Assessment of Unstructured Euler Methods for Sonic Boom Pressure Signatures Using Grid Refinement and Domain Rotation Methods

Susan Cliff

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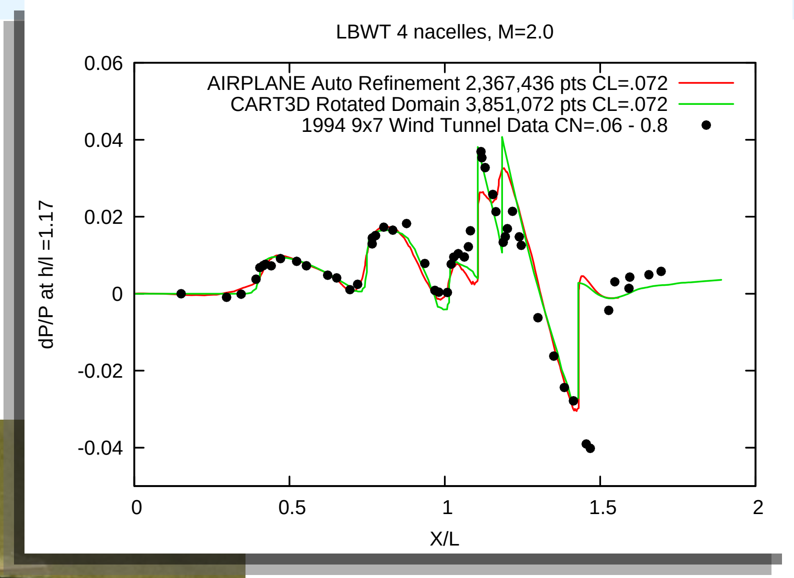
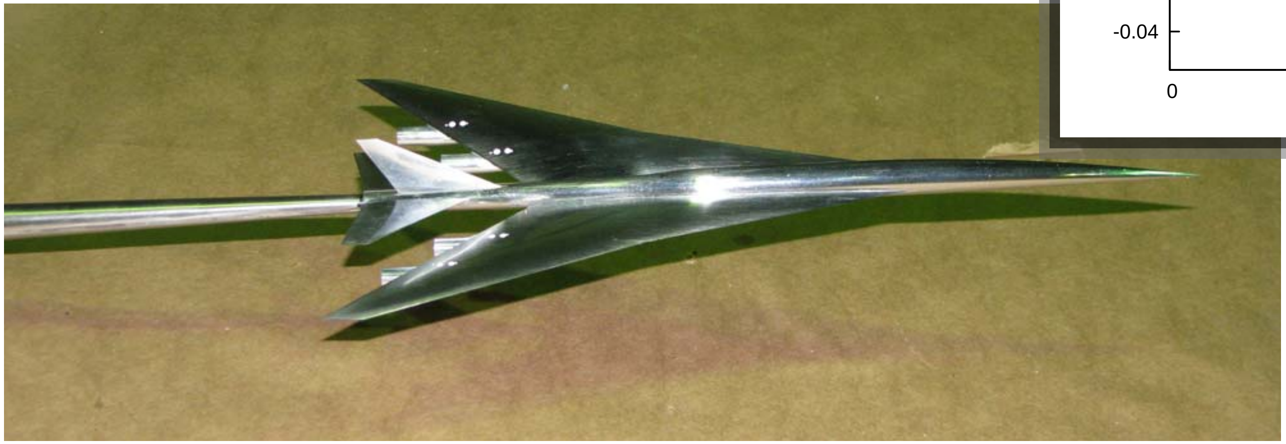




Acknowledgments

Scott Thomas

Matt McMullen

John Melton

Don Durston

Euler Unstructured Methods Studied

- AIRPLANE
  - Tetrahedral body-fitted volume grid
  - Smooth gradation from dense surface to outer boundaries
  - No specific orientation of volume cells
  - Refinement occurs *after* initial volume mesh is generated

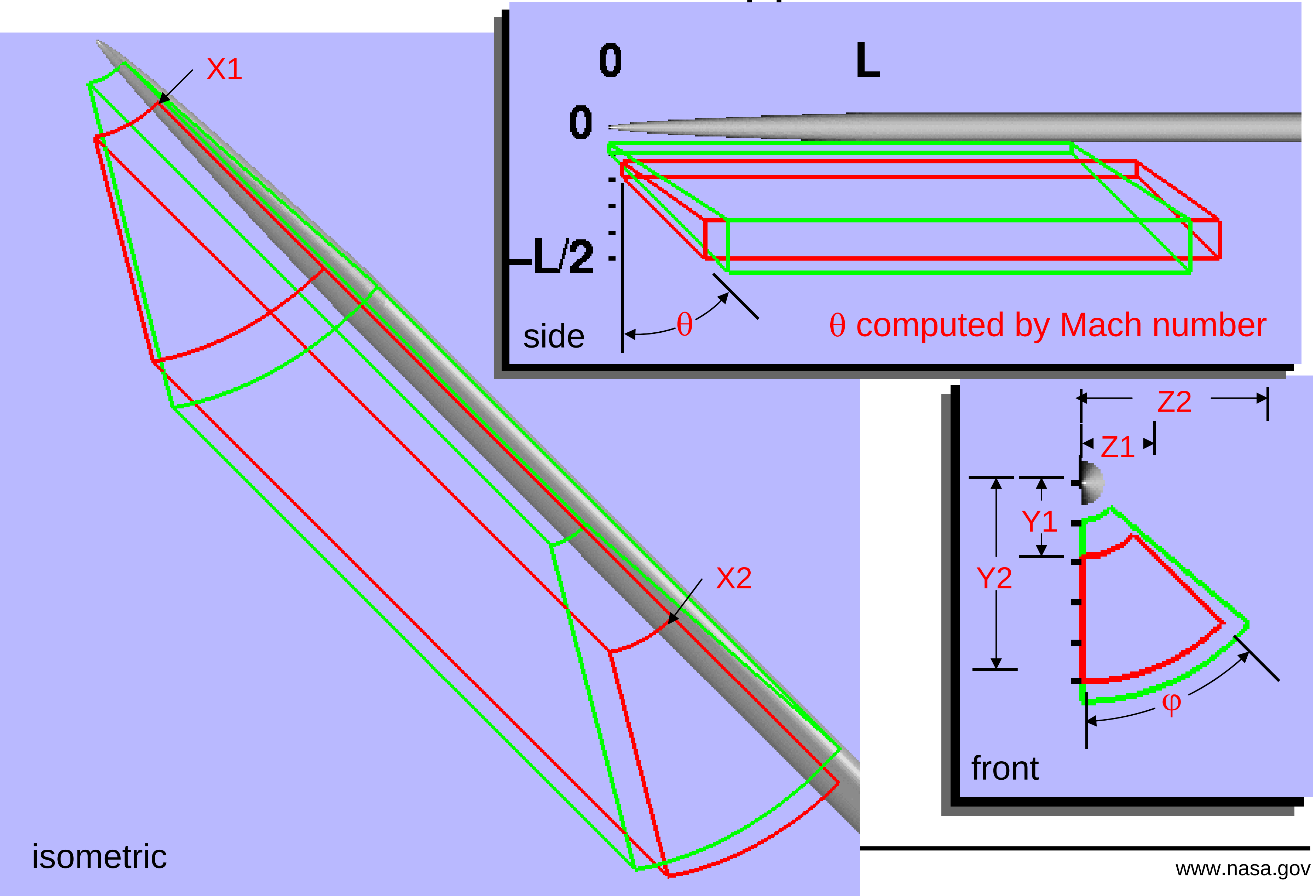
- CART3D
  - Cartesian non body-fitted volume grid
  - 2 to 1 (minimum) gradation from dense surface to outer boundaries
  - Volume cells oriented vertical/horizontal regardless of model angle of attack
  - Refinement occurs *during* volume mesh generation

Assessment Study Goals & Grid Characterization

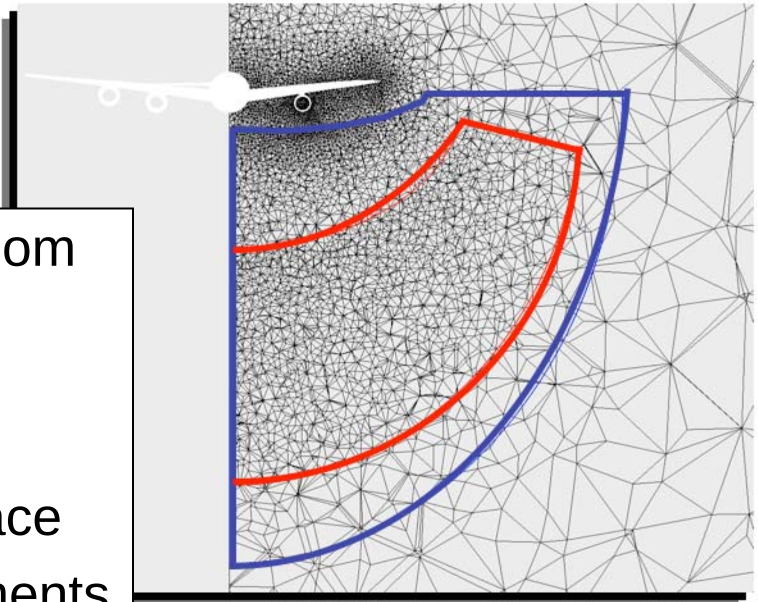
- Develop efficient and accurate sonic boom analysis method
  - Suitable for aerodynamic shape optimization
    - Computational grids of reasonable size
  - Refinement level and zone boundaries non-changing during design
    - Improved gradient information
    - Sufficiently dense to permit vehicle changes without loss of accuracy

- Characterization of grids established on series of known shapes with experimental data
  - Edge length as a function of vehicle length evaluated on several vehicle types
    - Characterized by sampling the volume grid at cutting planes
      - symmetry plane
      - X/L of ½,1,and 3/2.
  - Provides guidelines for alternative vehicle shapes with unknown boom levels

Elliptical-Annular Swept Sector (EASS) Volume Grid Refinement Approach



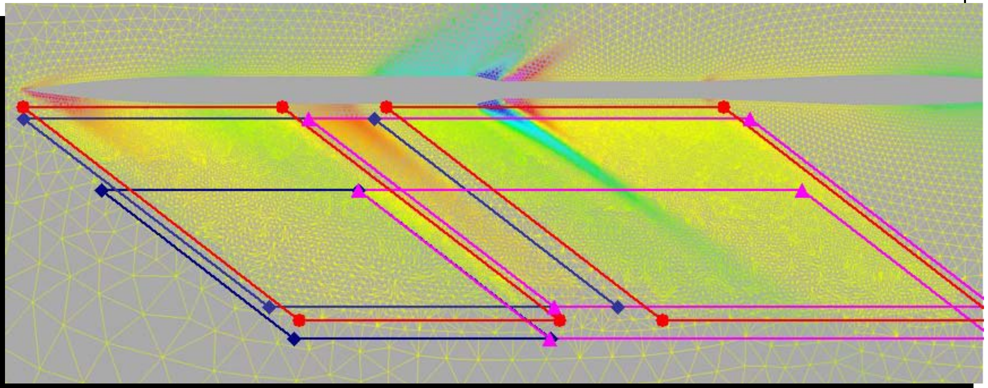
Benefits of EASS Grid Refinement



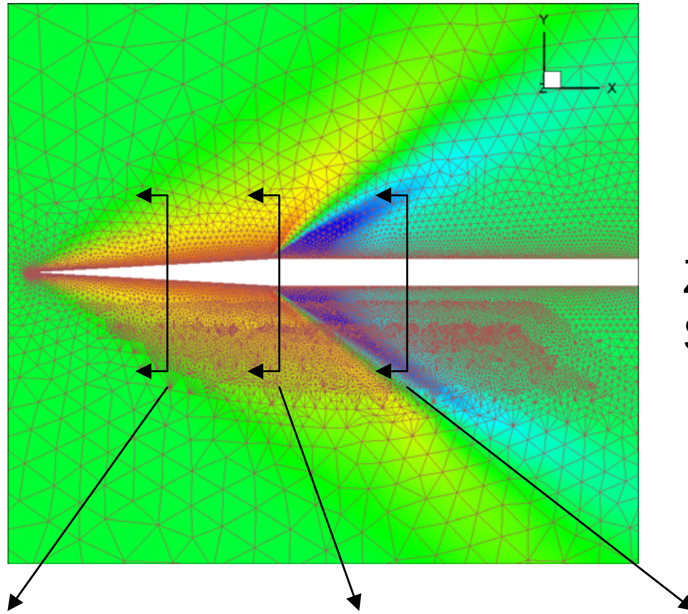
- Refines in zone of influence for sonic boom computations
  - Swept at Mach angle
  - Annular (donut) shape allows for refinement some distance from surface
  - Refinement nesting (multiple refinements in coarse regions)
  - Elliptical shape for winged configurations
  - Circular shape for cylindrical components
  - Simple to evaluate 3D effects (φ – off track angle)

Sonic Boom Prediction Technique

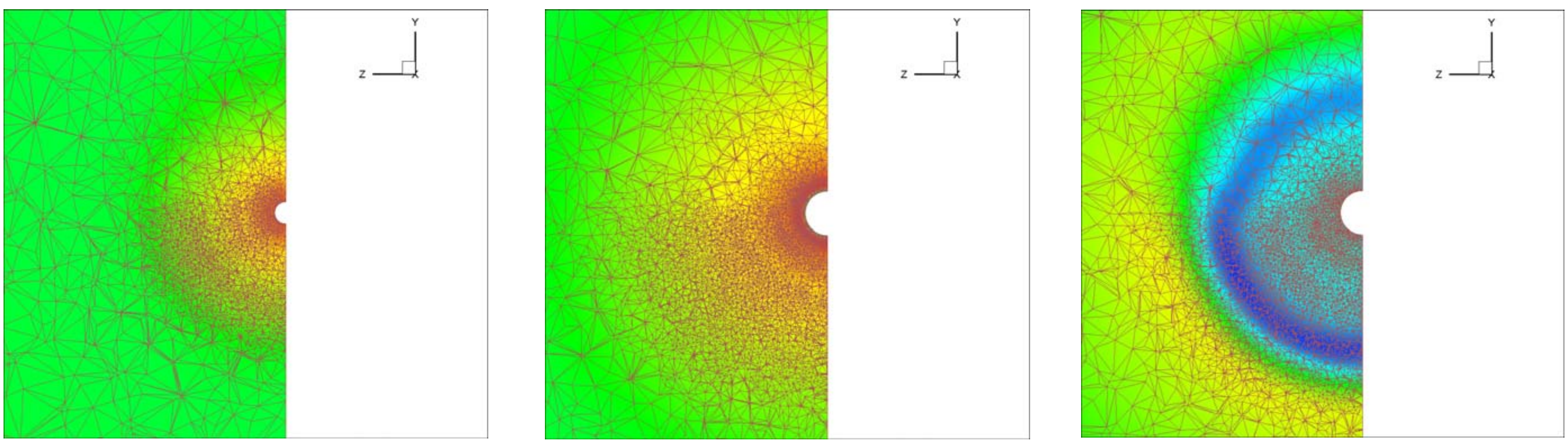
- Utilize EASS Refinement Regions
  - AIRPLANE: Tetrahedra edge split *after* grid generation
  - CART3D: Cartesian grid generated with uniform refinement of square cells *during* grid generation
- Refine grid until little or no variation in signature
  - Correlation with experiment is suitable for design
  - Add refinement regions for minimal variation in cell size (AIRPLANE)
- Extrapolate using NFBOOM (ANET) from 0.4 body lengths to the experimental distance
  - Reduces grid size for design with optimization



Cone Cylinder: AIRPLANE EASS Refinement



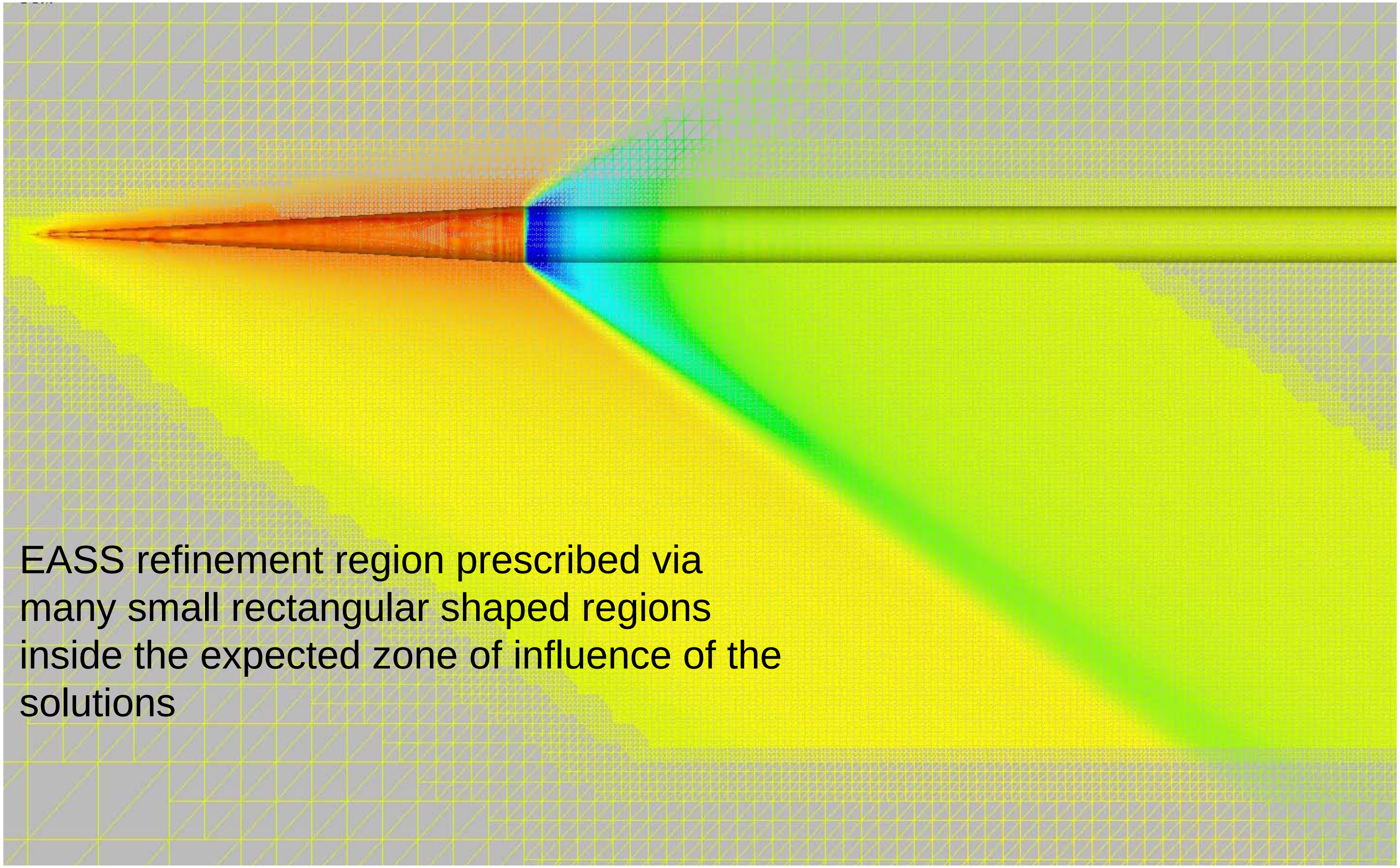
Z = 0
Symmetry Plane



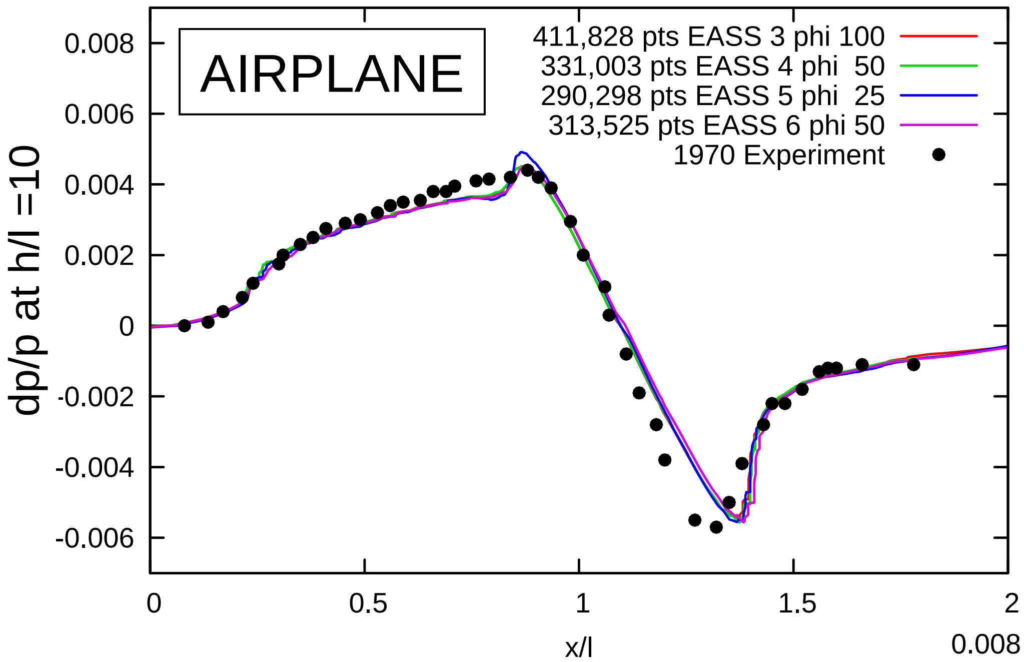
X= 4.3 (L/2) X= 8.6 (L) X=12.9 (3L/2)

Cone Cylinder: CART3D EASS Refinement

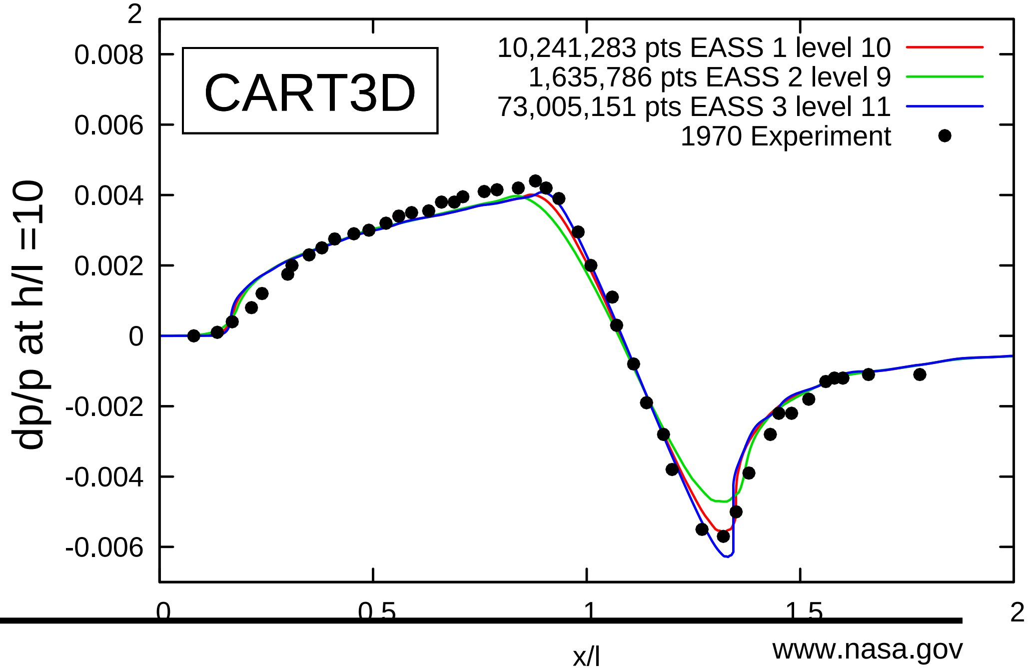
Symmetry Plane for Refinement Level 10



Cone Cylinder - Mach 1.68, AoA 0.0

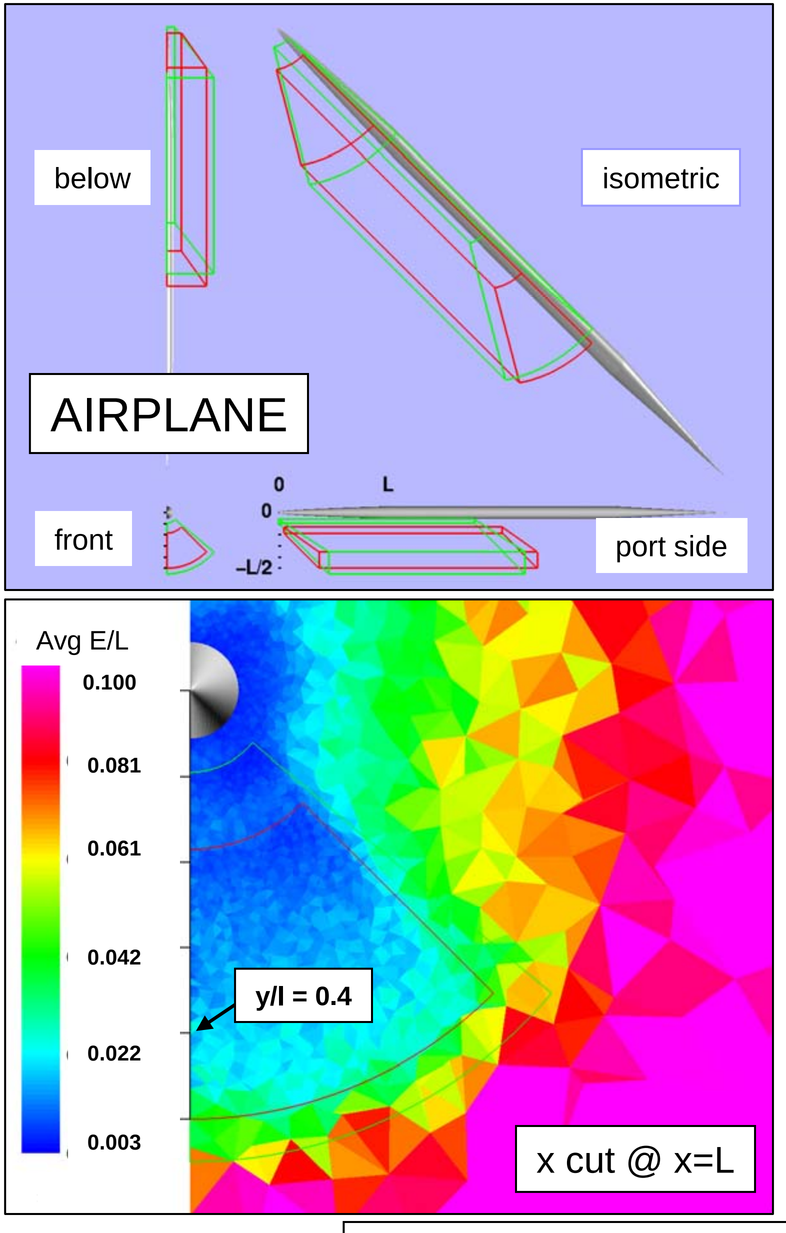


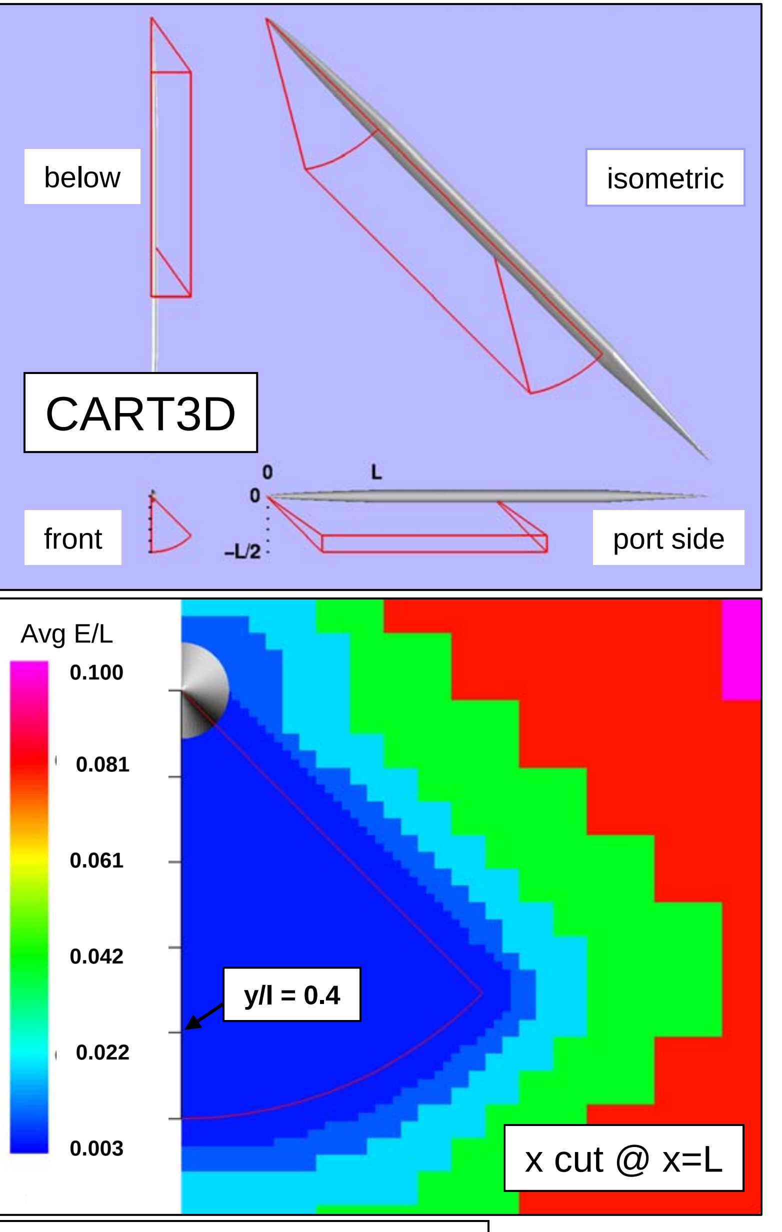
data extrapolated from h/l = 0.4



Experimental data from ARC 9x7

Example of EASS Characterization (Cone Cylinder)





Cells colored by average edge length divided by body length

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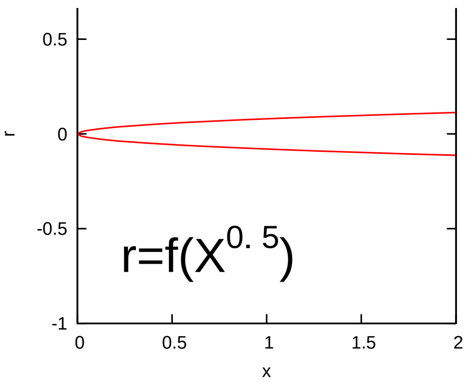
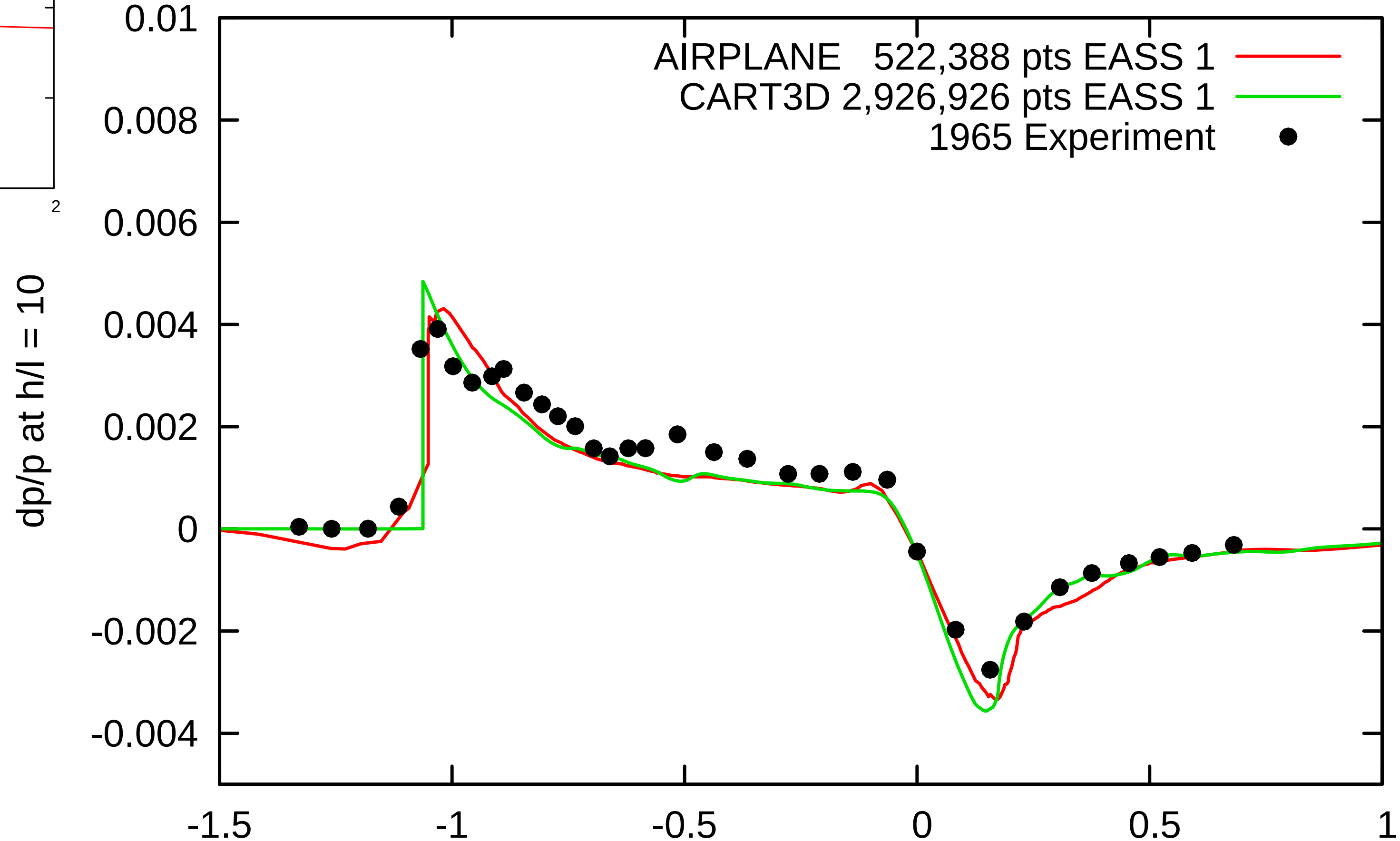
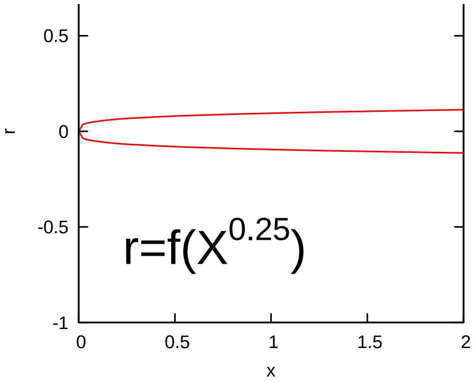
Parabolic Body of Revolution-Cylinder
Mach 1.41, AoA = 0.0

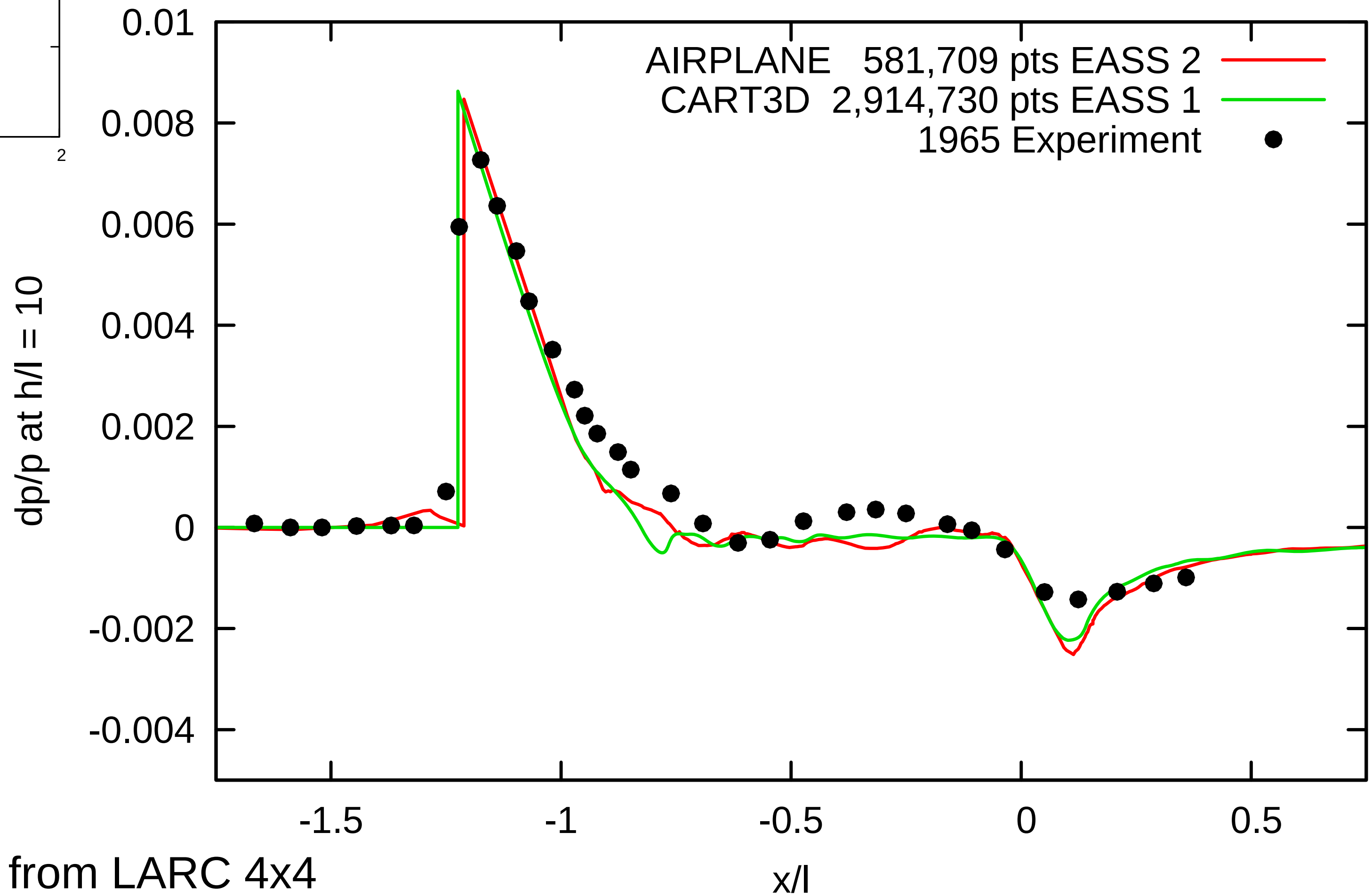




Experimental data from LARC 4x4

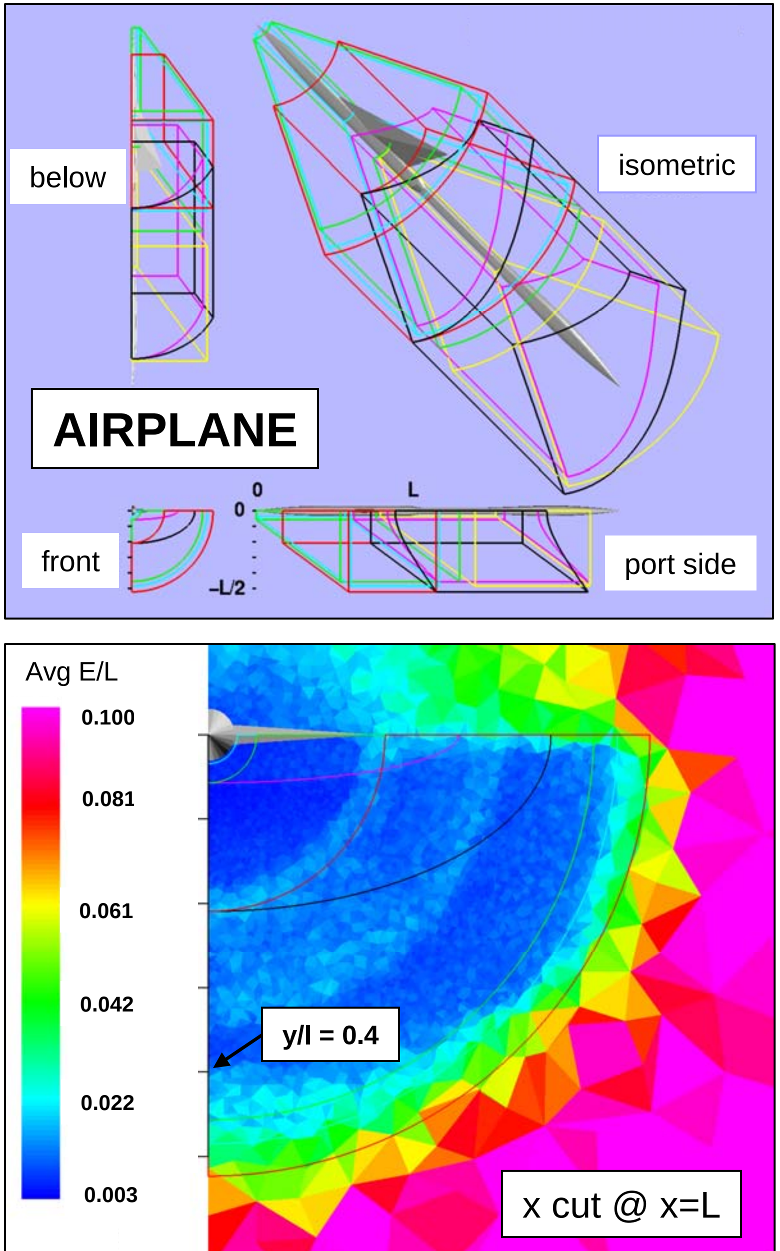
Quartic Body of Revolution-Cylinder
Mach 1.41, AoA = 0.0

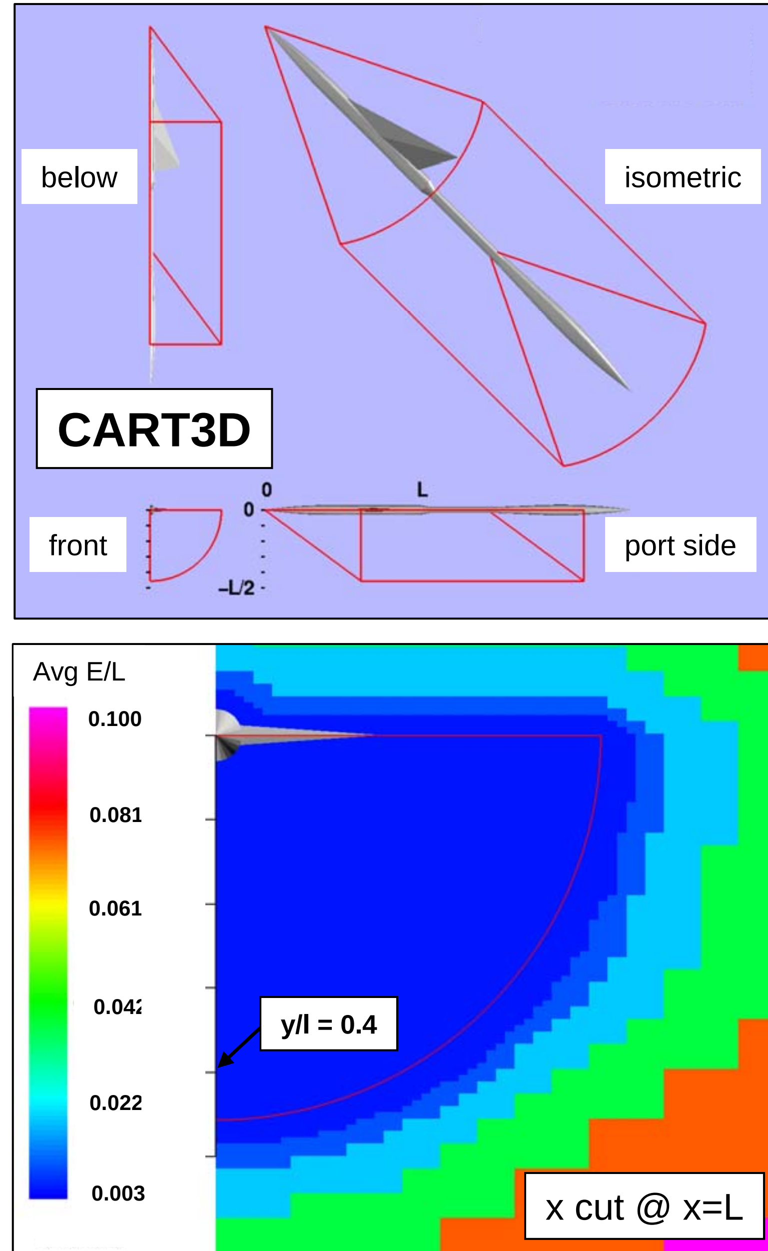




Experimental data from LARC 4x4

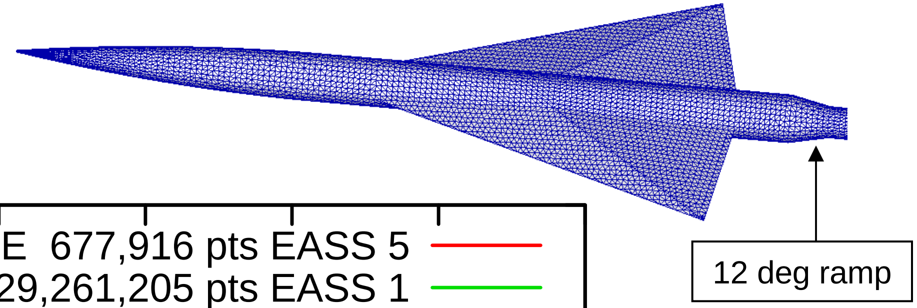
Example of EASS Characterization (Delta Wing Body)

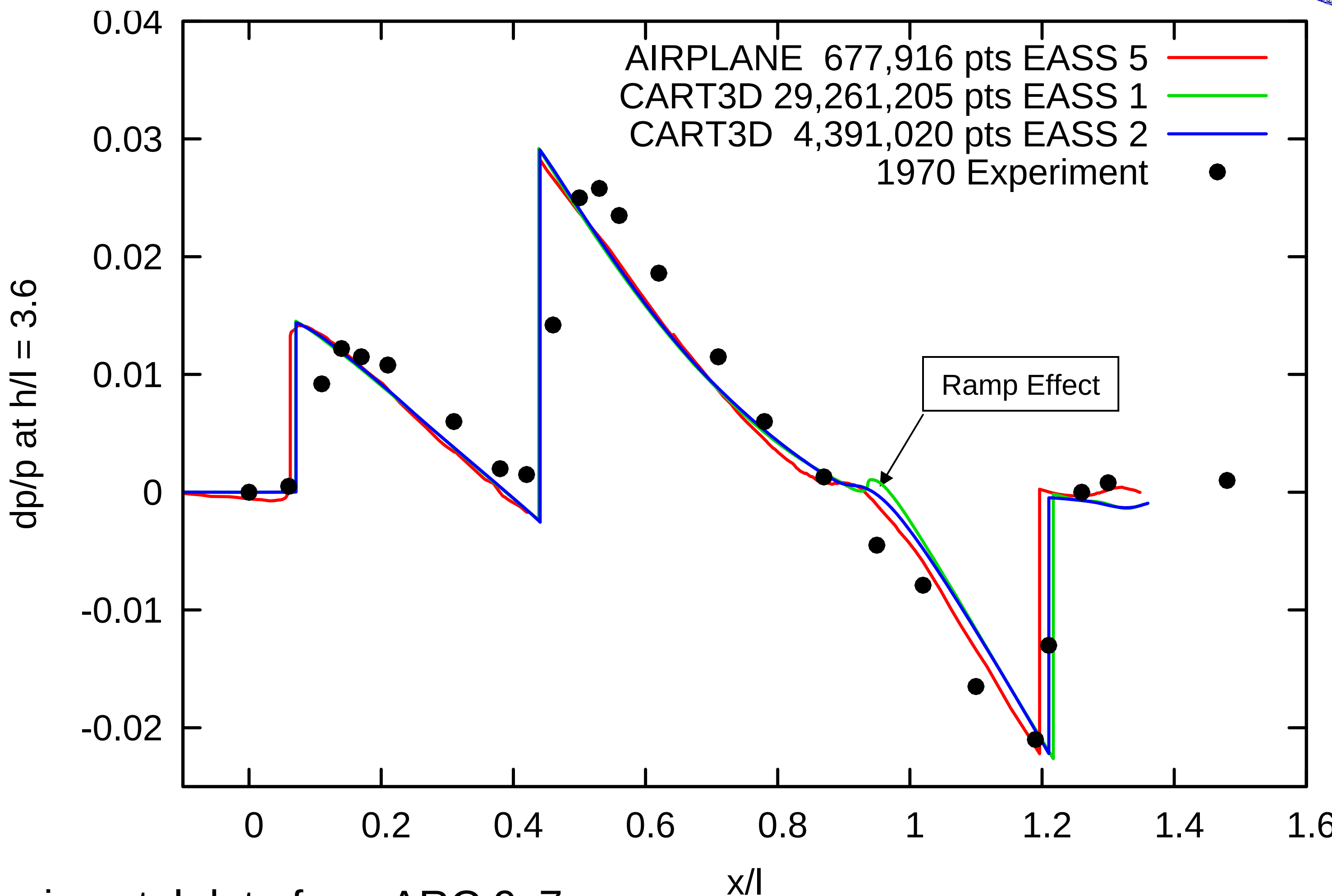




Cells colored by average edge length divided by body length

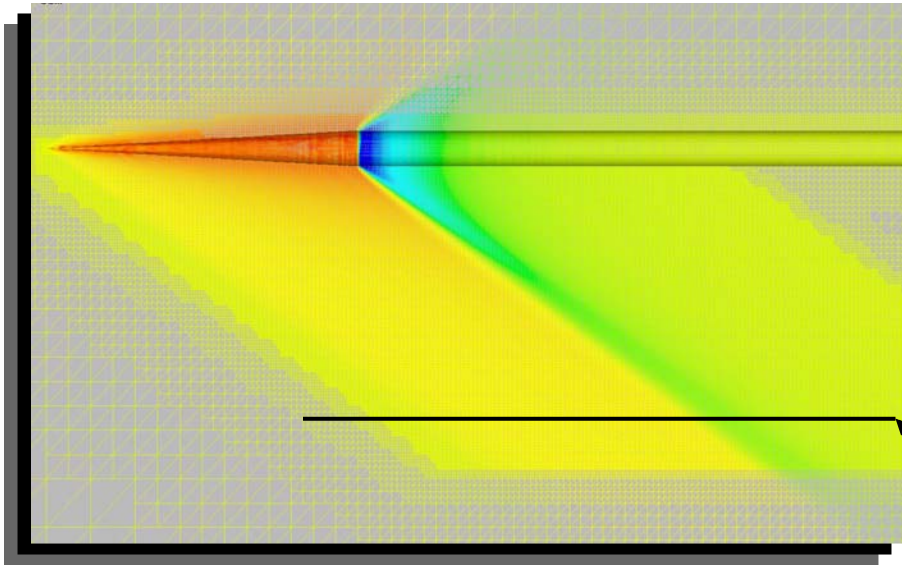
69° Delta Wing Body
Mach 1.68, CL = 0.15





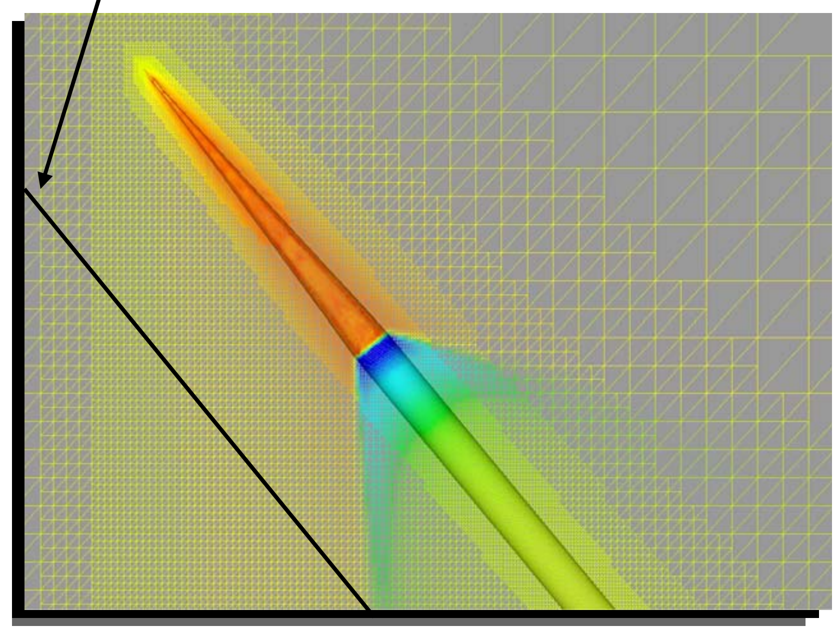
Experimental data from ARC 9x7

CART3D Domain Rotation Study



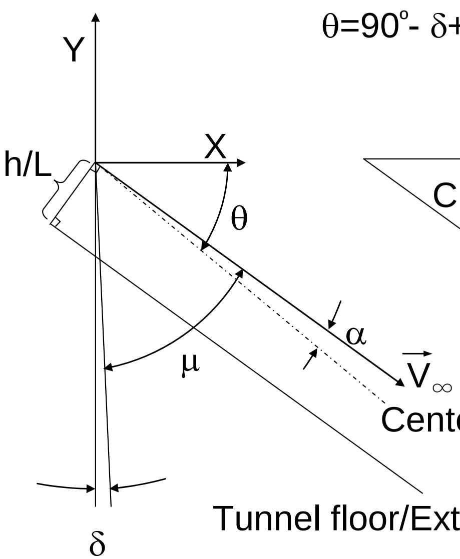
Align Mach angle with grid by vehicle rotation

Pressure signature extraction lines



Grid Rotation Formula:

$\theta = 90^{\circ} - \delta + \alpha - \arcsin(1/M_{\infty})$



Legend

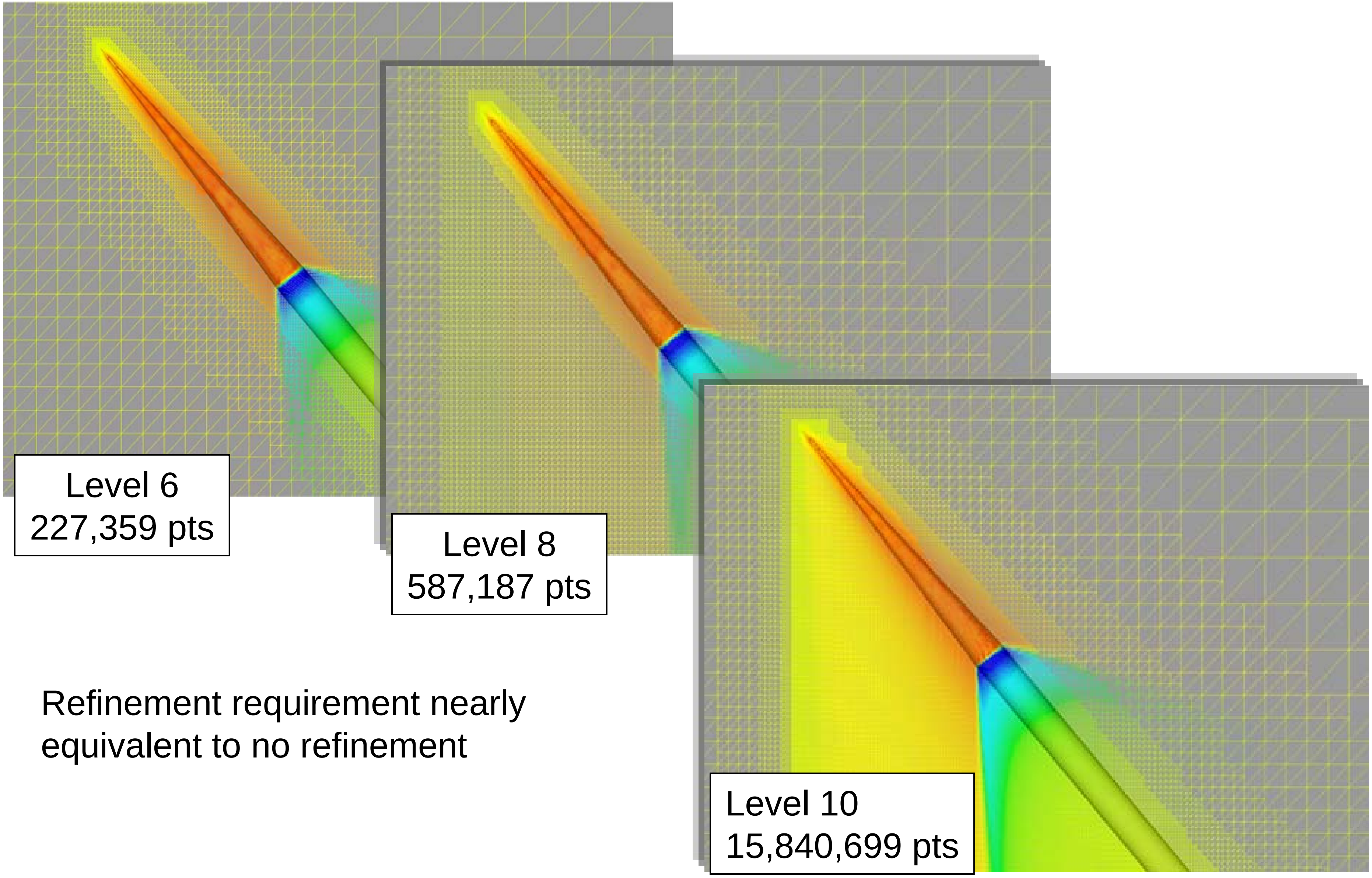
Characteristic angle: $\mu = \arcsin(1/M_{\infty})$

Aircraft rotation angle: θ

Grid offset angle: δ

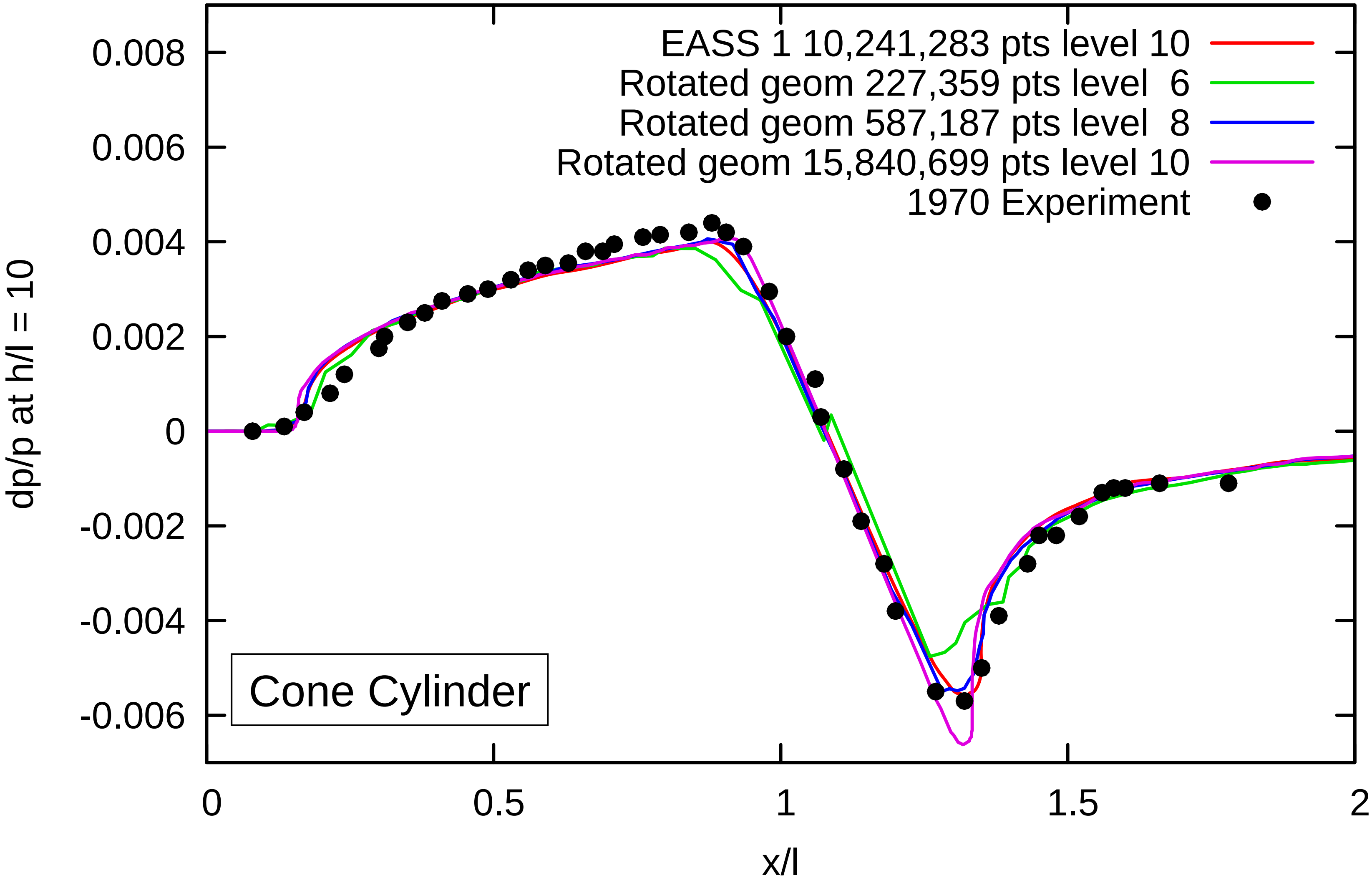
Angle of attack: α

CART3D Domain Rotation Study

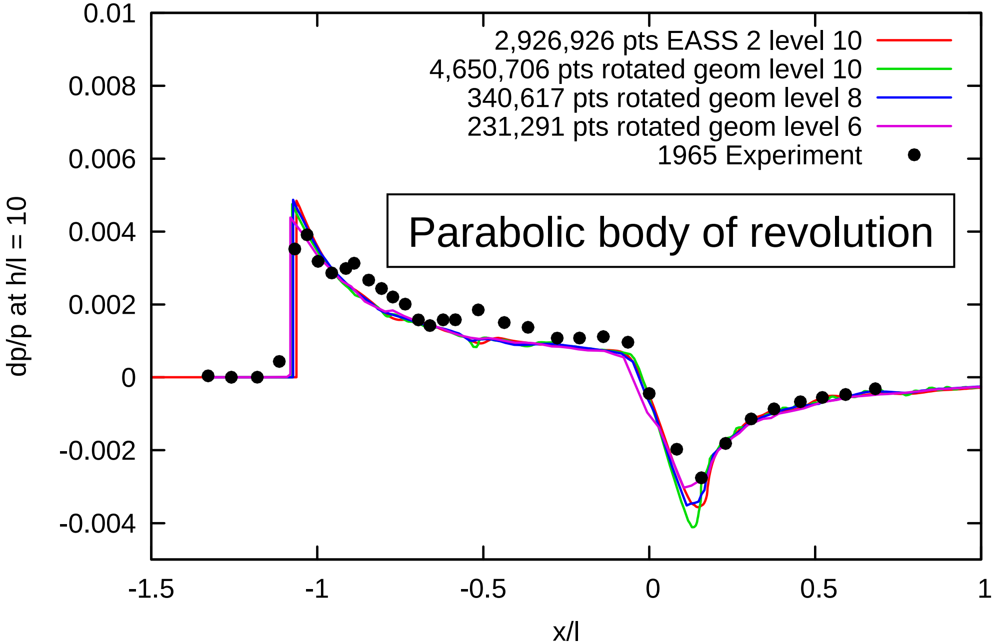


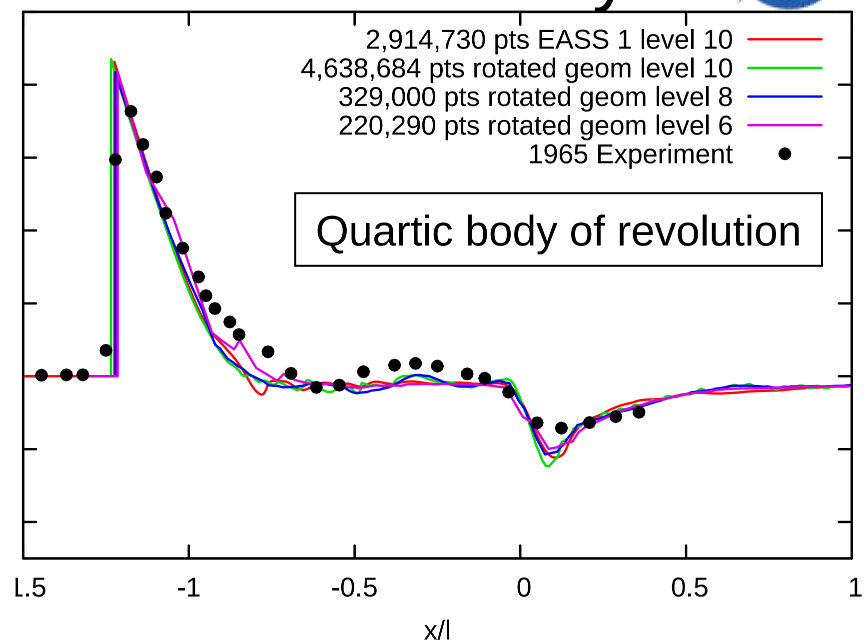
Refinement requirement nearly equivalent to no refinement

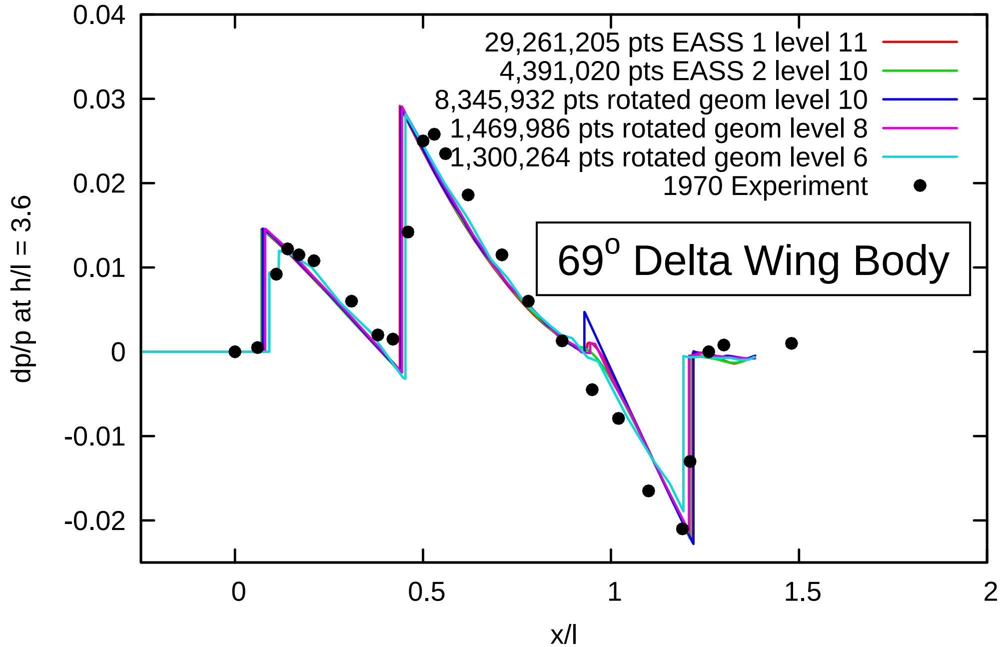
Rotation Results & Grid Refinement Study



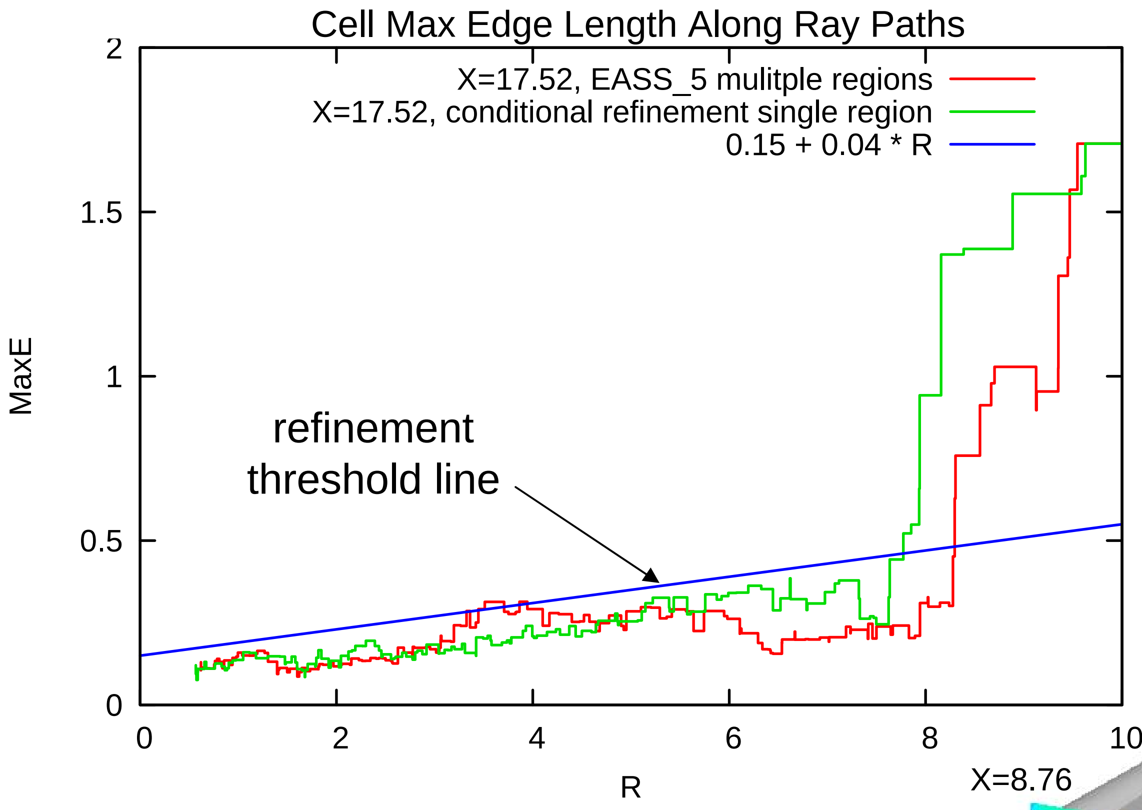
Domain Rotation & Grid Refinement Study

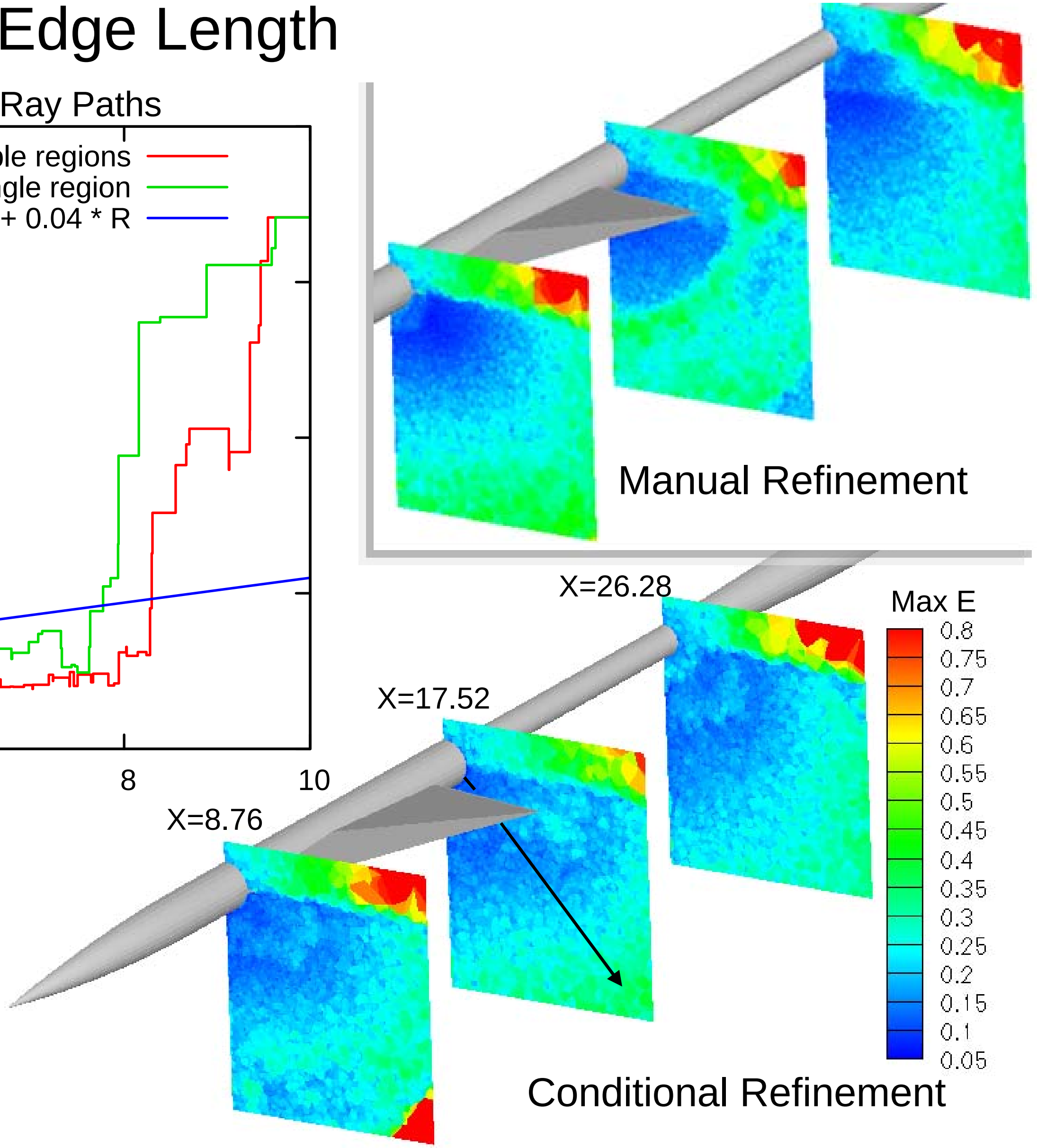






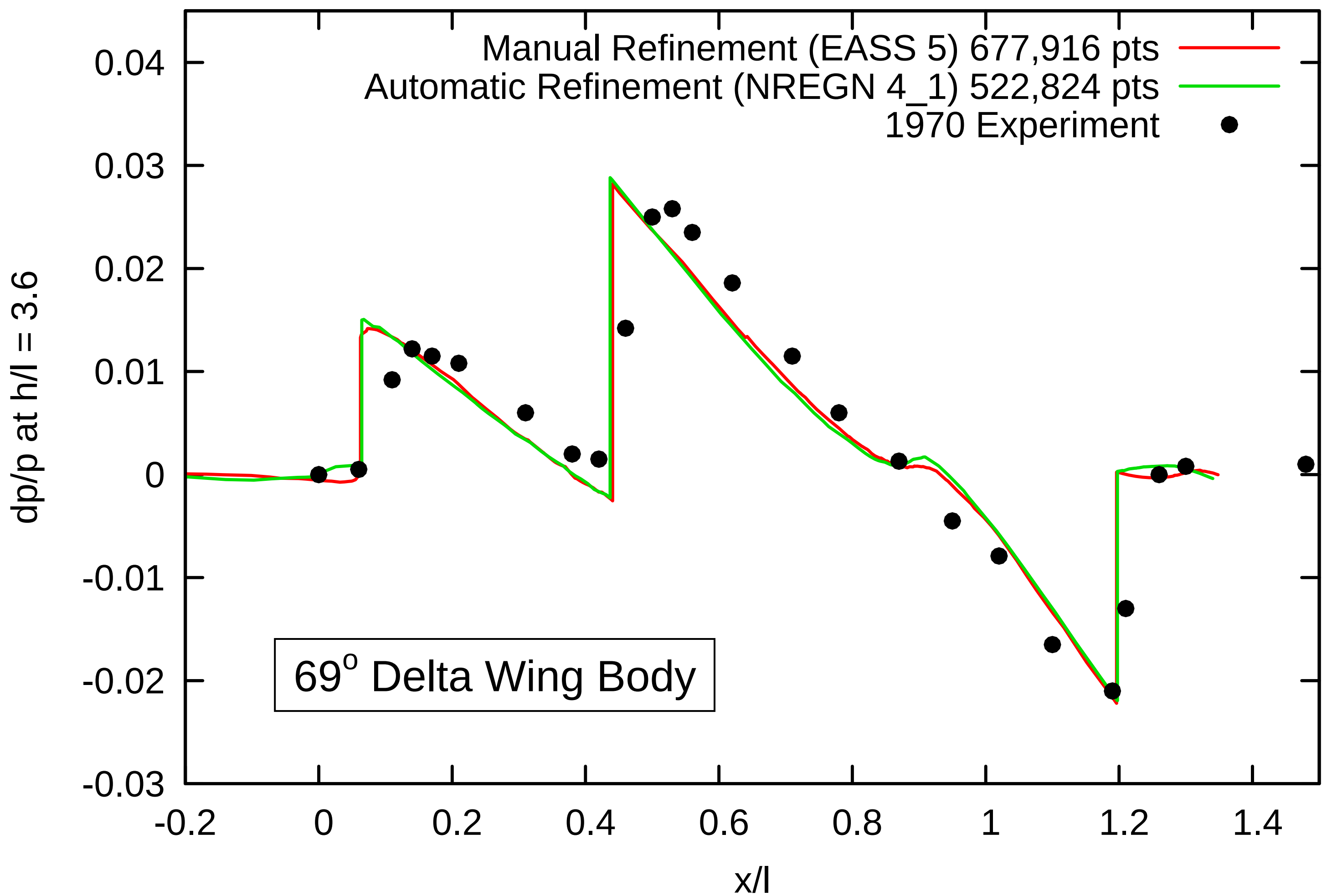
AIRPLANE Automatic Cell Refinement Based on Edge Length



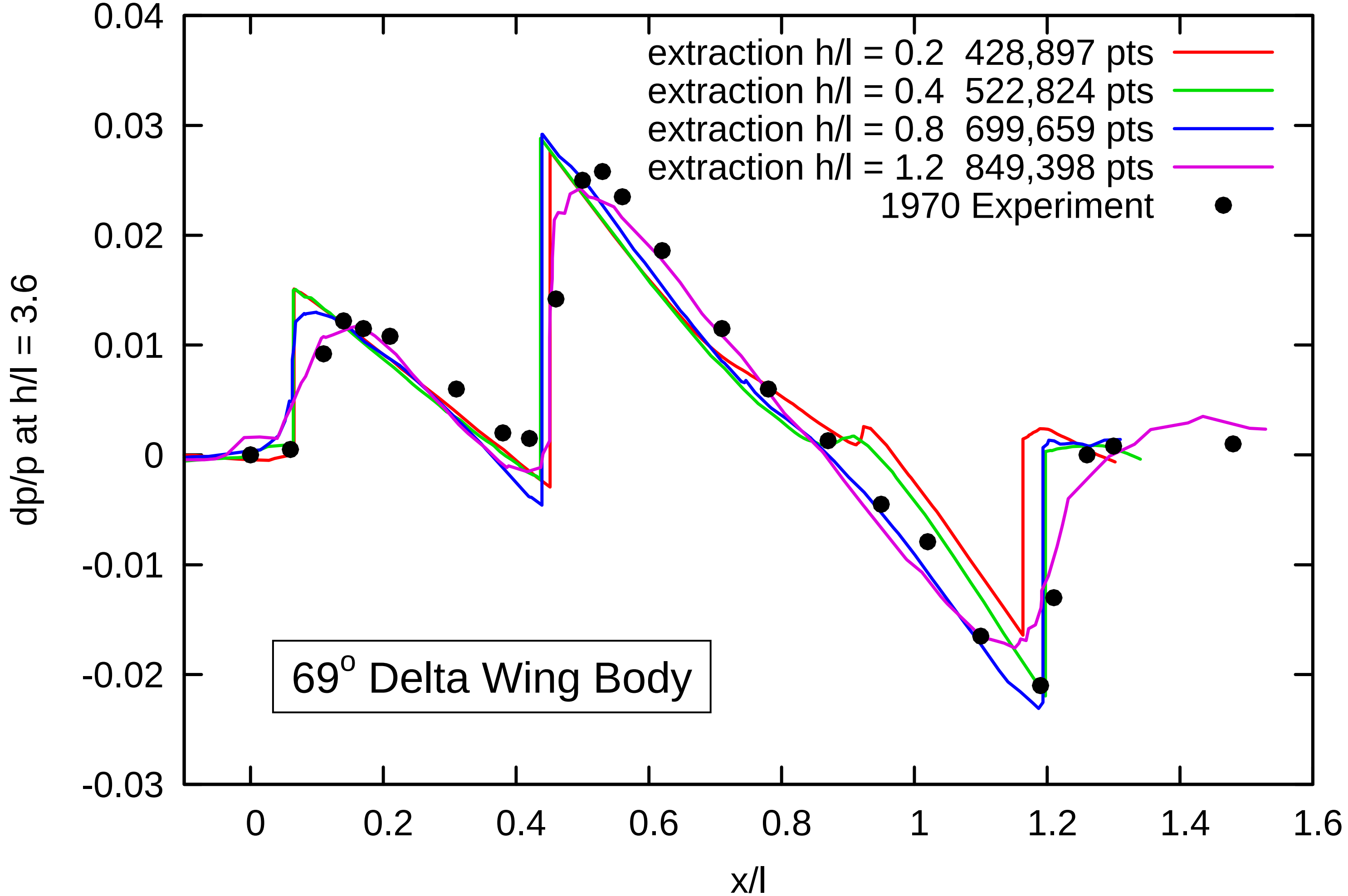


- Simplifies the process of defining EASS refinement regions
- Only necessary to provide a single refinement region

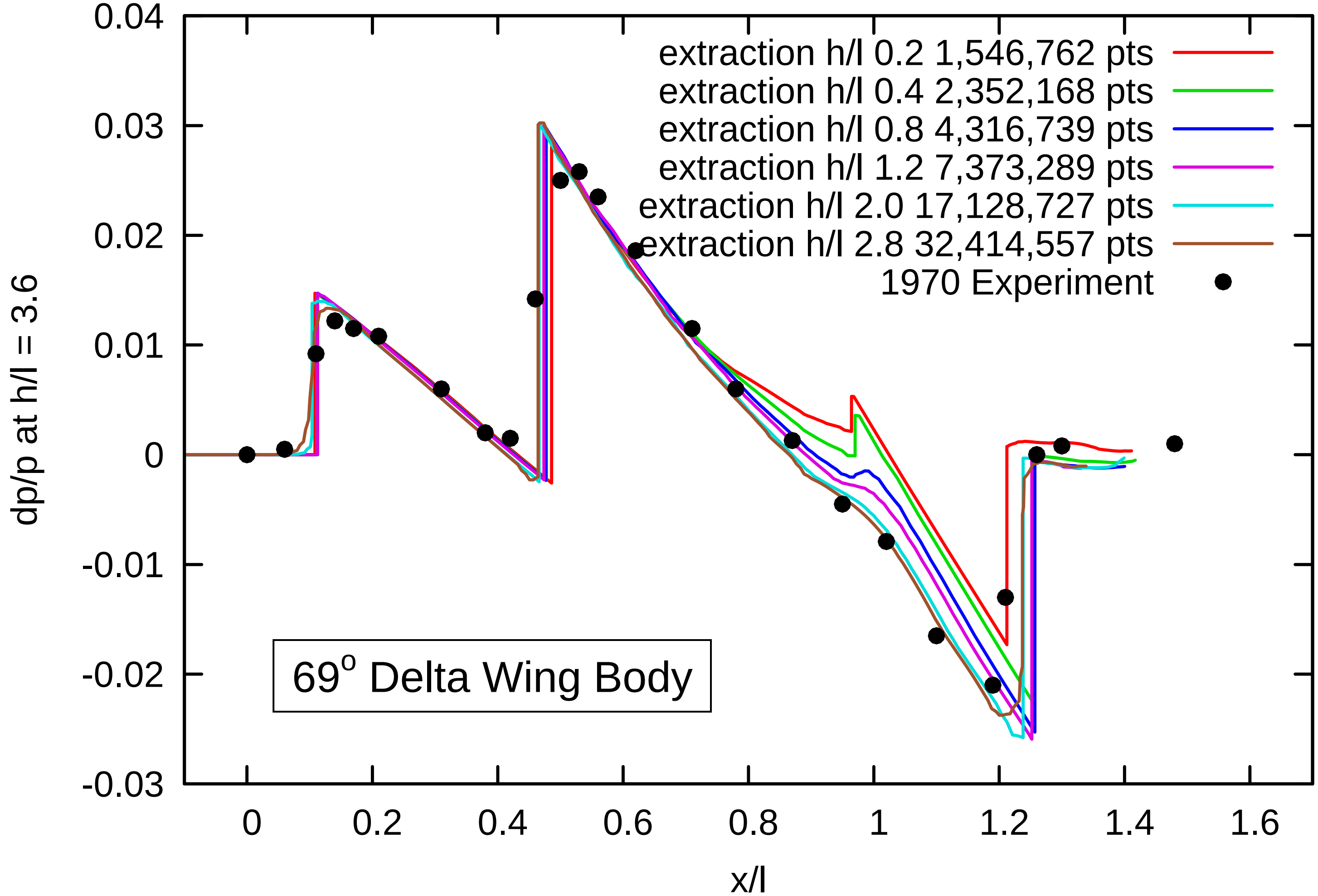
Validation of AIRPLANE Auto Cell Refinement
Auto Refinement vs. Manual



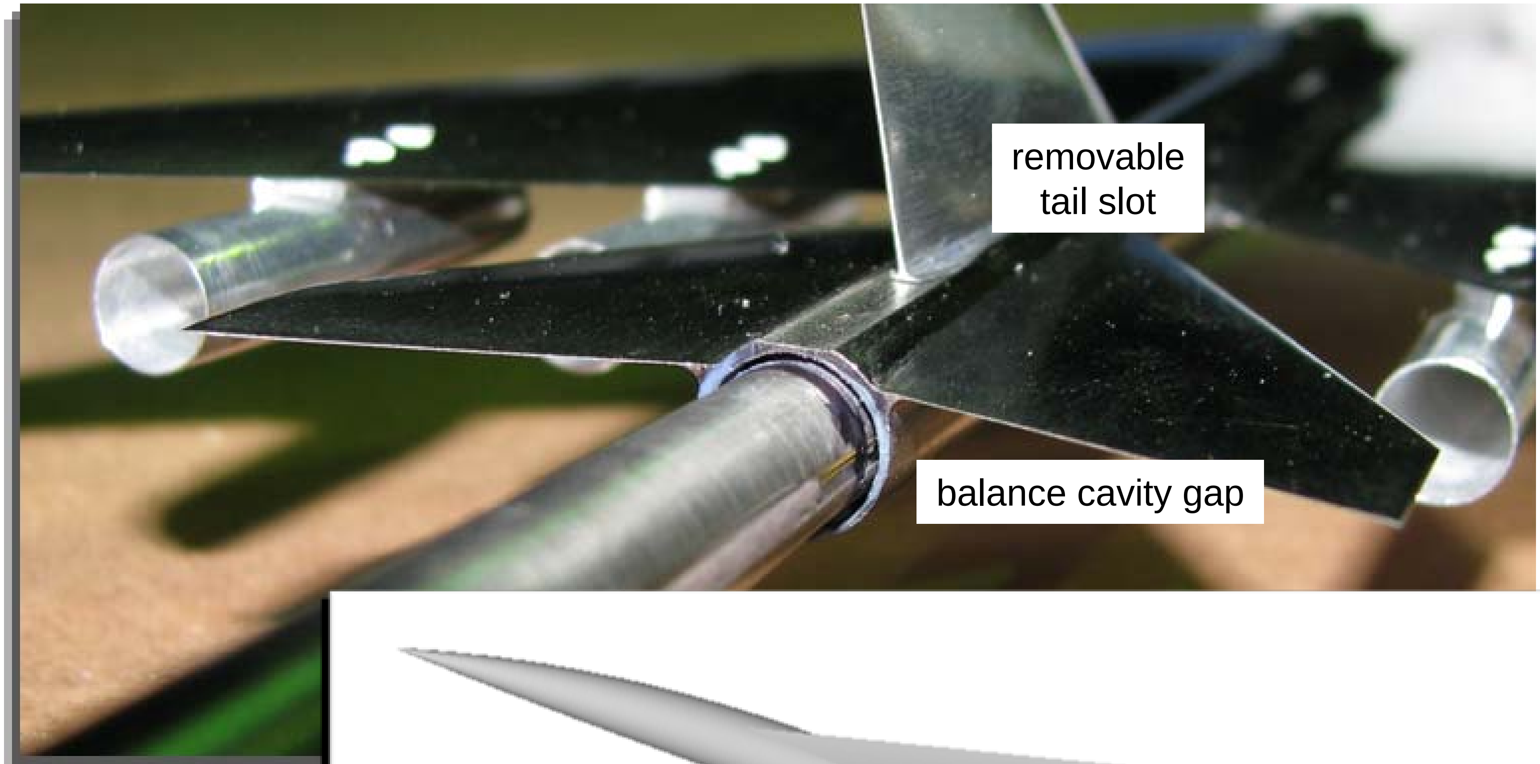
Delta Wing Body Signature Extraction Distance Study with AIRPLANE via Auto Refinement

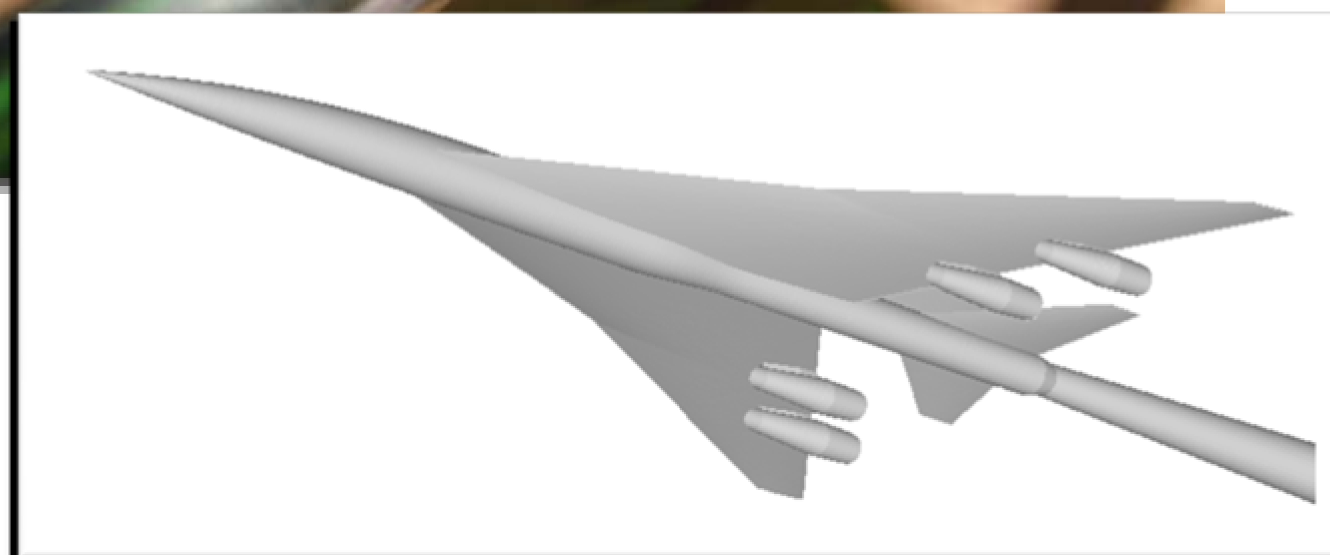


Signature Extraction Distance Study with CART3D Domain Rotation

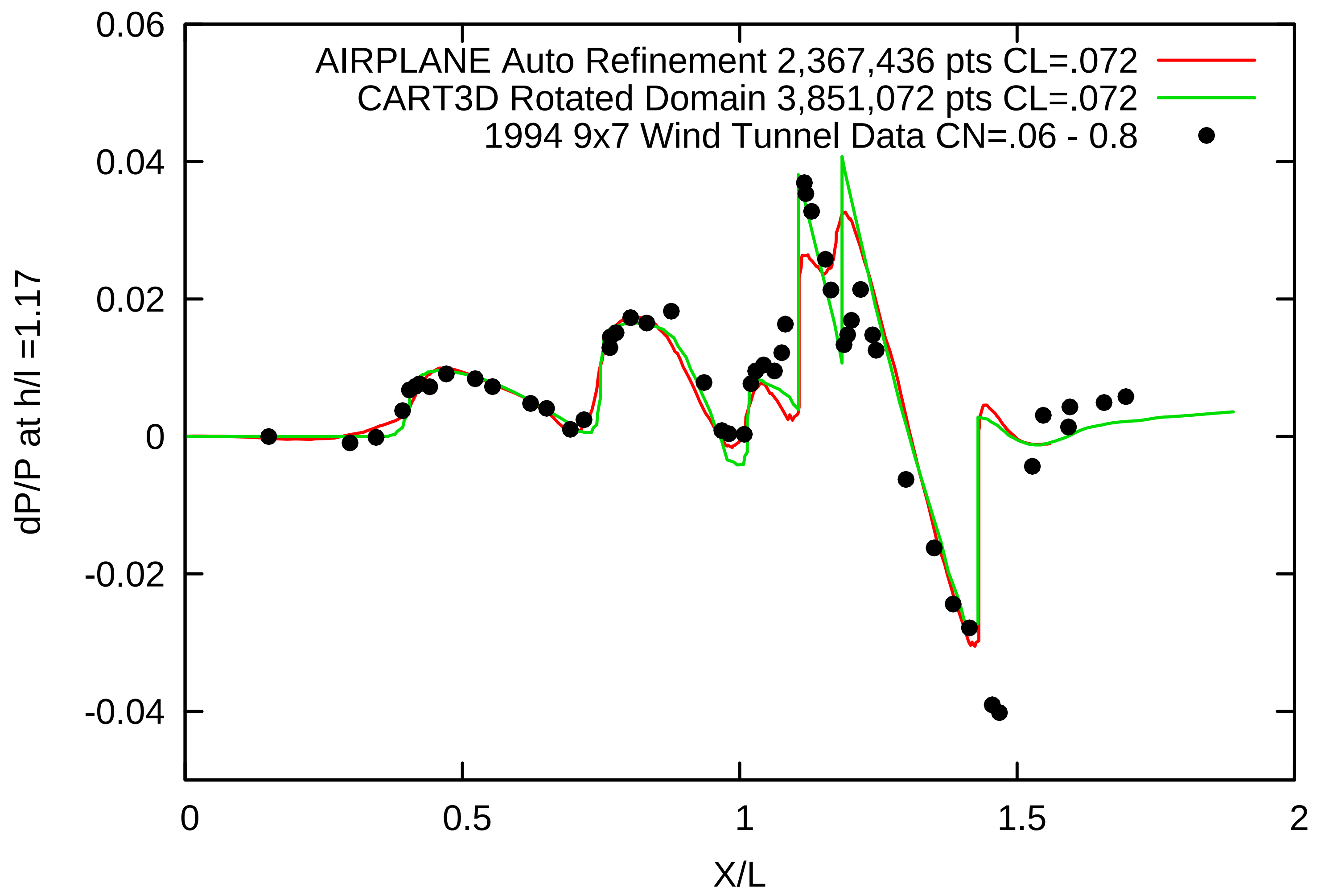


Low Boom Wing Tail (LBWT) 4 Nacelle





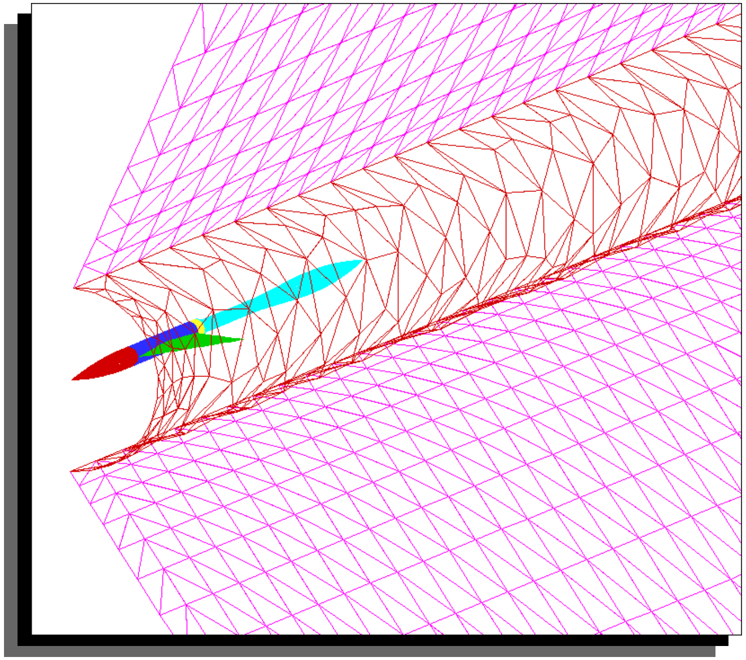
LBWT 4 Nacelle Results using New Techniques

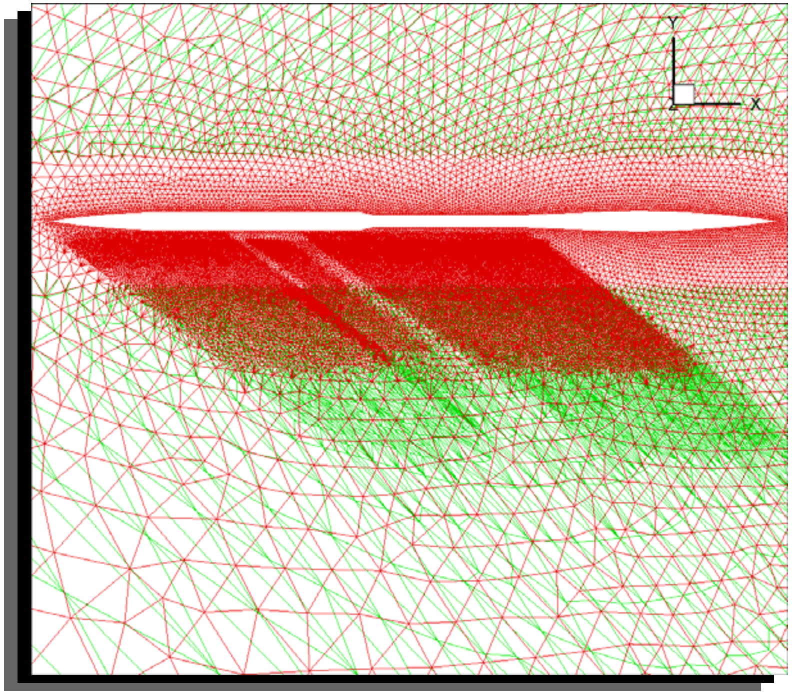


Current Endeavors

Reduce Refinement to One Direction in Outer Flowfield

- AIRPLANE:
  - Swept prismatic cylindrical grid
  - Tetrahedral grid stretching





Concluding Remarks

- EASS refinement offers a simple method for refinement
- Domain rotation reduces the grid requirements
- Extrapolating from 0.4 body lengths works well and is adequate for design
- AIRPLANE becomes inefficient and dissipative for h/l's greater than 0.8 without grid alignment and stretching
- More Information in NASA TM-2008-21568