Comparing Anisotropic Output-Based Grid Adaptation Methods by Decomposition

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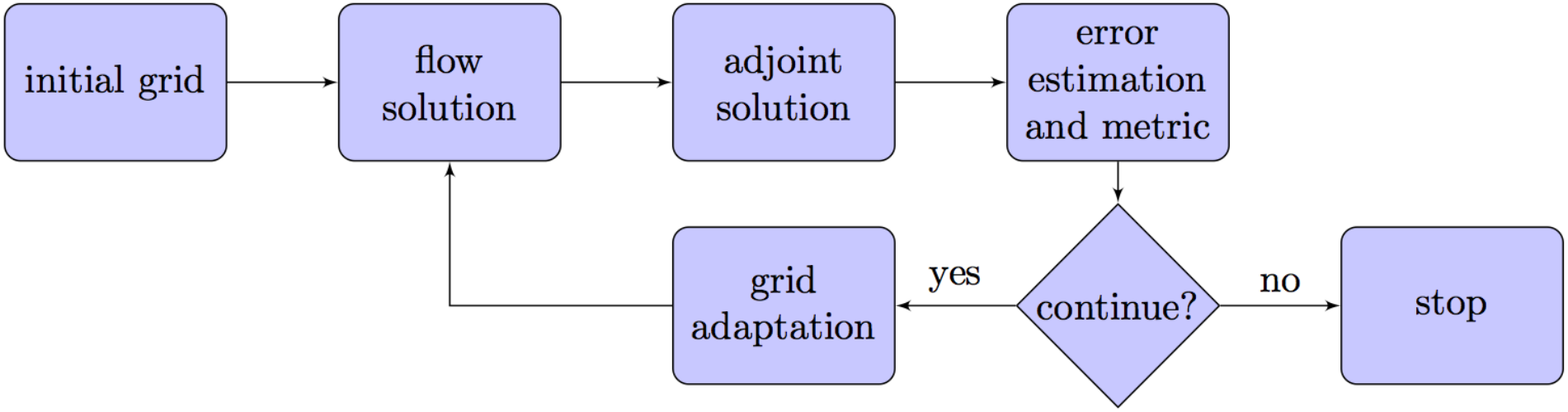
Motivation

- **Mesh generation and adaptivity continue to be significant bottlenecks in the CFD workflow, and very little government investment has been targeted in these areas.**
  - CFD Vision 2030 Study (NASA-CR-2014-218178)

Approach

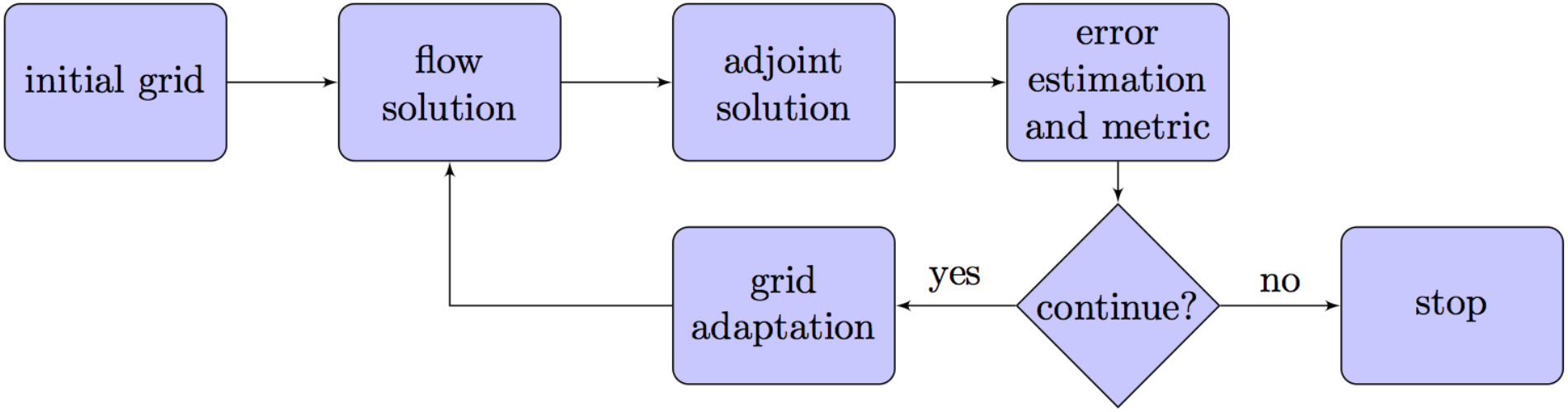
- Create and sustain collaboration in solution adaptive research with a goal of addressing the CFD Vision 2030 goals of automation, uncertainty quantification, and robustness
  - Leverage research groups across different organizations around the world

Output-Based Adaptation Process



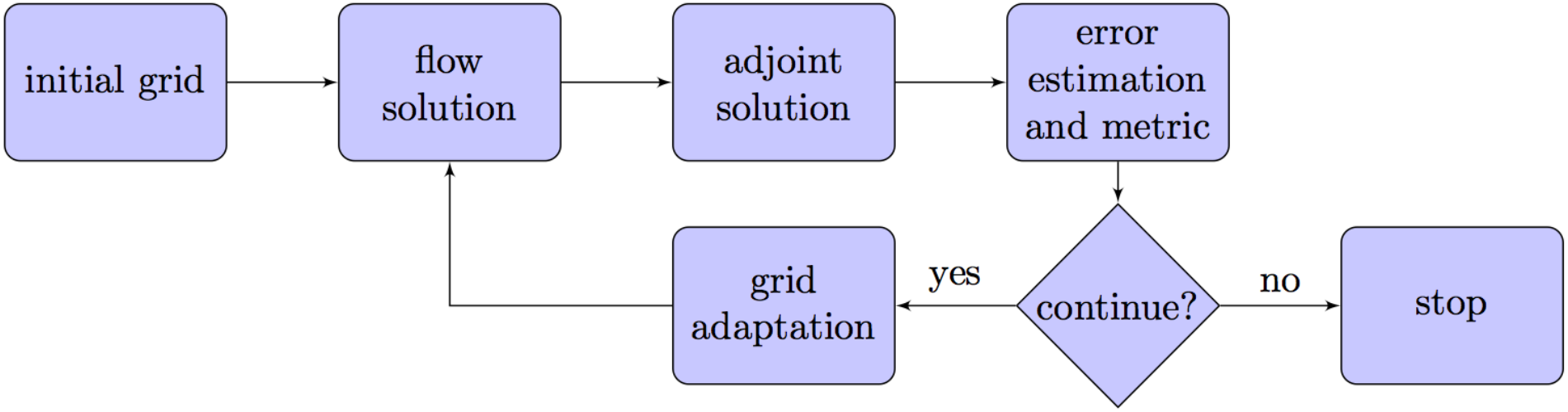
- Use error estimation and grid adaptation to reduce the requirements on the initial grid

Output-Based Adaptation Process



- There are may elements involved and they need to be right for the entire procedure to converge
  - To ensure correctness, examine elements individually and as a whole

Output-Based Adaptation Process



- Today we will focus on grid adaptation mechanics for triangular and tetrahedral grids
  - In the context of specified spacing field and solution error estimation procedures

Metric

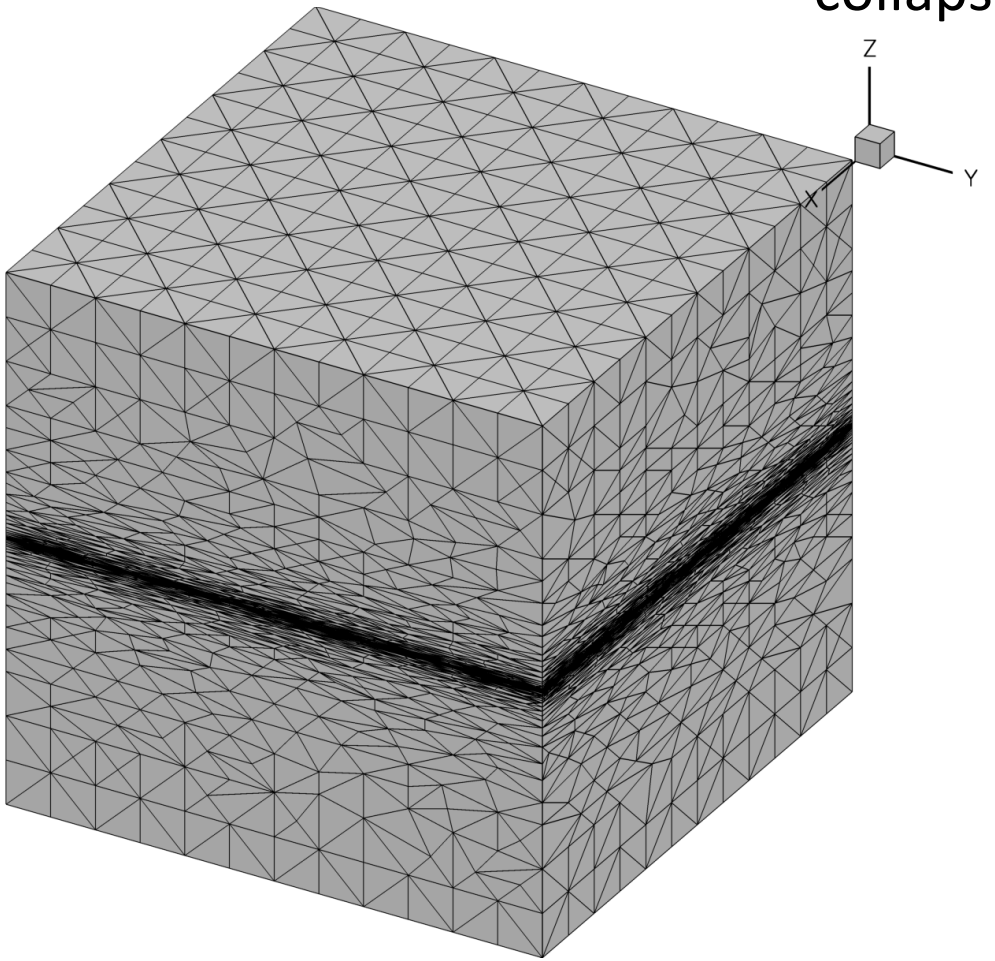
- Examine metric-based approaches to unstructured grid adaption
- Metric is a 3x3 (or 2x2 in 2D) matrix to define an orthogonal basis and spacing in each basis vector direction
  - Stored at each vertex in the mesh and interpolated as needed
- Edge lengths are computed in the metric
  - An ideal grid has all unit-length edges in metric

3D Prescribed Metric Field

- Very simple metric field, but still illustrative
- Defined in a unit square
- X-spacing and Y-spacing is constant 0.1
- Z-spacing varies linearly from 0.1 at the top and bottom to 0.001 at the center of the square
- Introduction of the adaptive mechanics

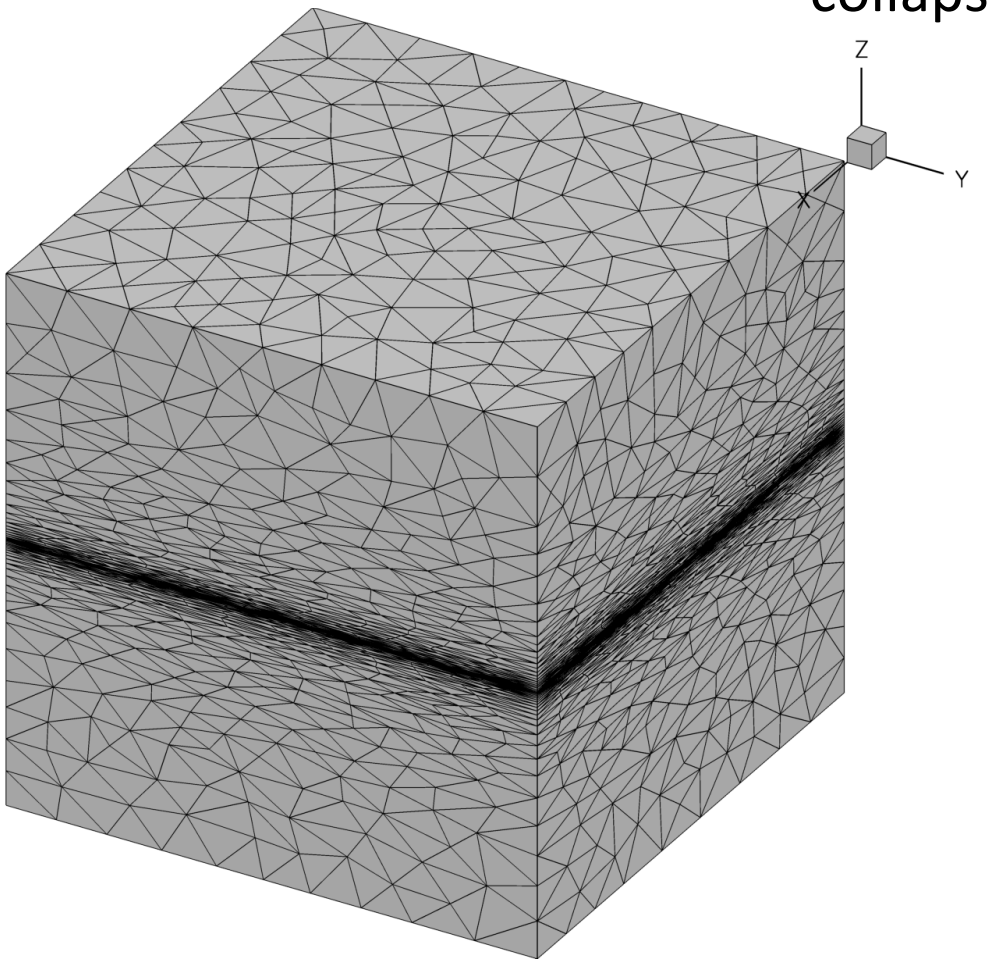
refine/two

Edge-based algorithm using only insertion and collapse operators



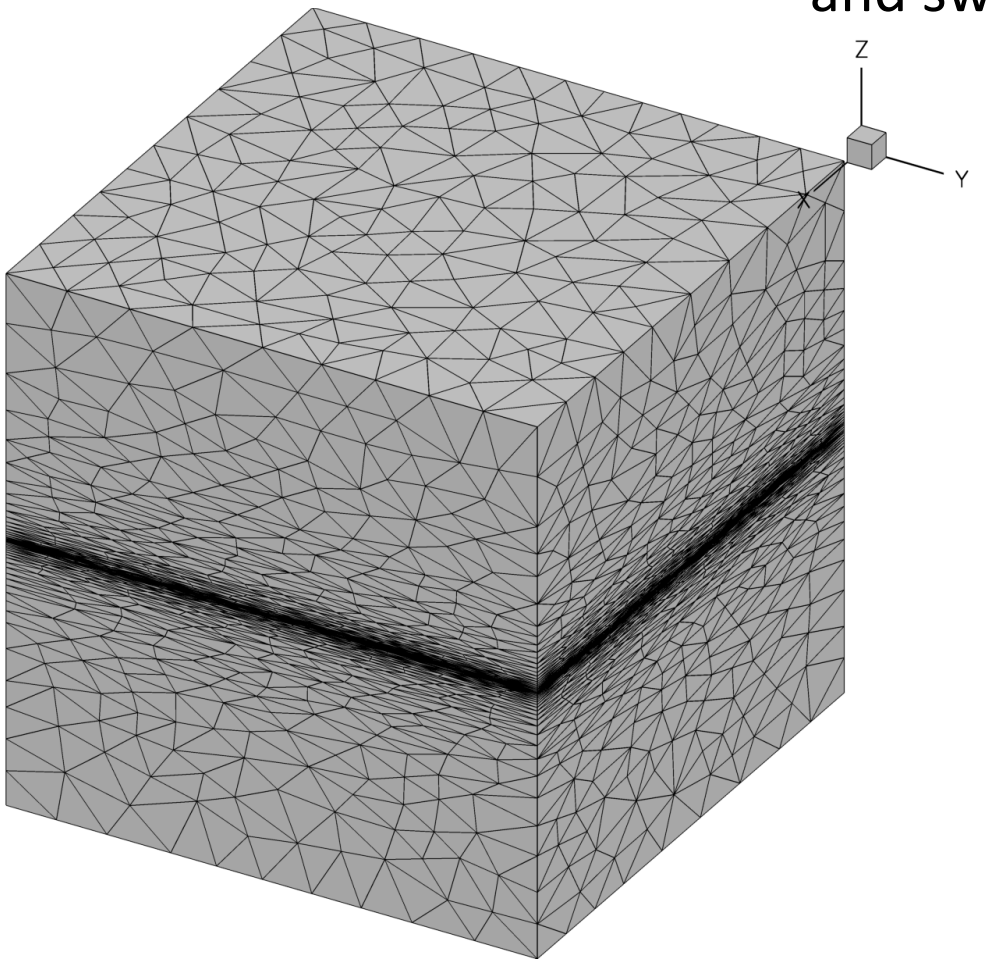
EPIC-IC

Edge-based algorithm using only insertion and collapse operators



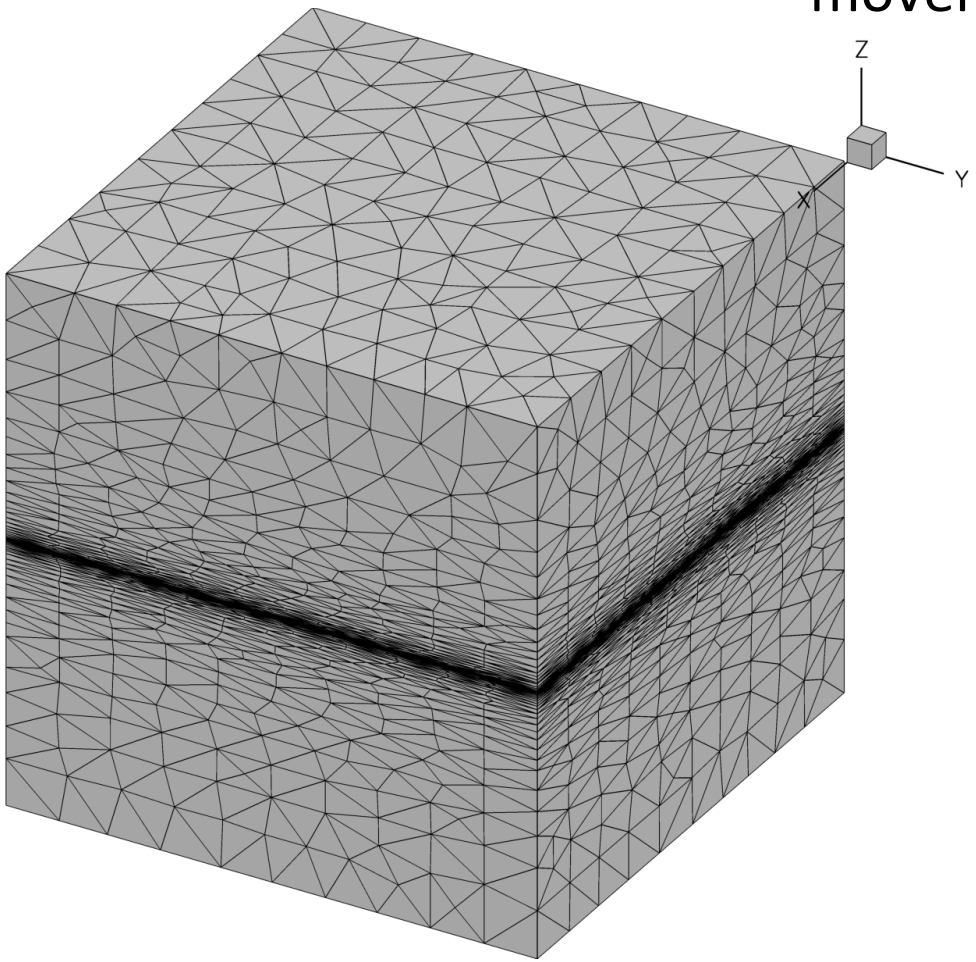
EPIC-ICS

Edge-based algorithm using insertion, collapse and swap



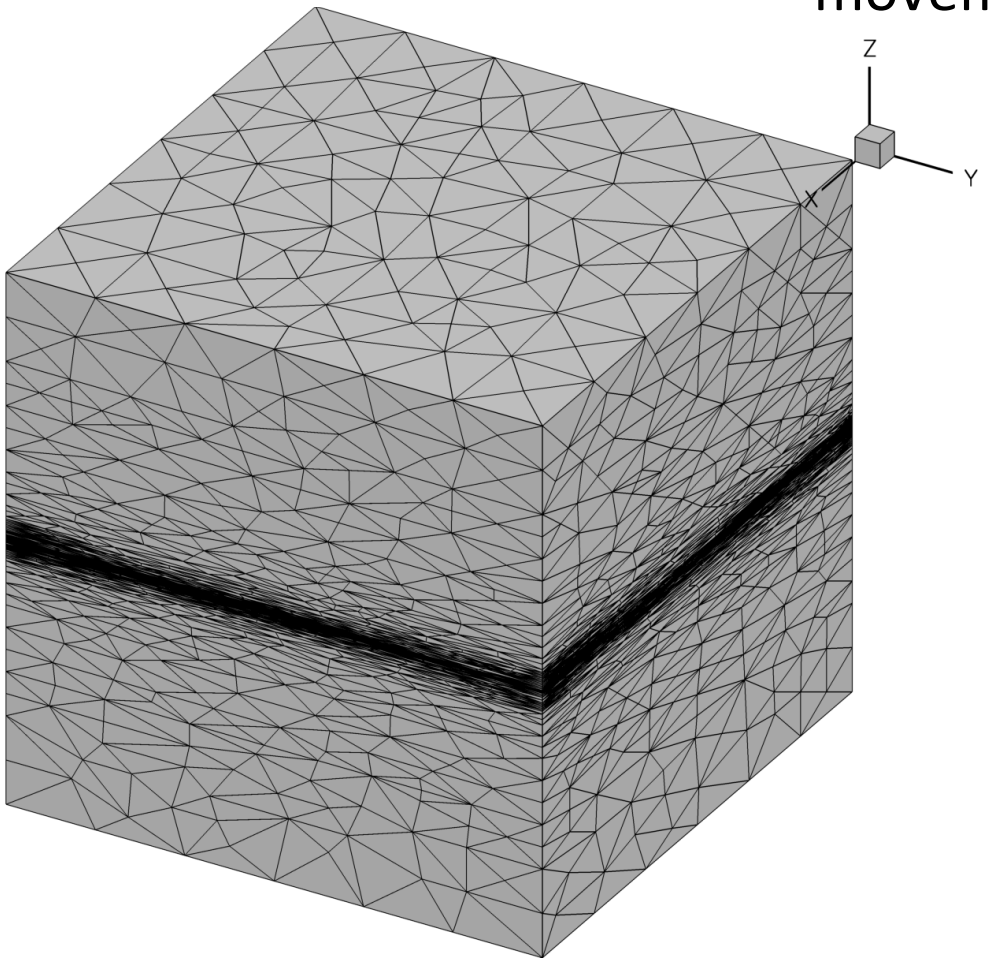
EPIC-ICSM

Edge-based with insertion, collapse, swap, and node movement



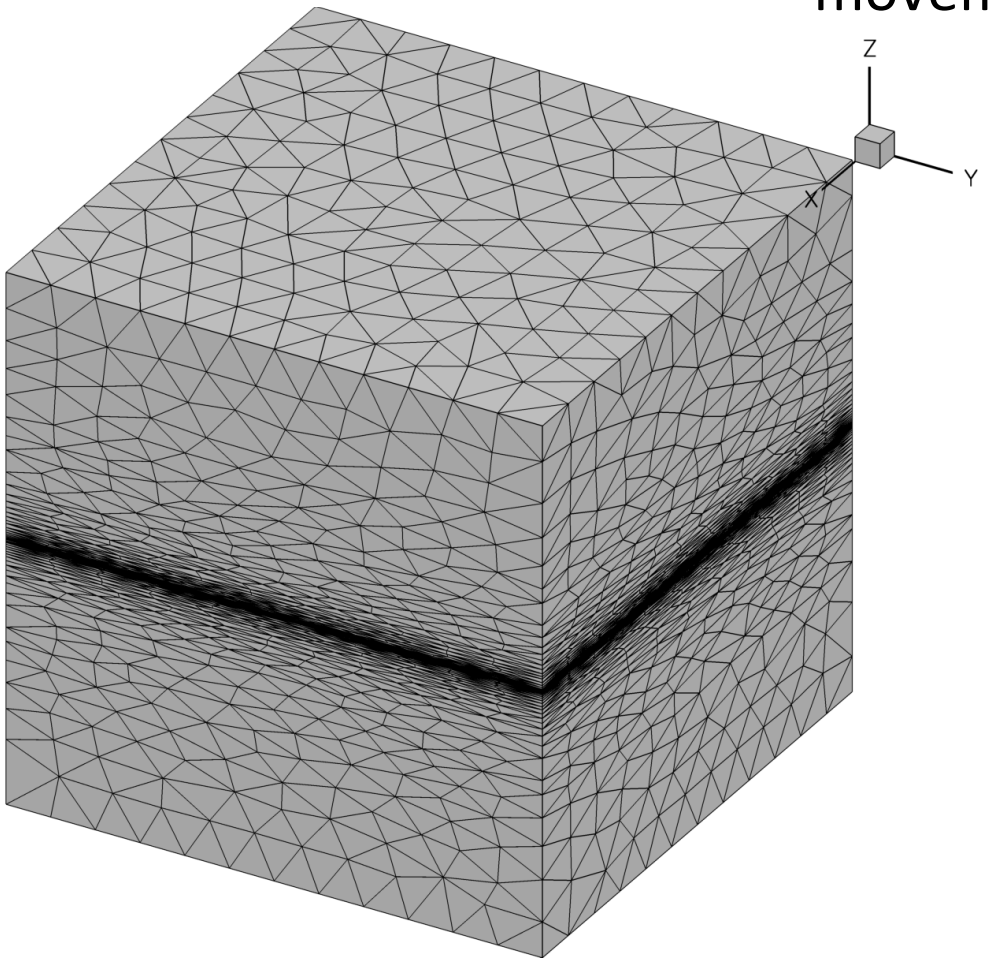
refine/one

Edge-based with insertion, collapse, swap, and node movement



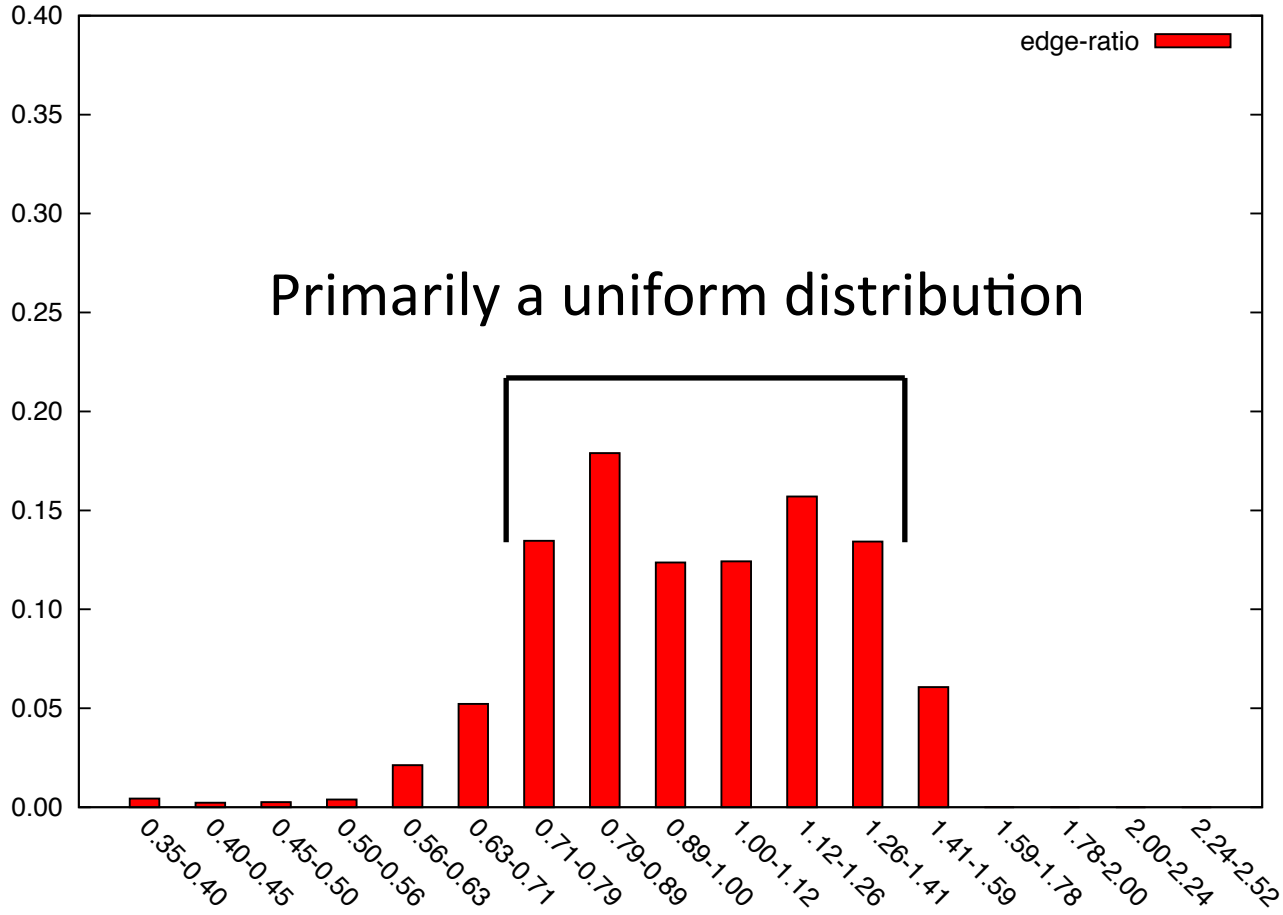
Feflo.a

Cavity-based with insertion, collapse, swap, and node movement



refine/two

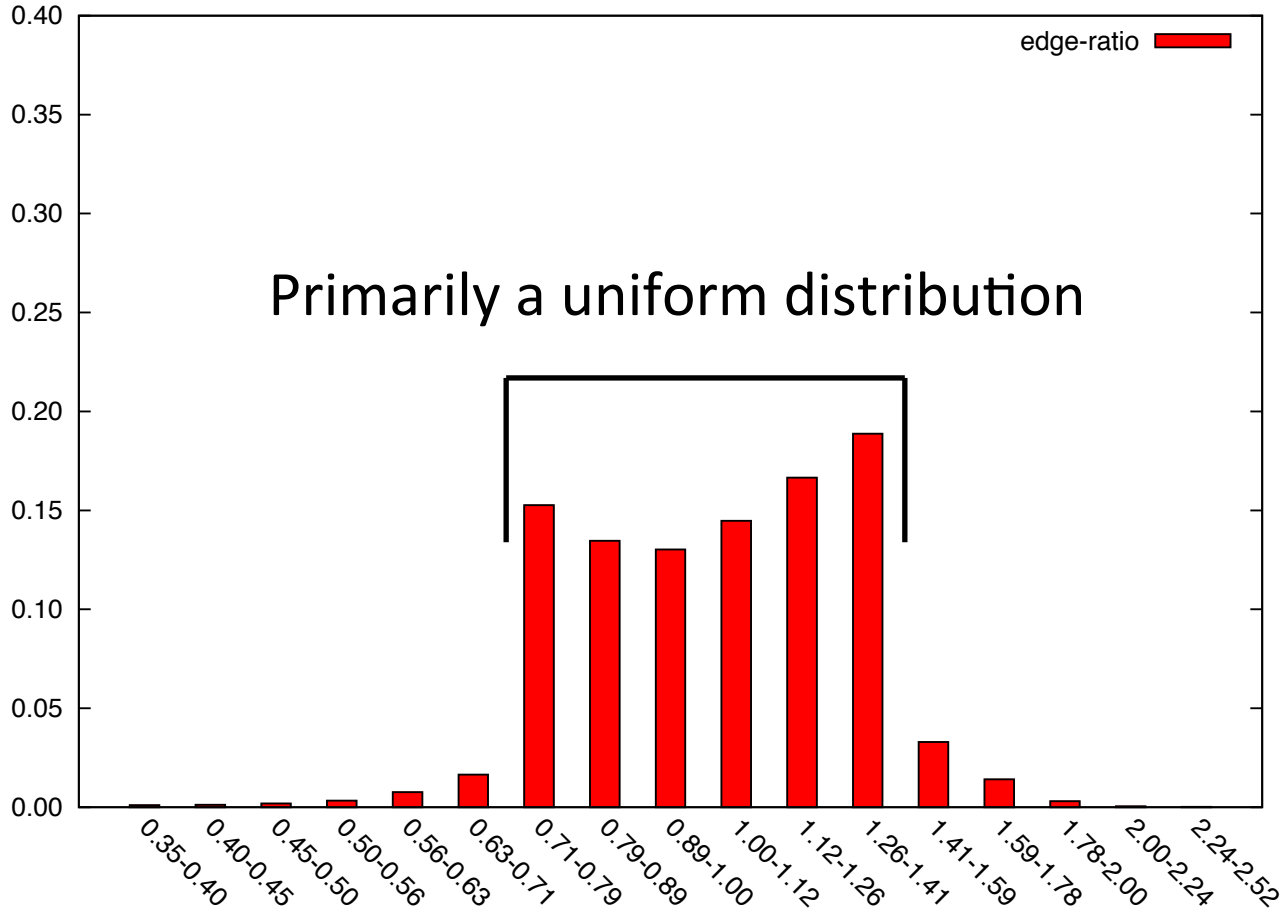
Edge-based algorithm using only insertion and collapse operators



Edge length in metric

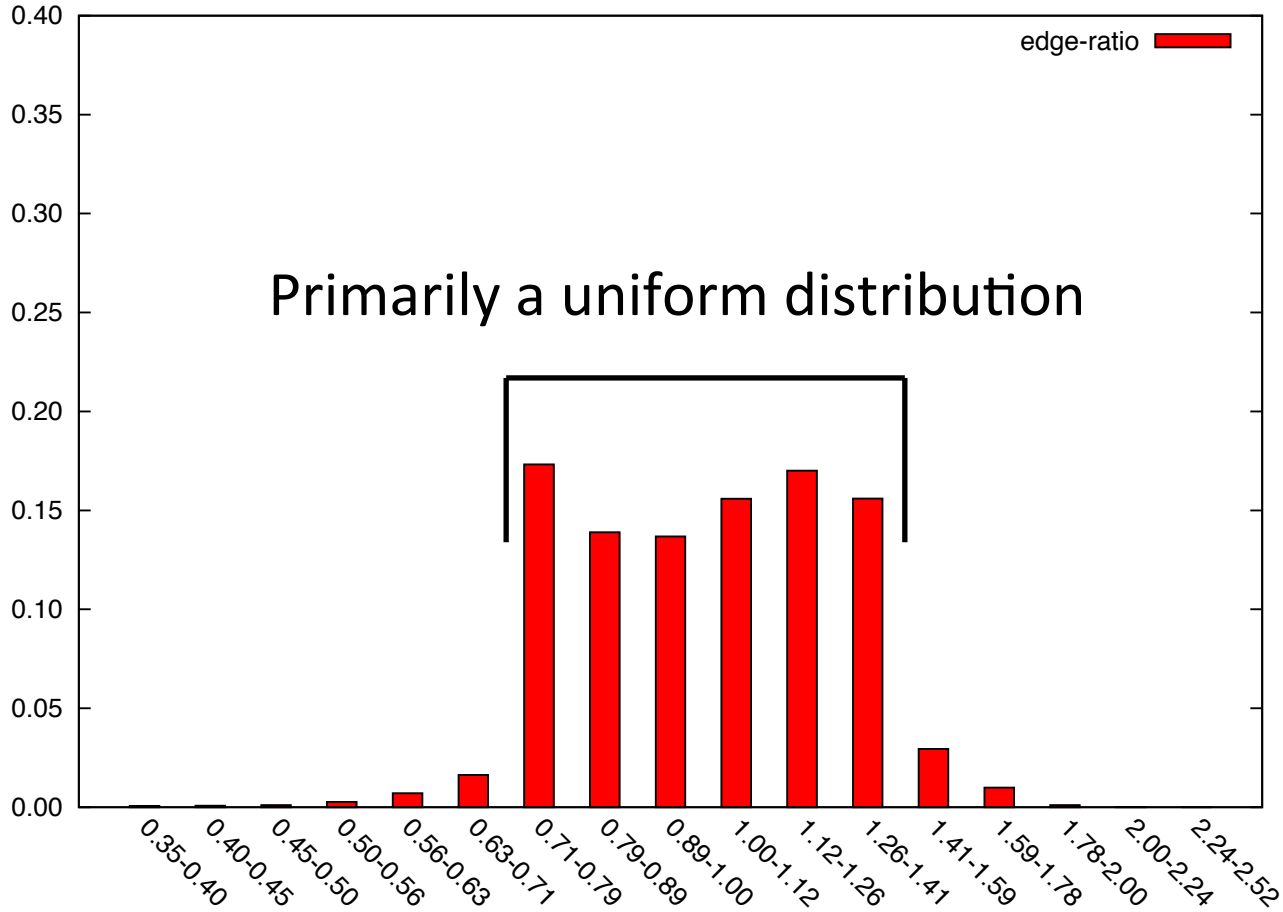
EPIC-IC

Edge-based algorithm using only insertion and collapse operators



EPIC-ICS

Edge-based algorithm using insertion, collapse and swap



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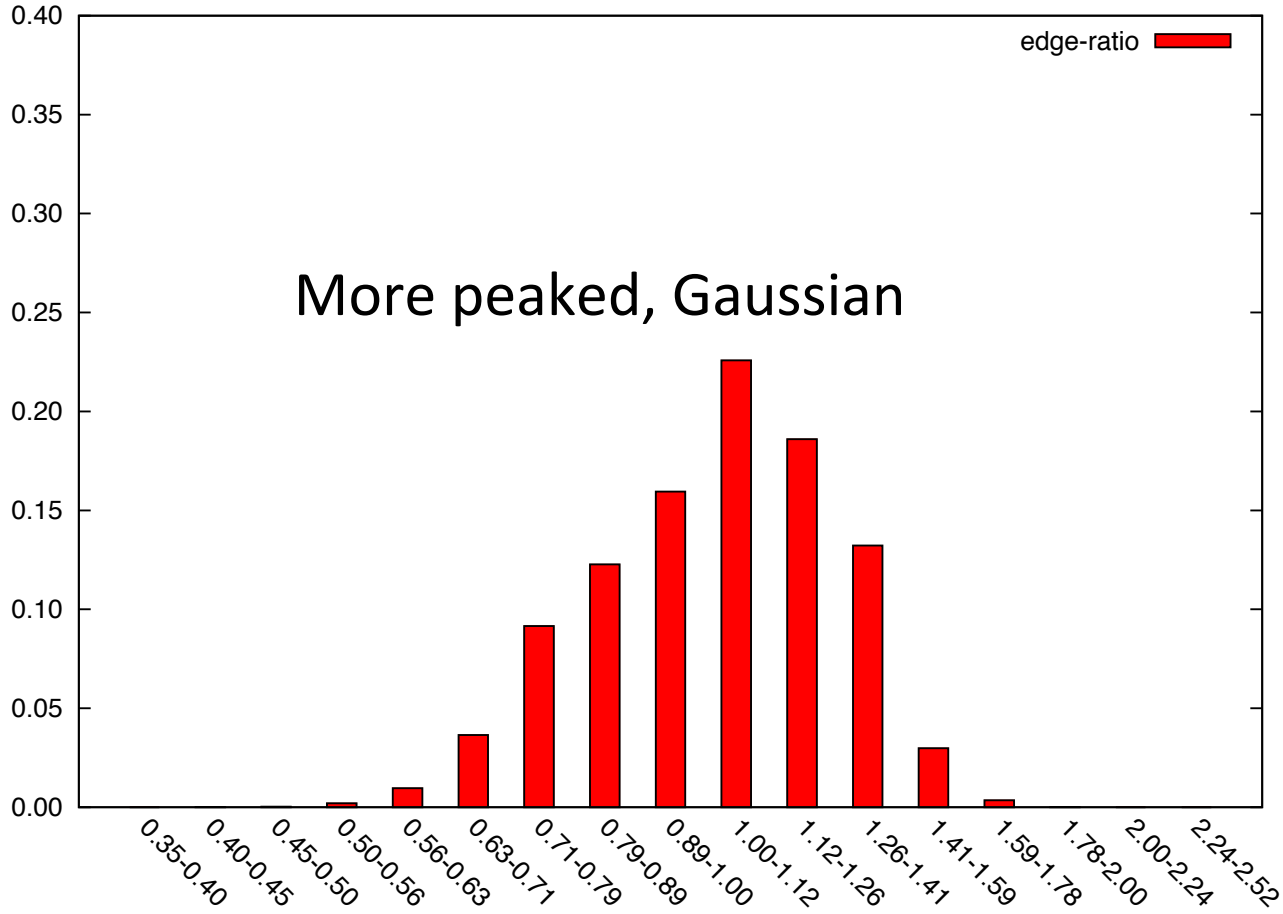
Edge-based with insertion, collapse, swap, and node movement



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refine/one

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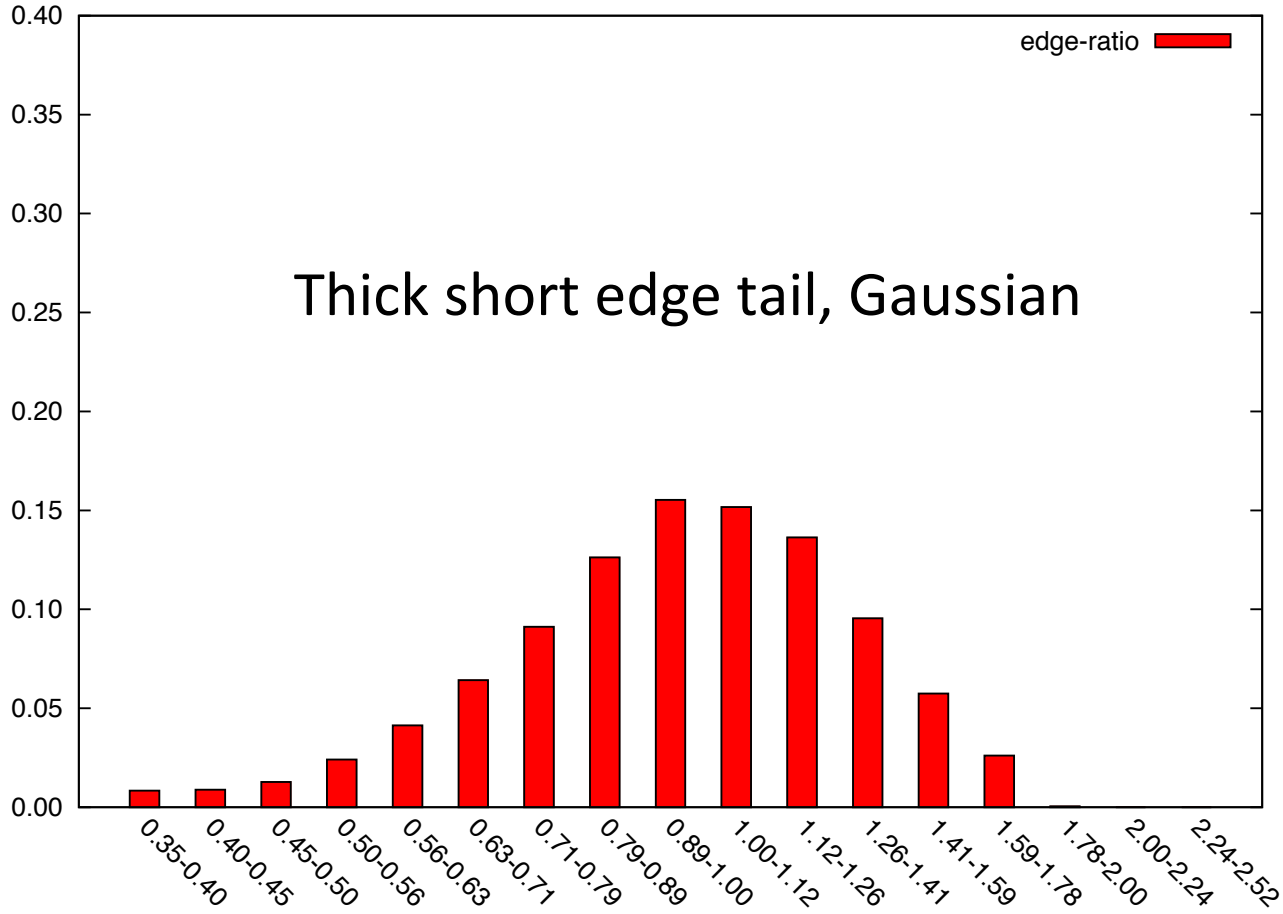

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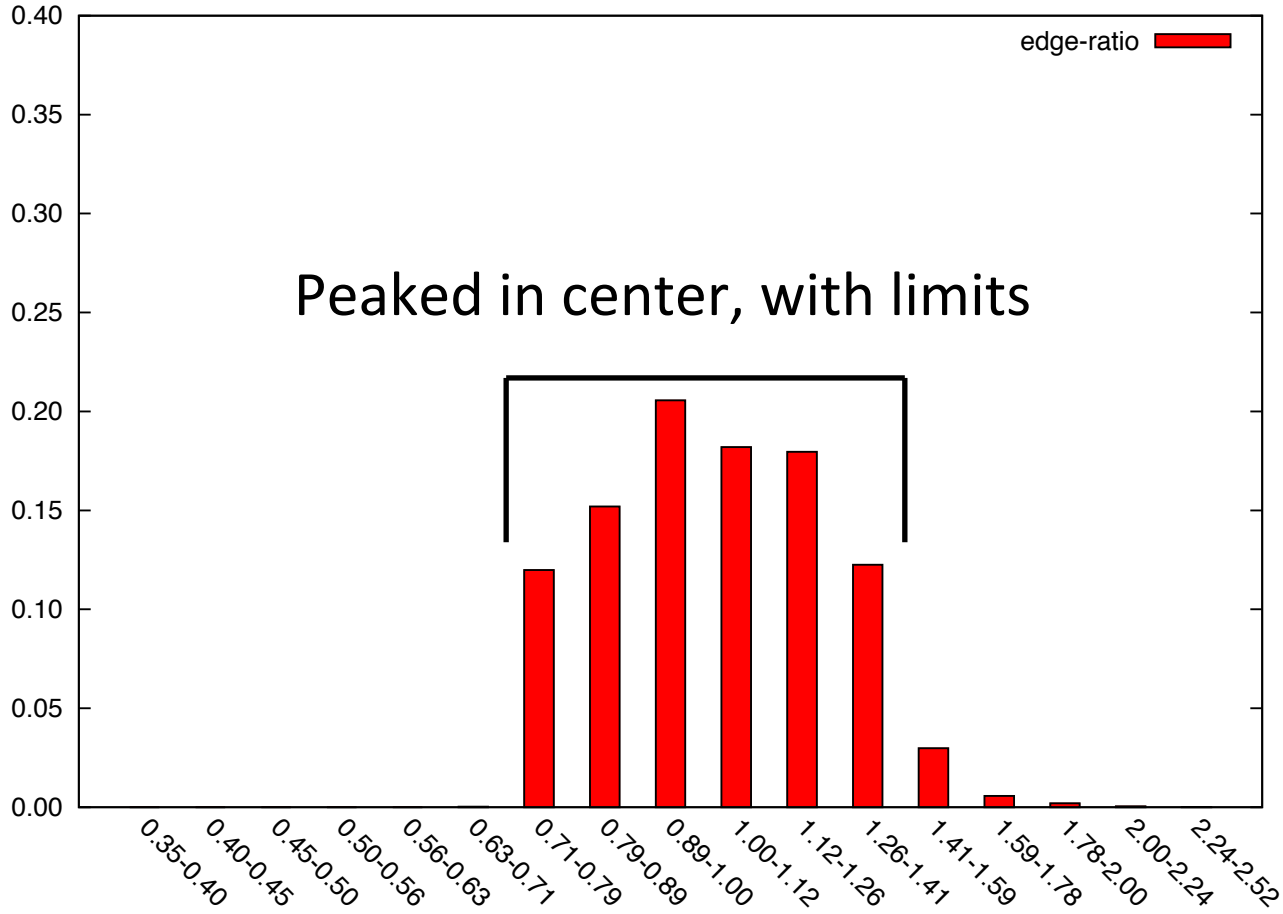
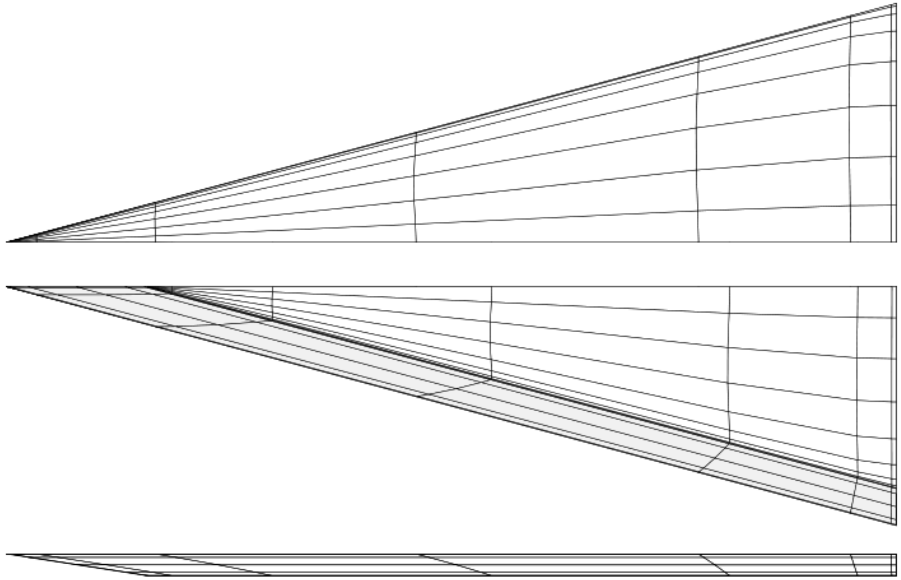
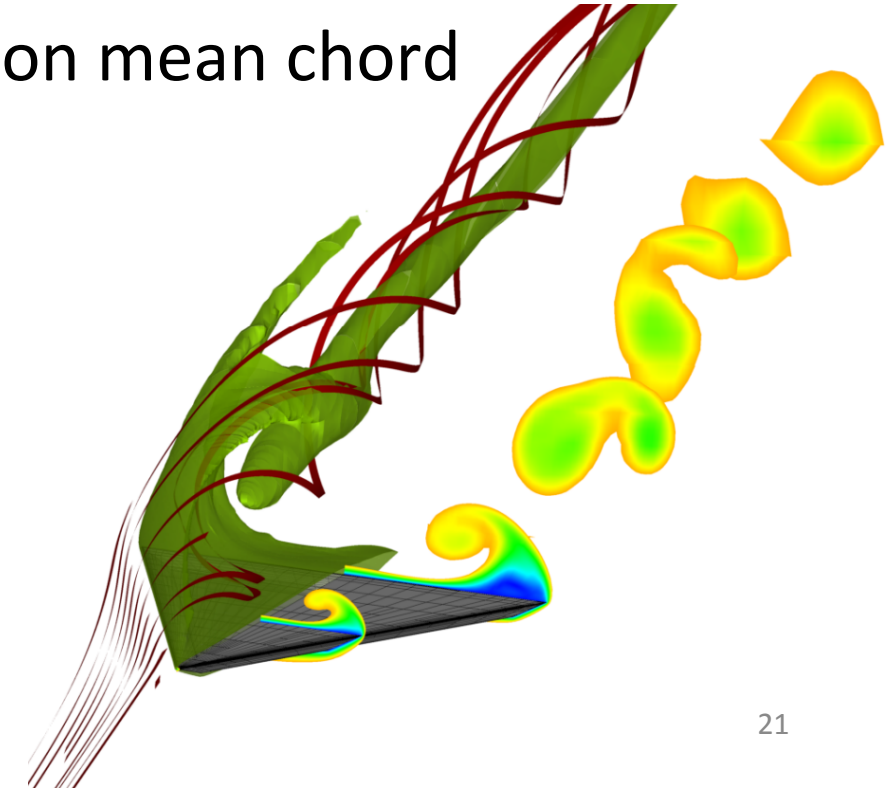


Edge length in metric

Laminar Delta Wing

- International Workshop on High-Order CFD Methods test case
  - Mach 0.3, 12.5^{o} angle of attack, and 4000 Reynolds number based on mean chord



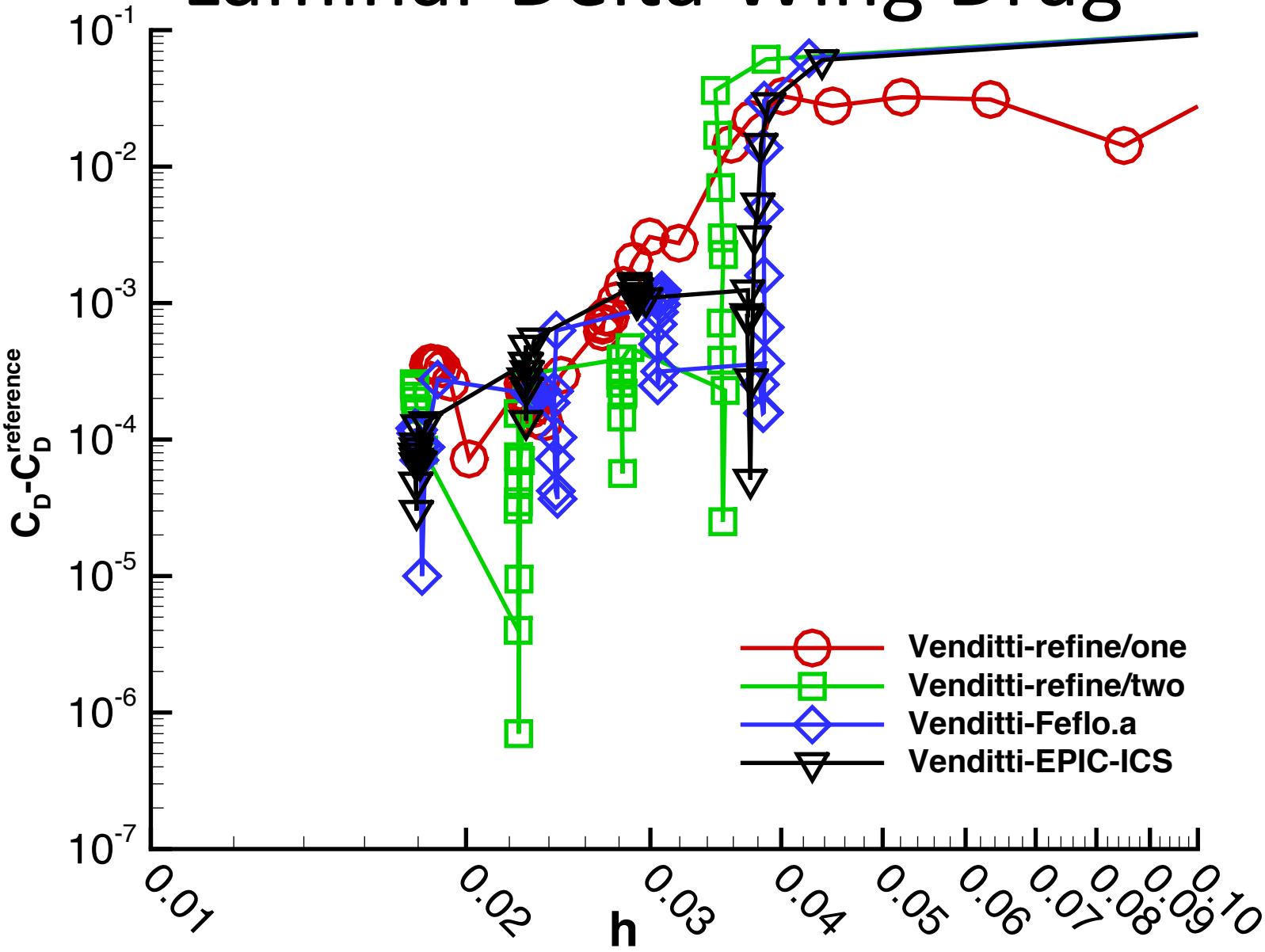


[Leicht and Hartmann JCP 2010]

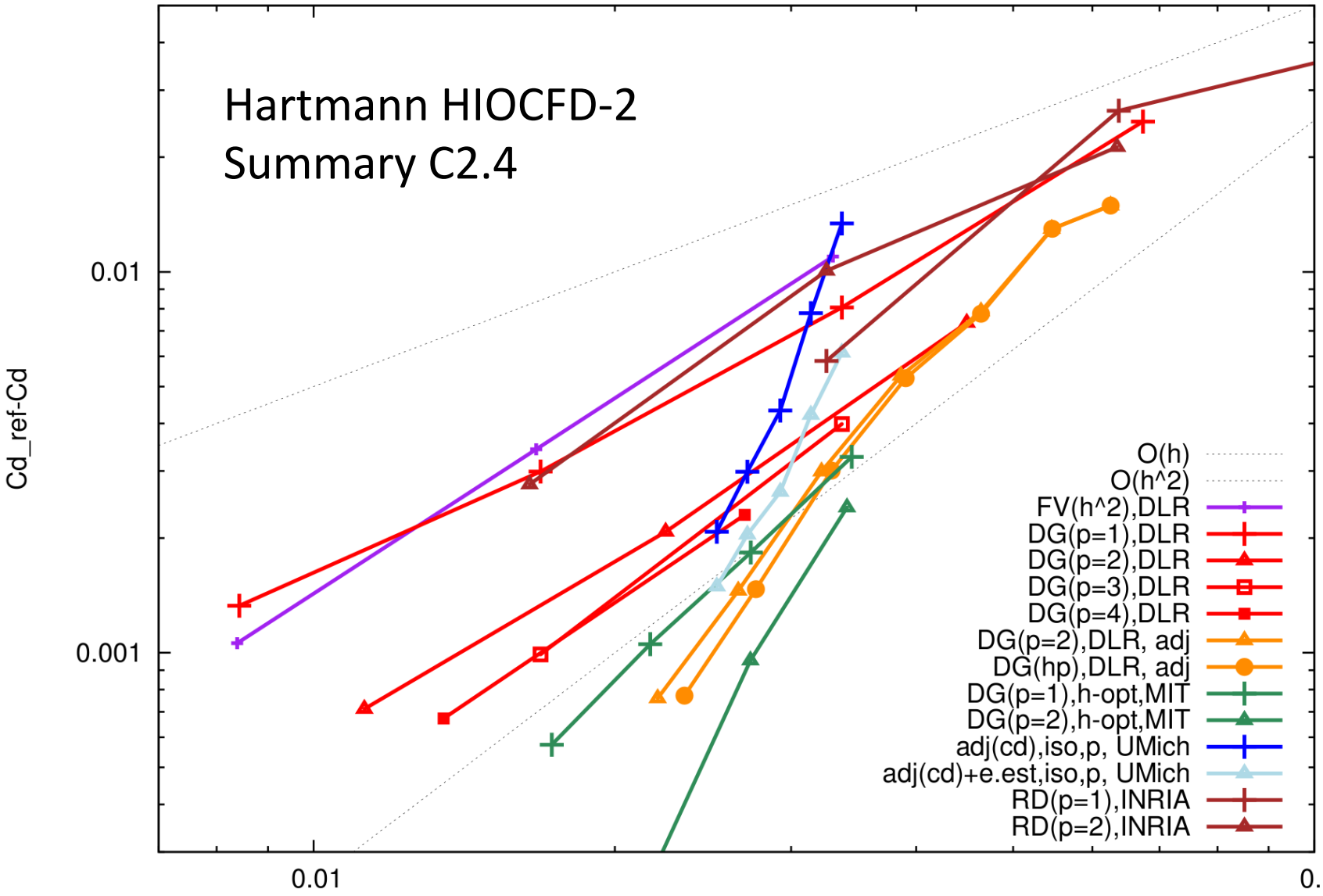
Laminar Delta Wing

- International Workshop on High-Order CFD Methods (HIOCFD) test case
  - Mach 0.3, 12.5^{o} angle of attack, and 4000 Reynolds number based on mean chord
- Venditti metric with refine/one, refine/two, Feflo.a, and EPIC-ICS
- Multiple adaptations at series of increasing complexity (size request)

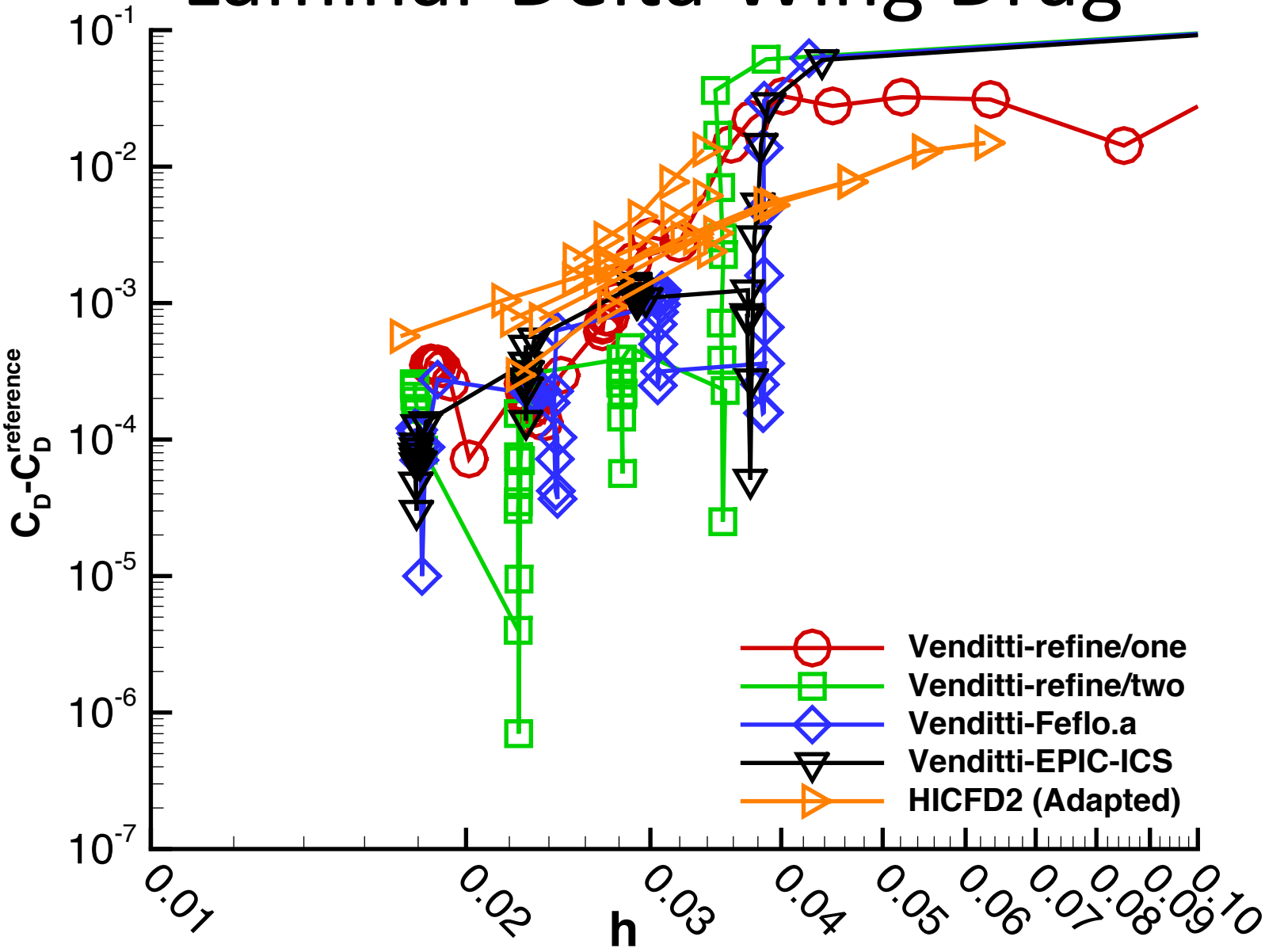
Laminar Delta Wing Drag

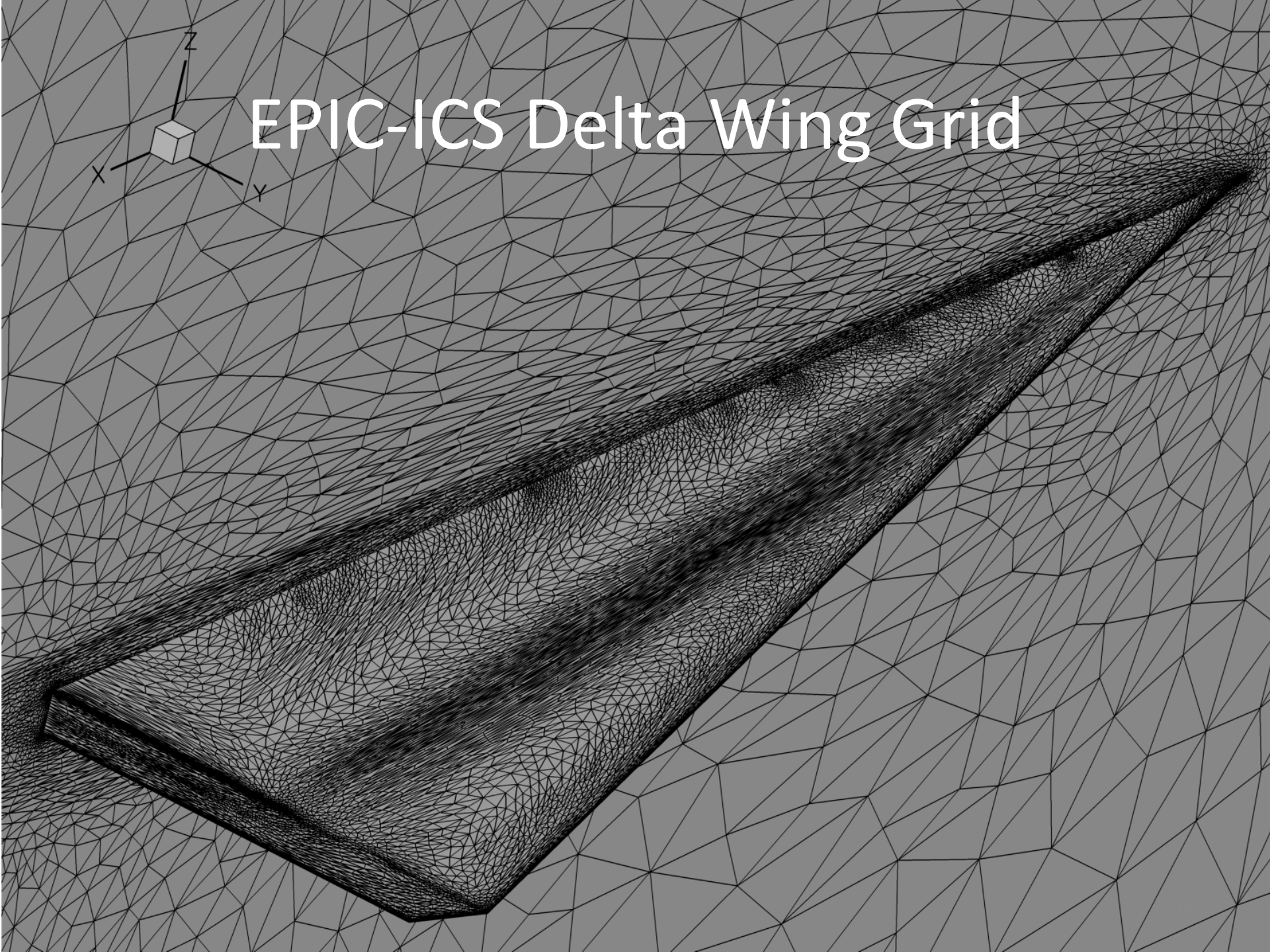


Laminar Delta Wing Drag



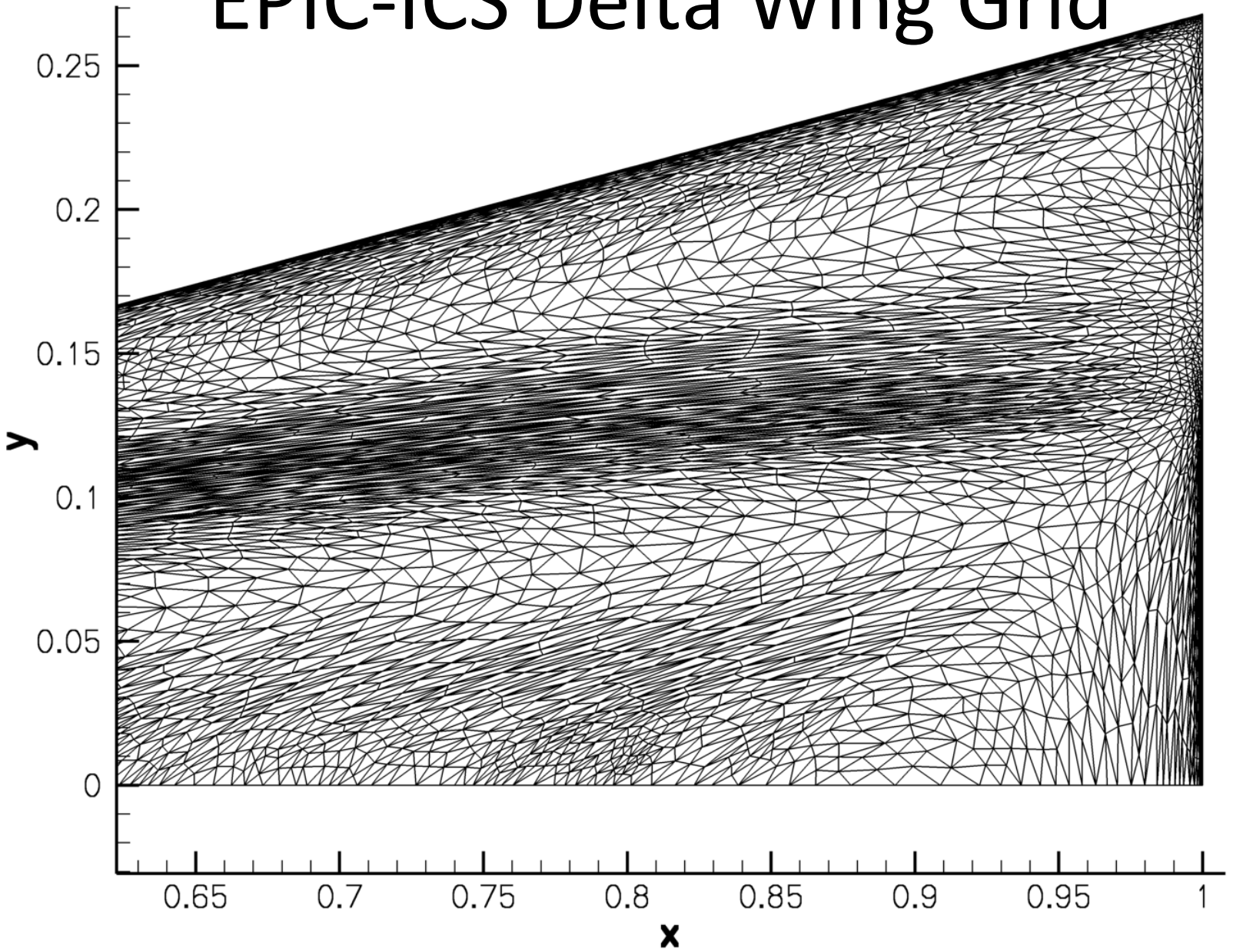
Laminar Delta Wing Drag





EPIC-ICS Delta Wing Grid

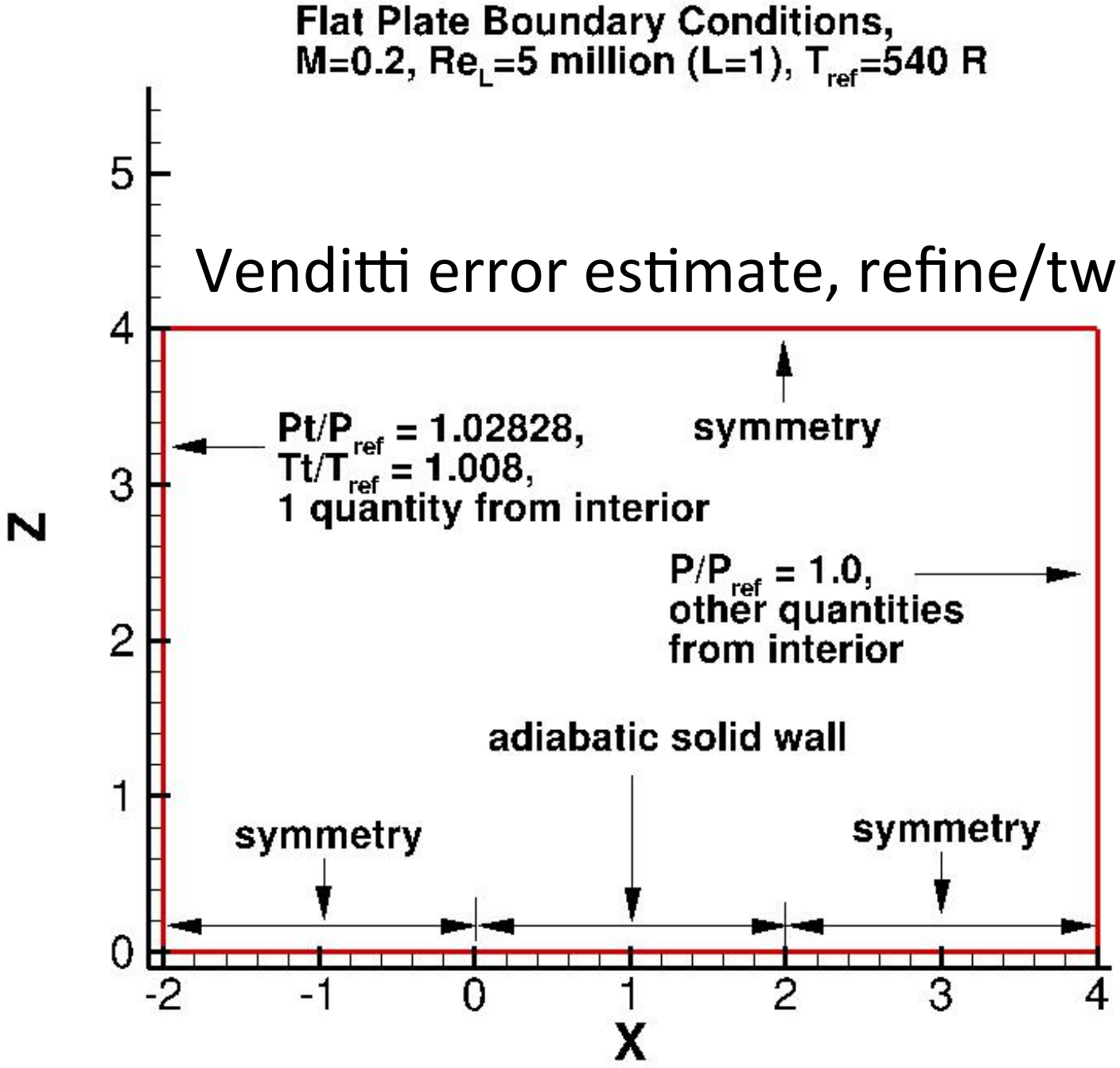
EPIC-ICS Delta Wing Grid



2D Flat Plate

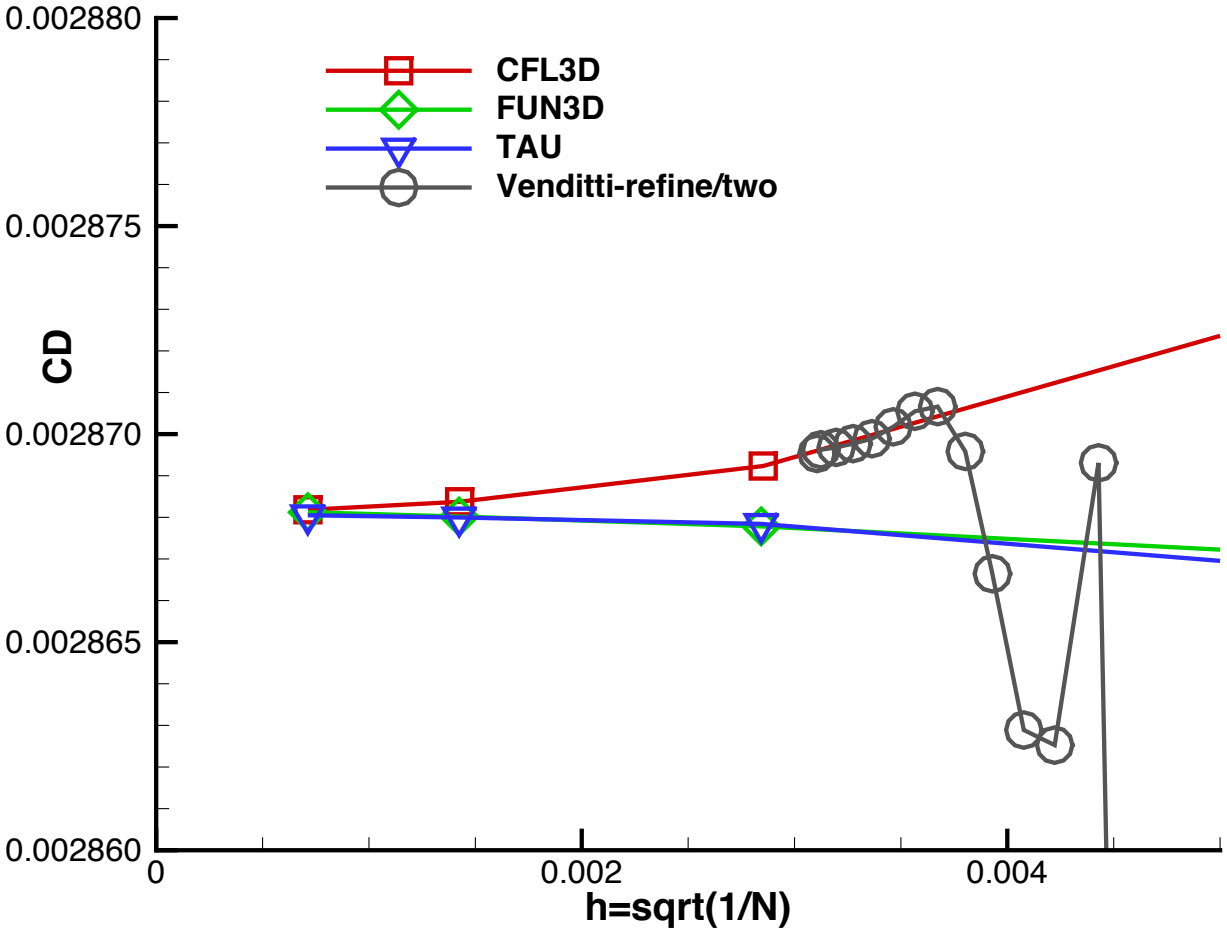
- Available on the Turbulence Modeling Resource (TMR) website
- Examined in a SciTech 2015 special session
- Not a production capability yet
  - Plagued by iterative convergence and Hessian reconstruction (error estimation) issues
  - Grid adaption mechanics are available for this case (1000-1 aspect ratio for solver robustness)

- Venditti error estimate, refine/two



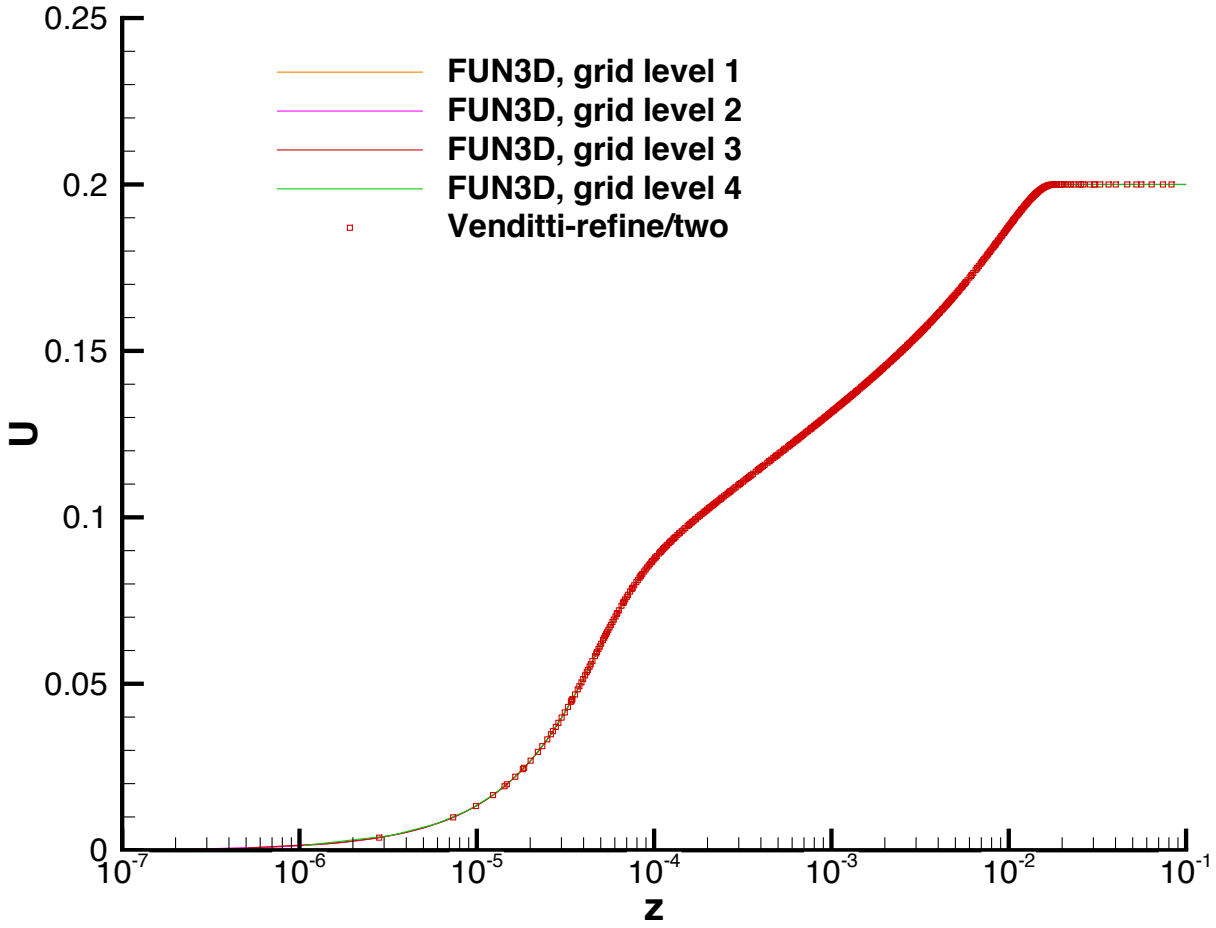
2D Flat Plate Drag Convergence

- Tracking of CFL3D drag coincidental



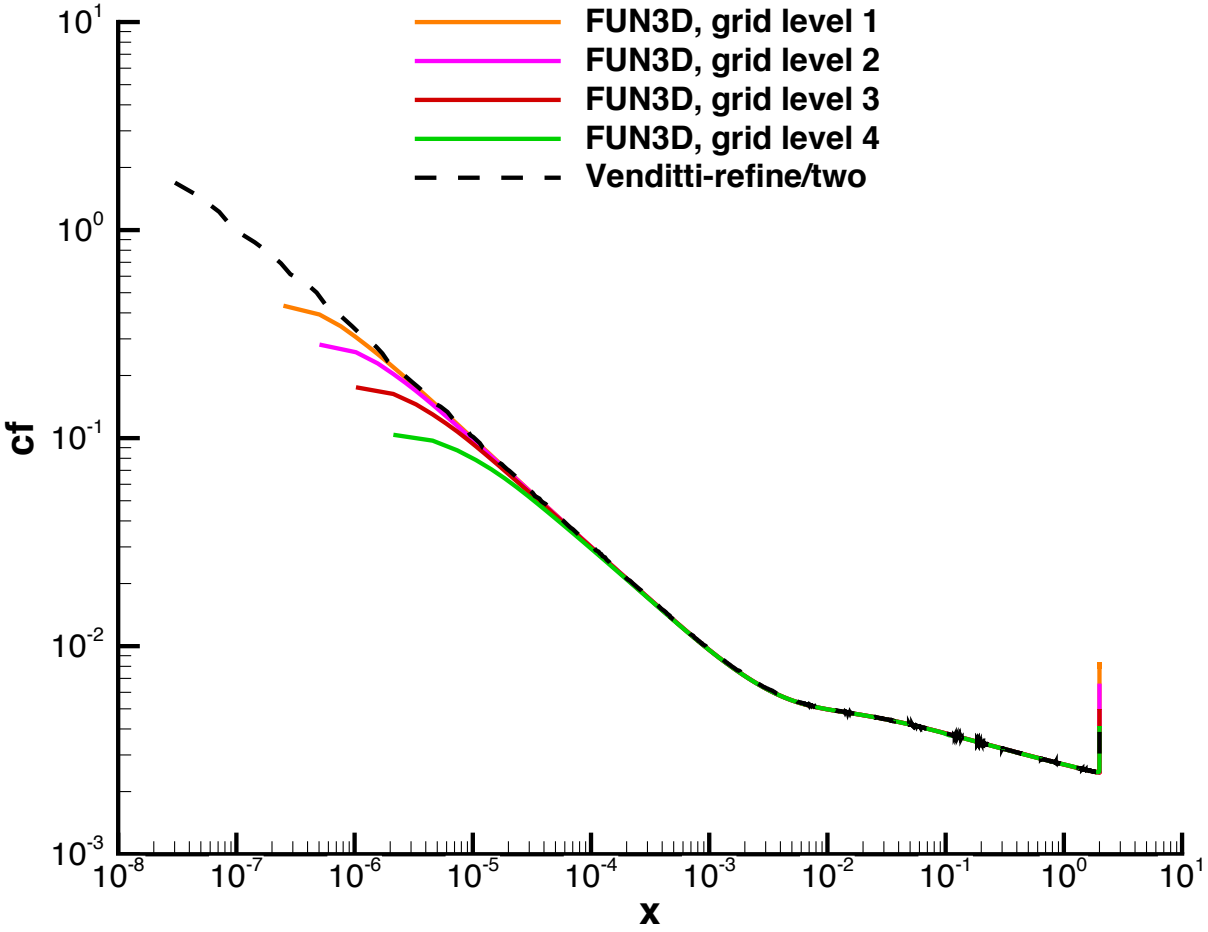
2D Flat Plate Velocity Profile

- Overlays structured grid result



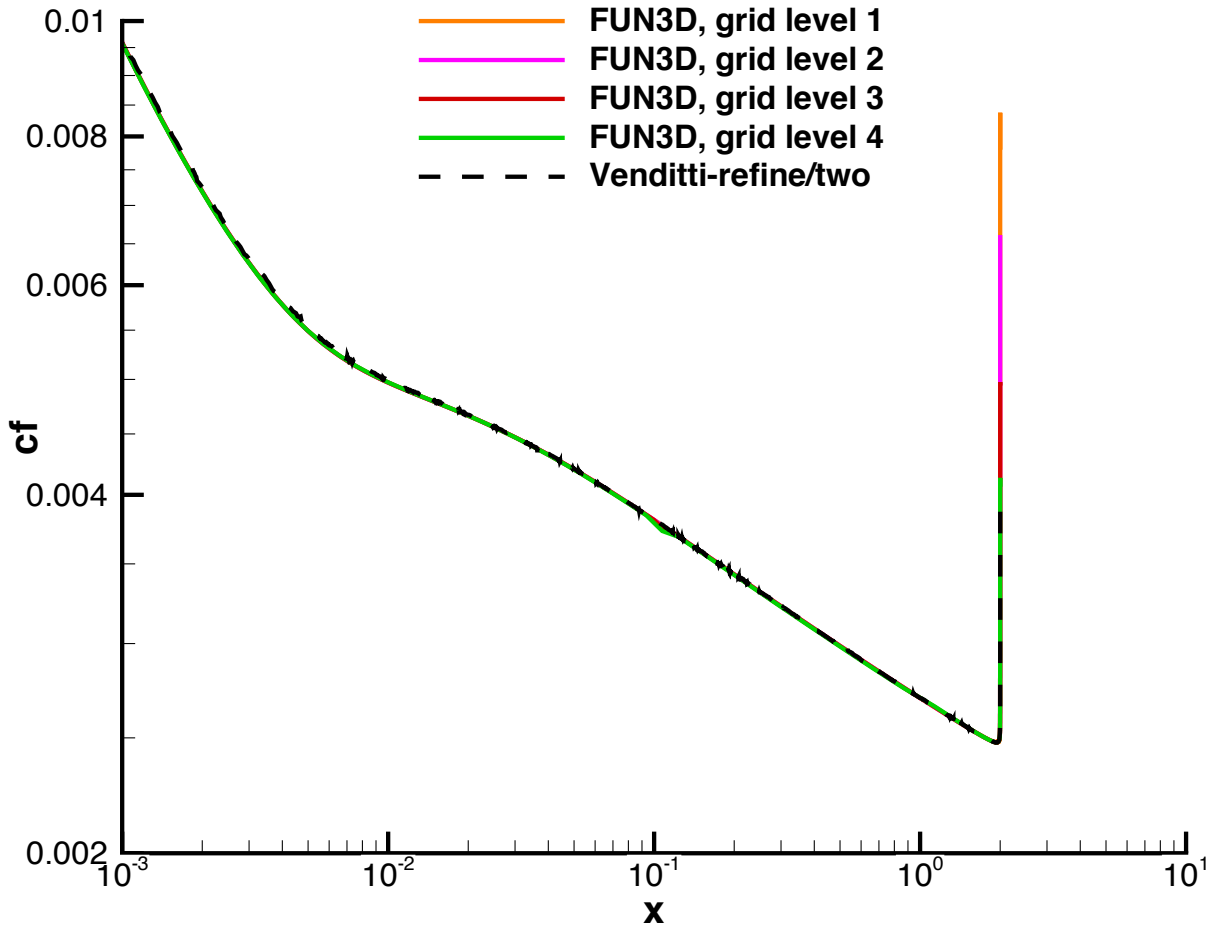
2D Flat Plate Skin Friction

- Better resolves leading edge singularity



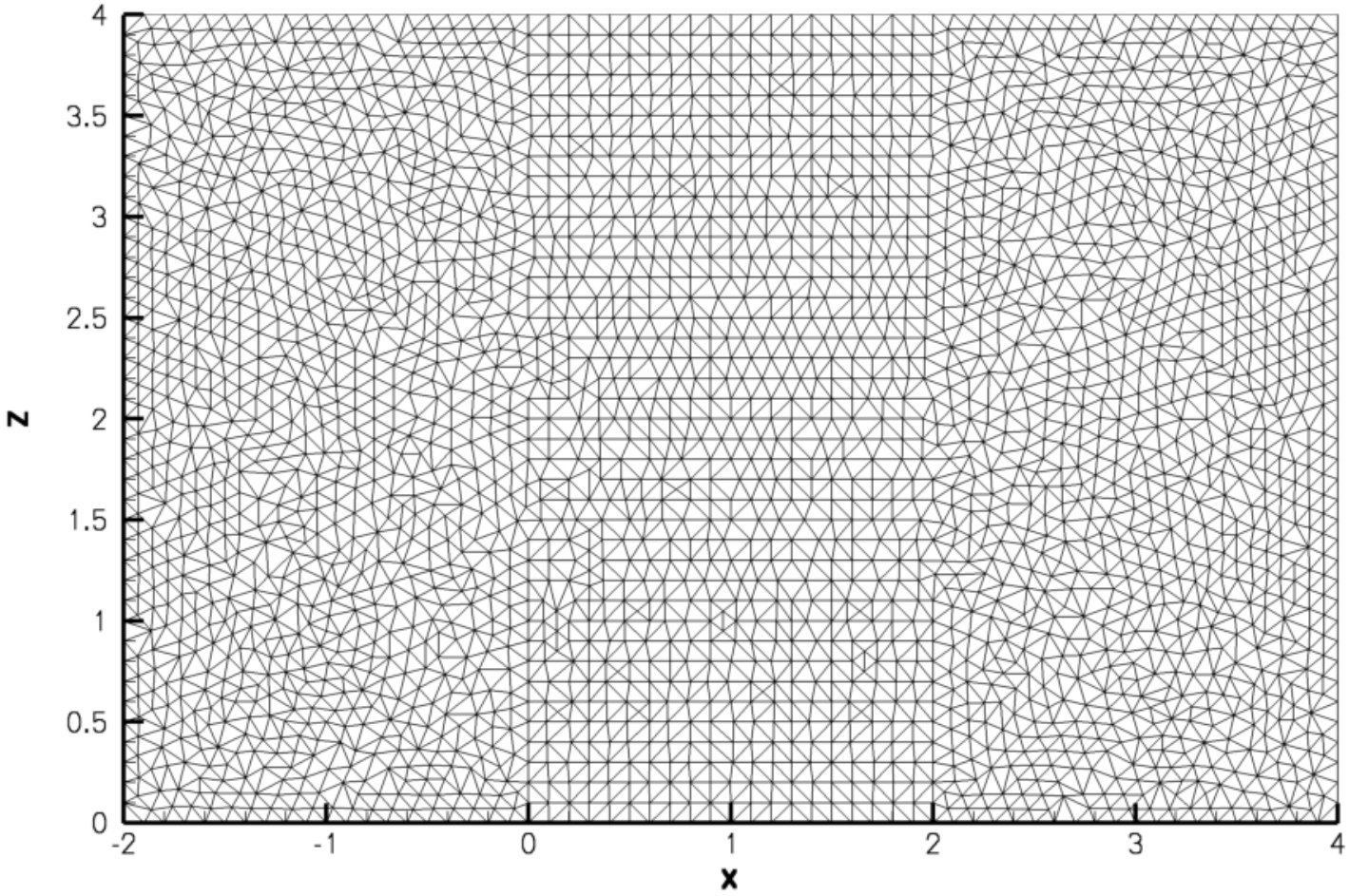
2D Flat Plate Skin Friction

- Slight noise in skin friction



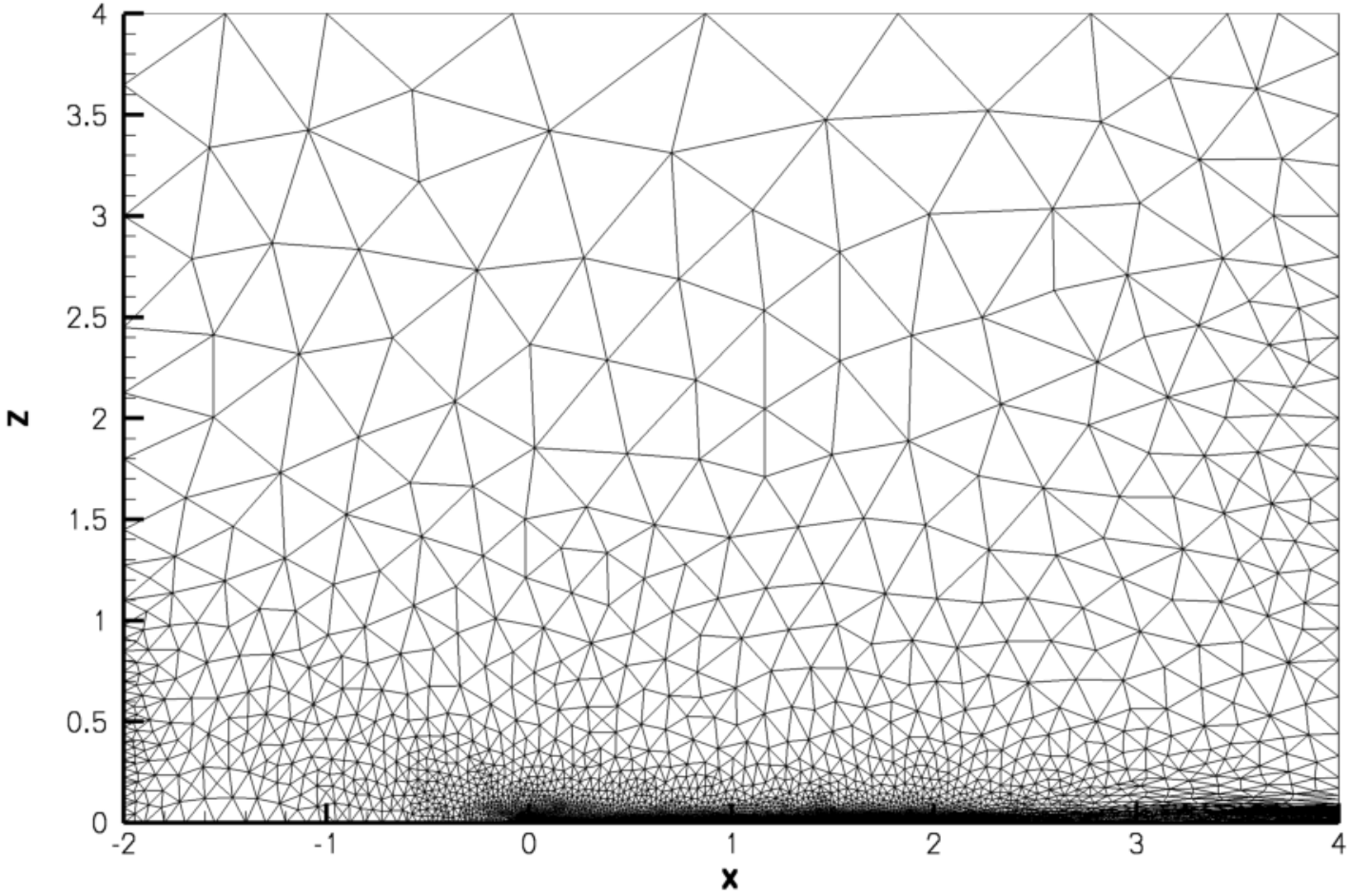
2D Flat Plate Grid

- Initial grid is uniform and isotropic



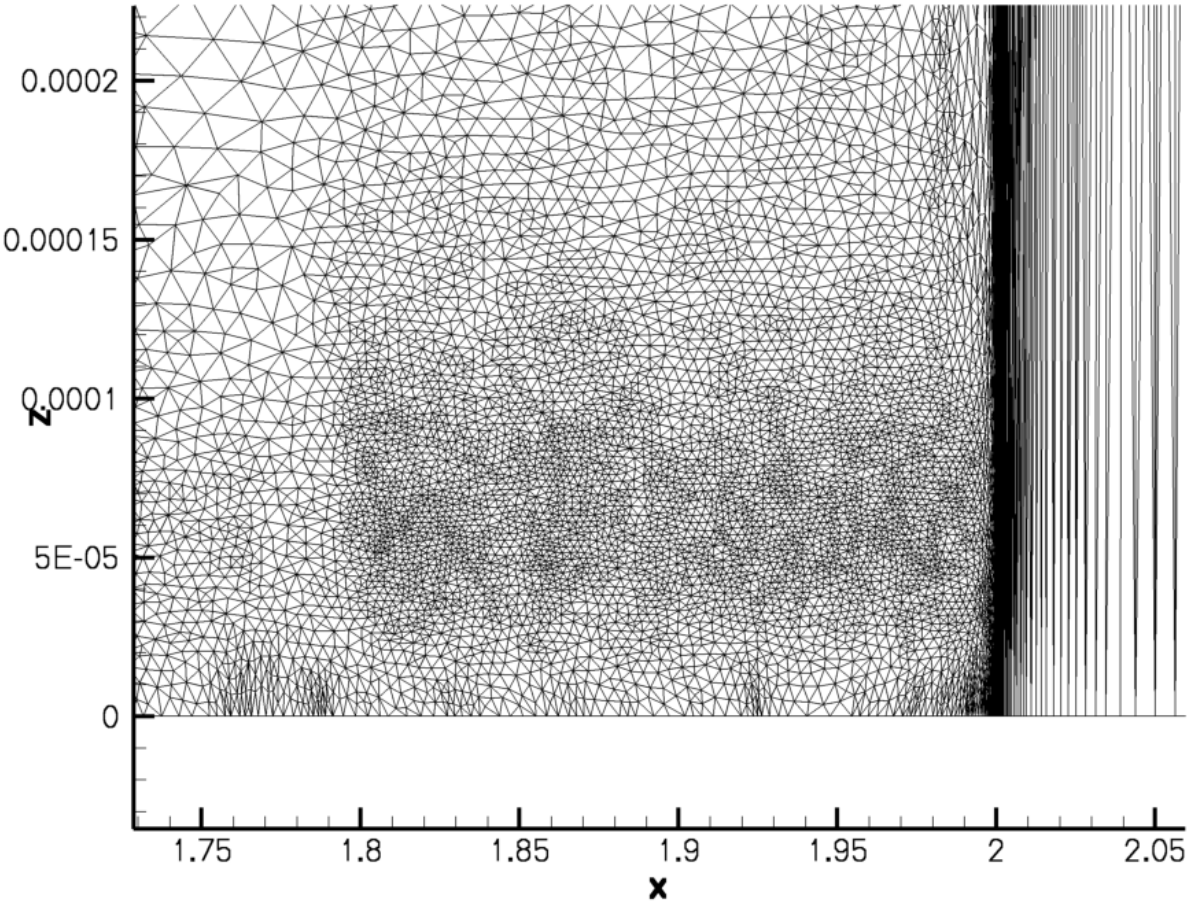
2D Flat Plate Grid

- Anisotropic refinement near the plate



2D Flat Plate Z-Scaled Grid

- 1000-1 refinement appears isotropic



Summary

- Simple specified metric illustrates the properties of each adaptive mechanics tool
  - Statistics in paper verify histogram observations
- Nominally second order adaptive finite volume scheme competitive with HIOCFD-2 results in terms of drag error per degree of freedom for multiple grid adaptation tools
  - Avenue for collaboration on solver technology, error estimation, and tetrahedral grid adaptation

Summary

- While not a routine capability, turbulent 2D flat plate shows promise
  - Hampered by solver robustness for under resolved flow features and high aspect ratio unstructured grids
  - Experimental solver technology and discretization improvements very helpful
  - Error estimation (Hessian reconstruction, particularly on boundaries) should be improved to produce smoother metric variation

In the Paper

- Compiled statistics to quantify edge length histograms
- 2D specified metric field
- Diamond airfoil Mach 2 drag adaptation
  - 2D triangles and 3D extruded to unit span tetrahedra
  - Comparison of Venditti and INRIA Optimal-Goal metrics
- Description of the error estimate procedures, Hessian reconstruction (boundary), and gradation control

Thank you!

- Turbulence Modeling Resource and High Order CFD Workshop websites invaluable
  - Big thank you to the people supporting these community resources

Future work

- SciTech 2016 paper and beyond (summarized in the paper)
  - Metric aligned grid elements
  - Curved boundaries and geometry access
  - Parallel execution
  - Error estimation
  - 2D and 3D RANS with turbulence modeling
  - Time-accurate simulation
- Engage researchers in a sustained effort and disseminate findings (paper, website, workshop)