First benchmark of the Unstructured Grid Adaptation Working Group

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Motivation

Finding 3 of the CFD Vision 2030 Study[1]

Mesh generation and adaptivity continue to be significant bottlenecks in the CFD [Computational Fluid Dynamics] workflow, and very little government investment has been targeted in these areas.

- Encourage new entrants into adaptive grid research
- Encourage detailed implementation discussion between researchers
- Define expected performance, not "eye-ball norm" or "high quality"

Published references are often incomplete

- Article page limits favor brevity
- Less successful approaches are not documented
- Why a particular implementation was chosen is omitted

[1] Slotnick et al. CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences NASA CR-2014-218178

Inspiration

Turbulence Modeling Resource

The objective is to provide a resource for CFD developers to:

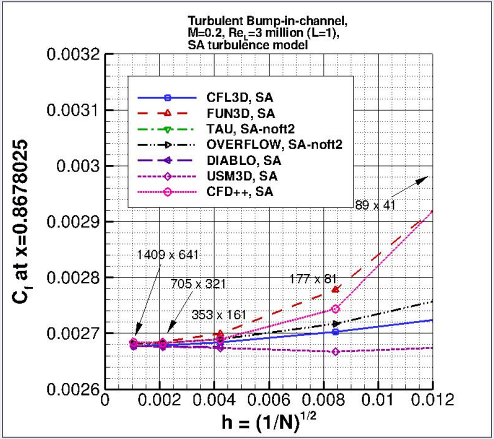
- Obtain accurate and up-to-date information on widely-used turbulence models, and
- Verify that models are implemented correctly.

Public website `https://turbmodels.larc.nasa.gov` provides:

- References, equations, and clarifications for each model
- CFD results for verification (is the model implemented correctly)
- Experimental measurements for validation (does the model represent reality)

Turbulence Modeling Resource

Seven independent implementations produce same result as grid is refined gives high confidence that the models are implemented consistently and correctly.



Related Work

AIAA Paper 2015-2292

Comparing Anisotropic Output-Based Grid Adaptation Methods by Decomposition

- 2D and 3D output-based and analytic-metric adaptation for planar geometries
- Descriptive statistics and output convergence to quantify performance

AIAA Paper 2016-3323

Unstructured Grid Adaptation: Status, Potential Impacts, and Recommended Investments Toward CFD Vision 2030

- Literature survey
- Unstructured grid adaptation status and 15 year forecast
- Recommendations for investment and potential impacts

Related Work

Today's Talk

First benchmark of the Unstructured Grid Adaptation Working Group

- 3D analytic-metric adaptation for a planar geometry and simple curved surface CAD model
- Creation of a benchmark repository and website

AIAA SciTech 2018

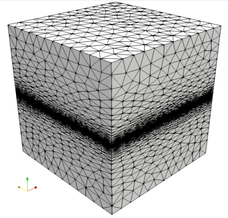
Unstructured Grid Adaptation and Solver Technology for Turbulent Flows

- 3D interpolation error and output-based metrics for hemisphere-cylinder and wing CAD models
- Test cases and results included in benchmark repository and website

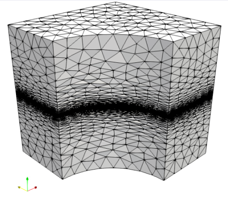
Outline

Test Cases

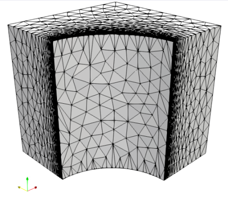
Cube, Linear Metric



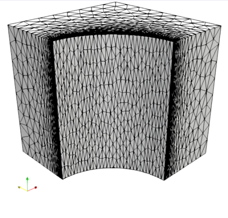
Cube-Cylinder, Linear Metric



Cube-Cylinder, Polar-1 Metric



Cube-Cylinder, Polar-2 Metric



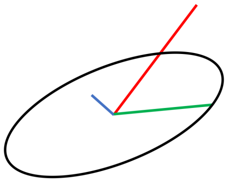
Evaluation

Inputs

- STEP and EGADS (Electronic Geometry Aircraft Design System) formats available for geometry description
- Initial grids
- Analytically defined metric field

Evaluation

Edge Length in Metric Visualized as an Ellipse



Measures

- Edge length evaluated in metric
- Element mean ratio evaluated in metric $f\left(\frac{Vol^{2/3}}{\sqrt{\Sigma EdgeLength^2}}\right)$
- Number of elements in mesh

Descriptive Statistics

- Histograms, minimum, and maximum

Methods

EPIC

- Boeing Company
- EPIC-IC: insertion and collapse
- EPIC-ICS: insertion, collapse, and swap
- EPIC-ICSM: insertion, collapse, swap, and node movement

refine

- NASA
- Version 1: insertion, collapse, swap, and node movement
- Version 2: insertion, collapse, and node movement

Methods

Omega_h

- Rensselaer Polytechnic Institute and Sandia National Laboratories
- Insertion, collapse, swap, and node movement for incremental projection

Pragmatic

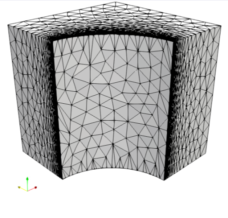
- Imperial College London
- Insertion, collapse, swap, and node movement

feflo.a

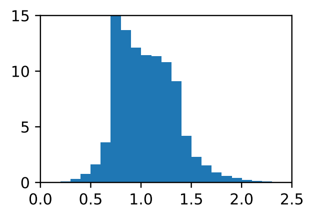
- INRIA
- Cavity-based operator

Cube-Cylinder, Polar-1 Metric Edge Length Histogram

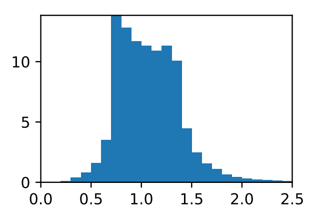
Cube-Cylinder, Polar-1 Metric



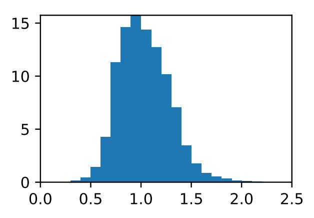
EPIC-ICS



EPIC-IC

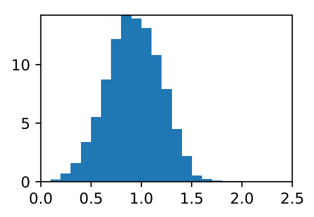


EPIC-ICSM

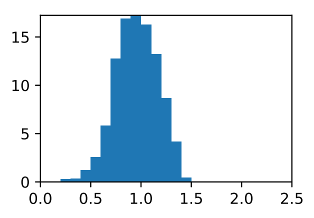


Cube-Cylinder, Polar-1 Metric Edge Length Histogram

refine



Pragmatic



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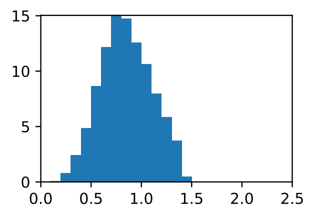

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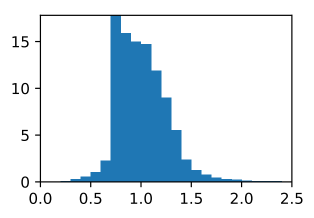
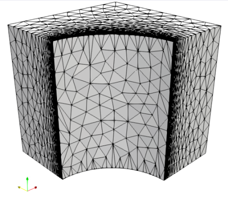


Learning

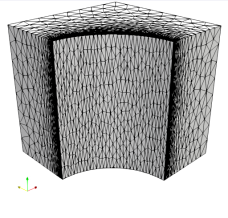
Gradation and Curvature

- Polar-1 had large gradation and was difficult to satisfy
- Polar-1 gradation gave raise to polar-2 with refinement in tangential direction
- Curvature based metric limits improved results even when evaluated with the original metric

Cube-Cylinder, Polar-1 Metric



Cube-Cylinder, Polar-2 Metric



Polar-1 and Polar-2 Comparison

Cube-Cylinder, Polar-1 Metric
Max Length in Metric

- 5.39 EPIC-IC
- 3.37 EPIC-ICS
- 3.14 EPIC-ICSM
- 1.71 Omega_h
- 1.74 Pragmatic
- 17.40 feflo.a
- 9.35 refine

Cube-Cylinder, Polar-2 Metric
Max Length in Metric

- 4.91 EPIC-IC
- 2.34 EPIC-ICS
- 2.30 EPIC-ICSM
- 1.81 Omega_h
- 1.73 Pragmatic
- 2.65 feflo.a
- 3.09 refine

Outline

Unstructured Grid Adaptation Working Group (UGAWG)

Organization

- Monthly virtual meetings
- Implementation details discussed
- Test cases selected
- Planning for publication and presentation

GitHub Group

`https://github.com/UGAWG` Repositories

- Documentation is sparse, but an introductory website can be added via GitHub Pages if community interest grows
- Meeting notes (committee-organization)
- Analytic metric test cases (adapt-benchmarks)
- Analytic metric results from this paper (adapt-results)
- Solution adaptive cases under development (solution-adapt-cases)
- Solution adaptive results under development (solution-adapt-results)

Outline

Summary

Motivation

- Introduced the context and inspiration for this work

Test Cases

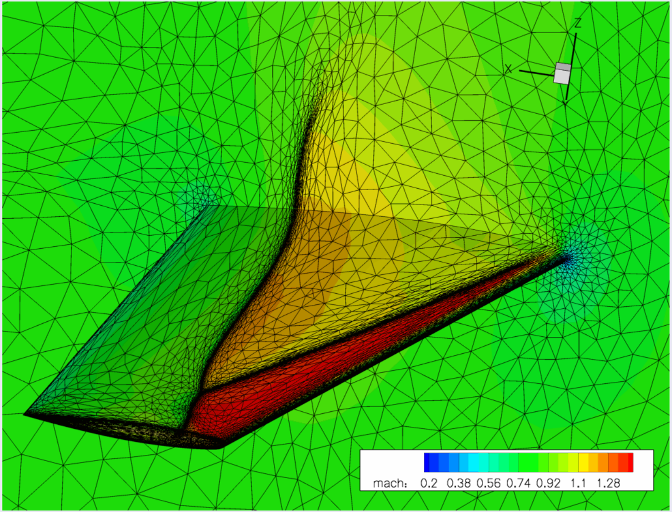
- Analytically described metrics on simple geometries that introduce curved geometry and curved metric principle axes
- Provided learning opportunity and forum to understand the impact of implementation details
- Resulting meshes available for up to eight methods applied to four cases

Organization

- Monthly virtual meeting for discussion and organization
- Test cases and results maintained in an accessible manner

Future Work

AIAA SciTech Special Session on Turbulent Solver Technology



Future Work[2]

Through systemic creation and evaluation of benchmark cases

- Error estimation for turbulent flows (Reynolds-averaged or Eddy-resolving)
- Metric interpretation and adaptive mechanics on curved geometries
- Accept issues present in typical CAD geometries
- Adaptive curved meshes for higher-order schemes
- Efficiency on current and emerging high performance computing platforms
- Evaluation of individual local grid operators in isolation

Adaptive grid computations displace fixed grids as the default

- Technology diffusion strategy
- Partnership with commercial entities

[2] Identified in AIAA Paper 2016-3323

Participate

https://github.com/UGAWG

- Resulting meshes available for analysis or comparison to new methods
- Add meshes from new methods
- Define new test cases

Join virtual meeting

- UGAWG@Mail.EmailHorse.com
- Mike.Park@NASA.gov
- Understand the impact of implementation details