Cylinder centerline aligned with free-stream vector
- Cylinder length 2L—3L



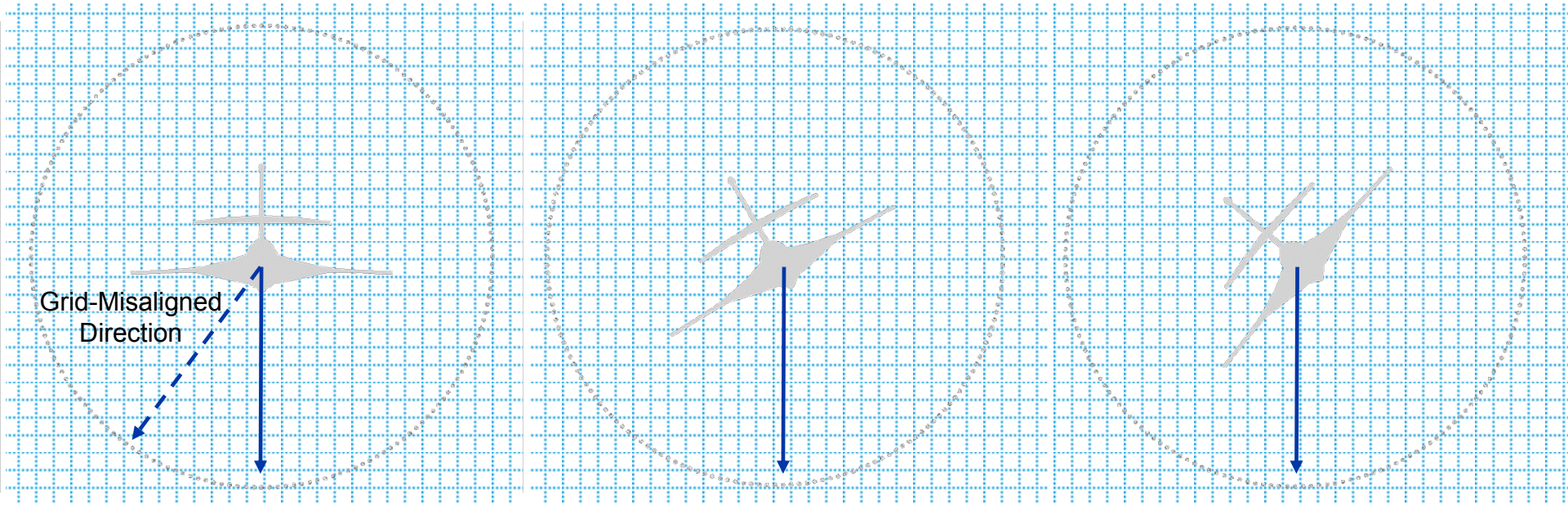




General Cart3D Setup (Cont.)

Model Rotated for Grid-Aligned Azimuth Directions

- Model rotated about the free-stream velocity vector for each azimuth direction
- Requested azimuth directions are grid-aligned
- Non-adapted grids utilize pre-specified density boxes
- Model is rotated in pitch for grid-aligned shocks (including offset for sonic glitch)
- Adapted grids pursued to lower error on pressure signature functional

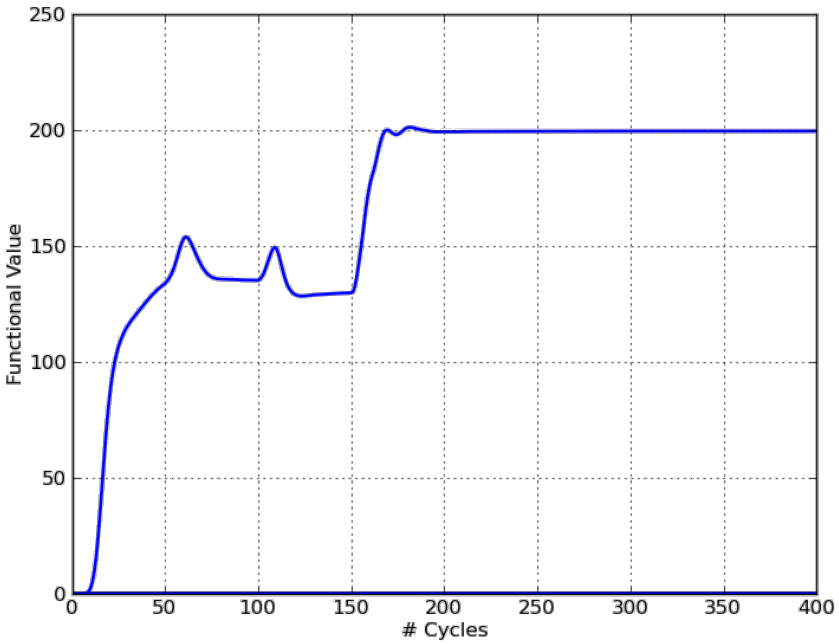


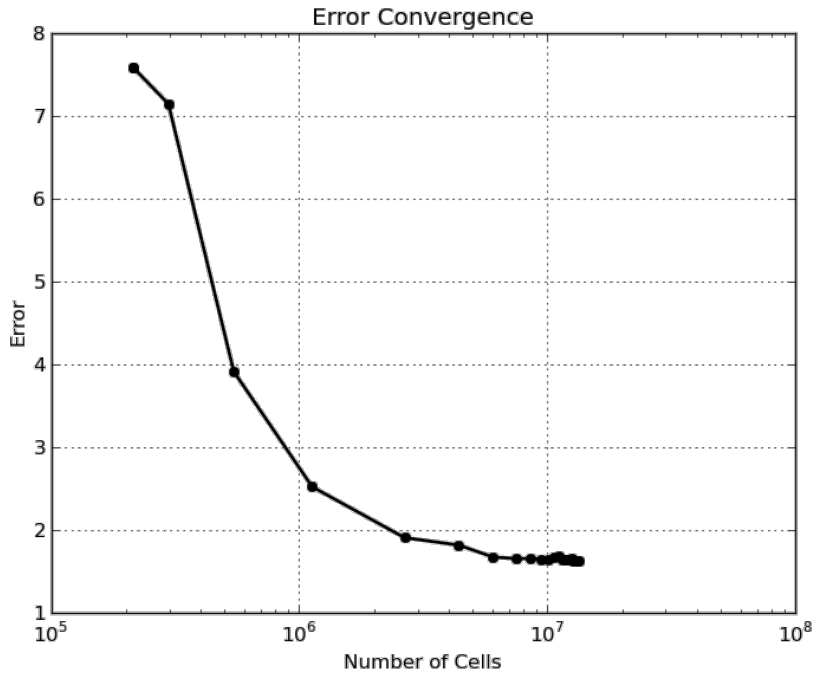
0 deg. Grid-Aligned | 30 deg. Grid-Aligned | 50 deg. Grid-Aligned

General Cart3D Setup (Cont.)

Functional Convergence Monitored

- Functional convergence of all line sensors tracked
- Total functional convergence tracked for each adaptation cycle
  - Same for non-adapted cases
- Adaptation functional weighting emphasized grid-aligned azimuth direction
- Adaptation cycles chosen until further error improvement not seen
- Smallest resolution is 2.4 cm for all cases

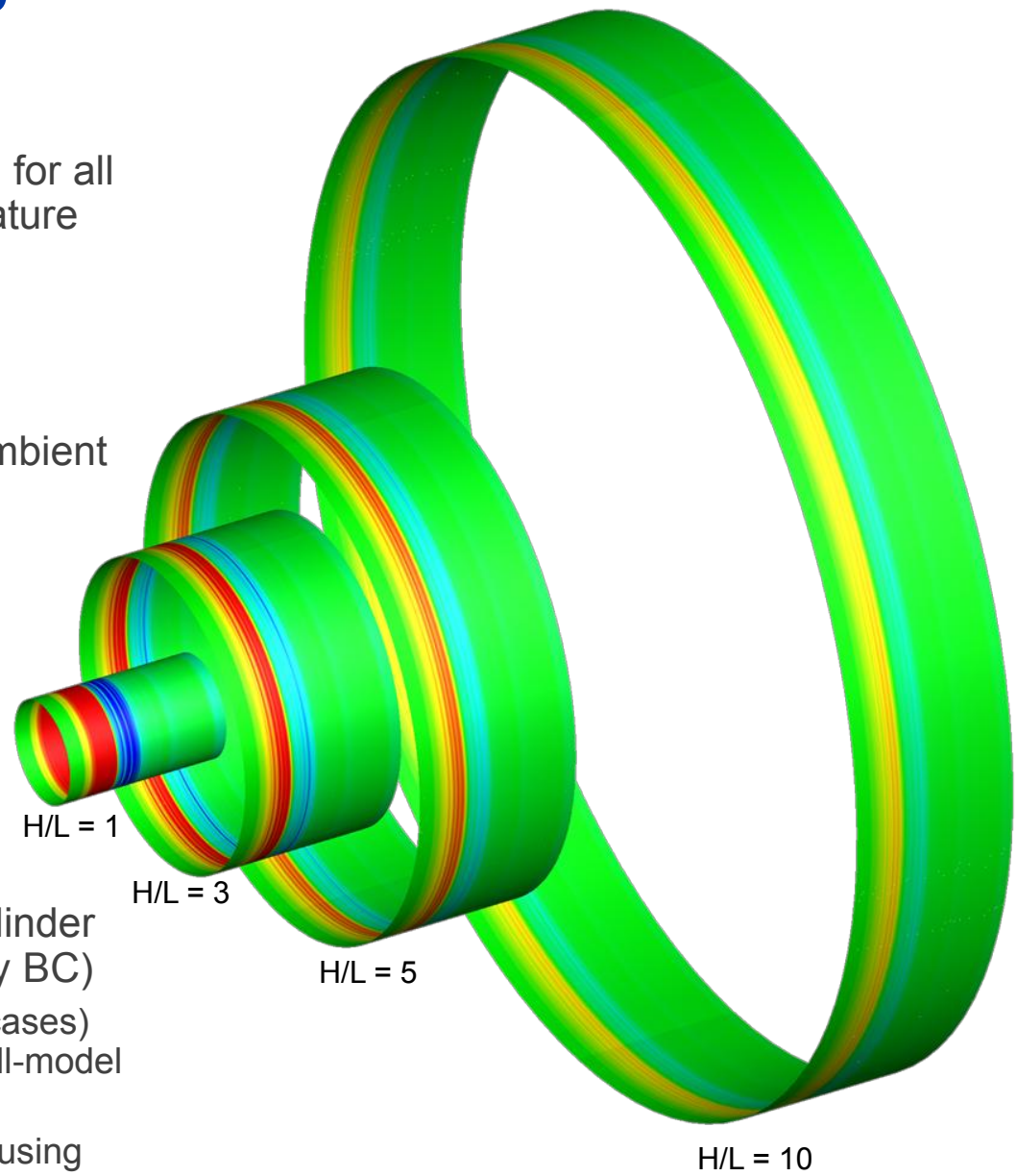




Space-Marching Setup

Concentric Cylinder Output

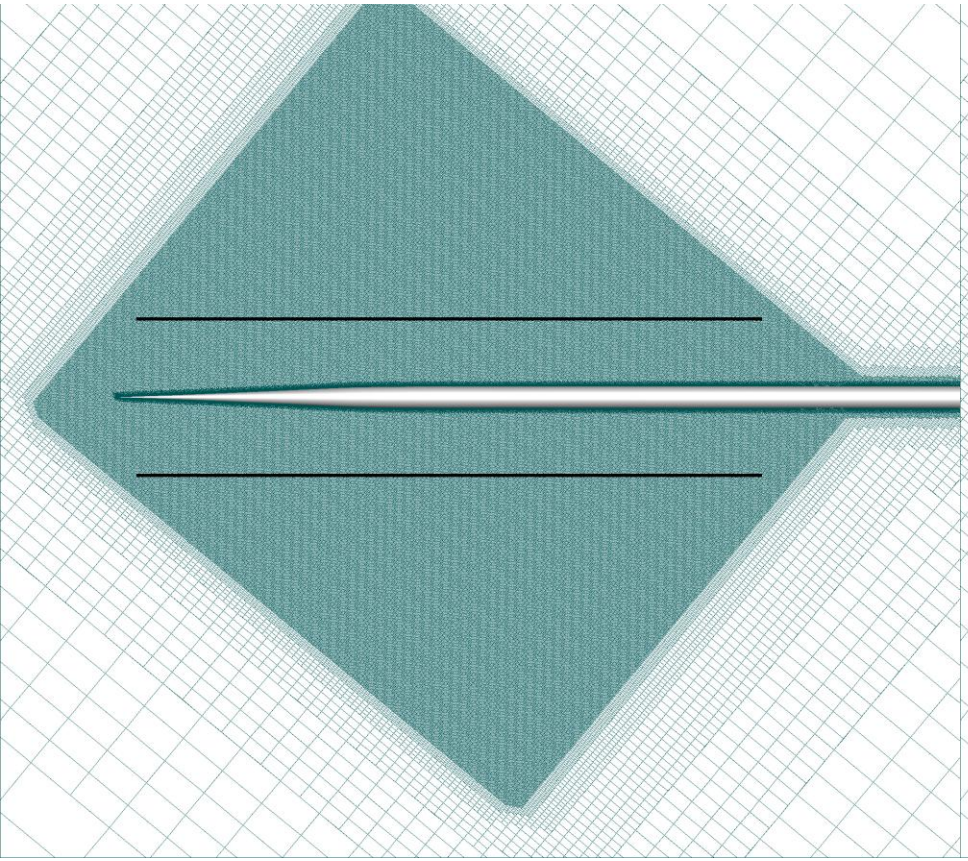
- High accuracy signature propagation for all azimuth directions to a “frozen” signature with smaller computational expense
- MPI parallelism
- Ideal atmospheric model captures ambient change for large H/L
- Enables smaller CFD domain
- Introduced in AIAA 2016-2037



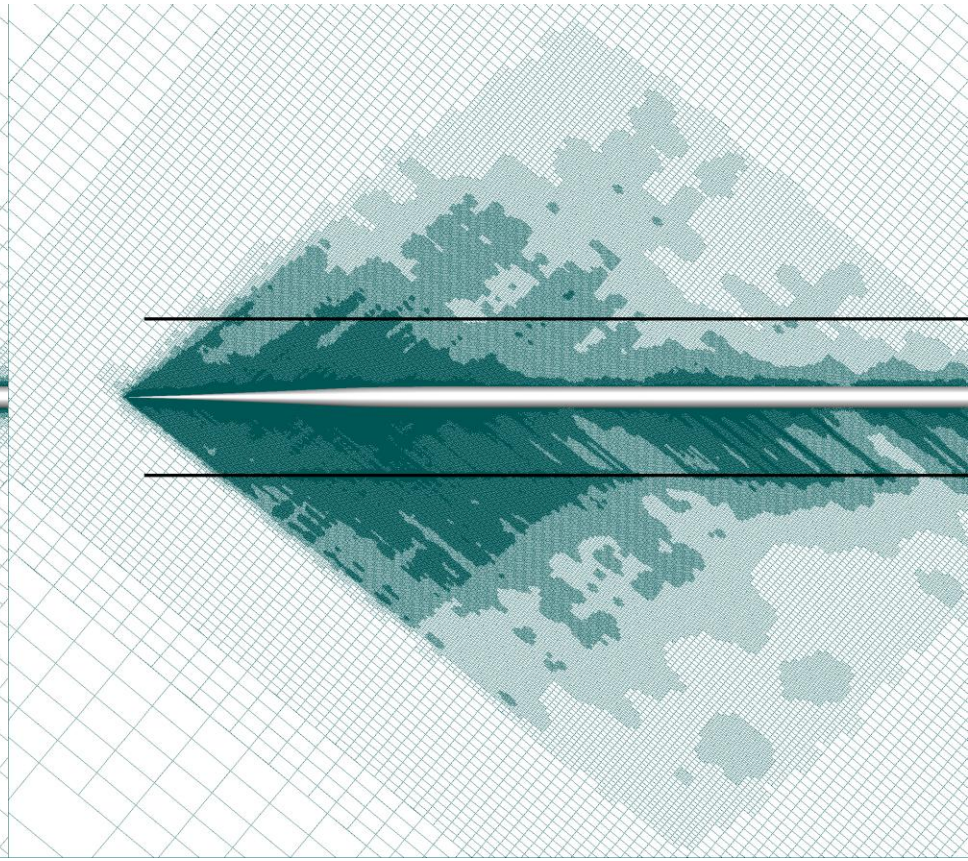
- Full-cylinder propagation and half-cylinder propagation available (with symmetry BC)
  - Initial data sets (JAXA and NASA 25D cases) incorrectly used the symmetry BC for full-model cases
  - Analyses rerun without a symmetry BC using full-cylinder propagation and submitted

Axisymmetric Equivalent Area Case

Non-Adapted Grid
22601287 cells

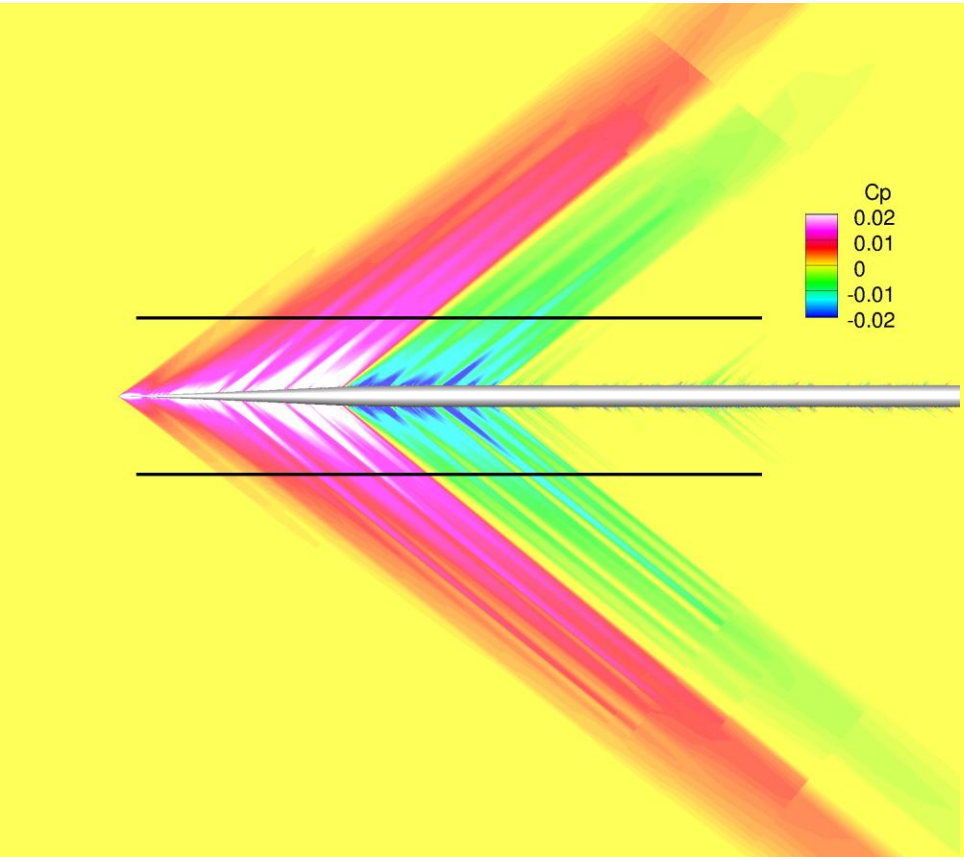


Adapted Grid #25
41394292 cells

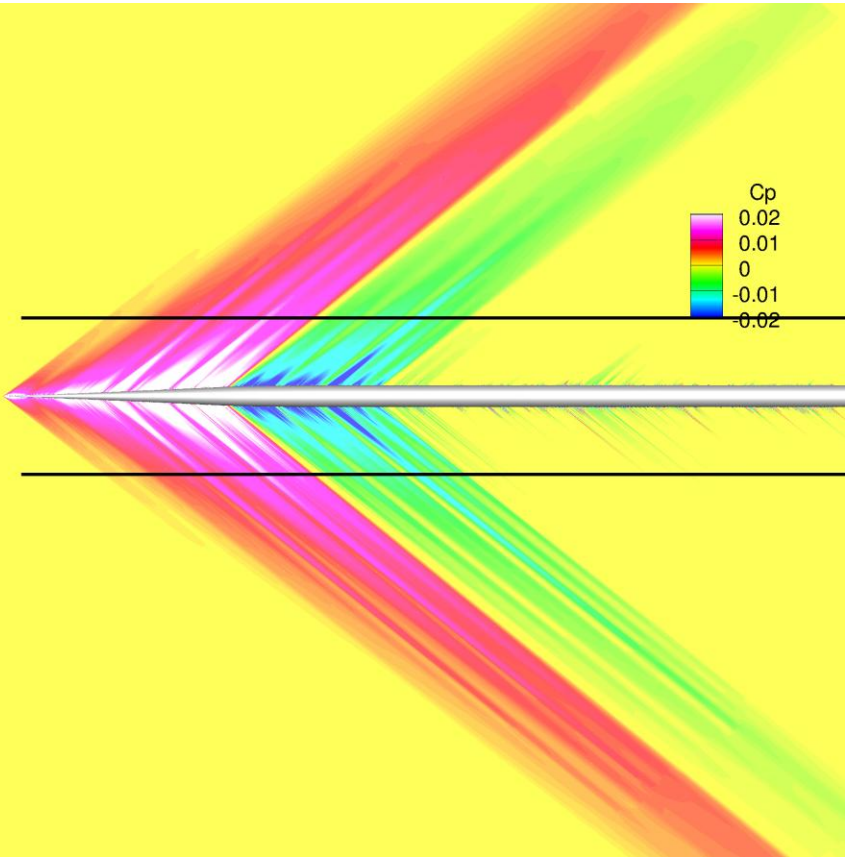


Axisymmetric Equivalent Area Case

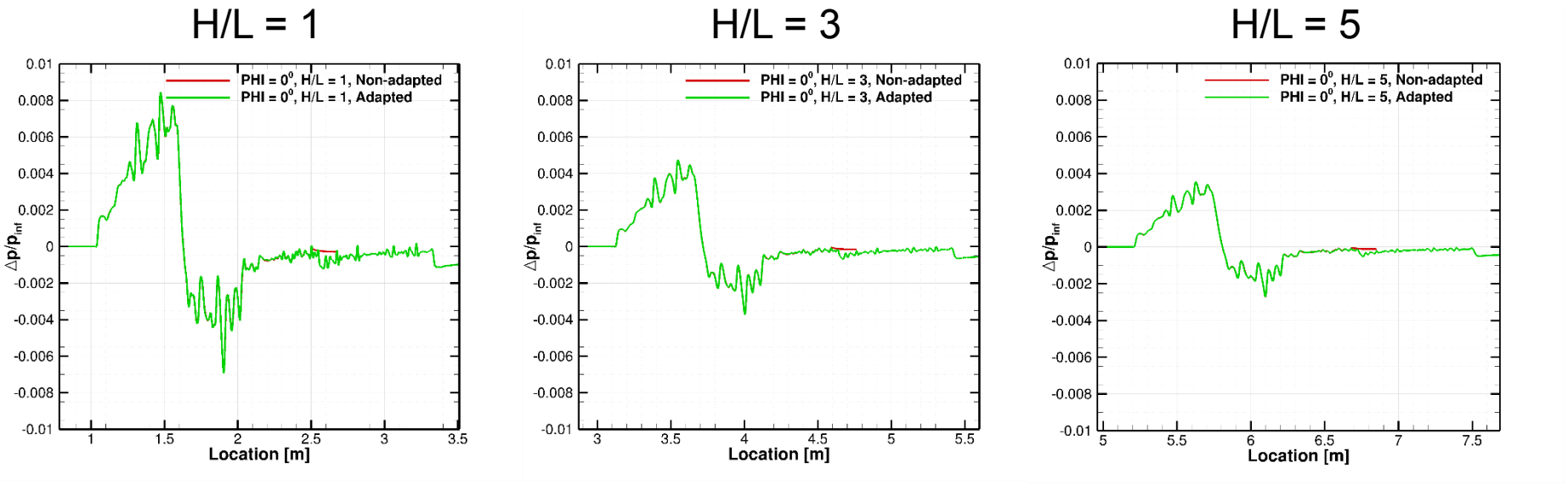
Non-Adapted Grid



Adapted Grid #8



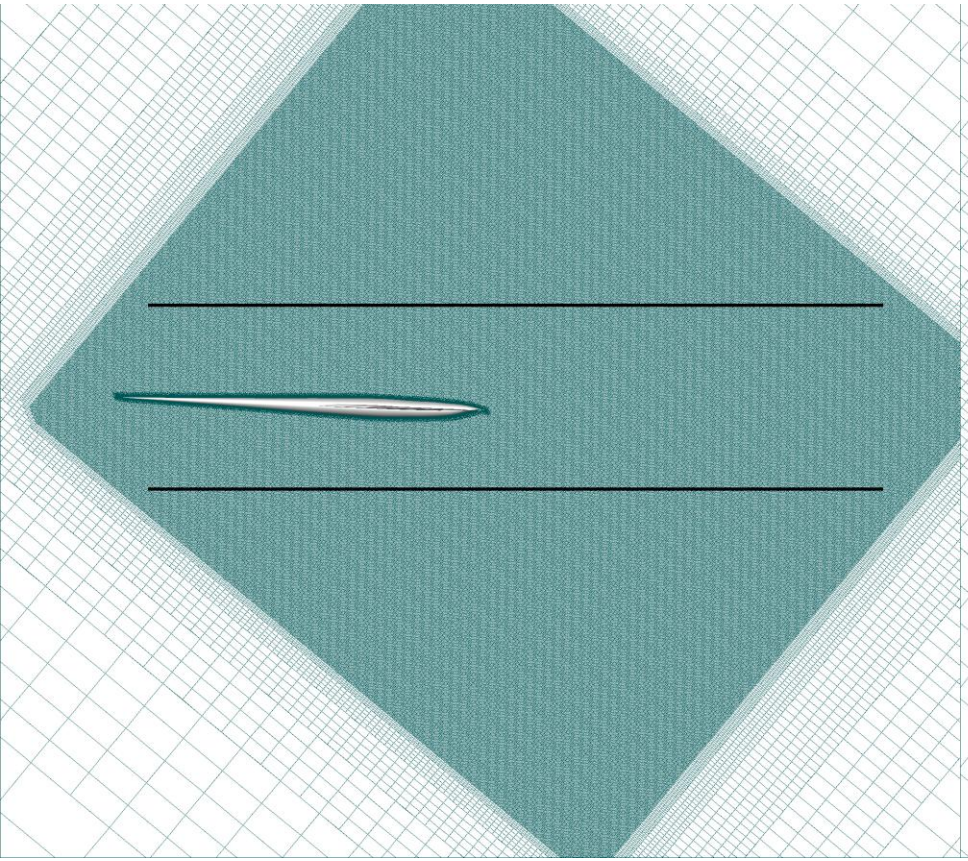
Axisymmetric Equivalent Area Case



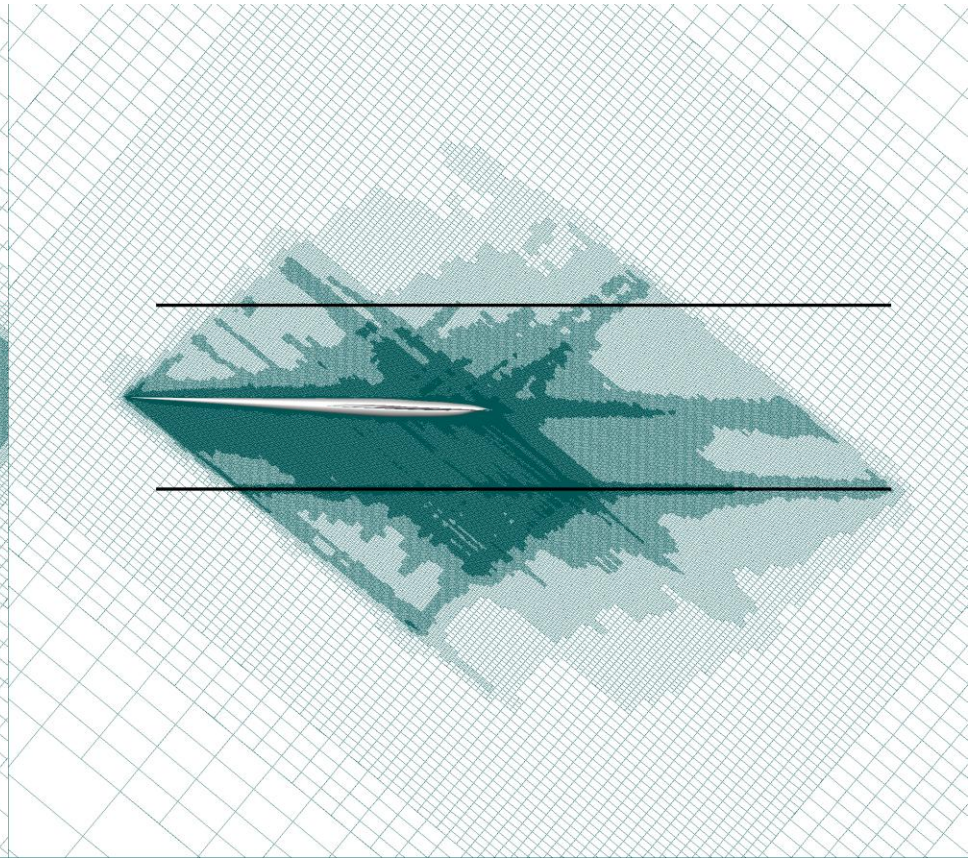
Non-adapted and adapted signatures agree well

JAXA Wing Body Case

Non-Adapted Grid
28809383 cells

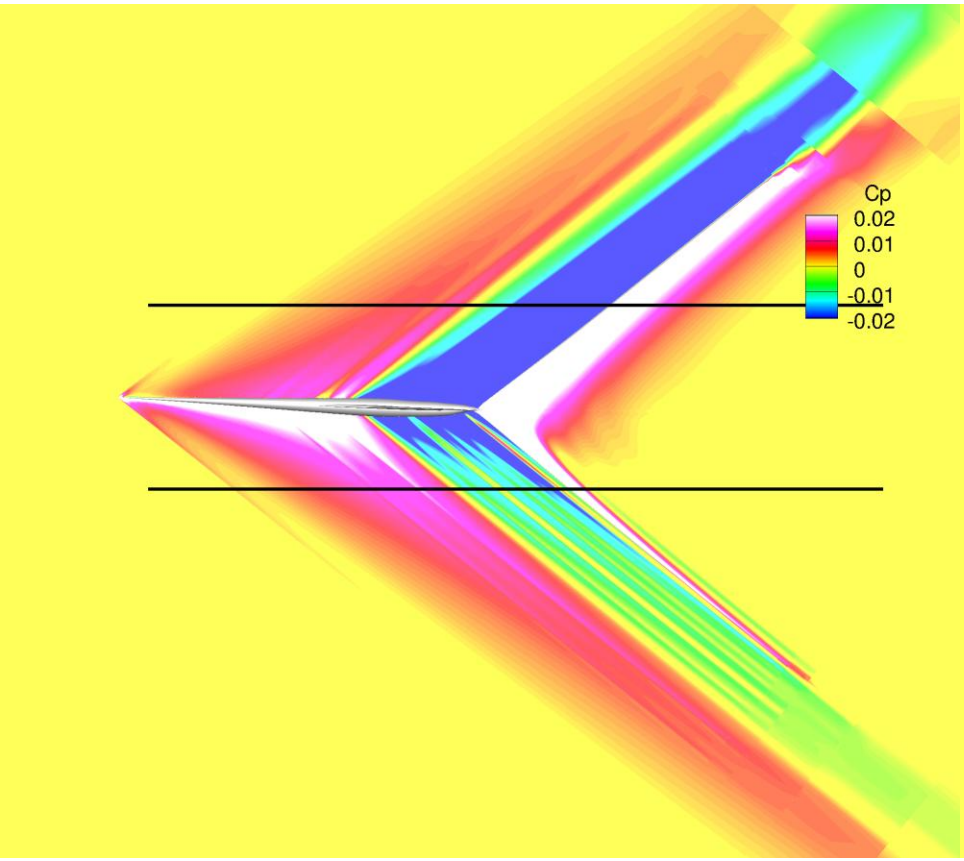


Adapted Grid #25
19536135 cells

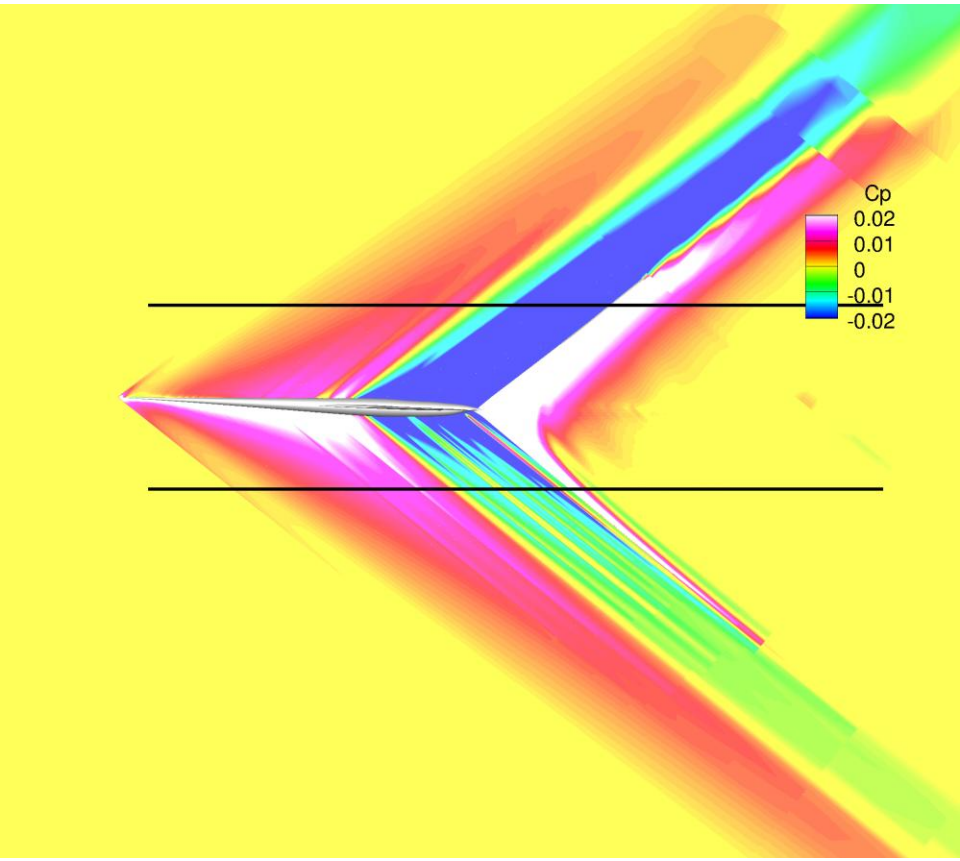


JAXA Wing Body Case

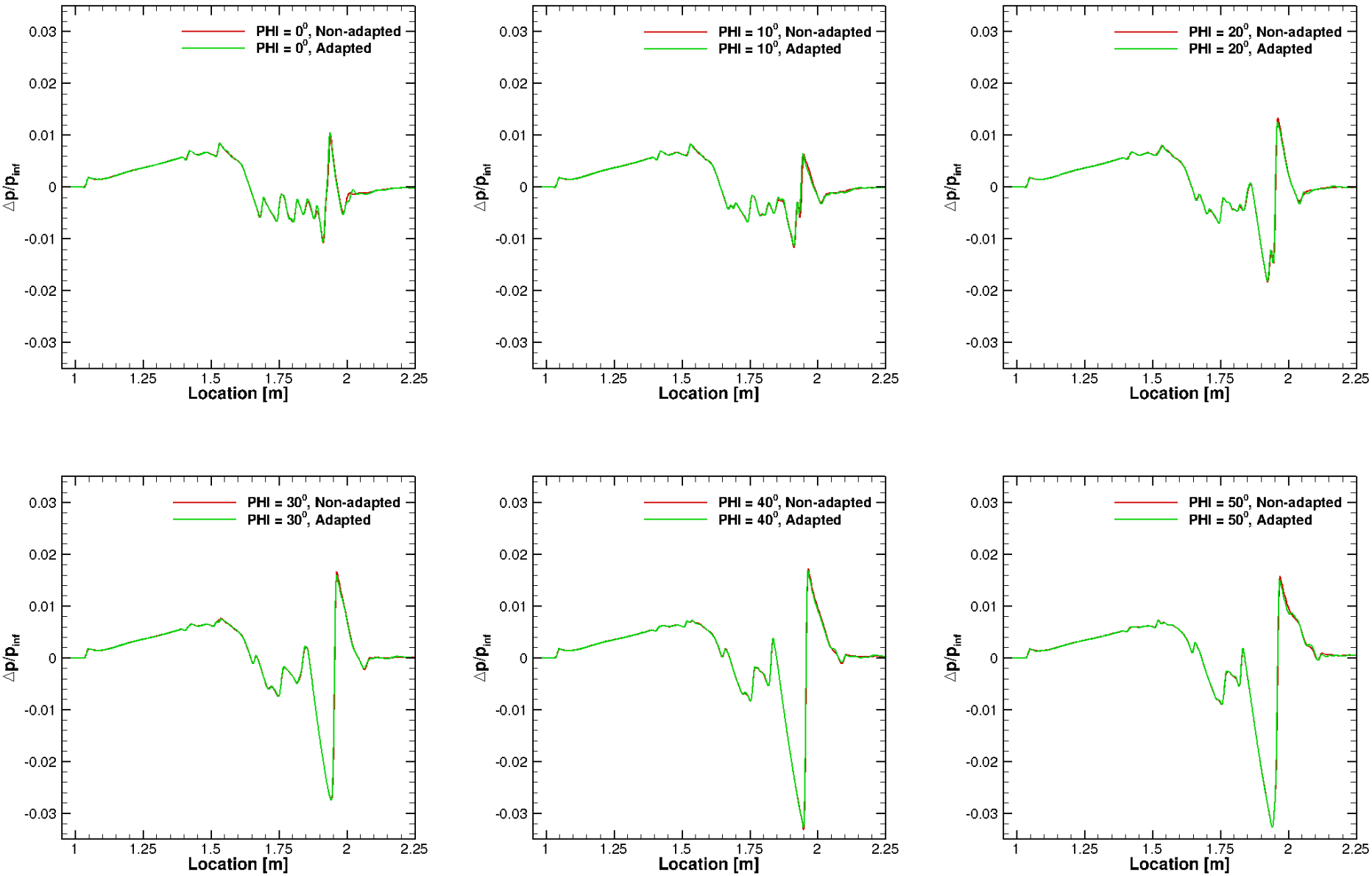
Non-Adapted Grid



Adapted Grid #25



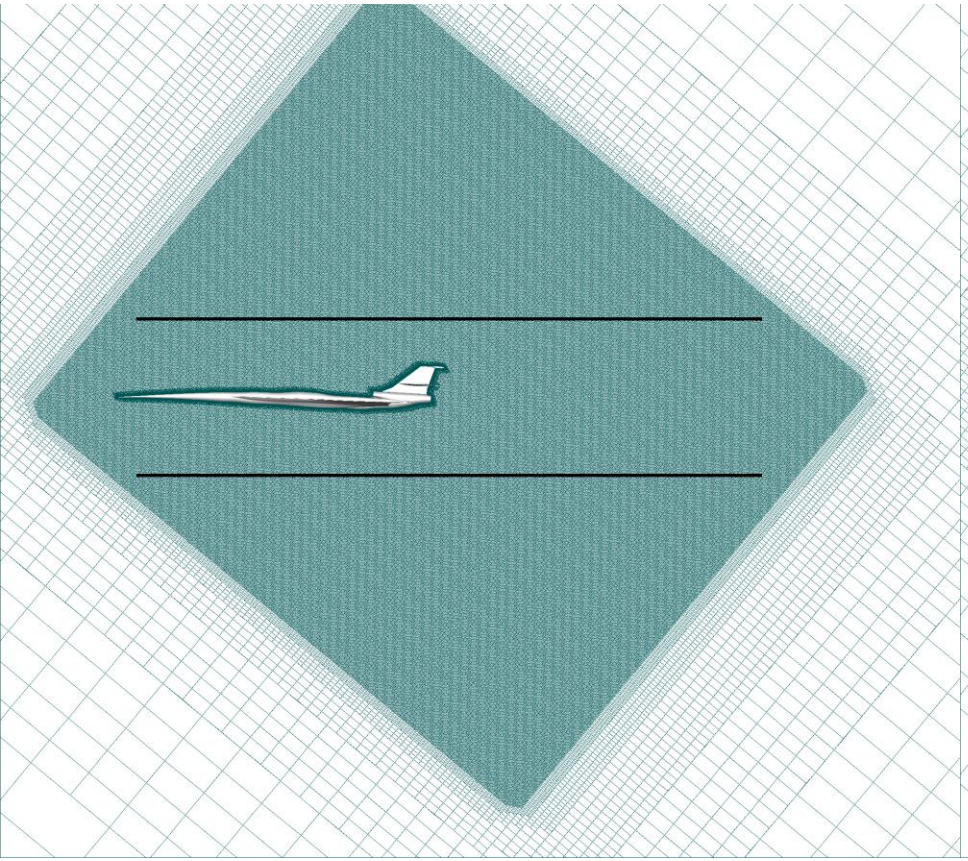
JAXA Wing Body Case: H/L = 0.85



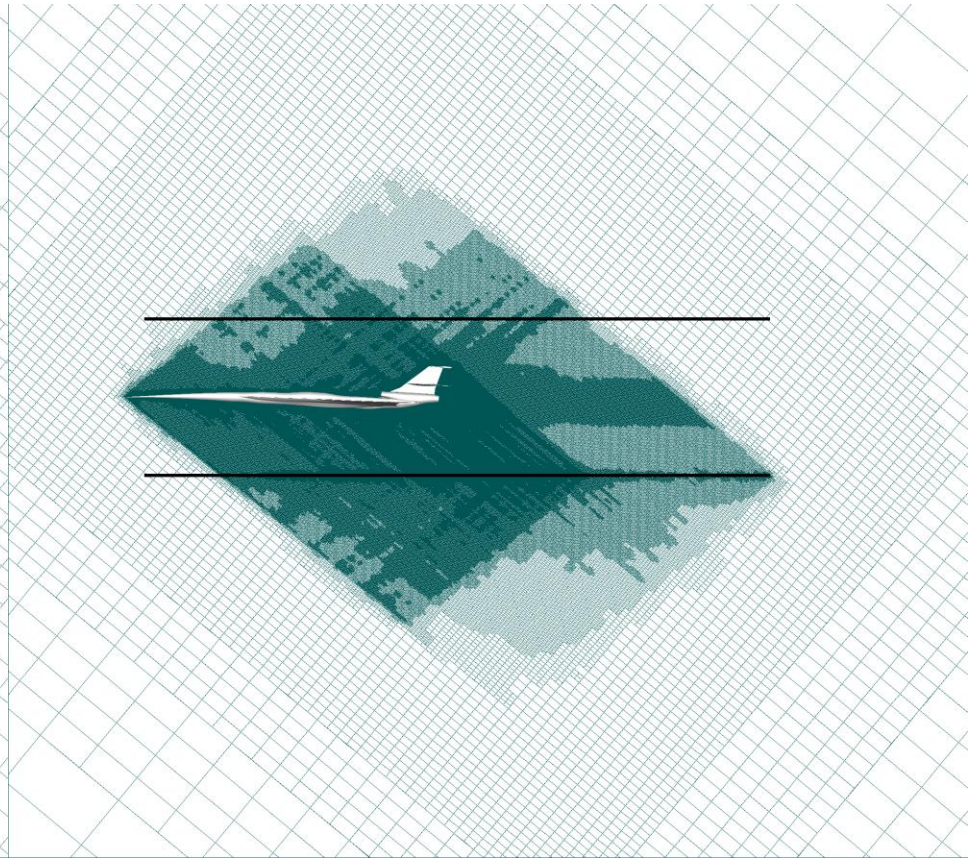
Non-adapted and adapted signatures agree well

NASA 25D with Flow-Through Nacelle Case

Non-Adapted Grid
19994779 cells

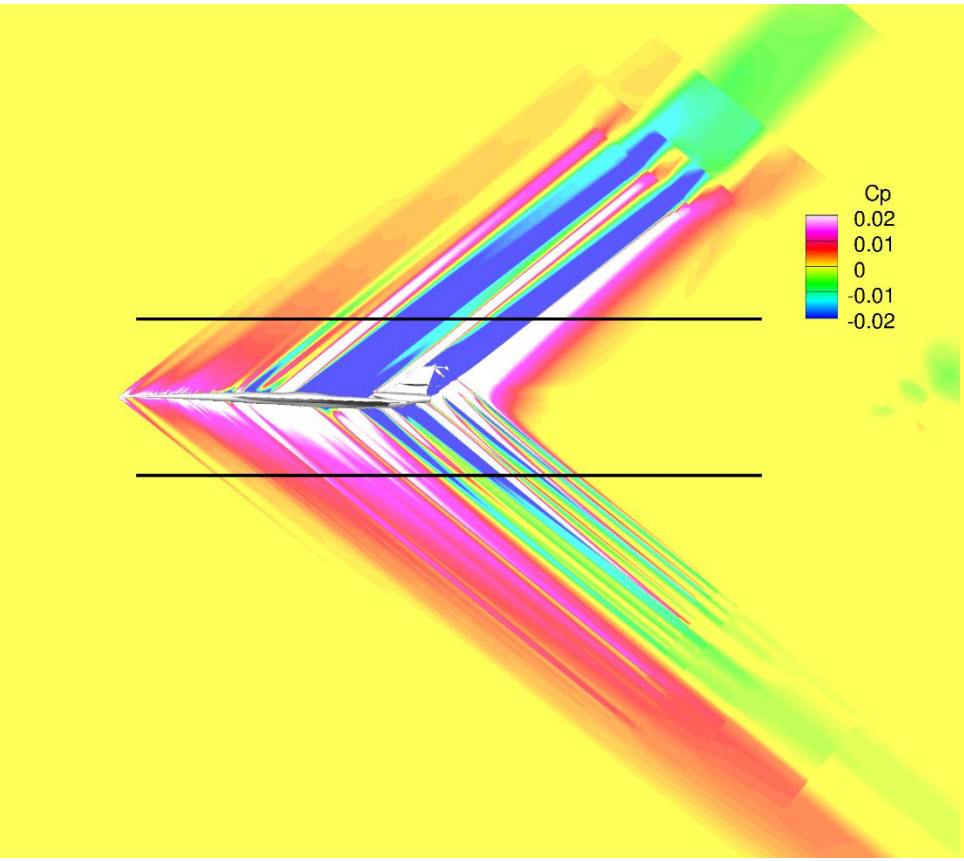


Adapted Grid #25
49107331 cells

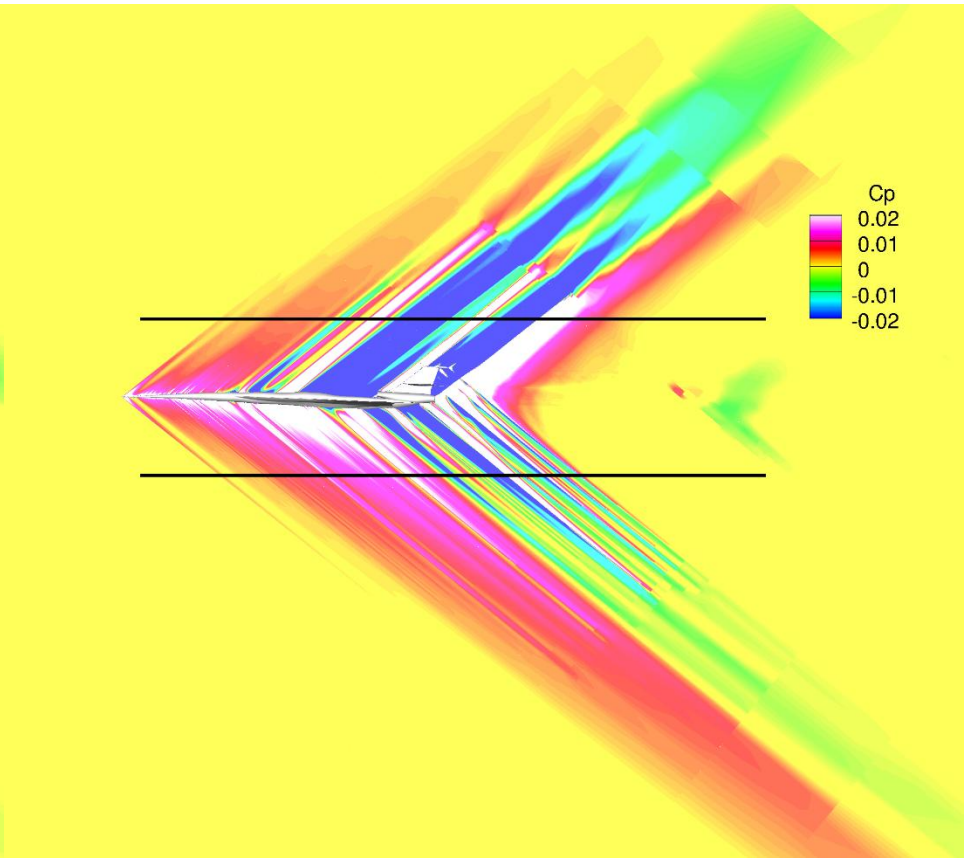


NASA 25D with Flow-Through Nacelle Case

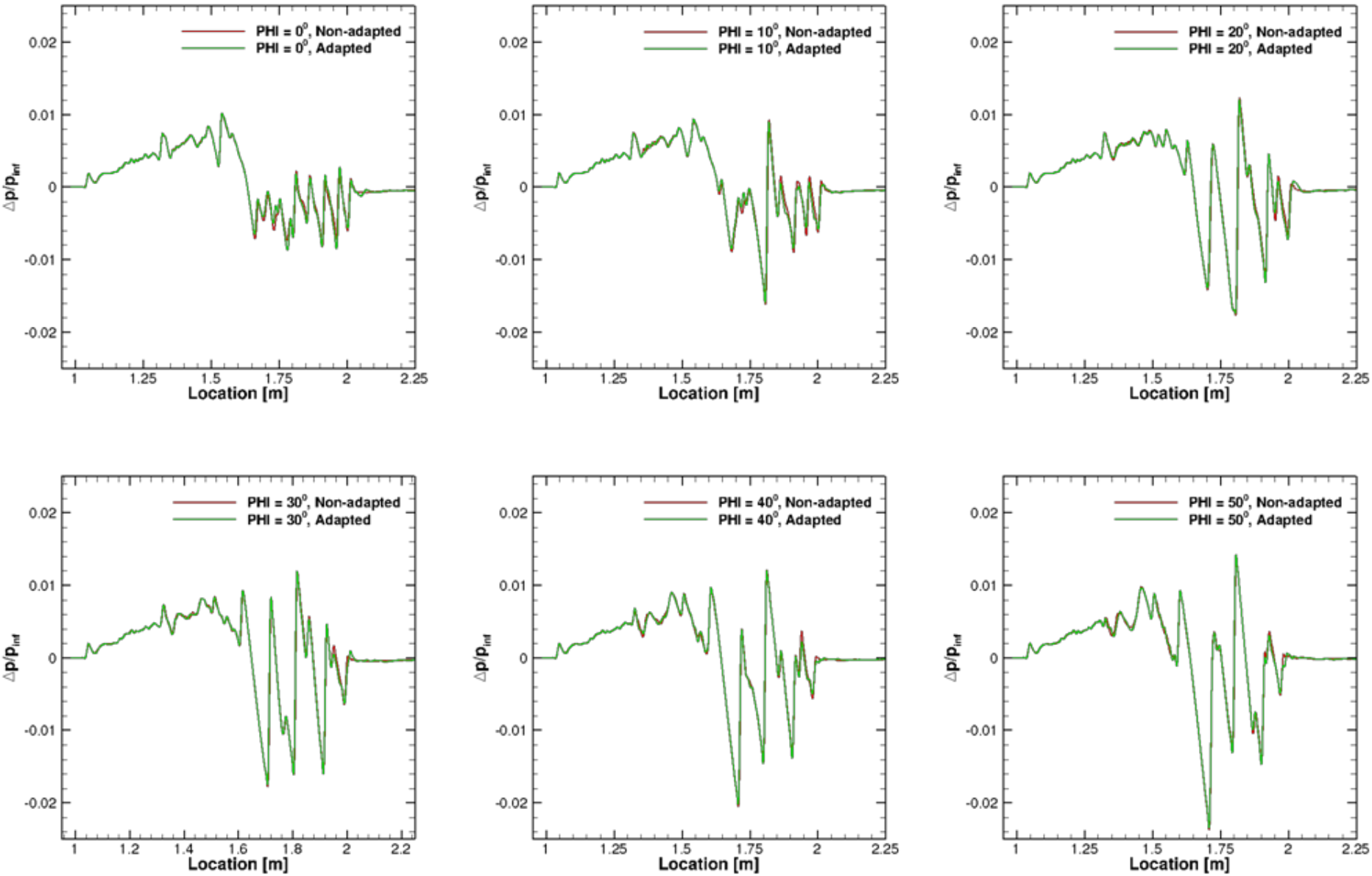
Non-Adapted Grid



Adapted Grid #25



NASA 25D with Flow-Through Nacelle Case: H/L = 1



Non-adapted and adapted signatures agree well

Conclusions

FUN3D Analysis

- HLLC Inviscid flux method with Van Leer flux limiter provide nearfield results with low dissipation
  - However some nearfield signature features are unphysical
  - Convergence stalled on some provided grids
- Results similar for all inviscid flux methods and limiters tried in the study
  - Van Leer flux construction with hvanalbada flux limiter yields the most dissipative solution

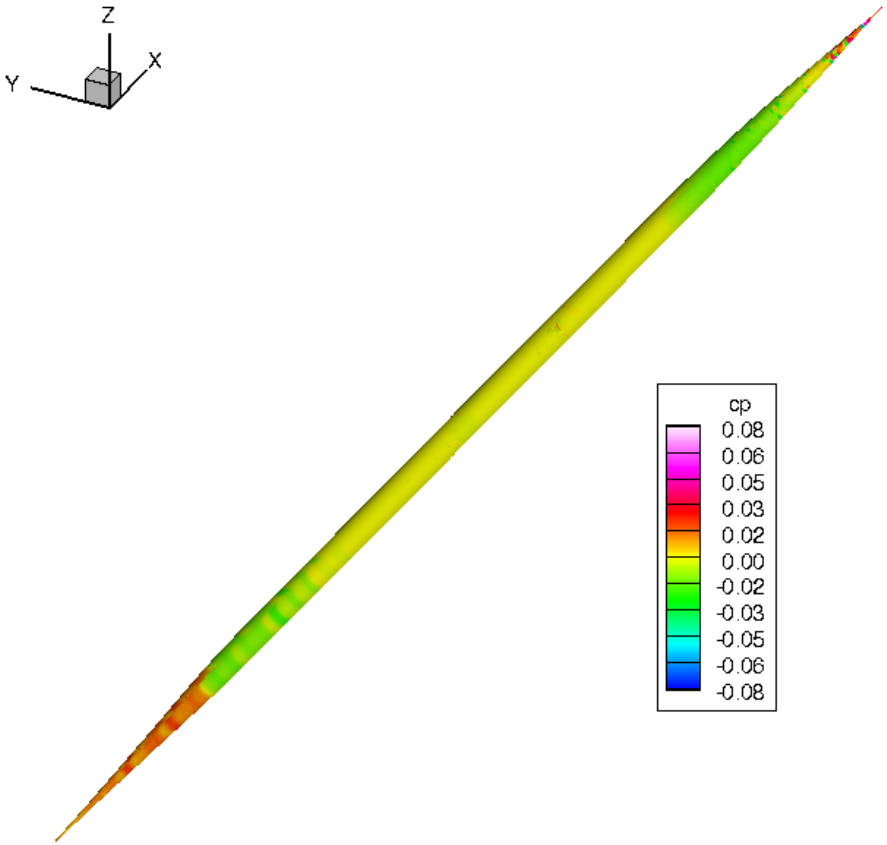
Cart3d Analysis

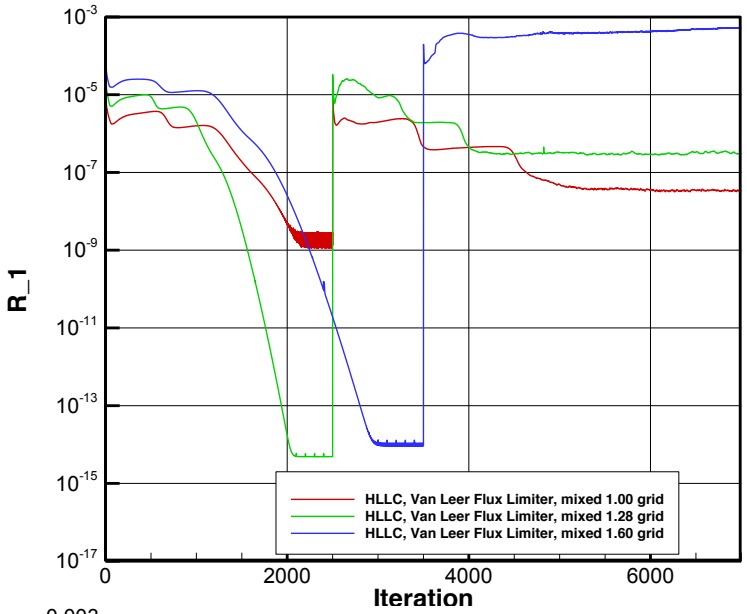
- Non-adapted and adapted signatures agreed well
- Full-cylinder propagation needed for full-models
  - Setting a symmetry BC will yield incorrect signature shapes
- Space-marching capability greatly reduces computational expense
  - Full-cylinder propagation more efficient and accurate than conducting the same simulation in CFD alone

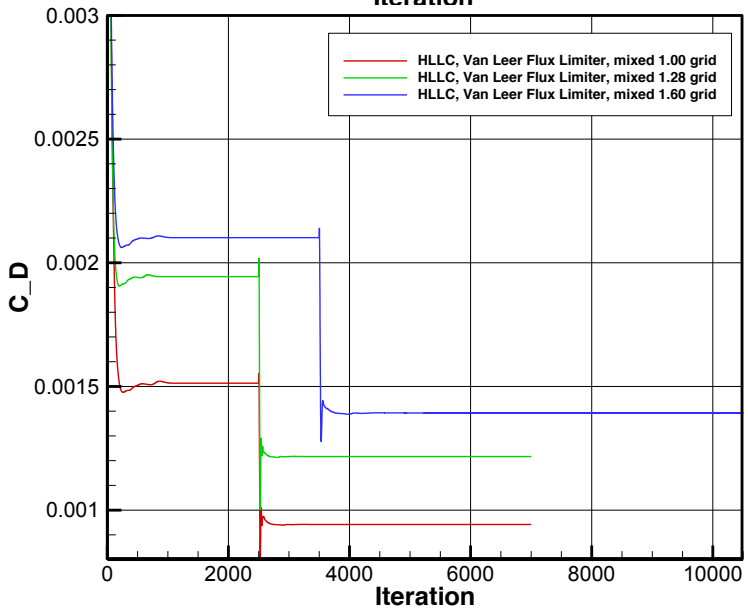
Questions?

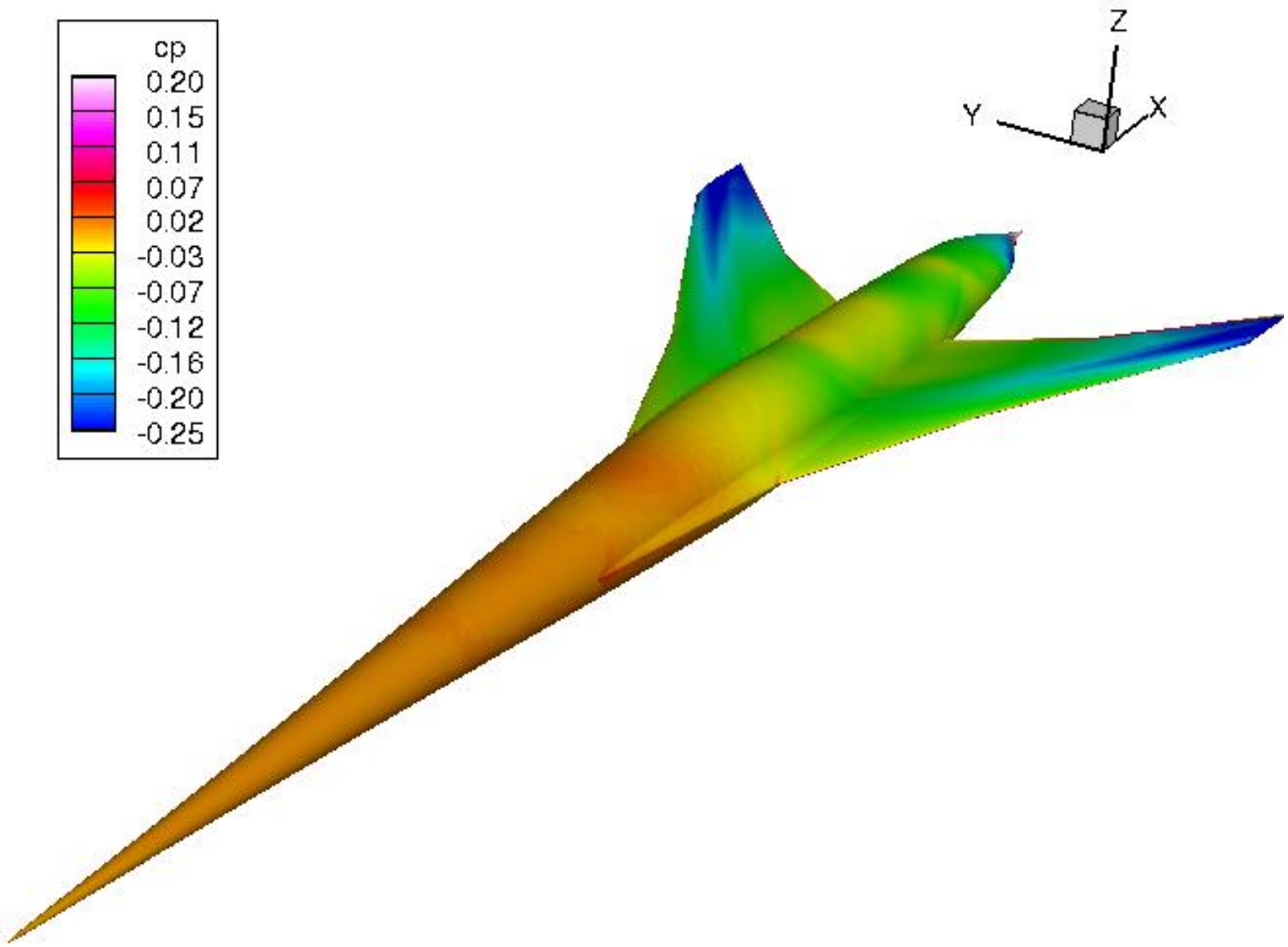
BOEING

FUN3D Cp Contours and Convergence for NASA 25D Axisymmetric Body

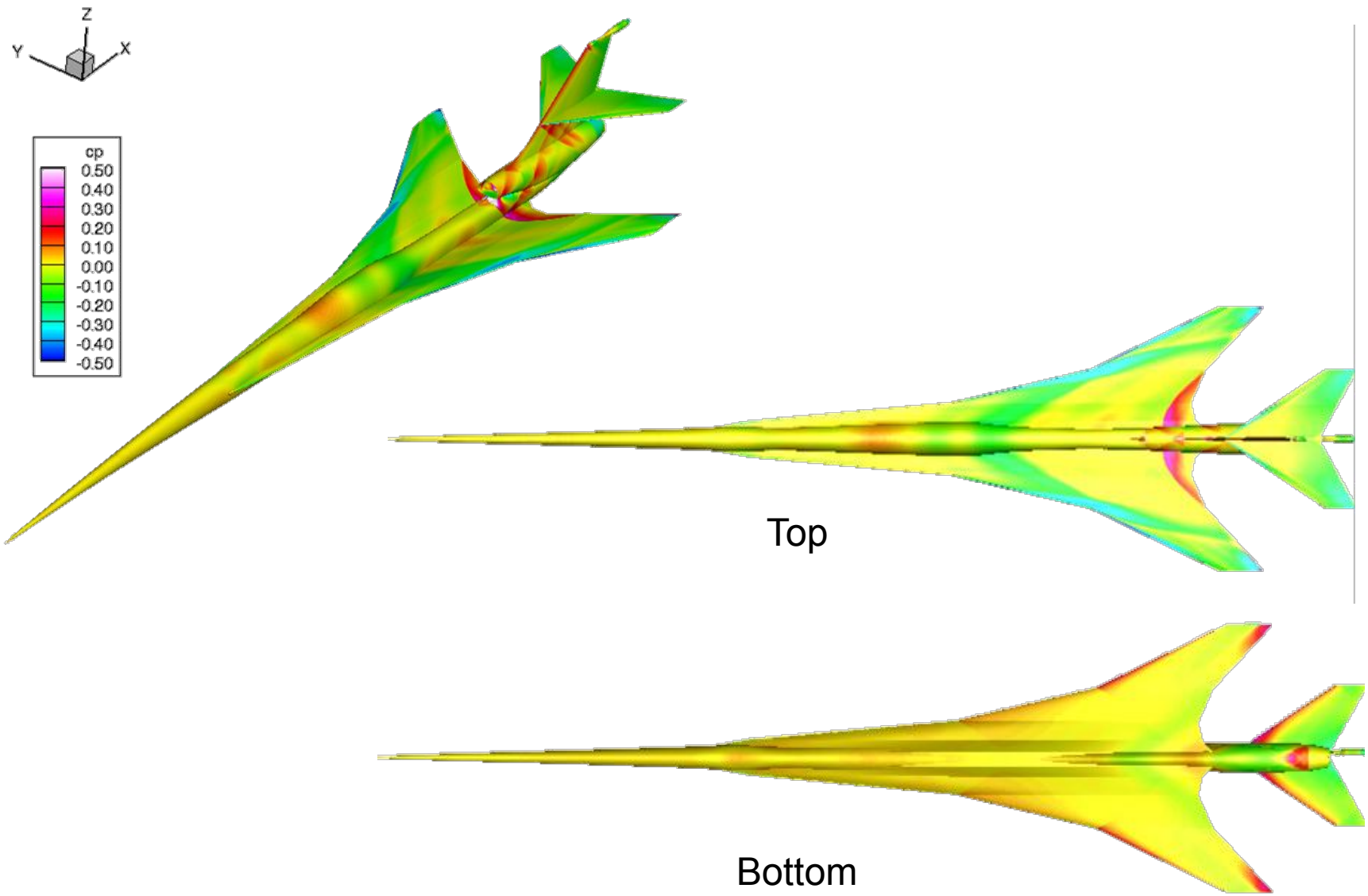




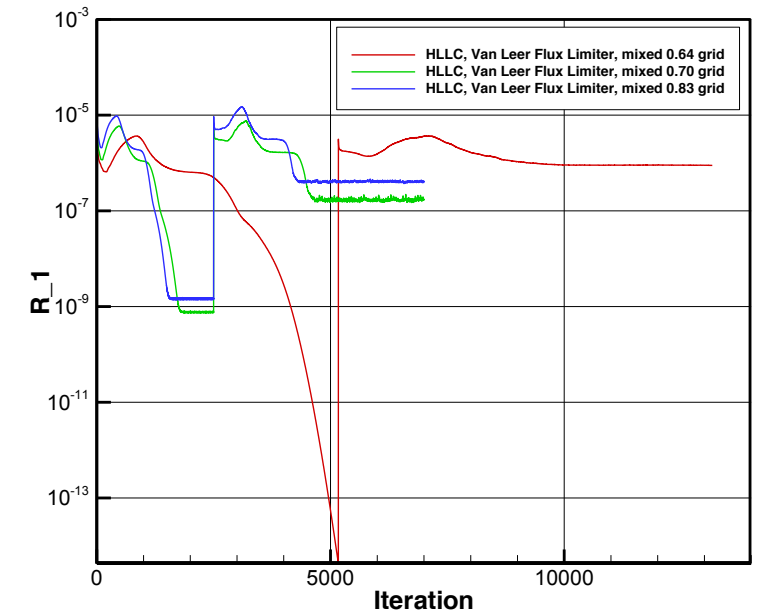


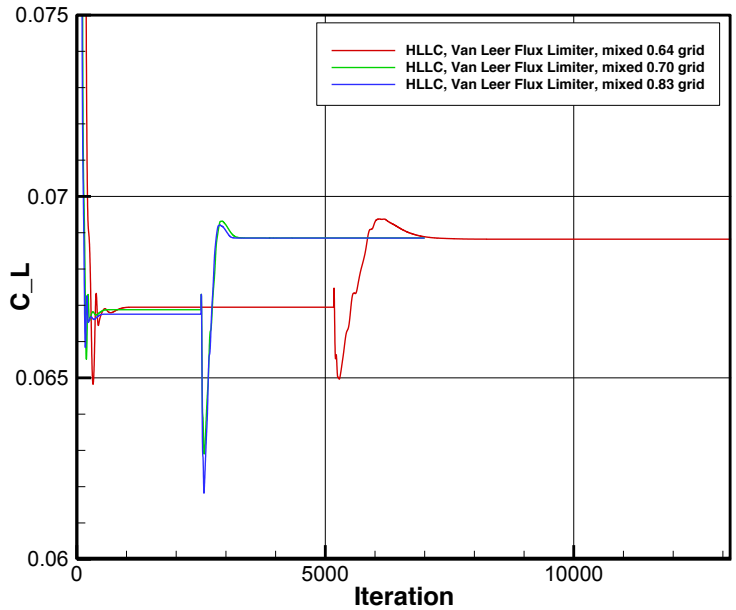

cp
0.20
0.15
0.11
0.07
0.02
-0.03
-0.07
-0.12
-0.16
-0.20
-0.25
Z
Y
X

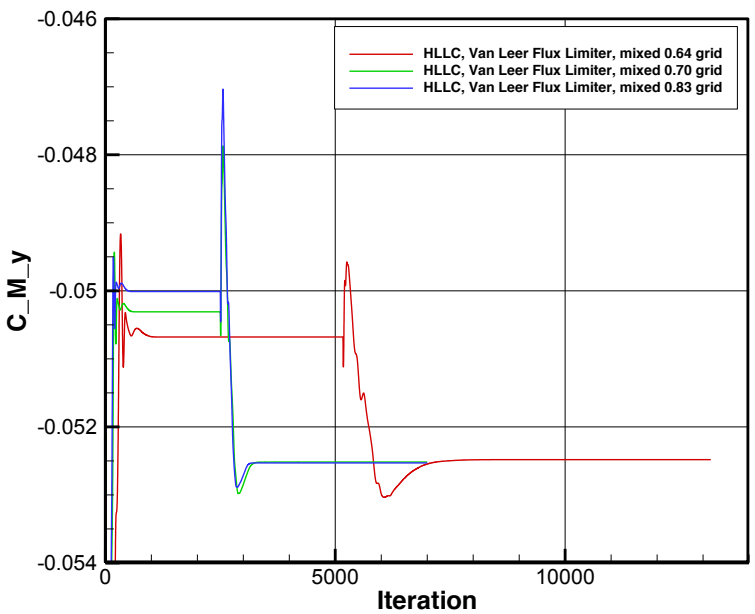
FUN3D Cp Contours for NASA 25D with FTN

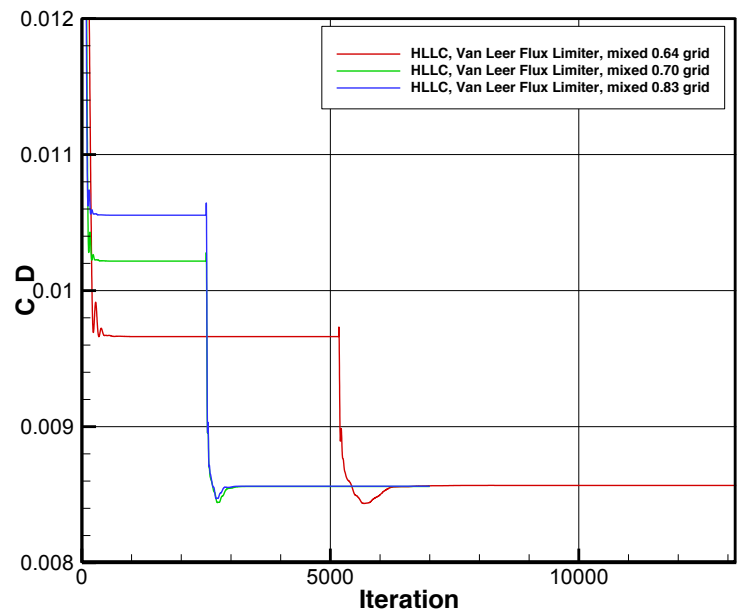


FUN3D Convergence Histories for NASA 25D with FTN

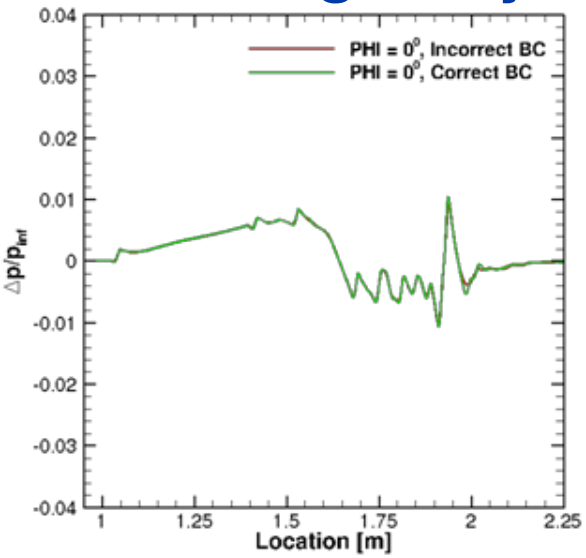


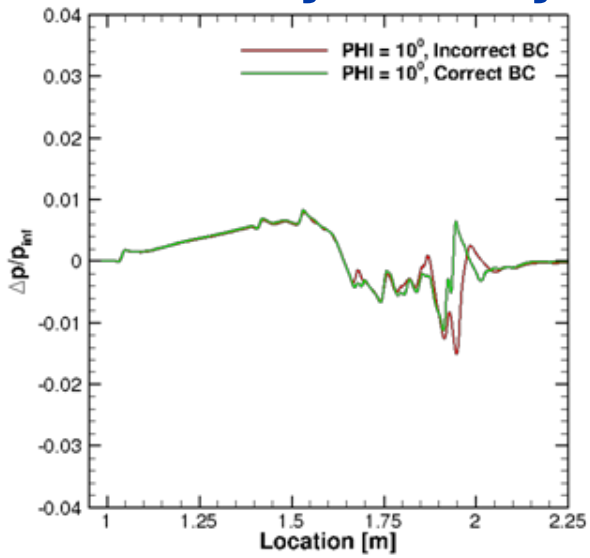


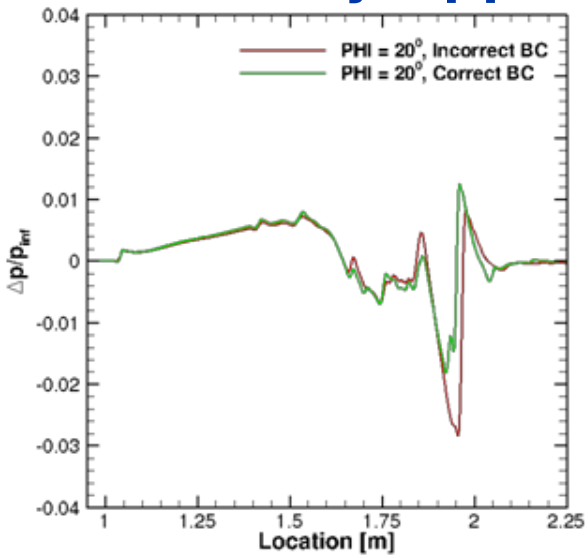


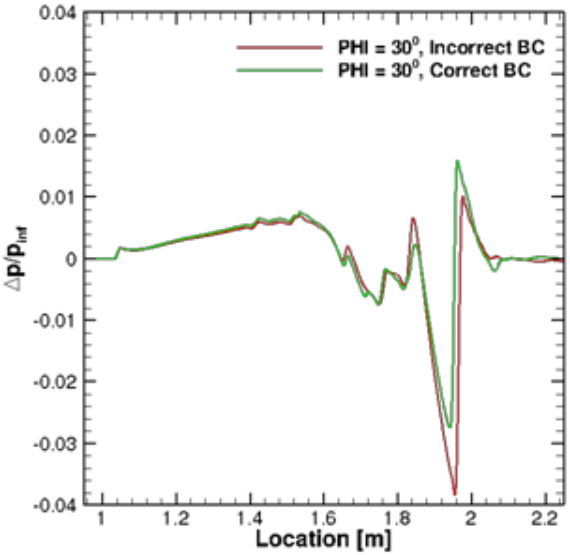


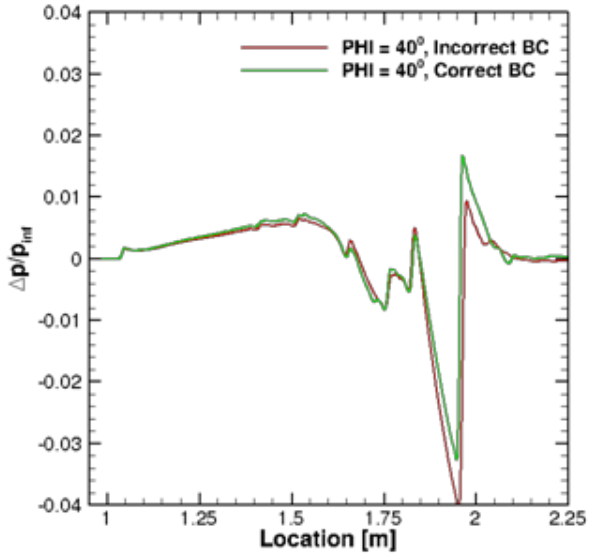
JAXA Wing Body H/L = 0.85: Symmetry BC Incorrectly Applied

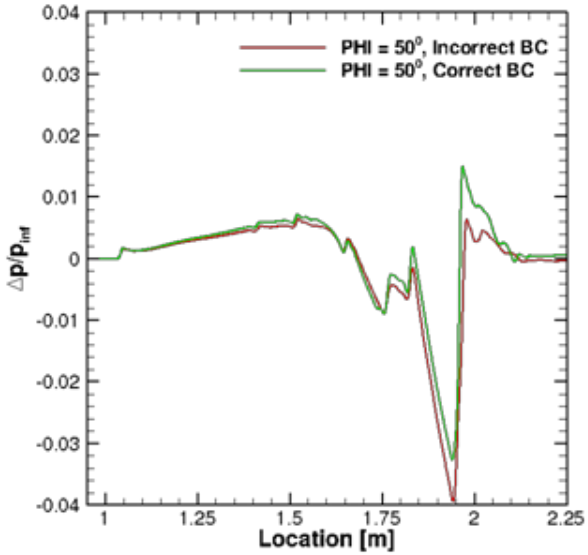












NASA 25D H/L = 1: Symmetry BC Incorrectly Applied