# Geometry Modeling for Unstructured Mesh Adaptation

Michael Park, Bil Kleb, and William Jones
*NASA Langley Research Center*

Joshua Krakos and Todd Michal
*The Boeing Company*

Adrien Loseille
*INRIA Saclay-île-de-France*

Robert Haimes
*Massachusetts Institute of Technology*

John Dannenhoffer
*Syracuse University*

17 June 2019

# Motivation

## Technology roadmap of the CFD Vision 2030 Study[1]

"Focused research programs in streamlined CAD access and interfacing, large-scale mesh generation, and automated optimal adaptive meshing techniques are required."

## Supporting Certification by Analysis

- Demands the accurate simulation of steady and time-dependent separated flows for complex configurations (e.g., maximum lift of transport aircraft)
- Requires improved automation and robustness for complex geometry models and database creation (outside center of flight envelope where CFD typically applied)
- Includes verification and validation exercises for the entire adaptive mesh toolchain

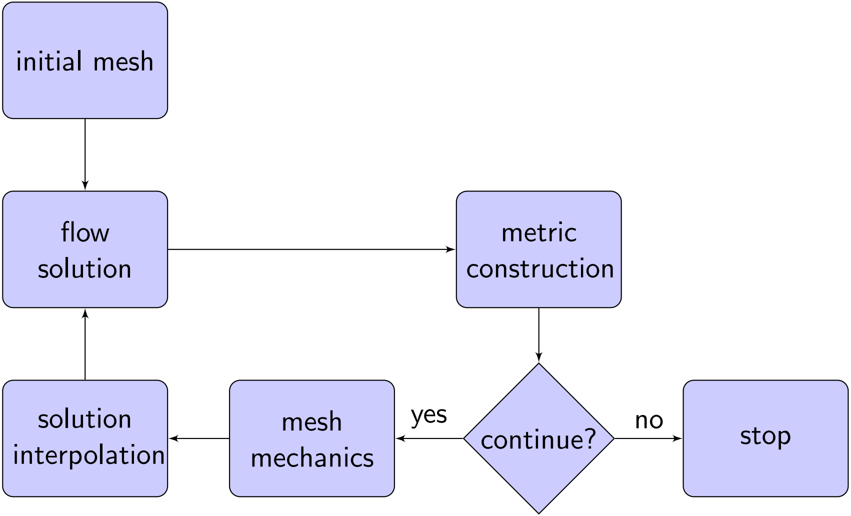
[1] Slotnick et al. NASA CR-2014-218178

# Motivation

## Methodology

- Summarize common intended and unintended artifacts of geometry models
- Present approaches to accept or mitigate these artifacts
- Two independent implementations of metric-based unstructured mesh adaptation
- Evaluate integrated mesh adaptation process performance on AIAA workshop geometries
  - Realistic level of designer intended artifacts
  - Contain typical unintended construction artifacts

# Integrated Mesh Adaptation Process

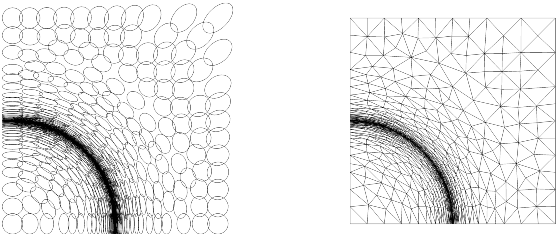


# Metric-Based Unstructured Mesh Adaptation

## Metric field

- Describes a request of mesh density, stretching, and orientation
- Constructed to control interpolation or output error

## Continuous metric field rendered as ellipses and unit mesh



# Multiscale Metric

## Controls interpolation error in a scalar field

- Hessian reconstructed from solution
- Local scaling[2] to control interpolation error $L^P$-norm of smooth and nonsmooth features simultaneously
- Classical Hessian methods (no local scaling) control the $L^\infty$-norm (nonsmooth features only)

[2] Loseille, Dervieux, Frey, and Alauzet, AIAA-2007-4186

# Mesh Mechanics

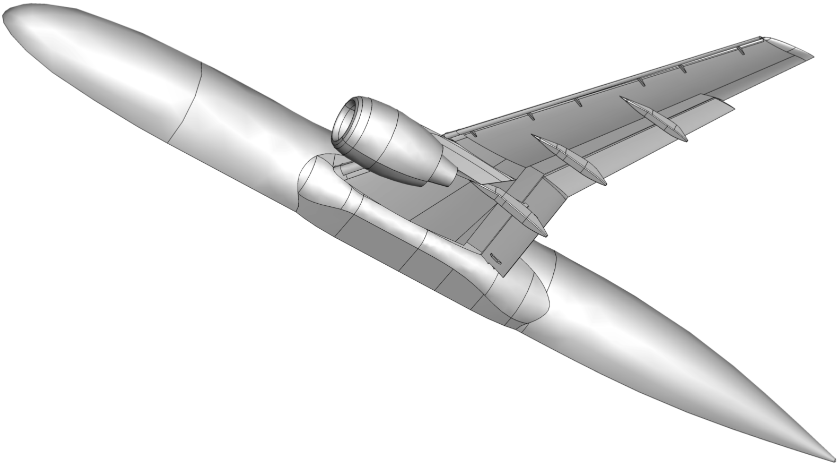
## Unstructured grid

- Simplicies (triangles and tetrahedra)
- Conforming to a geometry model Boundary REPresentation (BREP)
- Parallel execution after initial grid generation

# Outline

# Intended Geometry Model Complexity

Small features, close proximity between bodies, and many features (e.g., JAXA Standard Model (JSM) with nacelle)



# Unintended Geometry Model Artifacts

## These issues are pervasive[3,4,5]

inadequate tolerances, discontinuous parameterization, degeneracy, periodicity, small edges, sliver faces, narrow faces, excessive detail, or inconvenient topology

## Mitigation approaches presented here assume model import is possible!

small gaps, missing faces, duplicate surfaces, overlapping surfaces, self-intersecting surfaces, inaccurate p-curves, incorrect edge orientation, cusps, intersecting edges, or voids

---

[3] Chawner, "Survey Results – Mesh Generation and CAD Interoperability," Another Fine Mesh Pointwise Blog 13-JUN-2018

[4] Taylor, "Analysis of Participant Questionnaires submitted to the 1st AIAA Geometry and Mesh Generation Workshop," AIAA Paper 2018–129

[5] Gammon, Bucklow, and Fairey, "A Review of Common Geometry Issues Affecting Mesh Generation," AIAA Paper 2018–1402

# Mitigation Strategies

## In paper, not covered in detail here

- Virtual topology or quilting for more convenient topology
- Higher order surrogate surfaces for direct evaluation or to support evaluation of an underlying geometry model
- Parametric degeneracy and periodicity support

# Outline

# Geometric constraints

## Purpose

- Ensure that the metric spacing request is compatible with the geometry
- Augments the solution-based metric via intersection
- Satisfied on the initial mesh and active throughout the adaptive sequence until the solution-based metric size request becomes smaller than the constraint
- Increase likelihood of future mesh operation success with the potential side effect of increase cost

## Geometry-based metric

- Feature size (length of short edge, width of narrow face)
- Curvature of edges and surfaces

# Outline

# Integrated Mesh Adaptation Processes

## Toolset used at Boeing

- MADCAP (Modular Aerodynamic Design Computational Analysis Process)
- EPIC (Edge Primitive Insertion and Collapse)
- GGNS (General Geometry Navier-Stokes)

## Toolset used at NASA

- OpenCSM and EGADS in ESP (Engineering Sketch Pad)
- refine
- TetGen or AFLR (Advancing-Front/Local-Reconnection)
- FUN3D-FV (Fully-Unstructured Navier-Stokes 3D Finite Volume)

# Initial mesh

## Initial mesh process

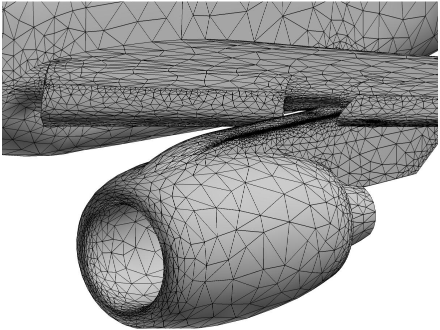
- Coarse surface mesh via EGADS tessellation or MADCAP
- Surface mesh adapted to geometry metric
- Volume filled with isotropic TetGen or AFLR mesh
- Volume mesh adapted to geometry metric

# Outline

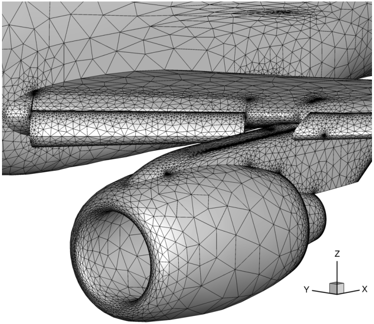
# JAXA Standard Model (JSM)

## Initial geometry adapted surface

MADCAP+EPIC



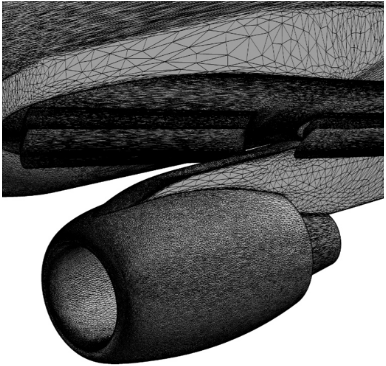
EGADS+refine



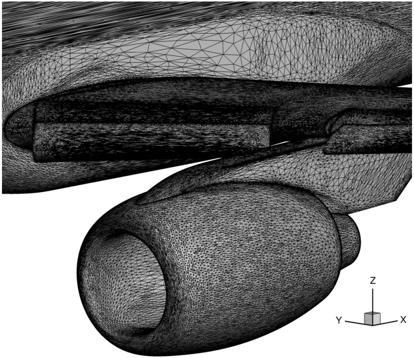
# JAXA Standard Model (JSM)

Adapted at 10.47 angle of attack, 0.172 Mach, 1.93M $Re_{MAC}$

MADCAP+EPIC (7.4M)

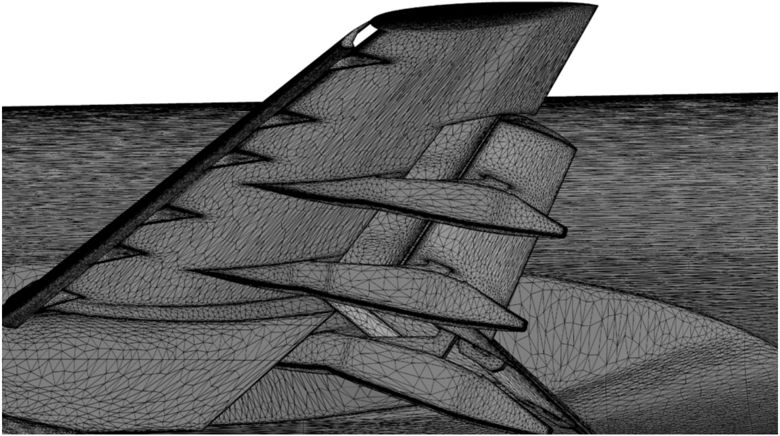


EGADS+refine (4.5M)



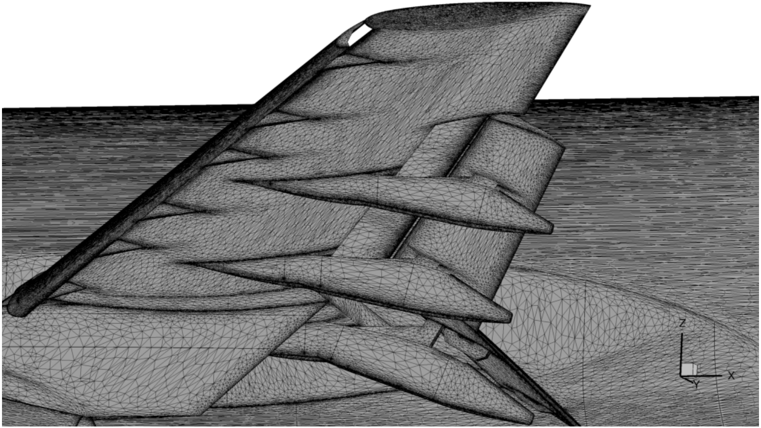
# JAXA Standard Model (JSM)

Adapted with GGNS+EPIC (7.4M)



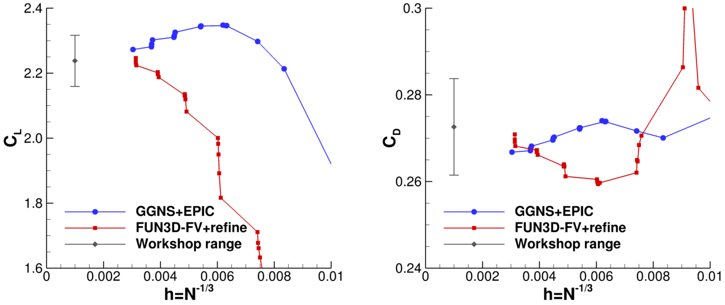
# JAXA Standard Model (JSM)

Adapted with FUN3D-FV+refine (4.5M)



# JAXA Standard Model (JSM)

Adapted at 10.47 angle of attack, 0.172 Mach, 1.93M $Re_{MAC}$

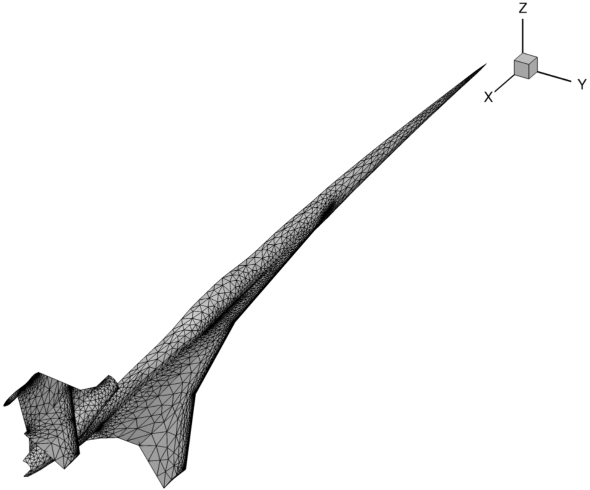


# Outline

# C25D Flowthrough Nacelle (C25F)

## Initial geometry adapted surface

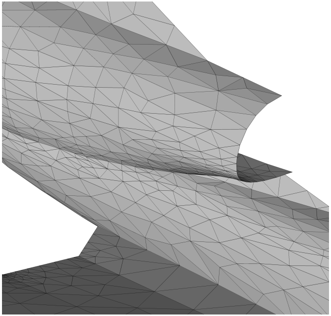
EGADS+refine



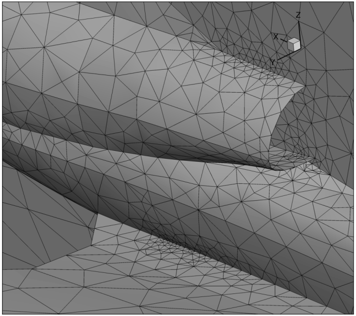
# C25D Flowthrough Nacelle (C25F)

## Initial geometry adapted surface

MADCAP+EPIC



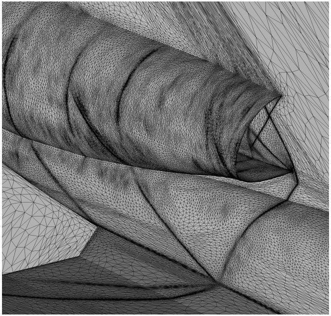
EGADS+refine



# C25D Flowthrough Nacelle (C25F)

## Adapted at 1.6 Mach, inviscid

MADCAP+EPIC (22M)



EGADS+refine (53M)

# Outline

# Conclusions

## Integrated mesh adaptation processes

- Unstructured to the wall, valid, and boundary conforming to geometry model
- Minimal modification to input geometry
- Includes initial mesh generation
- Intended (and unintended) geometry features resolved at increased cost

# Conclusions

## Needed investments

- Importing geometry still a bottleneck (this work assumes the model can be imported)
- Some classes of geometry "repair" eliminated by this work, but all manual interaction must be eliminated for automation
- Synergy between flow solver and adapted meshes key to decreasing wall-clock time, e.g., "strong solver," "grid suitability"
- Error estimation for steady and unsteady viscous flows

# Outreach and Acknowledgment

## Unstructured Grid Adaptation Working Group (UGAWG)

- Informal group with monthly virtual meetings
- `https://UGAWG.GitHub.io`
- Test cases available for analysis or developing new methods
- `UGAWG@Mail.EmailHorse.com` or `Mike.Park@NASA.gov`
- Diffuse verified adaptive mesh technology to displace fixed meshes where appropriate

## Acknowledgment

This work was partially supported by the Transformational Tools and Technologies (TTT) Project of the NASA Transformative Aeronautics Concepts Program (TACP)

# 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

## International Meshing Roundtable 2017

First benchmark of the Unstructured Grid Adaptation Working Group

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

## AIAA Paper 2018-1103

Unstructured Grid Adaptation and Solver Technology for Turbulent Flows

- Descriptive statistics of adapted grid metric conformity
- 3D interpolation error and output-based metrics for Hemisphere Cylinder and ONERA M6
- Test cases and results included in benchmark repository and website

# Related Work

## AIAA AVIATION Paper

Sketch-to-Solution: An Exploration of Viscous CFD with Automatic Grids

- Apply unstructured grid adaptation to a wide range of problems with comparison to verification and validation data

## AIAA AVIATION Paper

Geometry Modeling for Unstructured Mesh Adaptation

- Mechanical Computer-Aided Design (MCAD) integration
- Adaptation that accommodates typical intended and unintended MCAD construction issues