

# Boundary Representation Tolerance Impacts on Mesh Generation and Adaptation

Michael Park (*NASA Langley Research Center*)

Robert Haimes (*Massachusetts Institute of Technology*)

Nicholas Wyman and Patrick Baker (*Cadence Design Systems*)

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

02 August 2021

# Motivation

## Computational Fluid Dynamics (CFD) Vision 2030 Study<sup>1</sup>

- ▶ “make mesh generation and adaptation less burdensome and, ultimately, invisible to the CFD process”
- ▶ “many existing CAD geometry definitions are poorly suited for CFD analyses, either due to insufficient accuracy (non water-tight geometries often adequate for manufacturing purposes), or due to excessive detail not essential for the CFD analysis.”

## Geometry Modeling for Unstructured Mesh Adaptation<sup>2</sup>

- ▶ Automation of production CFD workflows enabled by unstructured mesh adaptation with geometry coupling
- ▶ Routine application has uncovered a common weakness in geometry models.

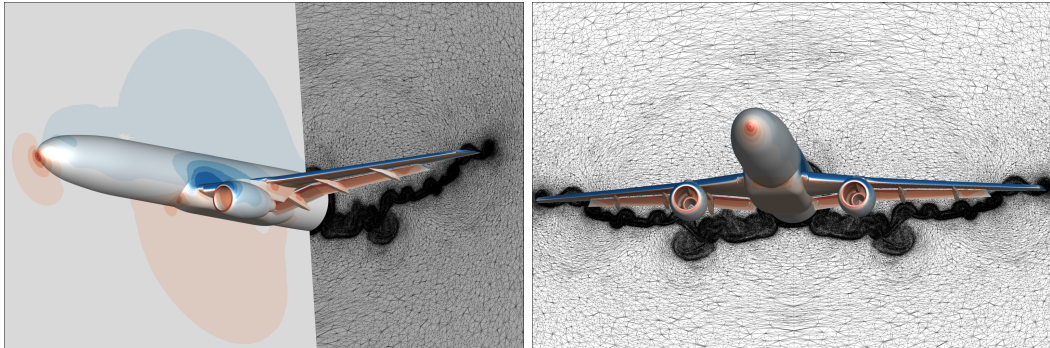
---

<sup>1</sup>Slotnick et al., NASA CR-2014-218178

<sup>2</sup>Park, et al., AIAA Paper 2019-2946

# High Lift System Simulation (JAXA Wing Body Nacelle)

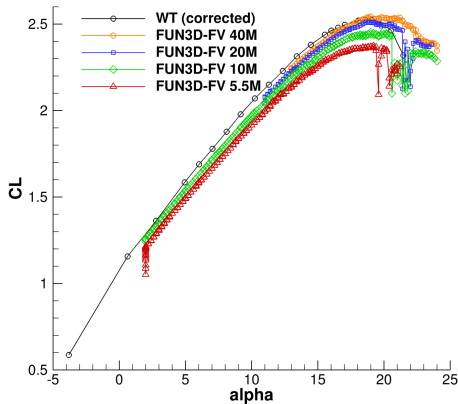
Automatically control solution interpolation error estimates



Geometry with slice through boundary layer and wake mesh

# High Lift System Simulation (Common Research Model)

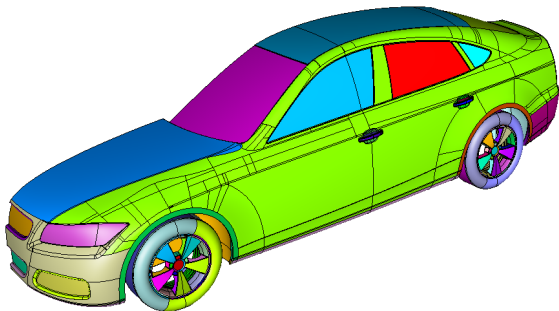
“Failure is not an option” in these production applications



Hundreds of meshes, denoted by symbols, each optimized to control estimated errors.

## Boundary REPresentation (BREP)

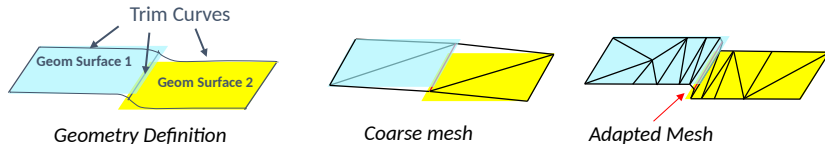
- Hierarchy of surface, curve, and point geometry with face, edge, and node topology that underpins modern mechanical CAD



DrivAer Smooth Underbody Fastback

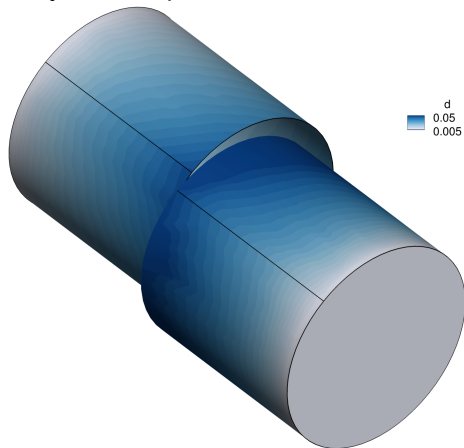
# Boundary REPresentation (BREP) Tolerance

- ▶ BREP tolerance is distance between the edge curve and its projection to the face surface
- ▶ Projection is proprietary and projected curves are rarely exported to common exchange formats (e.g., STEP), which requires reconstruction on import
- ▶ Locally larger than boundary layer meshing requirements in a majority of models
- ▶ Loose tolerances are identified by error estimation and attract refinement



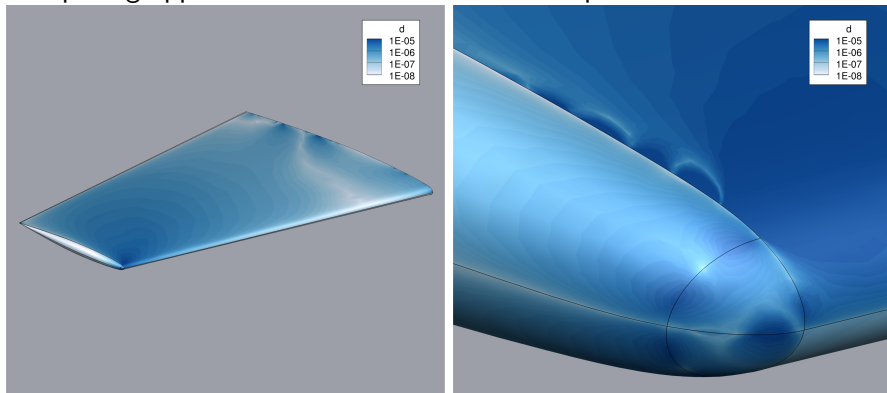
# Offset Cylinders

Analytic example created for illustration



Edge curve is on the rear cylinder surface,  
creating a periodic gap on the forward cylinder

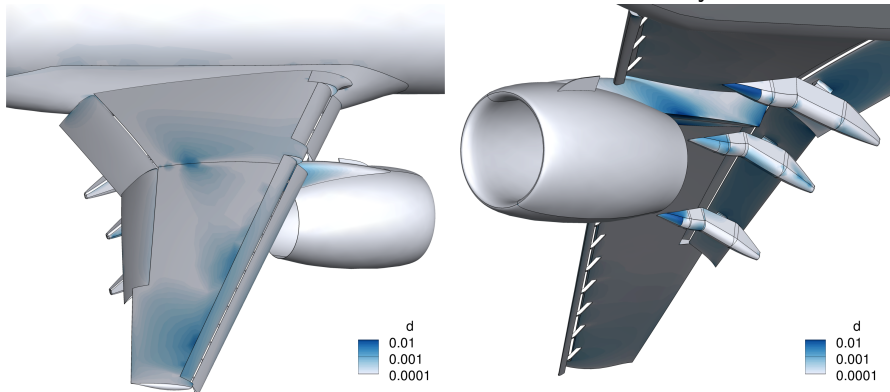
Viscous spacing approaches  $10^{-6}$  root chord for adapted meshes with  $10^7$  vertices



Different surface/curve parameterizations create oscillations

## Common Research Model – High Lift

Meshing guidelines<sup>3</sup> for the Fourth High Lift Prediction Workshop are 0.00239 inches for the coarsest mesh and 0.00035 inches for finest. Mean Aerodynamic Chord 275.8 in.



<sup>3</sup>[hiliftpw.larc.nasa.gov/Workshop4/Mesh-Generation-Guidelines-V11-3-Final.pdf](http://hiliftpw.larc.nasa.gov/Workshop4/Mesh-Generation-Guidelines-V11-3-Final.pdf)  
[Accessed 20-May-2021].

# Mitigation and Accommodation Strategies

## Virtual topology (quilting)

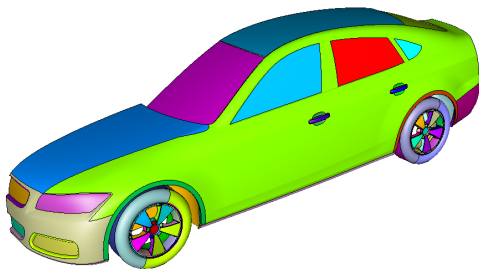
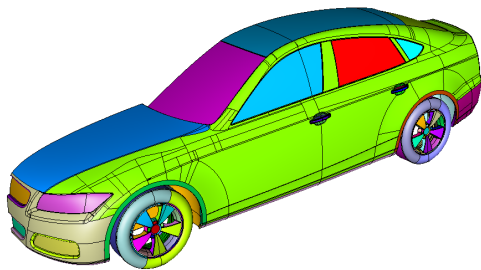
- ▶ Suppresses topology (edges) to create extended faces
- ▶ Reduces constraints on meshing and hides problematic or ambiguous topology near BREP tolerances

## Surrogates

- ▶ Provides alternate curves and surfaces to reduce BREP tolerance and improve smoothness

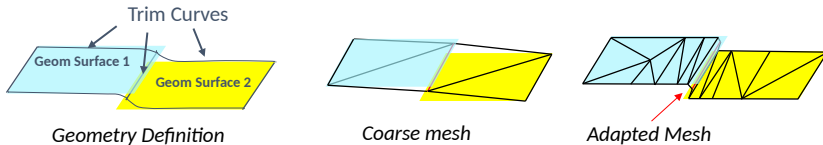
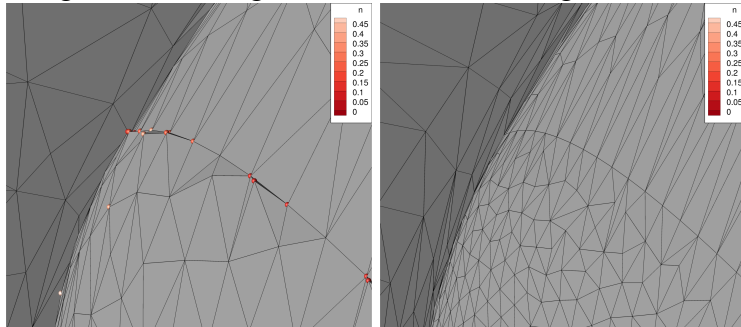
# DrivAer Smooth Underbody Fastback

Virtual topology or quilting to suppress meshing constraints



# Common Research Model – High Lift Flap Bracket Fairing

Surrogate cubic triangular surface with watertight construction



# Geometry Accommodation Progress

These pervasive issues<sup>4,5,6</sup> were addressed in *AIAA Paper 2019–2946* and **here** *discontinuous parameterization, degeneracy, periodicity, inadequate tolerances, inaccurate p-curves, small edges, sliver faces, narrow faces, cusps, inconvenient topology*, or excessive detail

Accommodation approaches presented assume model import is possible!

gaps, missing faces, duplicate surfaces, overlapping surfaces, self-intersecting curves/surfaces, incorrect edge orientation, or voids

---

<sup>4</sup>Chawner, “Survey Results – Mesh Generation and CAD Interoperability,” Another Fine Mesh Pointwise Blog 13-JUN-2018

<sup>5</sup>Taylor, “Analysis of Participant Questionnaires submitted to the 1st AIAA Geometry and Mesh Generation Workshop,” AIAA Paper 2018–129

<sup>6</sup>Gammon, Bucklow, and Fairey, “A Review of Common Geometry Issues Affecting Mesh Generation,” AIAA Paper 2018–1402

## Conclusions and Acknowledgments

- ▶ Previous improvements enabled production workflows for a large class of Boundary REPresentation (BREP) models created in Mechanical CAD systems
- ▶ BREP tolerances larger than viscous spacing requirements is common, which can lead to poor element shape or meshing failure
- ▶ Mitigation and accommodation approaches surveyed in paper with highlights provided
- ▶ Further progress demonstrated toward “invisible” meshing
- ▶ Continued research, implementation, and testing required for general availability of these techniques

This work was partially supported by the Transformational Tools and Technologies (TTT) Project of the NASA Transformative Aeronautics Concepts Program (TACP). This material is partially based on research sponsored by the U.S. Air Force under agreement number FA8650-20-2-2002.

# Outreach

## 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](mailto:UGAWG@Mail.EmailHorse.com) or [Mike.Park@NASA.gov](mailto:Mike.Park@NASA.gov)
- ▶ Diffuse verified adaptive mesh technology to automate meshing where appropriate