Progress in Geometry Modeling and Mesh Generation Toward the CFD Vision 2030

by
John Chawner & Nigel Taylor
17 June 2019

Placing The Study in Context

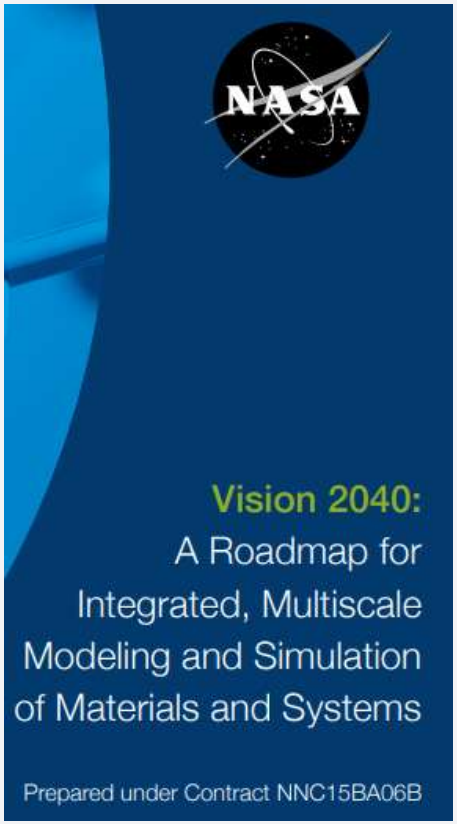
POINTWISE®
THE CHOICE FOR CFD MESHING

MBDA
MISSILE SYSTEMS

NASA/CR–2014-218178

CFD Vision 2030 Study: A Path to Revolutionary Computational Aerosciences

"a single engineer/scientist [is] able to conceive, create, analyze, and interpret a large ensemble of related simulations in a time-critical period (e.g. 24 hours), without individual managing each simulation, to a pre-specified level of accuracy."



ASSESS
www.assessinitiative.com

REVOLUTION in simulation
www.rev-sim.org

The Study & The MVCE TC

- 2015: "The Path to and State of Geometry and Meshing in 2030: Panel Summary"
- 2016: "Geometry, Mesh Generation, and the CFD 2030 Vision"
- 2017: 1st Geometry and Mesh Generation Workshop (GMGW-1)
- 2018: "Geometry Modelling: Underlying Concepts and Requirements for Computational Simulation"
- 2019: GMGW-2
- Future:
  - GMGW-3 (currently being planned)
  - AIAA Guide on geometry modeling for simulation (publication planned for 2020)

The Study's Challenges Refined

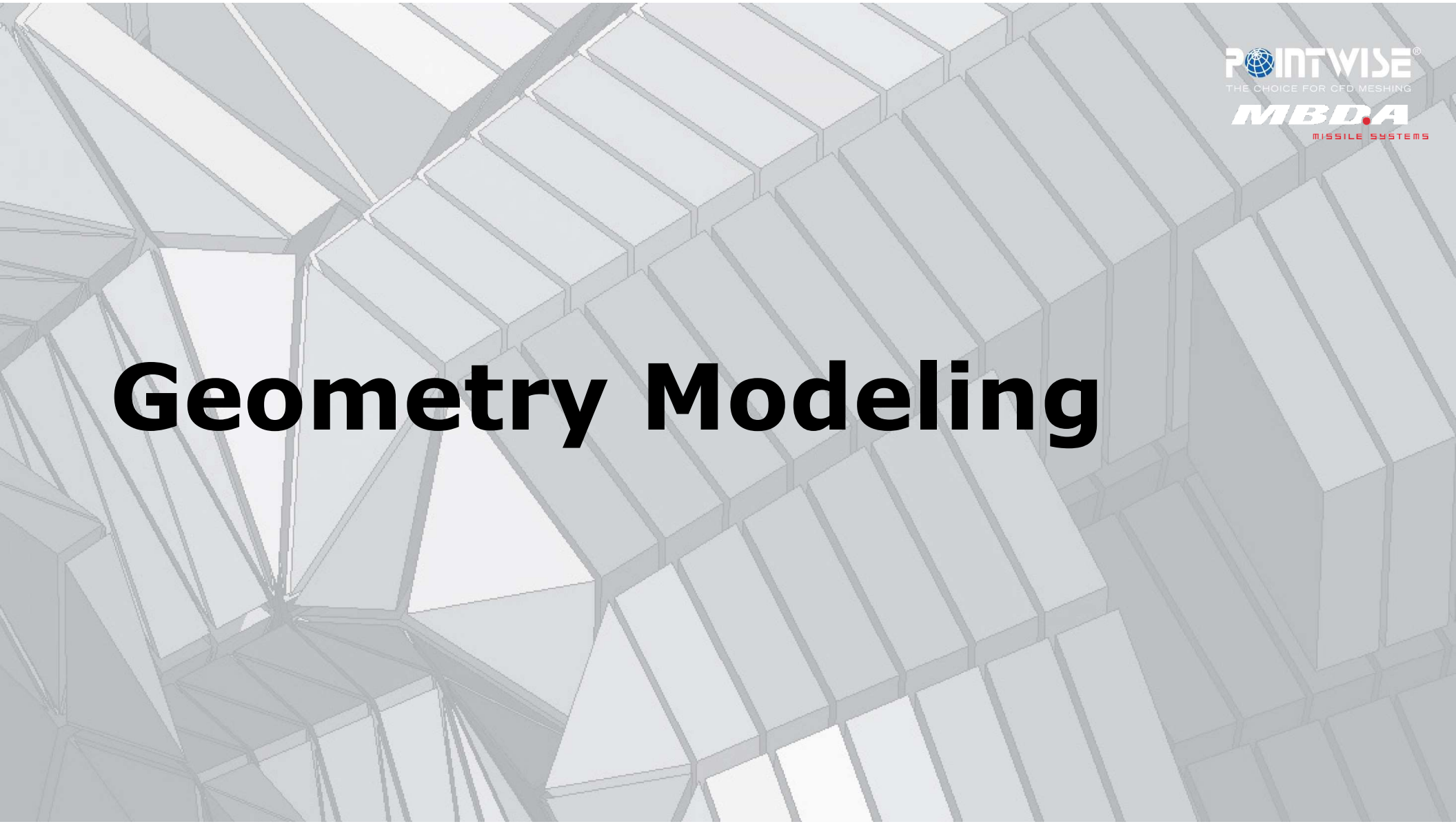
POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

Communication/Social

- Establish a common understanding of the principles underlying the construction and use of geometry models.
- The CFD community currently lacks the common vocabulary to discuss a mesh's suitability.

Progress Vectors

- Suitability
  - Validity
  - Quality
  - Resolution
  - Intent
- HPC Support
- Emerging Tech

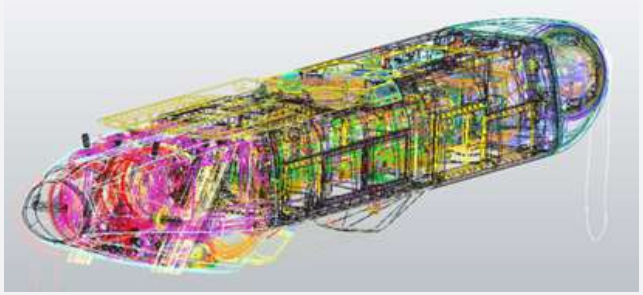


Geometry Modeling

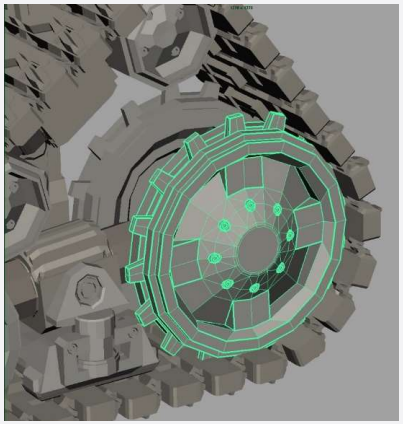
Suitability: Categorizing Geometry Models

POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

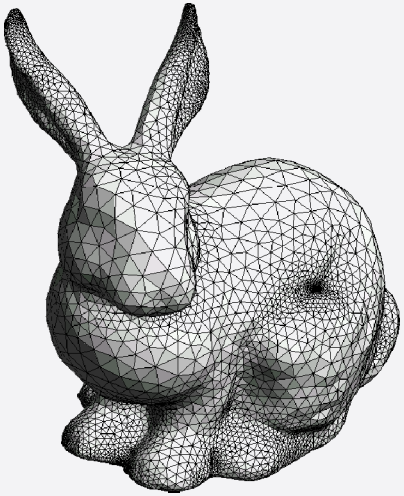
- Representation
  - Analytic: Boundary REPresentation NURBS
  - Analytic: Sub-Division
  - Discrete/Faceted
  - Spatial Occupancy
- Intent
  - Product Definition
  - Simulation
  - 3-D Scans
  - Animation Artifacts
  - Schematics



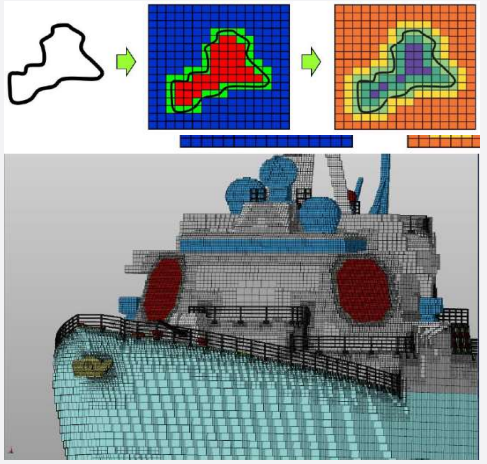
Boundary REPresentation



Sub-Division



Facets



Spatial Occupancy

Suitability: Intent, BREPs, and GMGW

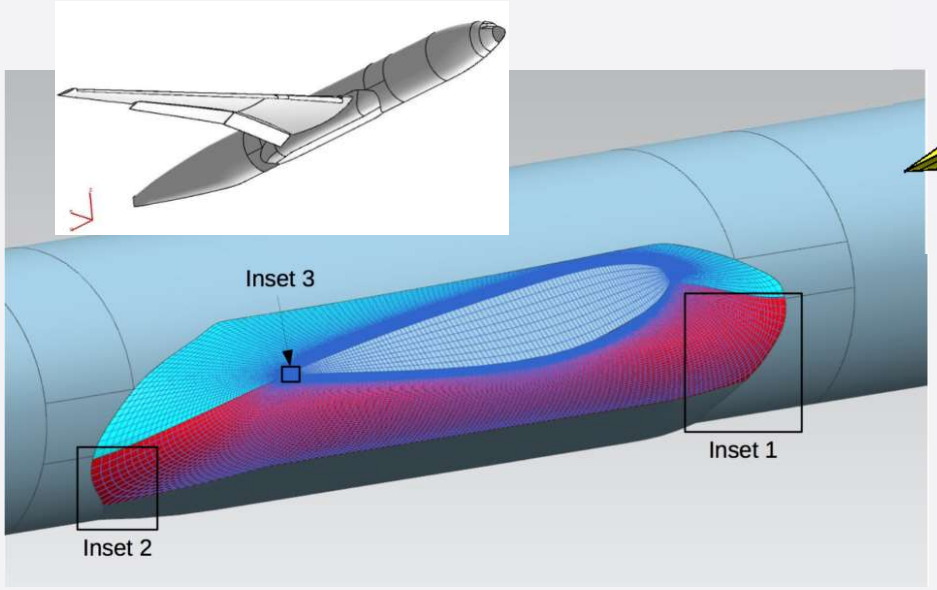
POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

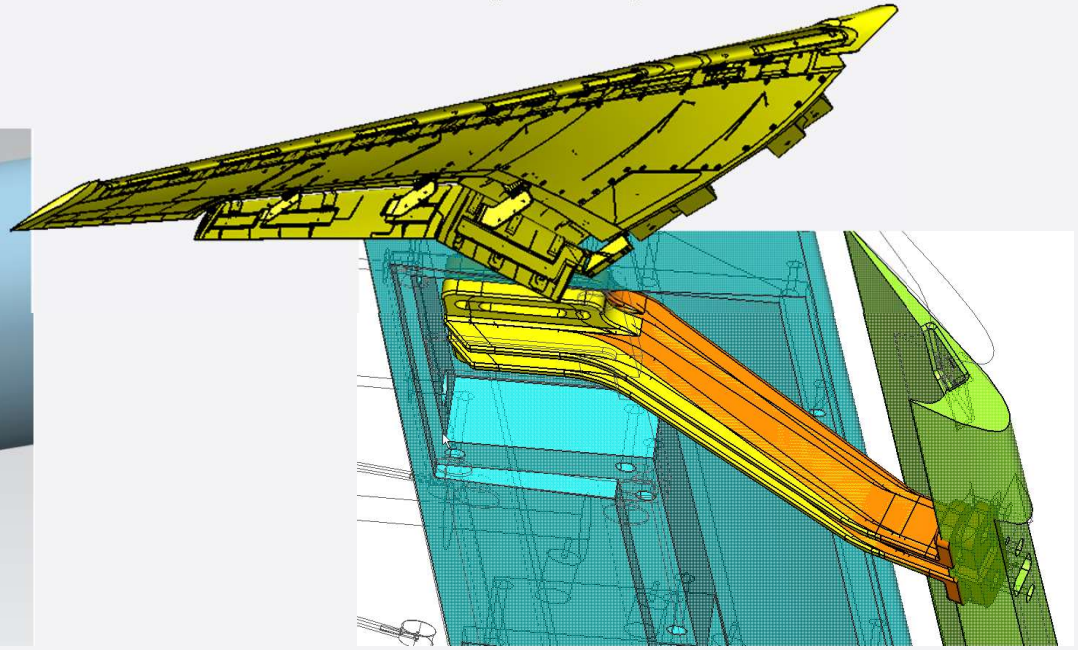
Simulation

- HL-CRM
- Relatively simple model
- Quirky BREP surfaces

Product Definition

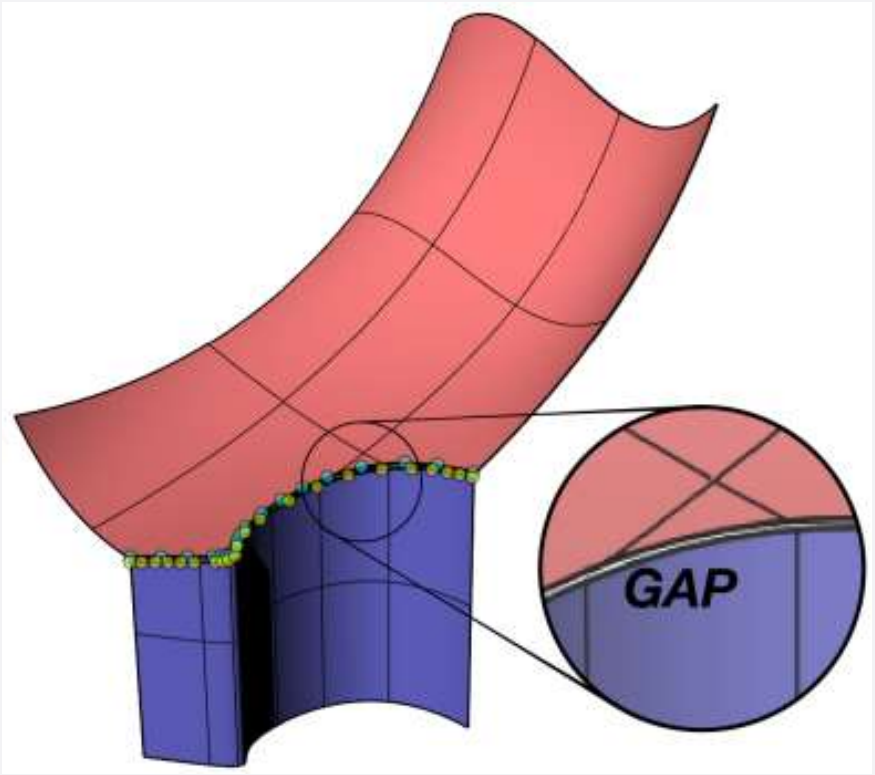
- HL-CRM-WT
- Relatively complex model
- Devoid of quirky surfaces

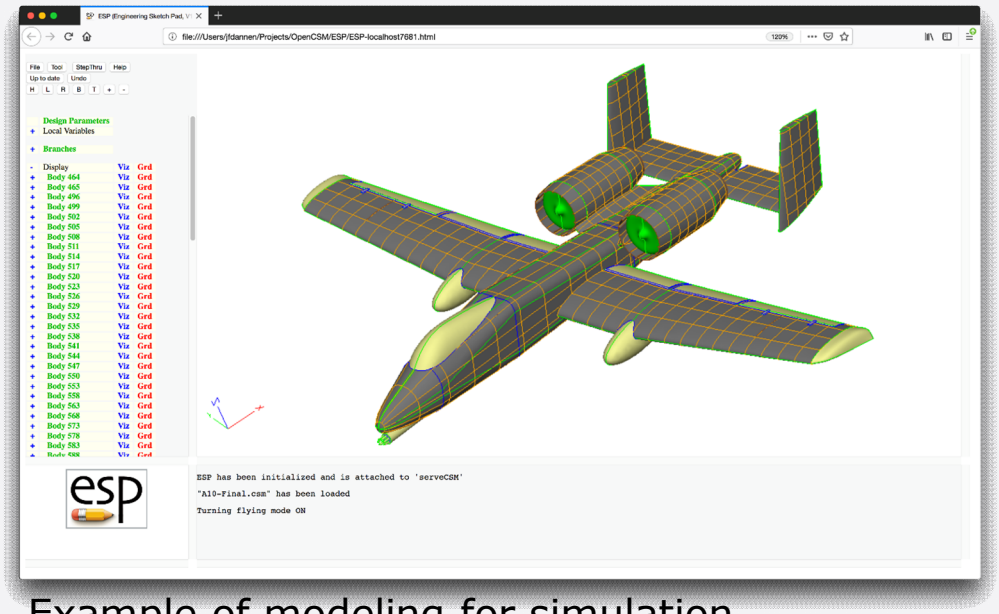




Suitability: Ambiguity in BREPs

- BREP models are not manifold geometrically.
- They are manifold topologically.





Example of modeling for simulation

Urick & Marussig - https://blog.pointwise.com/2017/11/29/why-cad-surface-geometry-is-inexact/

High Performance Computing: Kernels

POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

- Traditional BREP kernels were not designed for HPC.
  - Only sequential queries supported.
  - Cross-platform issues (hardware and operating system)
  - License scalability issues.
- Newer kernels are "HPC aware" from the start
  - EGADS (CAPS)
  - Boxer
  - Dyndrite
  - Geode
  - C3D
  - etc.

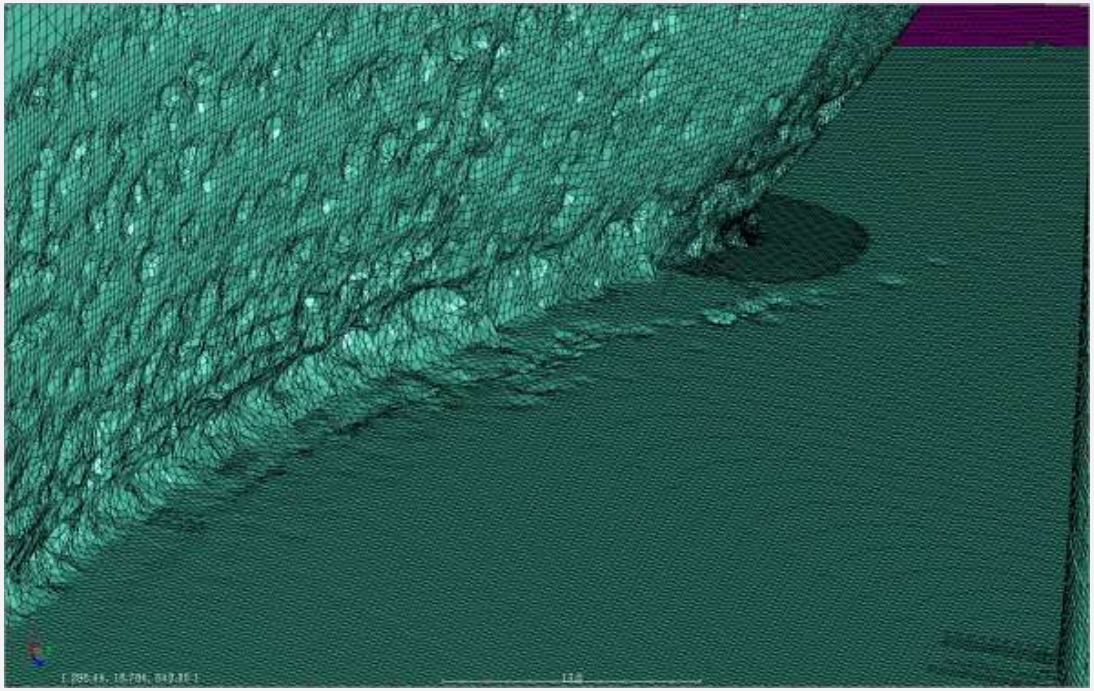
Complicating Factors

- Proper mapping of mesh to model
- Distributing the model across an HPC system

Emerging Tech: Manipulation & Control

POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

- The maturation of additive manufacturing allows us to manufacture products that cannot easily be design with BREPs in MCAD systems.
- Other representation types can truly enable design by simulation.

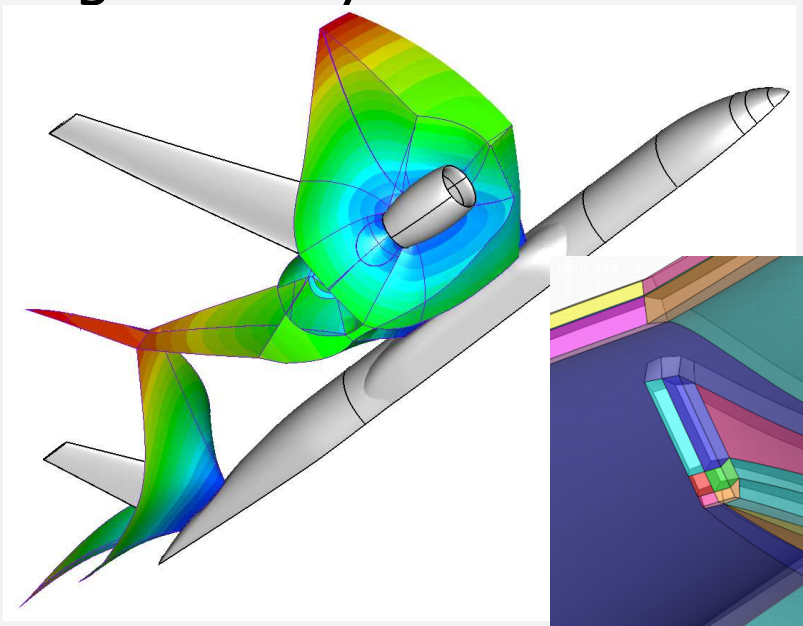


Turbine blade surface pitting modeled and simulated with a level set technique (via Cambridge Flow Solutions)

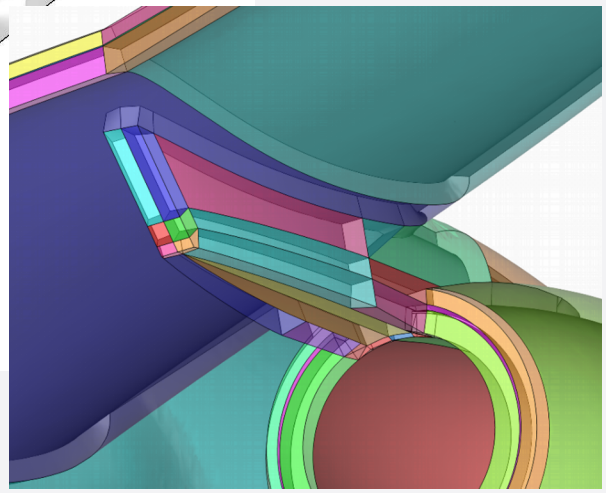
Emerging Tech: Geometric Reasoning

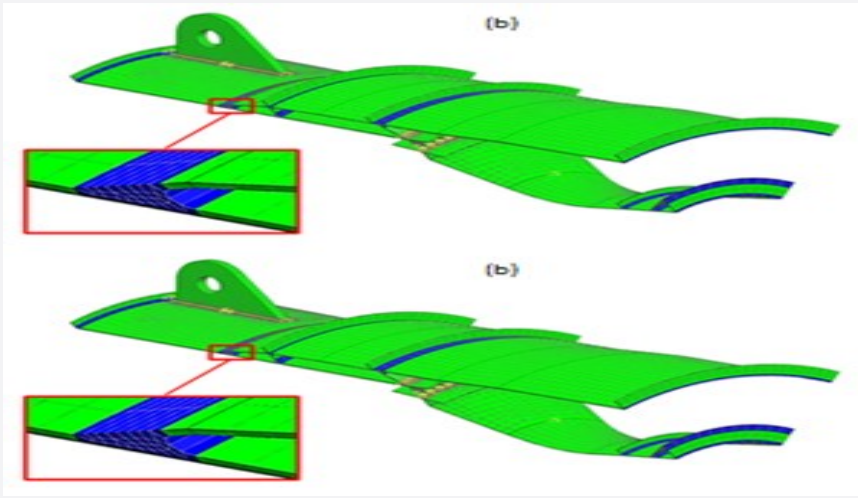
POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS

- Medial object technology allows simulation intent to be derived from the master model without altering the geometry.



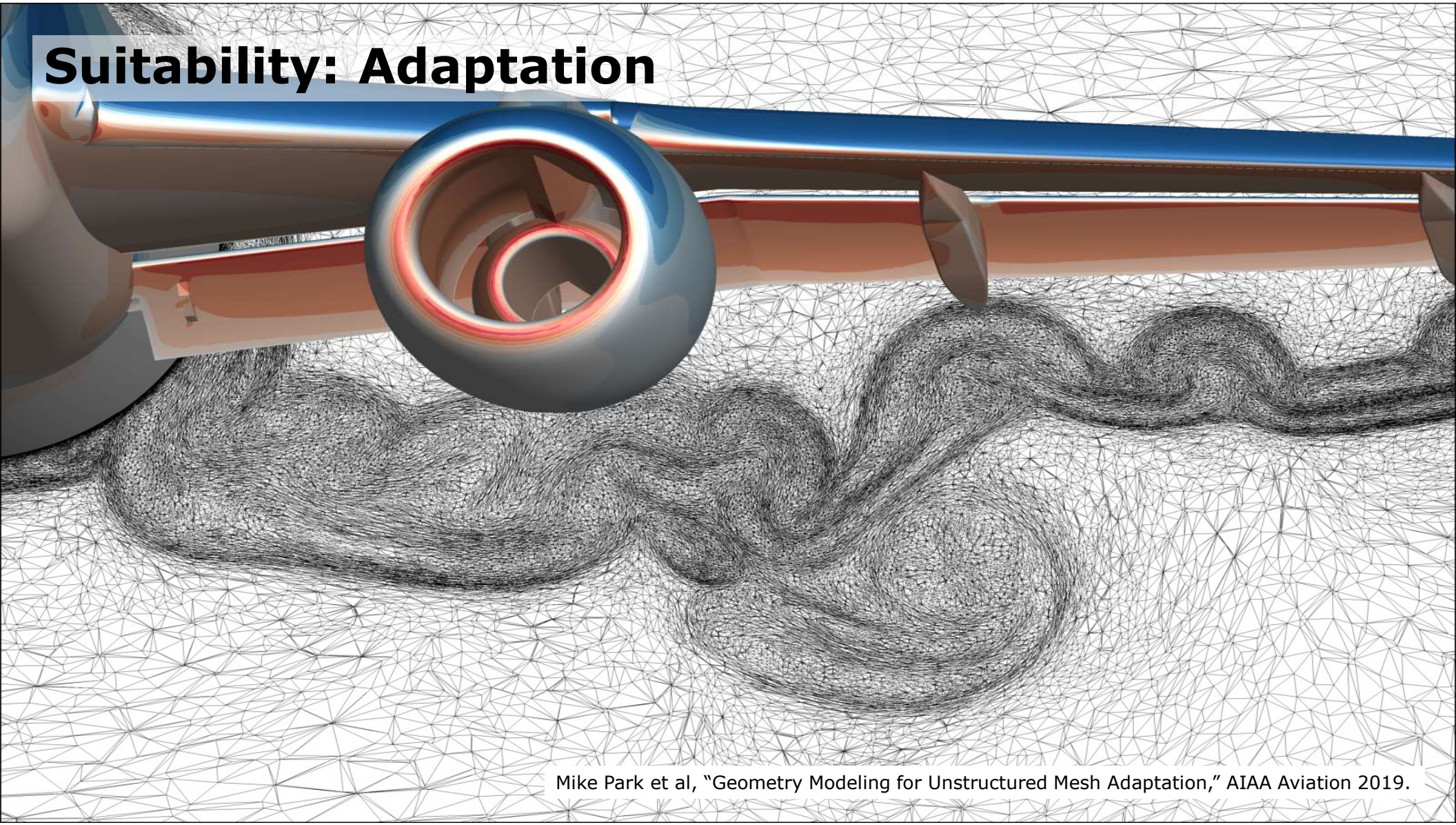
Courtesy ITI





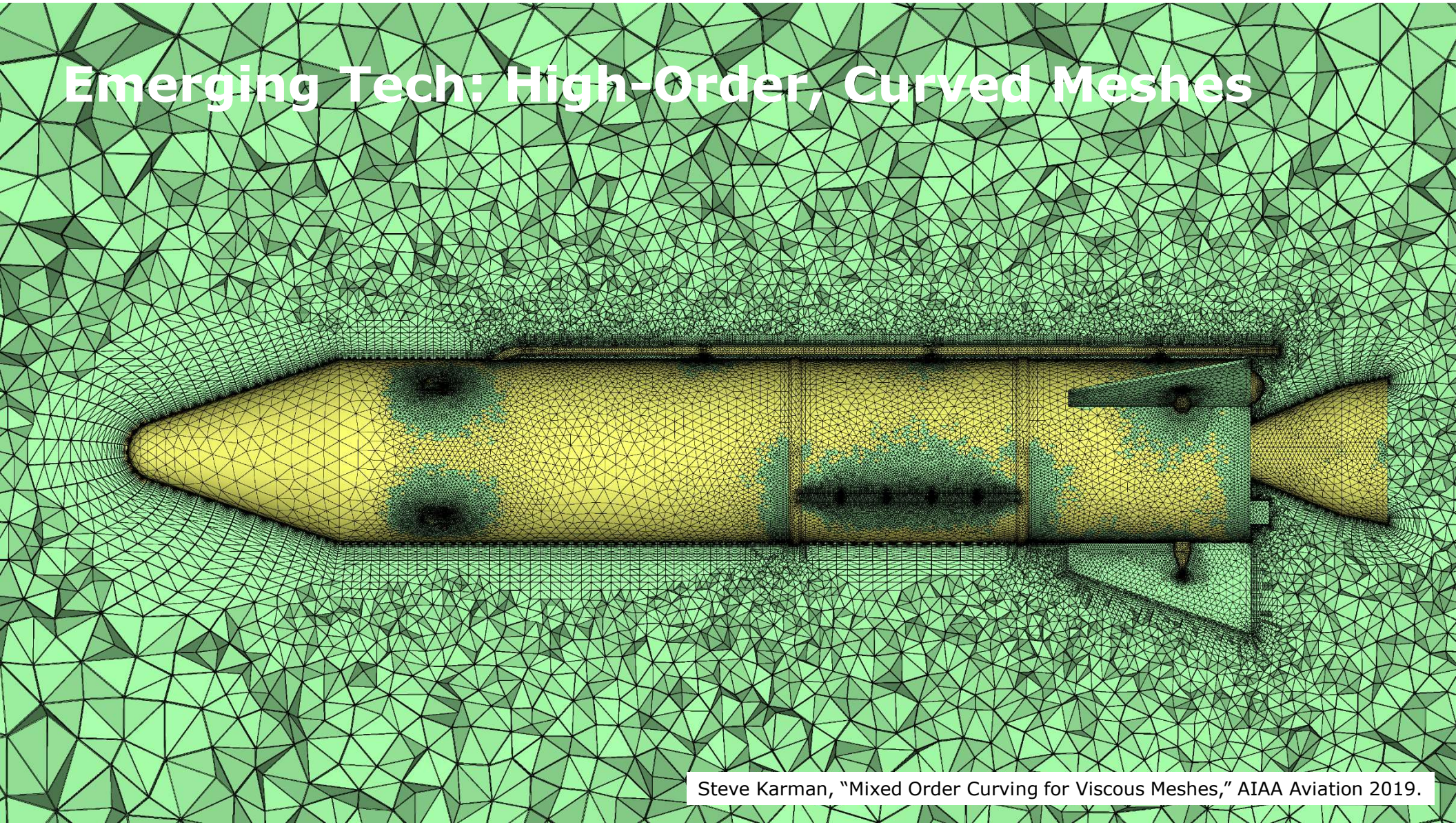
Meshing Progress

Suitability: Adaptation



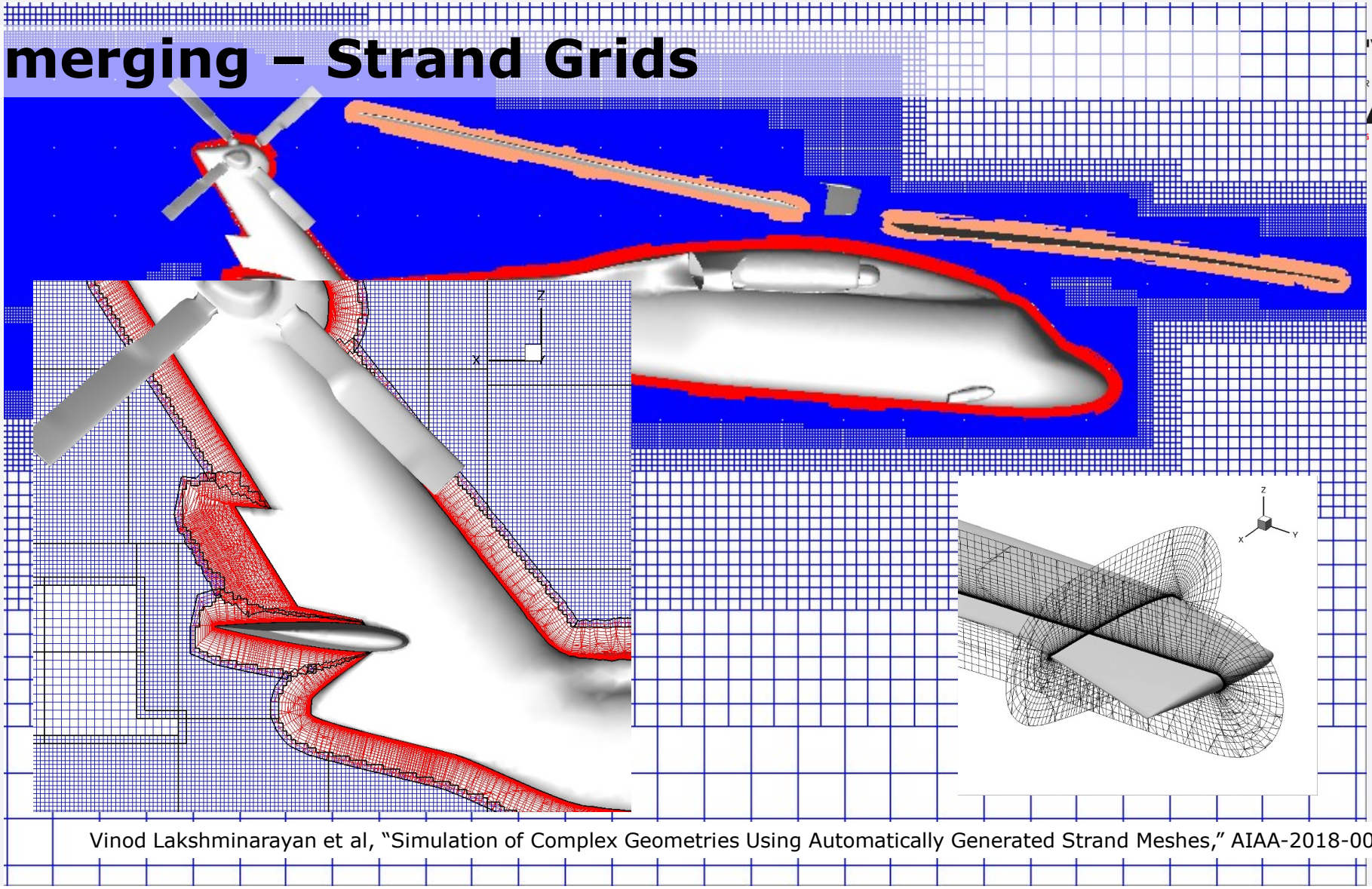
Mike Park et al, "Geometry Modeling for Unstructured Mesh Adaptation," AIAA Aviation 2019.

Emerging Tech: High-Order, Curved Meshes



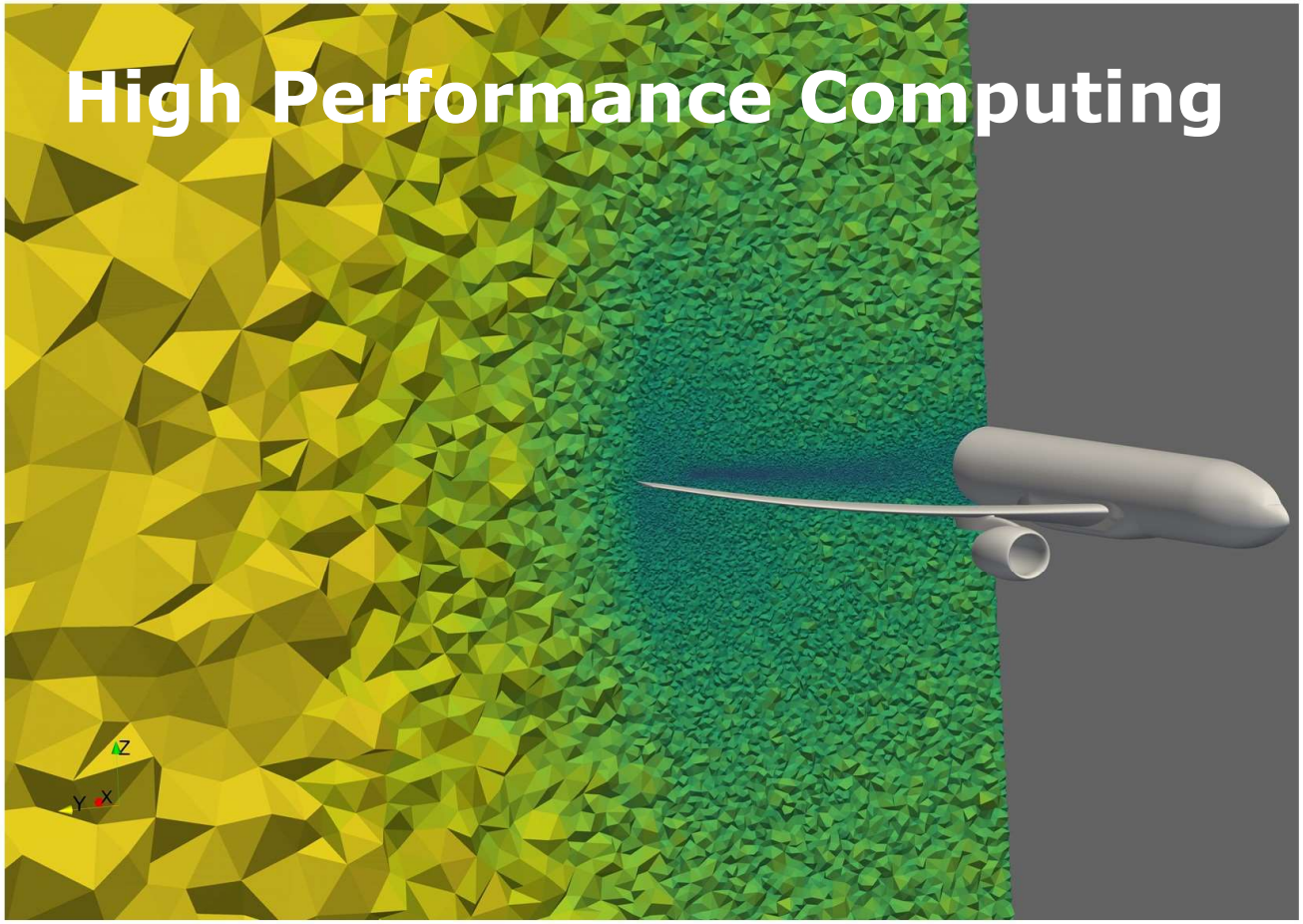
Steve Karman, “Mixed Order Curving for Viscous Meshes,” AIAA Aviation 2019.

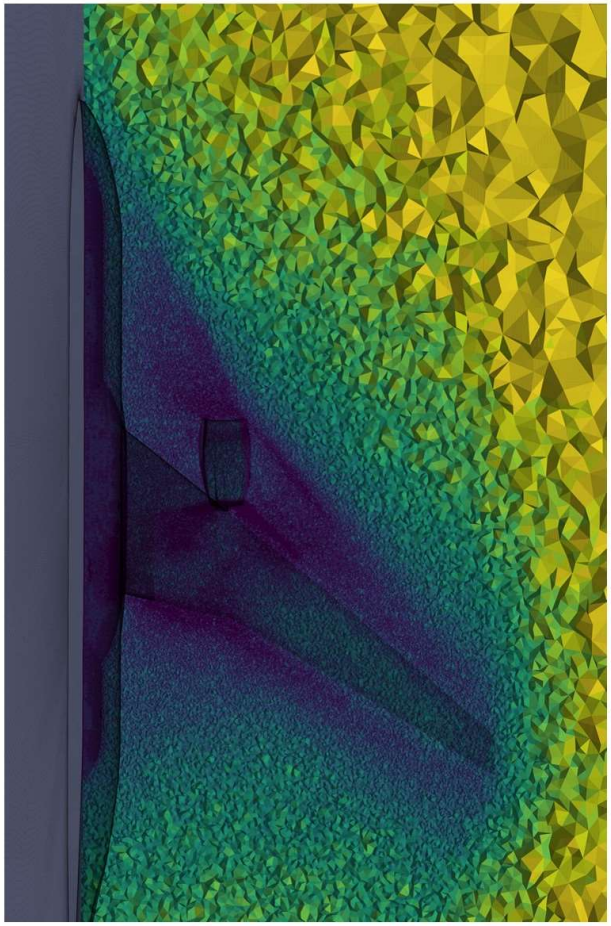
Emerging – Strand Grids



Vinod Lakshminarayan et al, "Simulation of Complex Geometries Using Automatically Generated Strand Meshes," AIAA-2018-0028.

High Performance Computing



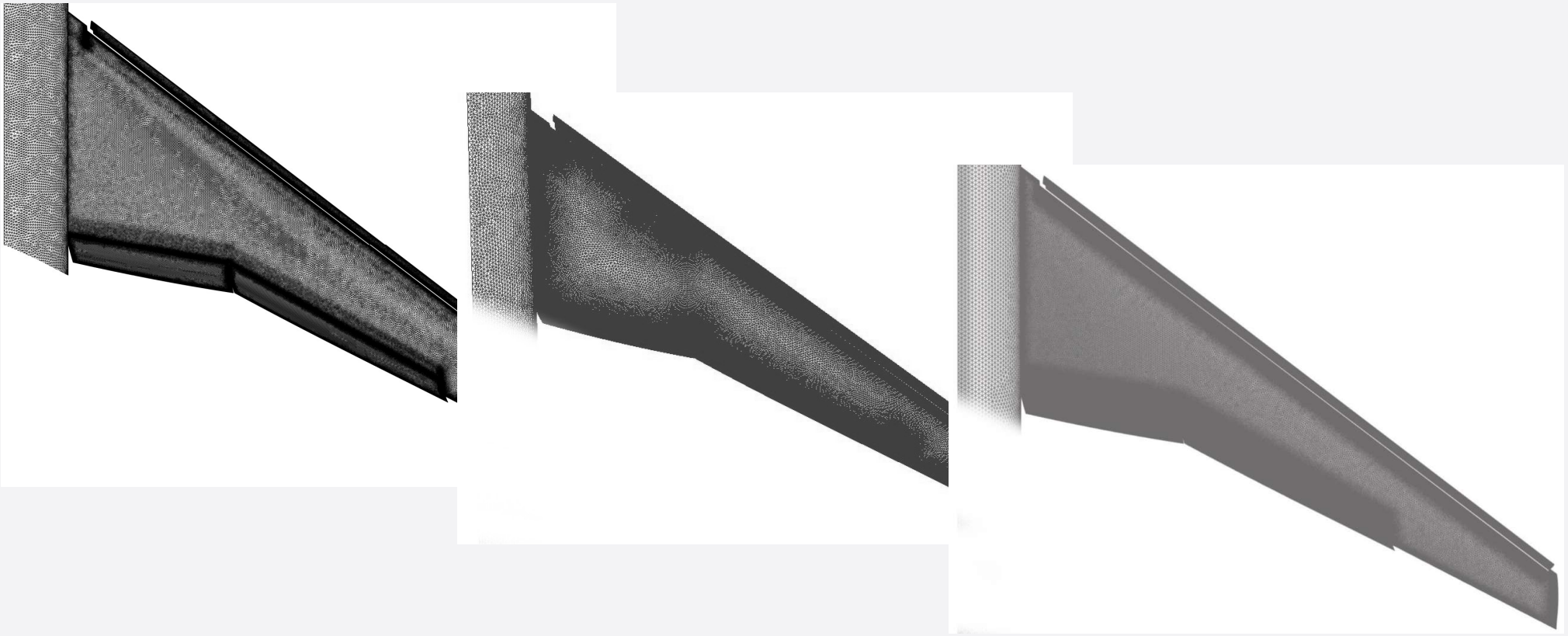


Center for Real-time Computing 2007

[1] "Fine-grained Speculative Topological Transformation Scheme for Local Reconnection Methods", Fotios Drakopoulos, Christos Tsolakis and Nikos Chrisochoides, *AIAA Journal*, (under revision), 2019

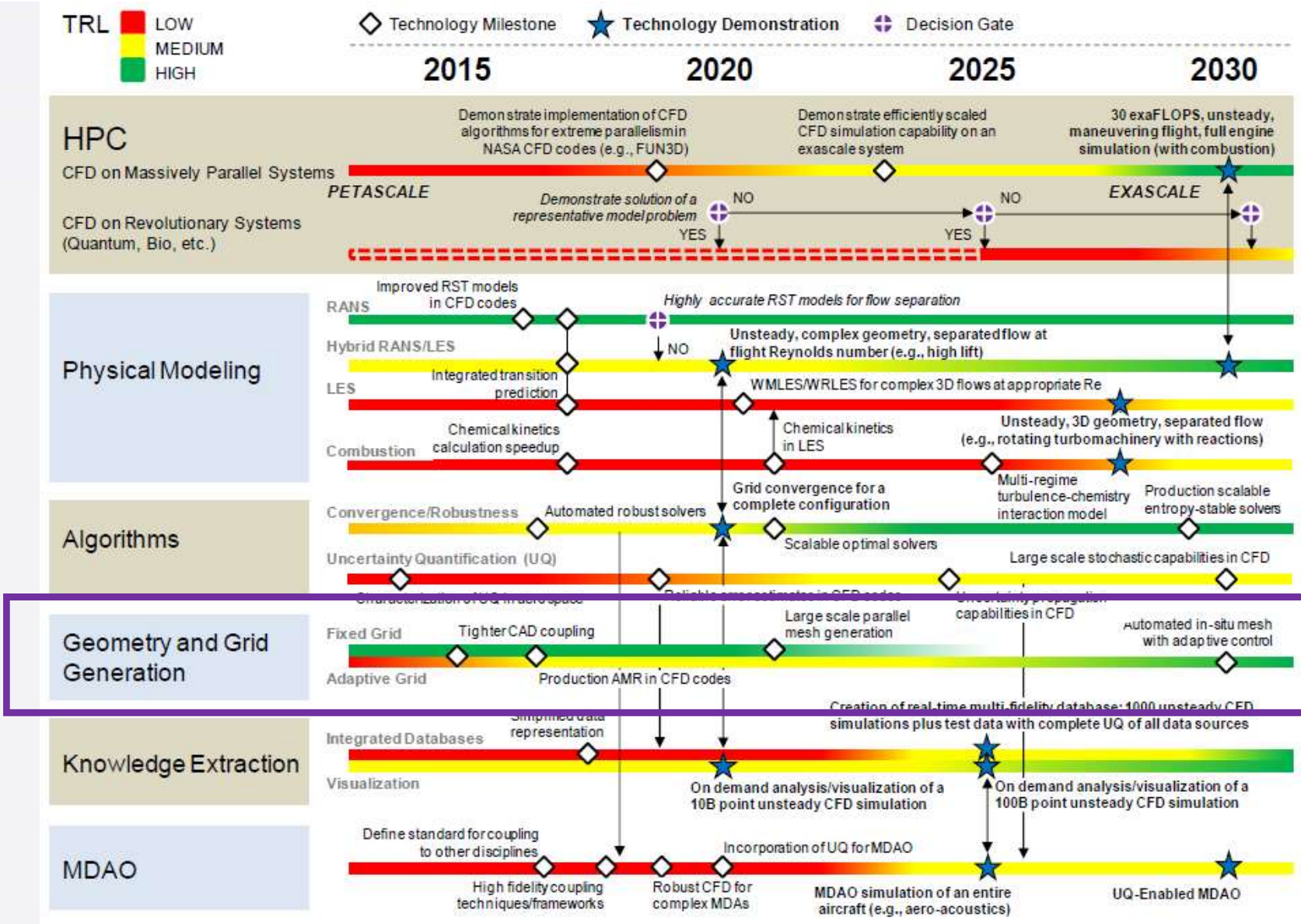
Suitability: Validity, Quality, Resolution

POINTWISE®
THE CHOICE FOR CFD MESHING
MBDA
MISSILE SYSTEMS



HL-CRM meshes from GMGW-2

Closing Remarks


TRL
LOW
MEDIUM
HIGH
Technology Milestone
Technology Demonstration
Decision Gate
2015
2020
2025
2030
HPC
CFD on Massively Parallel Systems
CFD on Revolutionary Systems (Quantum, Bio, etc.)
Demonstrate implementation of CFD algorithms for extreme parallelism in NASA CFD codes (e.g., FUN3D)
Demonstrate efficiently scaled CFD simulation capability on an exascale system
30 exaFLOPS, unsteady, maneuvering flight, full engine simulation (with combustion)
PETASCALE
EXASCALE
Demonstrate solution of a representative model problem
NO
YES
NO
YES
Physical Modeling
RANS
Improved RST models in CFD codes
Highly accurate RST models for flow separation
Hybrid RANS/LES
NO
Unsteady, complex geometry, separated flow at flight Reynolds number (e.g., high lift)
LES
Integrated transition prediction
WMLES/WRLES for complex 3D flows at appropriate Re
Combustion
Chemical kinetics calculation speedup
Chemical kinetics in LES
Unsteady, 3D geometry, separated flow (e.g., rotating turbomachinery with reactions)
Algorithms
Convergence/Robustness
Automated robust solvers
Grid convergence for a complete configuration
Multi-regime turbulence-chemistry interaction model
Production scalable entropy-stable solvers
Scalable optimal solvers
Uncertainty Quantification (UQ)
Large scale stochastic capabilities in CFD
Geometry and Grid Generation
Fixed Grid
Tighter CAD coupling
Large scale parallel mesh generation
Automated in-situ mesh with adaptive control
Adaptive Grid
Production AMR in CFD codes
Knowledge Extraction
Integrated Databases
Simplified data representation
Creation of real-time multi-fidelity database: 1000 unsteady CFD simulations plus test data with complete UQ of all data sources
Visualization
On demand analysis/visualization of a 10B point unsteady CFD simulation
On demand analysis/visualization of a 100B point unsteady CFD simulation
MDAO
Define standard for coupling to other disciplines
Incorporation of UQ for MDAO
High fidelity coupling techniques/frameworks
Robust CFD for complex MDAs
MDAO simulation of an entire aircraft (e.g., aero-acoustics)
UQ-Enabled MDAO

Acknowledgements

- Funding for Dr. Taylor's work on this paper provided by the UK Aerospace Technology Institute

- Thanks to private communications with and images from Mike Park, Mark Gammon, Stephen Ferguson, Nikos Chrisochoides, Christos Tsolakis, Vinod Lakshminarayan, Ben Rich, Ben Urick, Bob Haimes.
- Image of Sub-D model of Pixar's Wall*E from https://www.fxguide.com/featured/pixars-opensubdiv-v2-a-detailed-look/

www.cfd2030.com