Parallel Anisotropic Unstructured Grid Adaptation

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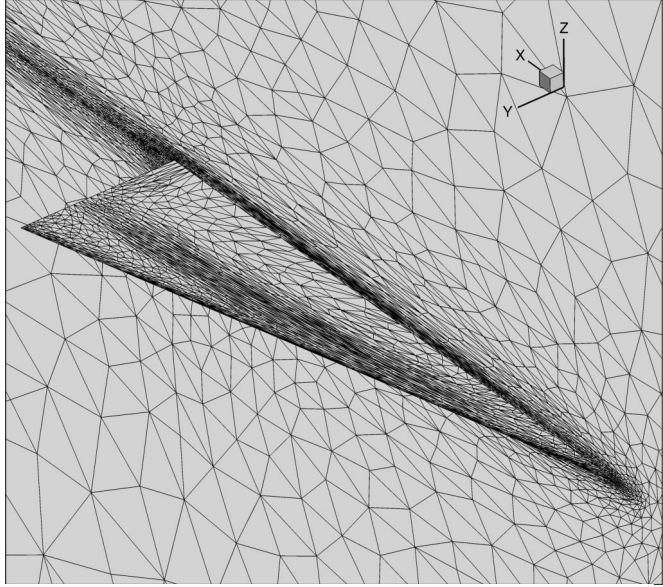
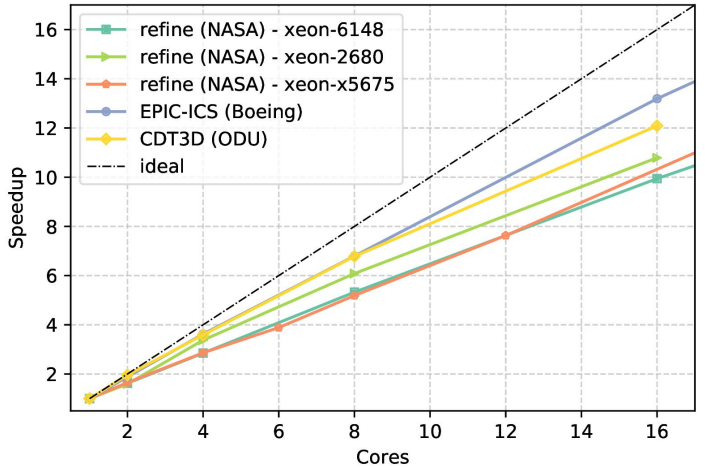
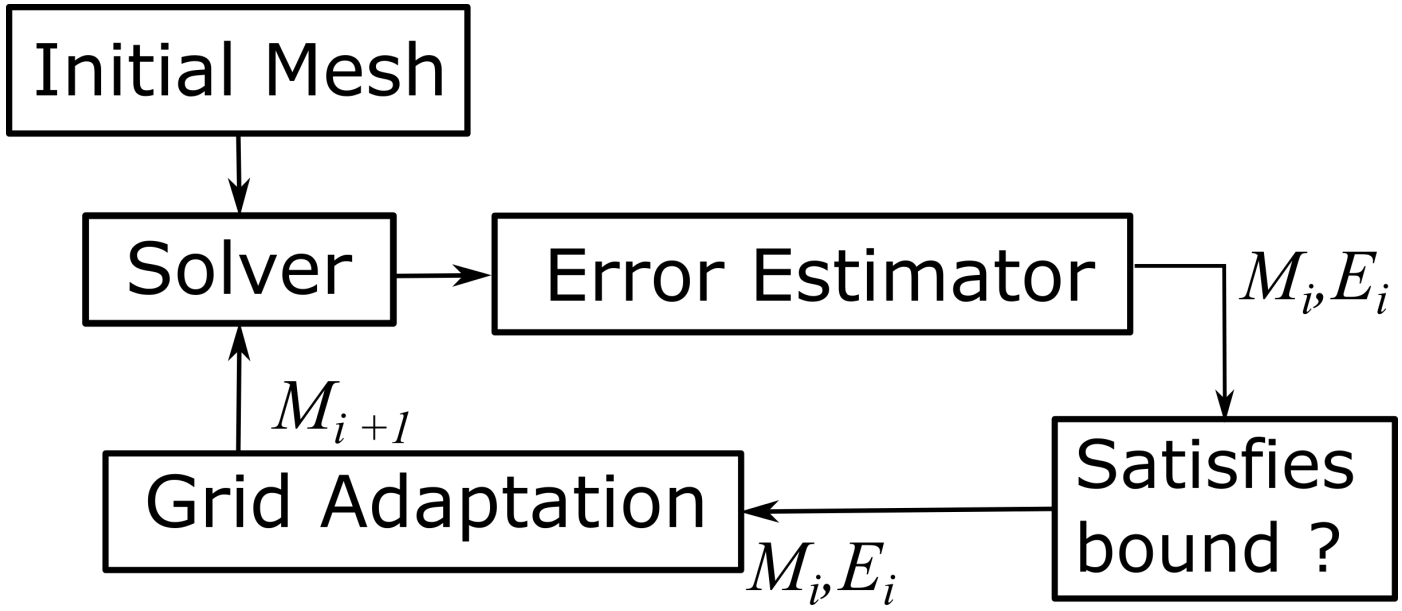
Todd Michal
The Boeing Company, St. Louis, MO





Grid adaptation as part of the CFD pipeline

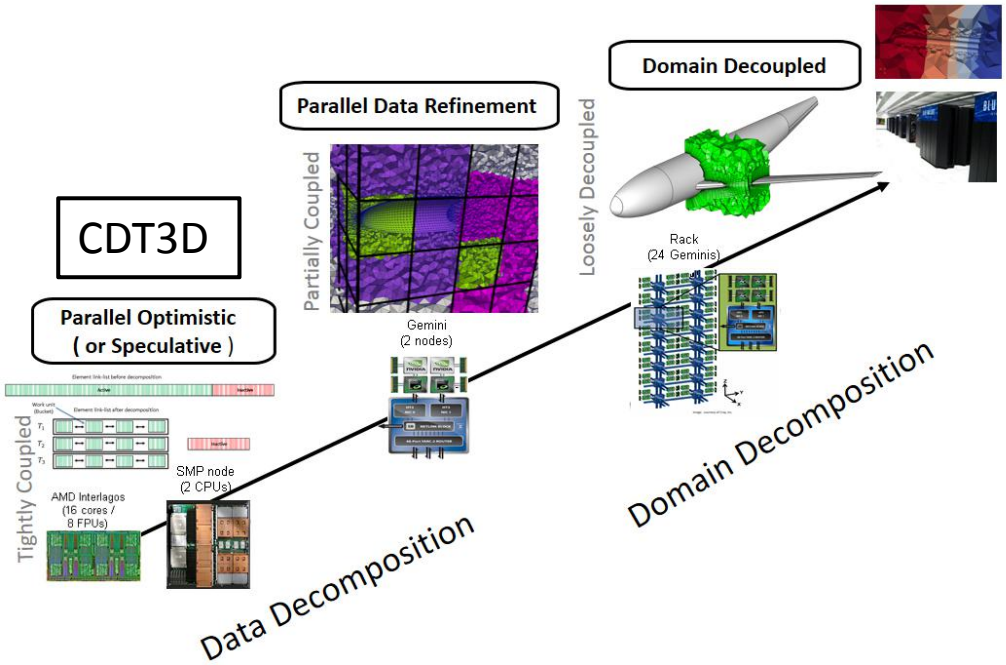


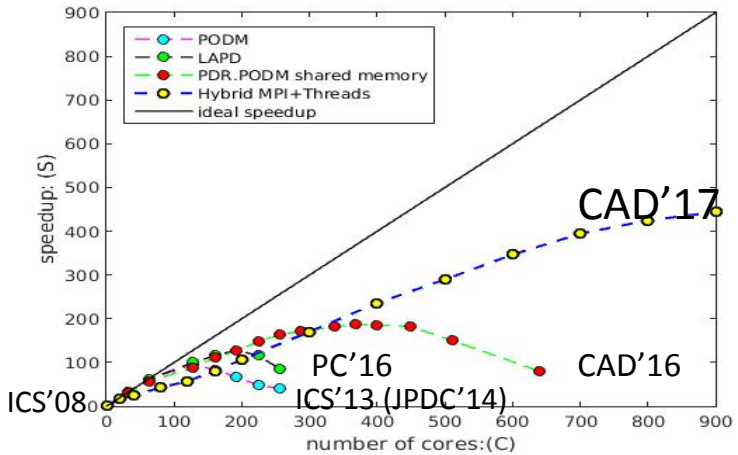
Grid Adaptation

- Anisotropic Metric
  - Supplies grid adaptation software with a metric tensor (3x3) that encapsulates desired size and direction
  - Analytic Metric
    - Easily evaluated function that models a curved flow shear layer
  - Multiscale
    - Recovered Mach Hessian, scaled to control L2 norm of interpolation error at specified complexity (adapted grid size)
    - Theory [1] and experiments [2] show second-order interpolation error control

[1] A. Loseille and F. Alauzet, "Continuous Mesh Framework Part I: Well-Posed Continuous Interpolation Error," SIAM J. Numer. Anal., vol. 49, no. 1, pp. 38–60, Jan. 2011.
[2] A. Loseille, A. Dervieux, P. Frey, and F. Alauzet, "Achievement of Global Second Order Mesh Convergence for Discontinuous Flows with Adapted Unstructured Meshes," , AIAA 2007-4186

Telescopic Approach for Grid Generation & Adaptation



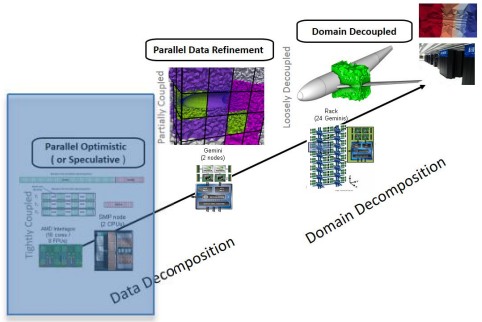


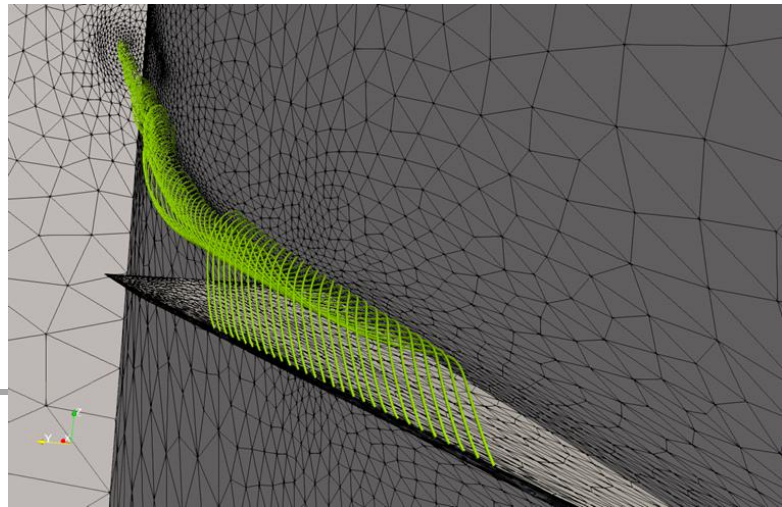
Telescopic Approach for Extreme-scale Parallel Mesh Generation for CFD Applications. Nikos Chrisochoides Published in AIAA Aviation Forum, Washington DC, June, 2016.

Methods (scalability-first)

CDT3D

- CRTC, Old Dominion University
- Data Decomposition
- Fine-grained scheme for local reconnection
- Speculative execution



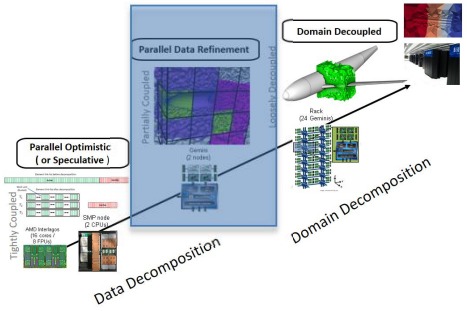


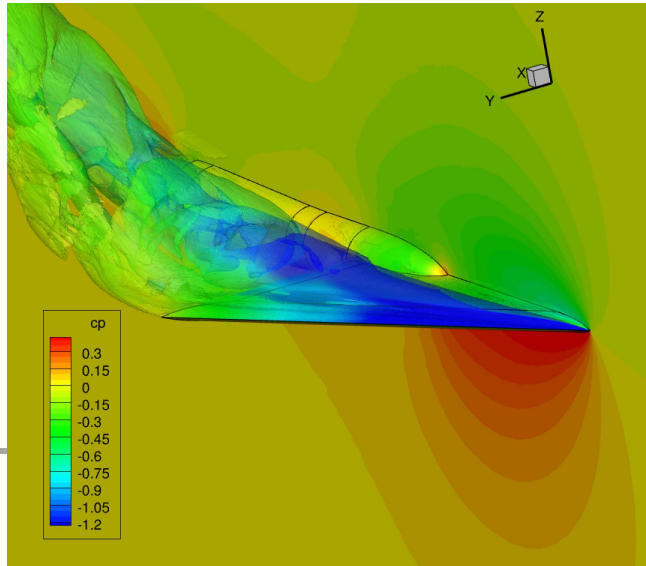
Fine-grained Speculative Topological Transformation Scheme for Local Reconnection Method. Fotios Drakopoulos, Christos Tsolakis and Nikos Chrisochoides. In AIAA Aviation Forum 2018, Atlanta, Georgia, June, 2018

Methods (scalability-first)

refine

- NASA/LaRC
- Domain decomposition (ParMetis/Zoltan)
- Local grid operators of element split, element collapse, and node movement
- Homogeneous programming model
- Message Passing





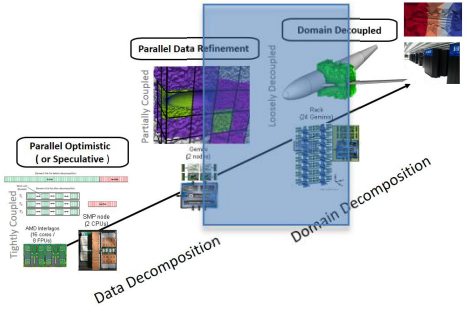
Center for Real-time Computing 2007

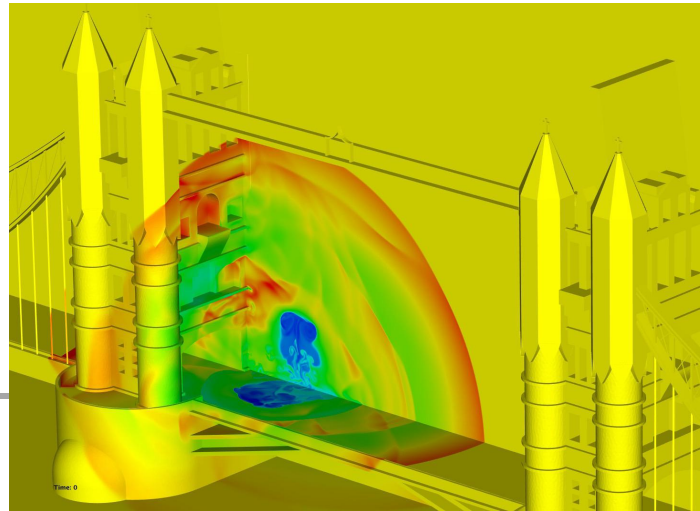
Park, M. A., and Darmofal, D. L., "Parallel Anisotropic Tetrahedral Adaptation," AIAA Paper 2008–917, 2008.

Methods (functionality-first)

Feflo.a

- INRIA
- Hierarchical Domain Decomposition
- Cavity operator
- Unix pipes



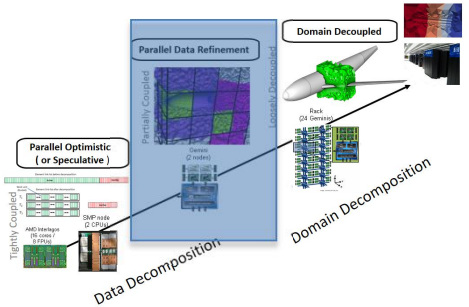


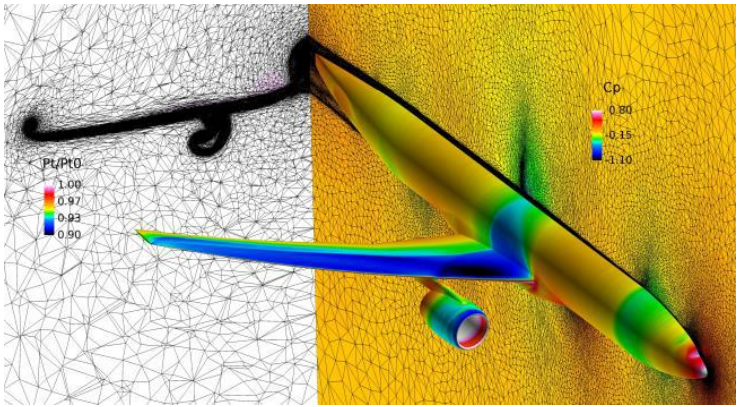
Loseille, A., Menier, V., and Alauzet, F., “Parallel Generation of Large-size Adapted Meshes,” Procedia Engineering, Vol. 124, 2015, pp. 57–69. International Meshing Roundtable

Methods (functionality-first)

EPIC

- The Boeing Company
- Coarse-grain parallelism at subdomain level
- Refinement, coarsening, reconnection and smoothing
- Message Passing



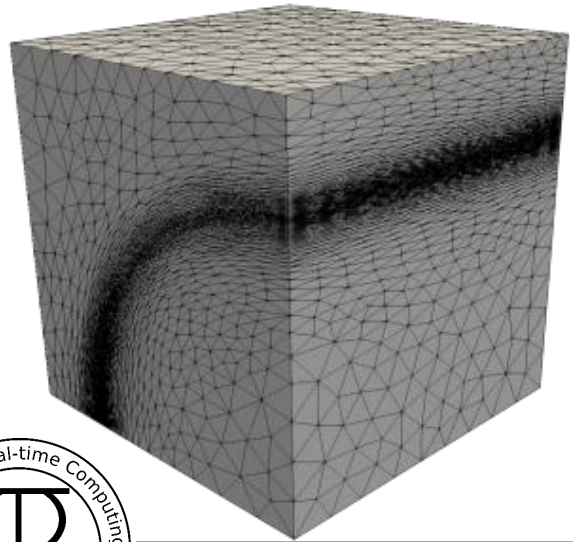


Michal, T., and Krakos, J., "Anisotropic Mesh Adaptation Through Edge Primitive Operations," AIAA Paper 2012–159, 2012.

Test Cases

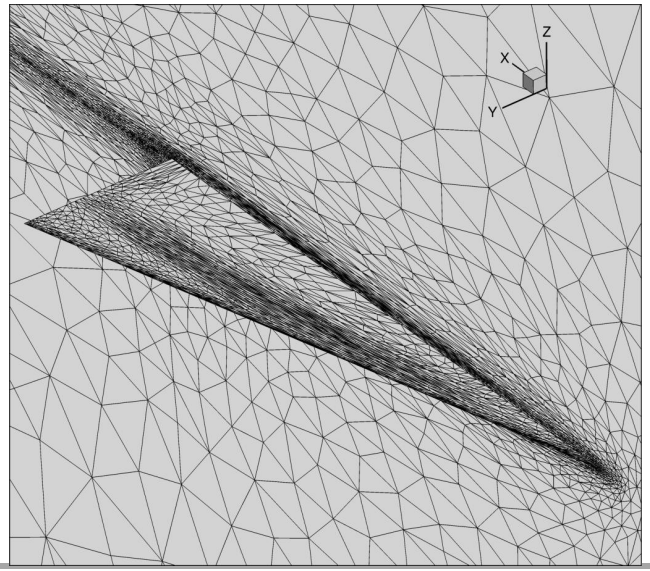
Metric tensor field :

- Analytic Metric
- Target Complexity 500k



Metric tensor field :

- Multiscale metric based on the Mach field
- Target Complexities 500k, 10M



Evaluation Criteria

- Scalability
  - Parallel execution time versus using sequential execution

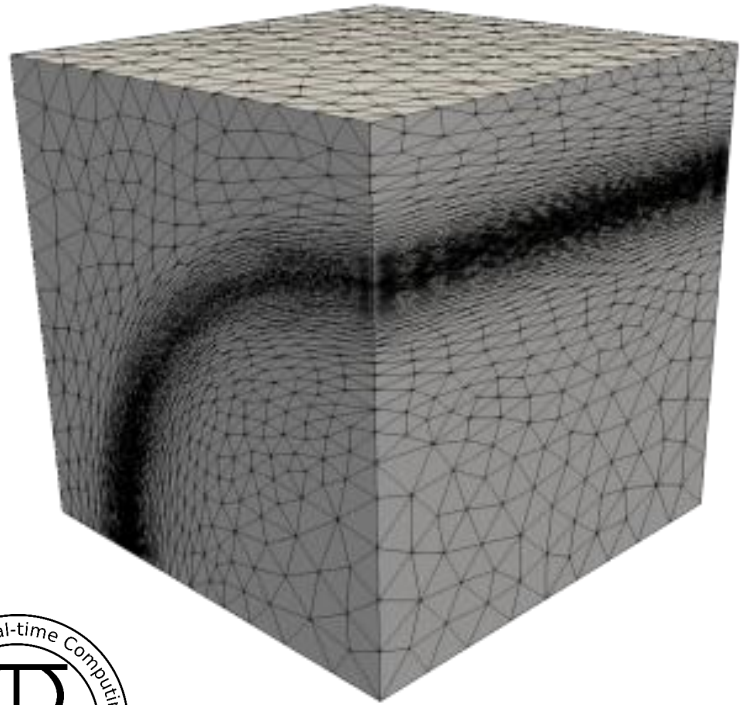
- Quality
  - Edge Length (in metric space)

$$\text{length}(a,b) = \frac{\ell_a - \ell_b}{\log(\ell_a) - \log(\ell_b)}$$

  - Mean ratio (in metric space)

$$\text{quality}(K) = f\left(\frac{\text{volume}^{2/3}}{\sqrt{\sum(\text{edge\_length})^2}}\right)$$

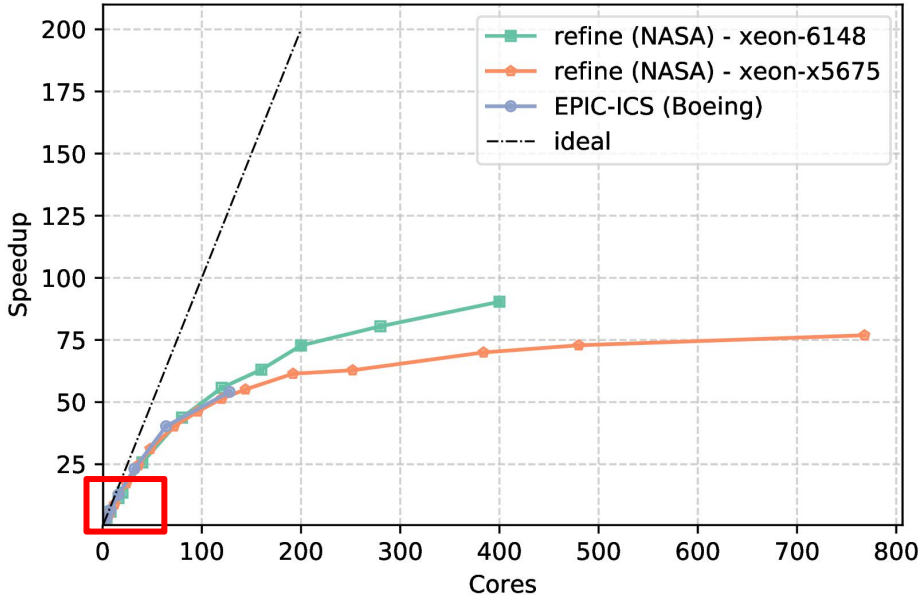
Case: Cube Polar-2

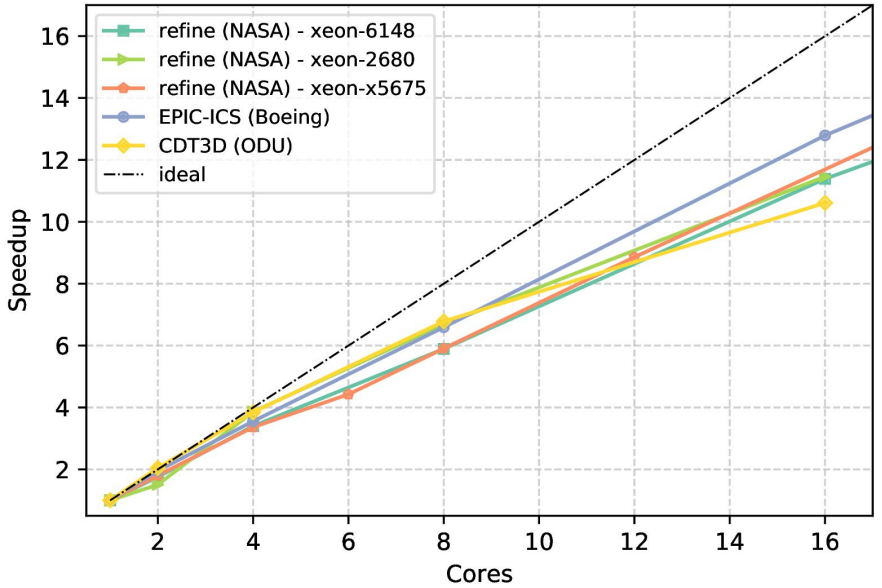


Metric tensor field :

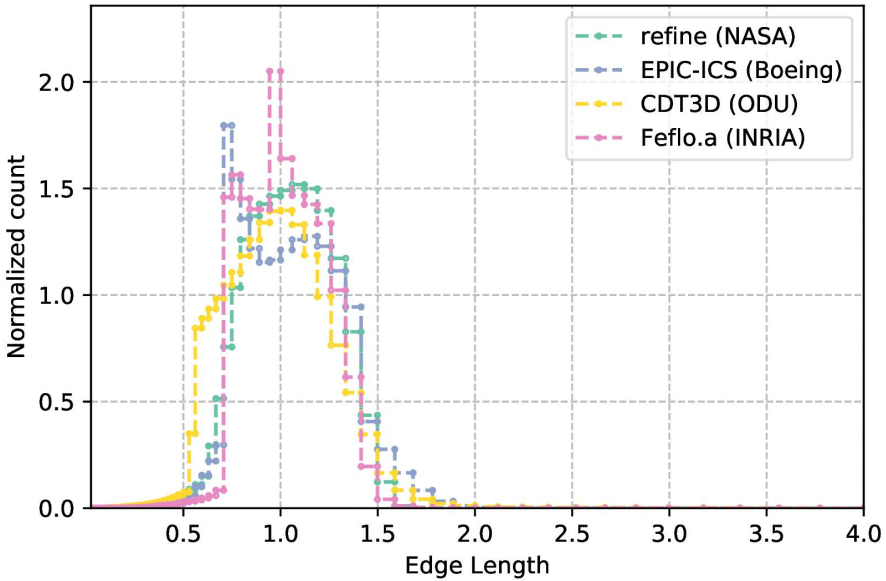
- Analytic Metric
- Target Complexity 500k

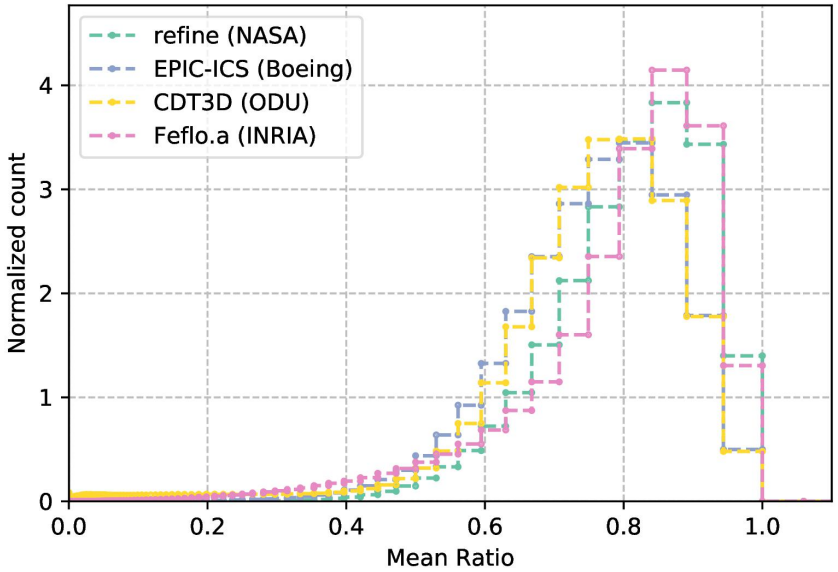
Cube Polar-2: Scalability results





Cube Polar-2: Metric conformity results





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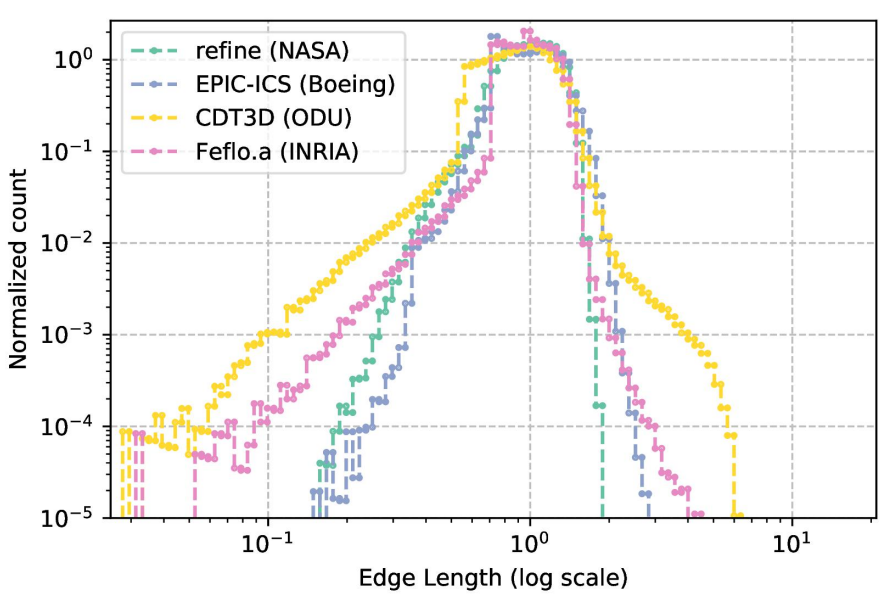
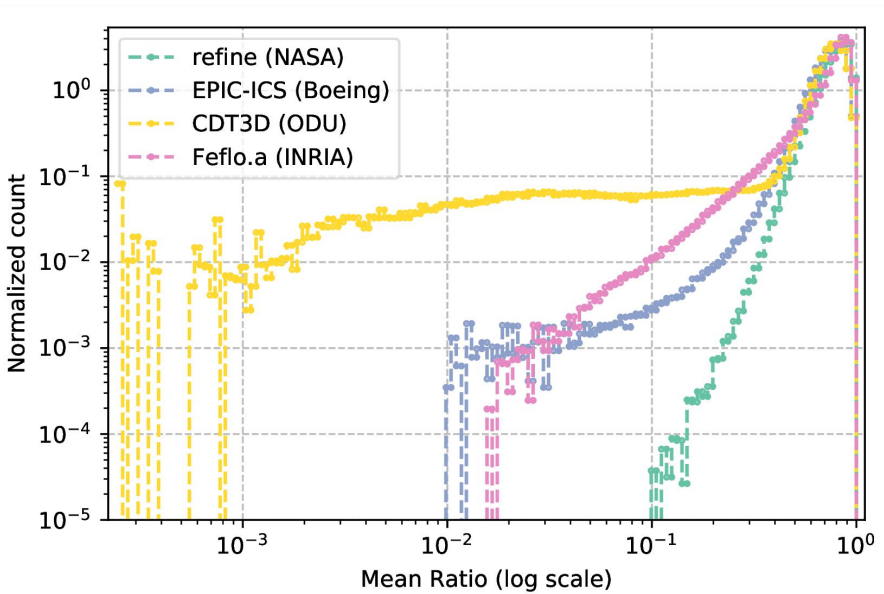
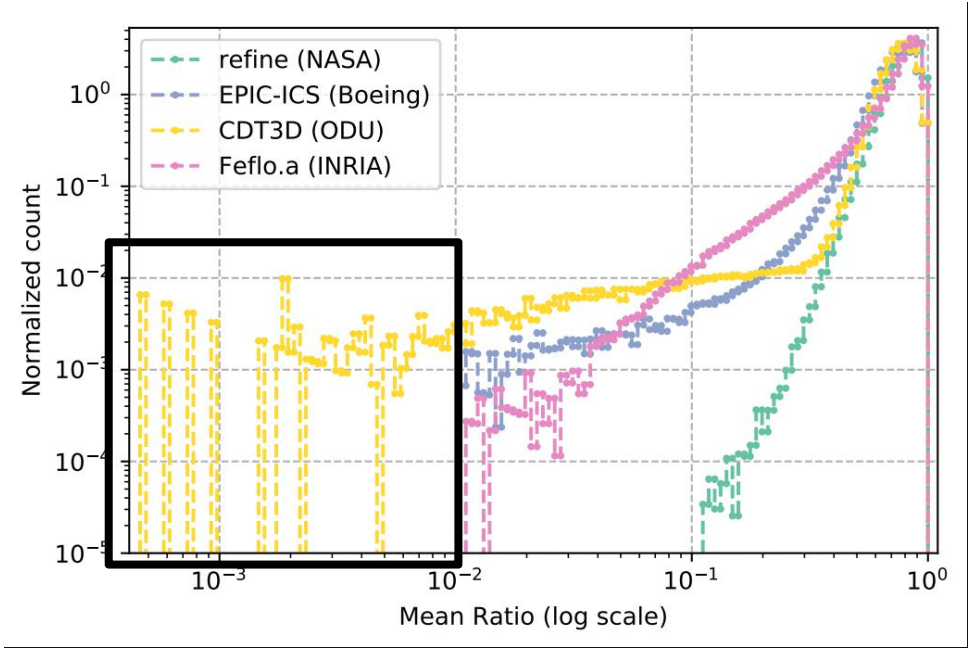
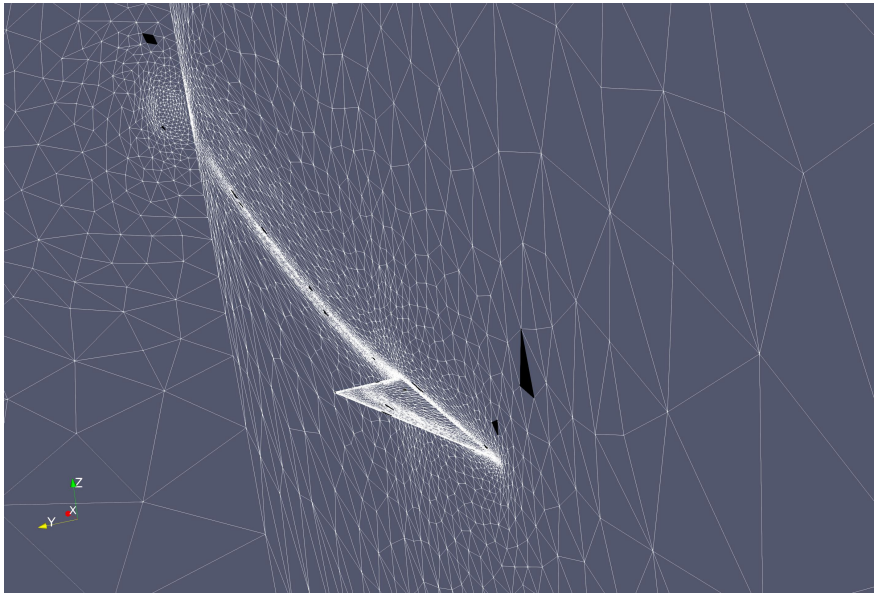


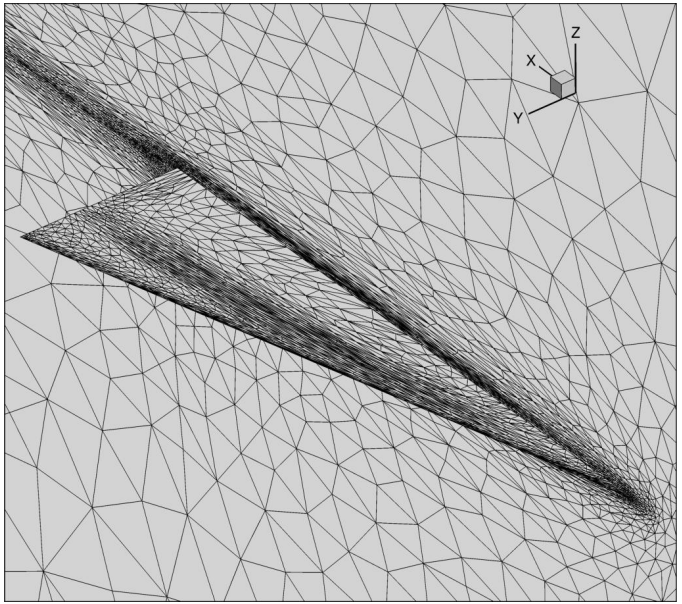


Metric conformity results (Delta Wing)





Delta Wing Laminar Flow



The 3D Laminar Delta Wing flow case [1]

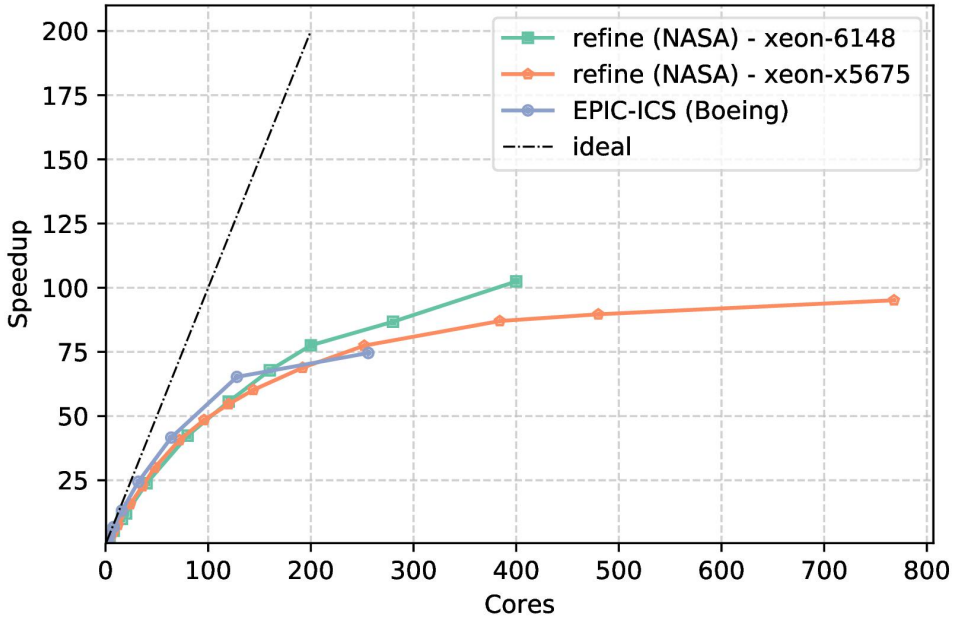
Freestream conditions:

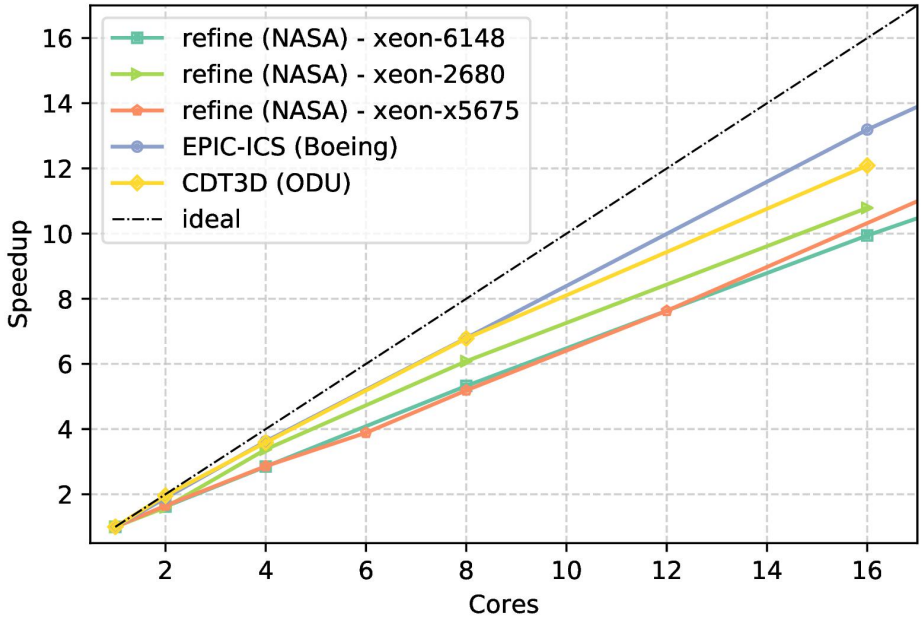
- 0.3 Mach,
- 4,000 Reynolds number (based on the root chord length)
- 12.5° angle of attack.

More details about the verification of the delta wing adaptation [2]

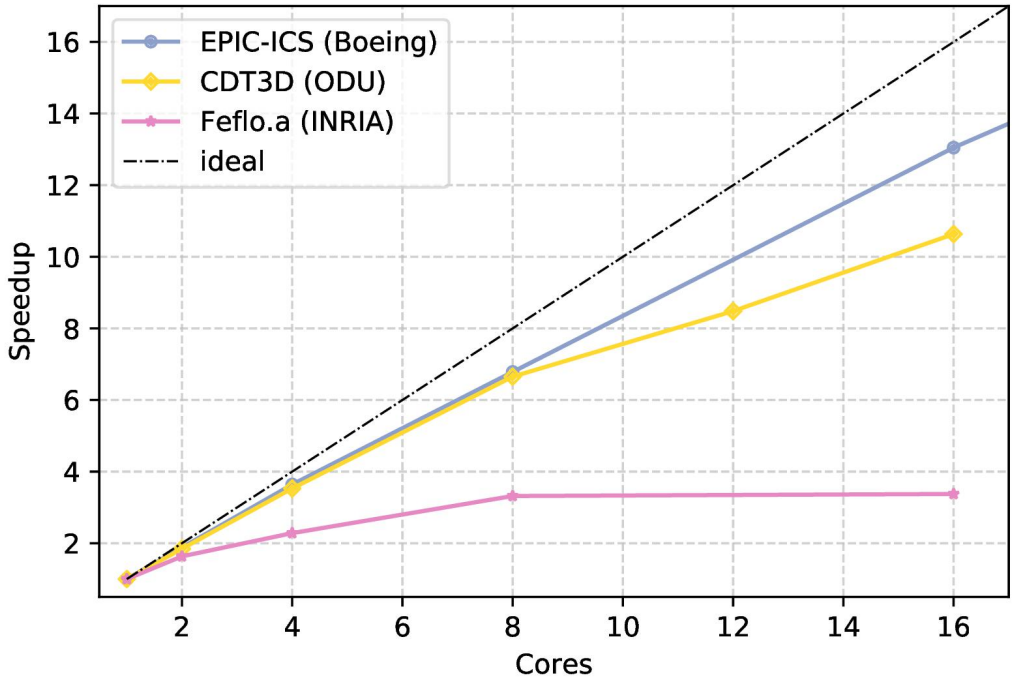
[1] Wang et al. *"High-Order CFD Methods: Current Status and Perspective,"* International Journal for Numerical Methods in Fluids, Vol. 72, No. 8, 2013
[2] Park, M. A. et al. "Verification of Unstructured Grid Adaptation Components," AIAA SciTech Forum 2019

Delta Wing Laminar Flow *(Target complexity 500k)*





Delta Wing Laminar Flow *(Target complexity 10M)*



Delta Wing Laminar Flow *(50k-> …. -> 12M)*

Feflo.a

cores	complexity	T_{prep}	T_{e2e}	elms/sec	pts/sec
1	50k → 500k	1.9	52.0	87,65K	13,57K
3	500k → 1.5m	6.2	82.5	132,78K	20,49K
6	1.5m → 3m	23.3	111.2	138,42K	21,41K
12	3m → 6m	68.3	155.0	160,91K	24,80K
24	6m → 12m	175	223.4	183,13K	28,26K

CDT3D

cores	complexity	T_{prep}	T_{e2e}	elms/sec	pts/sec
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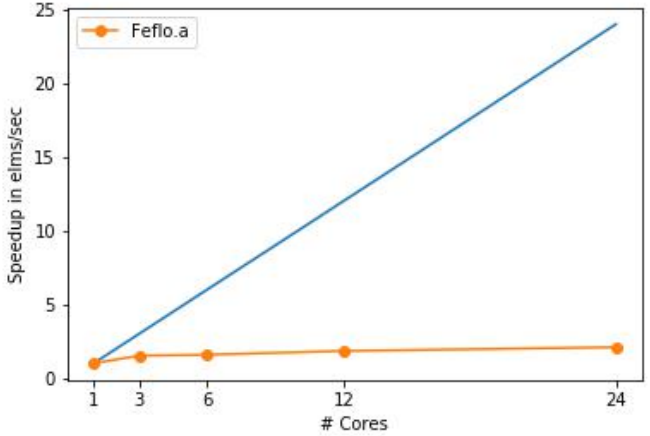
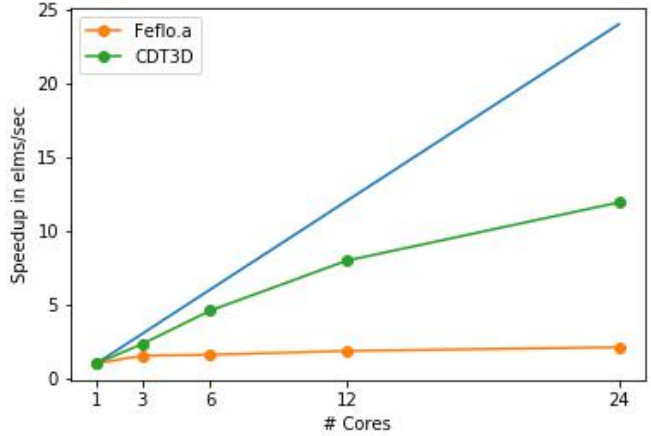
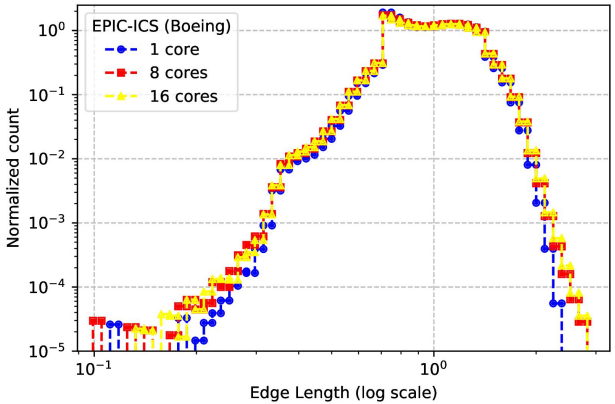
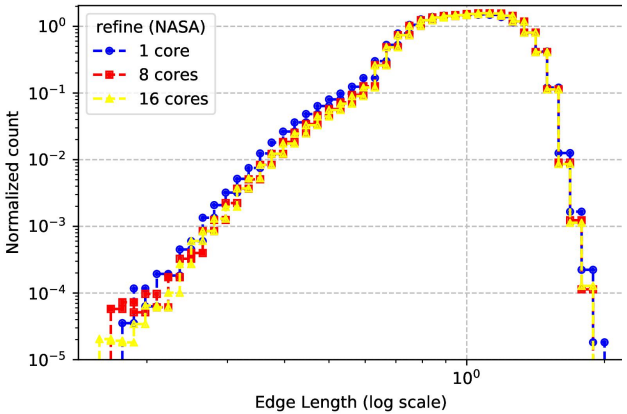
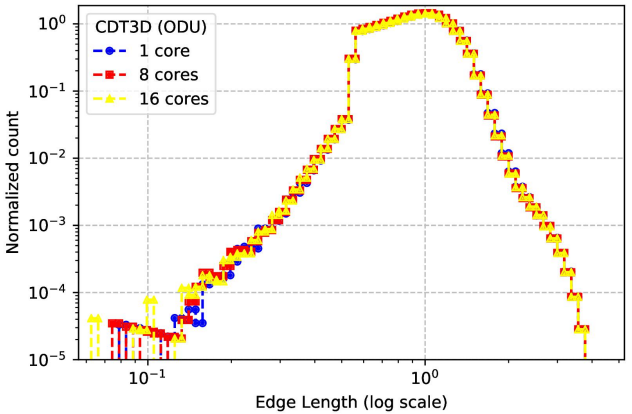




Stability



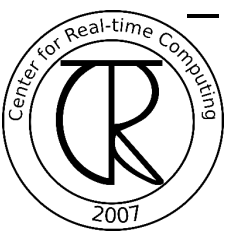




— Metric conformity is independent of number of cores

Follow-up Study

- Evaluate cases that involve balanced insertion and collapsing
  - Realistic applications utilize the full set of mesh operators
- Include curved geometries
  - Implemented through surrogate geometry or geometry kernel API
- Increase the problem size
- Include more parallel grid adaptation packages
- Educate algorithm changes to reduce execution time
  - refine now 50%-75% of the execution time reported in paper



Participate

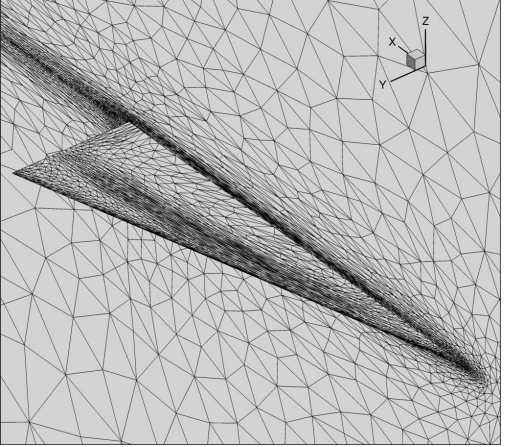
https://ugawg.github.io/

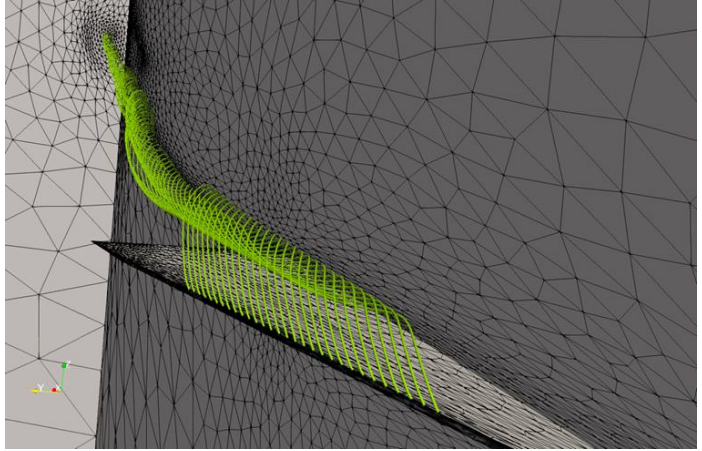
– Past papers & presentations

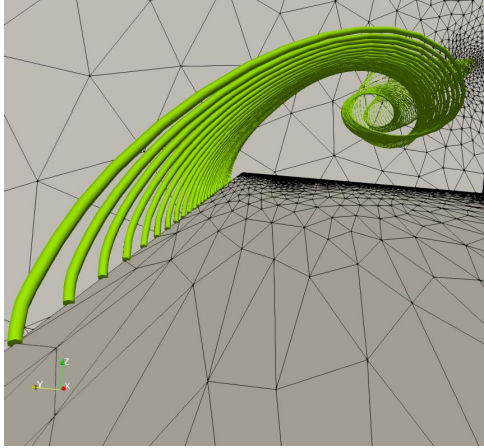
https://github.com/UGAWG

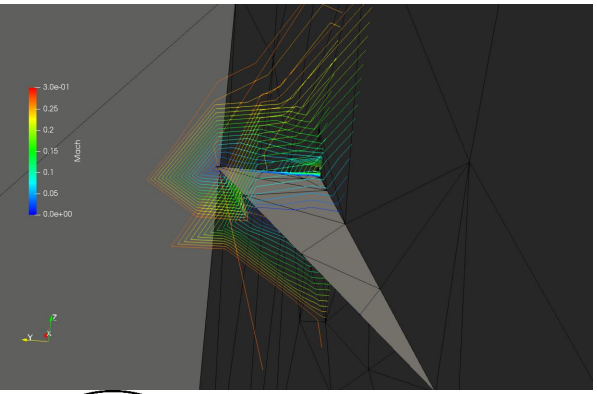
– Input Grids and metric fields

– Quality and speedup data

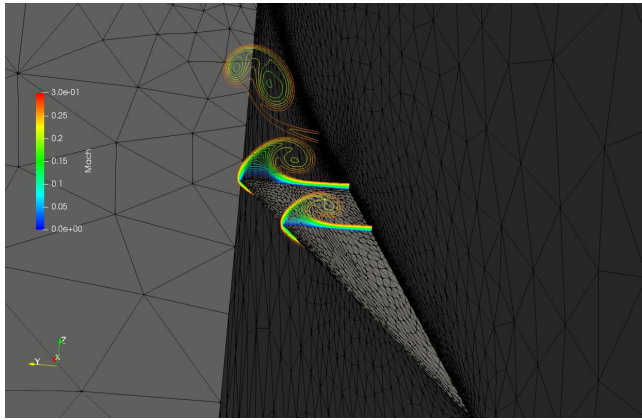








Thank you



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the Modeling and Simulation Fellowship at Old Dominion University and Richard T. Cheng Endowment.
This work was partially supported by the Transformational Tools and Technologies (TTT) Project of
the NASA Transformative Aeronautics Concepts Program (TACP)