A Meshing Perspective on Exascale CFD

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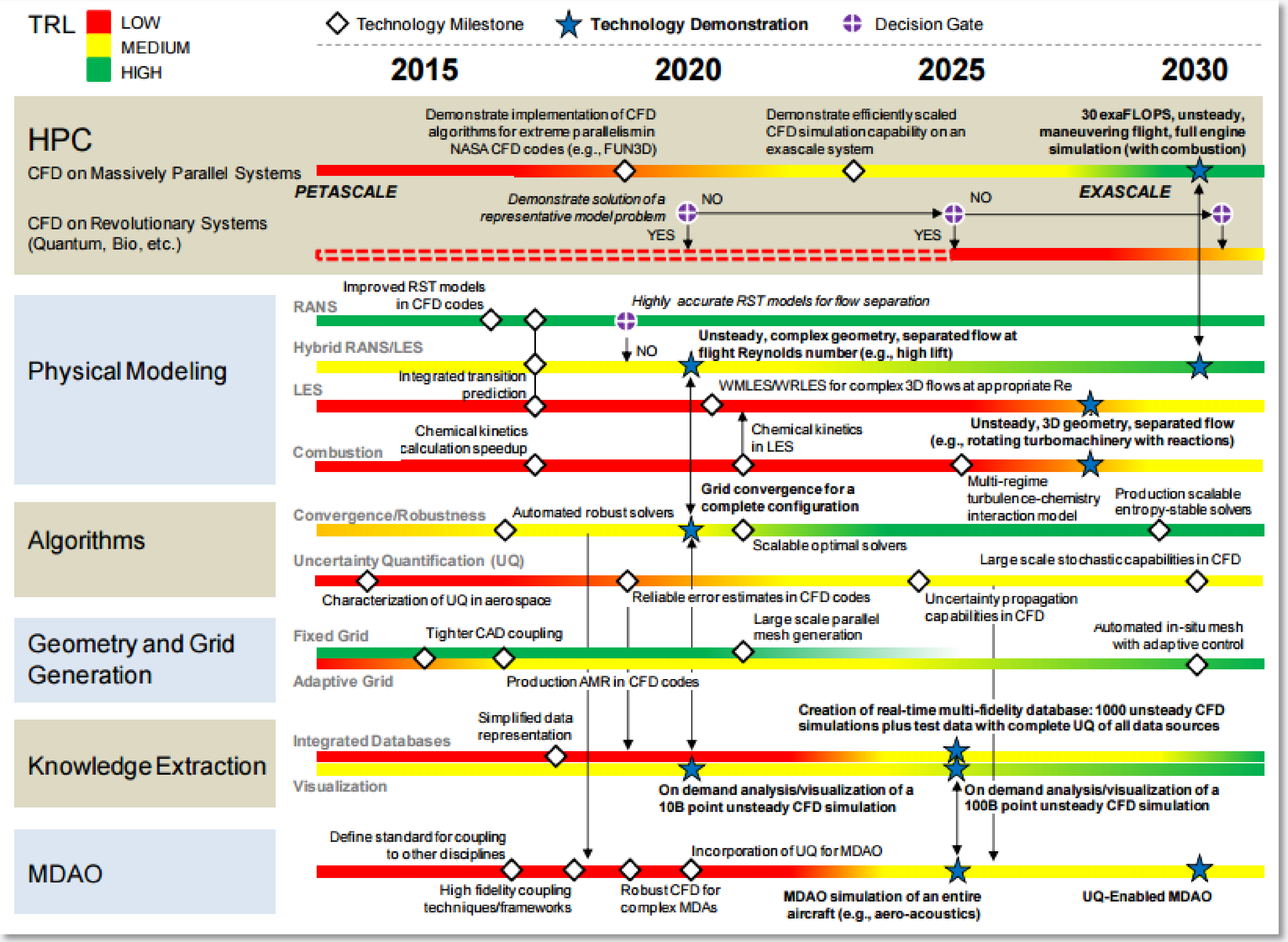
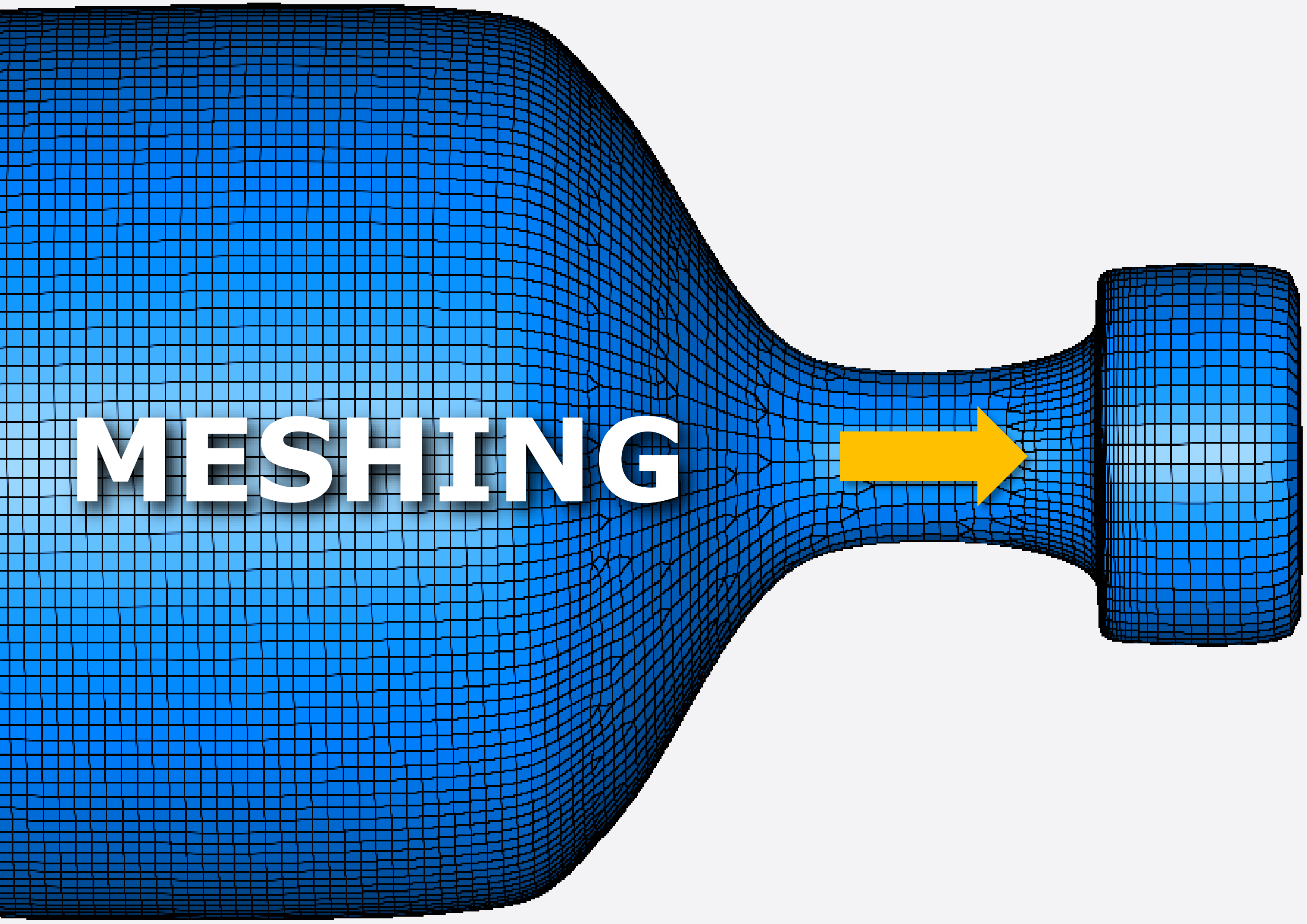
NASA CFD Vision 2030



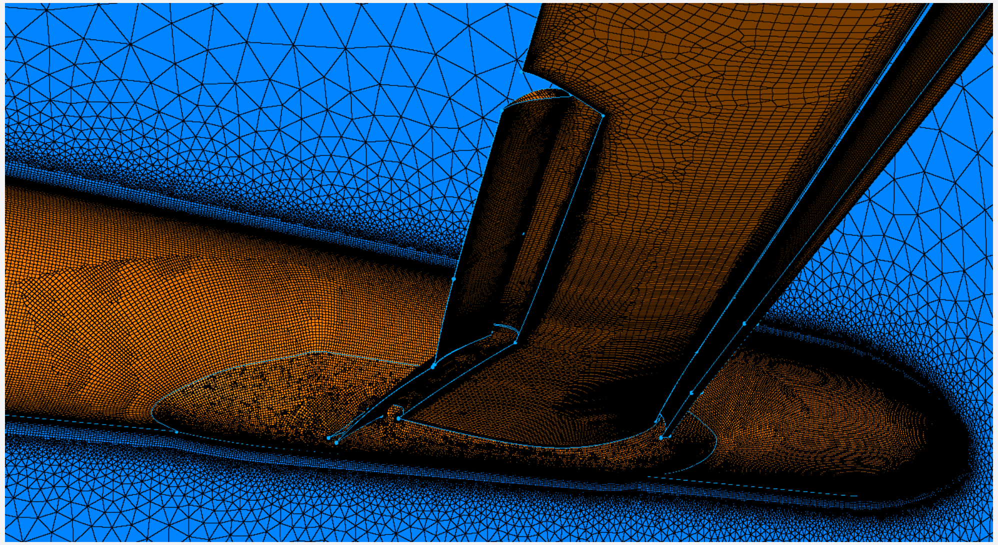
Reference: https://ntrs.nasa.gov/archive/nasa/casi.ntrs.nasa.gov/20140003093.pdf

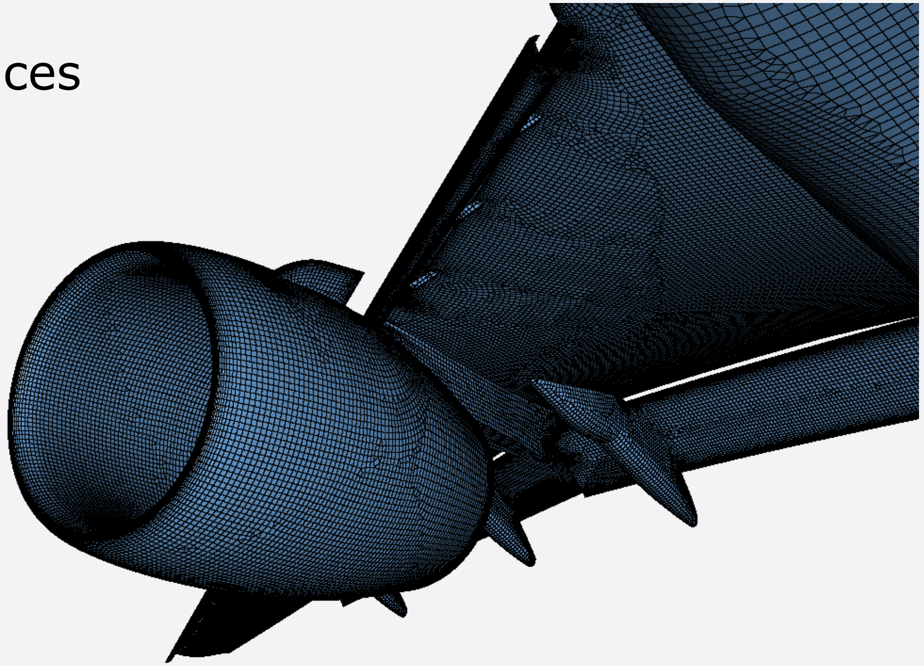


- CAD-Mesh Inadequacy
- Dominant Cost
- Principal Bottleneck
- Too Iterative
- Mesh Scaling

Geometry and Mesh Generation Workshop (GMGW)

- Sponsored by AIAA Meshing Visualization and Computational Environments Technical Committee
- Collaborative, open, and unbiased forum for meshing community
- Working to determine state-of-the-art in geometry and mesh generation technology and software for aircraft and spacecraft systems
  - Identification areas for improvement (performance, accuracy, applicability) in geometry processing and mesh generation
  - Quantification and documentation of best practices





GMGW

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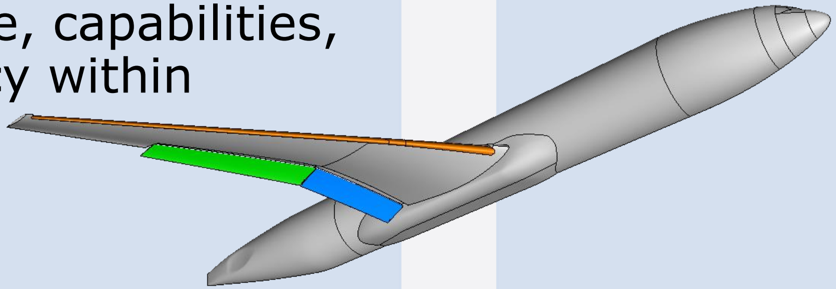
1st Geometry and Mesh Generation Workshop (GMGW-1)

- Partner: 3rd High Lift Prediction Workshop (HLPW-3)
- Mesh families created for NASA High Lift Common Research Model (CRM-HL)
- Finest unstructured mesh level was **exascale mesh**
- Results set baseline for performance, capabilities, and accuracy within community

June 2017

2nd Geometry and Mesh Generation Workshop (GMGW-2)

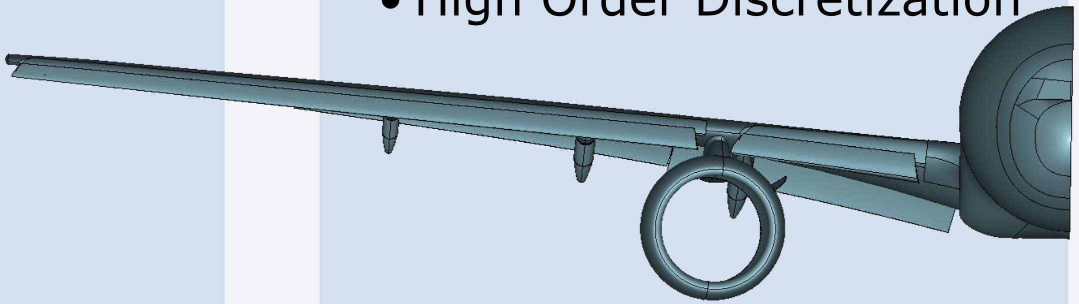
- **Exascale meshes** created for CRM-HL geometry
- CRM-HL mesh families created to measure progress since GMGW-1
- Parametric remeshing of an open aircraft geometry explored



January 2019

3rd Geometry and Mesh Generation Workshop (GMGW-3)

- Partner: 4th High Lift Prediction Workshop (HLPW-4)
- Technology Focus Groups working to answer key questions in:
  - Geometry Prep
  - Fixed Grid RANS
  - Mesh Adaption RANS
  - High Order Discretization



June 2021

Exascale Meshing Challenge

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Attempt to generate an **Class 10.5** resolution mesh for the HL-CRM Rev2 geometry model.

Class = Log_{10} (*Mesh Size*)

Year	Miniscule	Tiny	XCoarse	Coarse	Medium	Fine	XFine	Super Fine	Hero
2018	3.16M	10M	31.6M	100M	316M	1B	3.16B	10B	**31.6B**
2021	10M	31.6M	100M	316M	1B	3.16B	10B	**31.6B**	100B
2024	31.6M	100M	316M	1B	3.16B	10B	**31.6B**	100B	316B
2027	100M	316M	1B	3.16B	10B	**31.6B**	100B	316B	1T
2030	316M	1B	3.16B	10B	**31.6B**	100B	316B	1T	3.16T

Document where the mesh generation process breaks, has performance issues, or lacks functionality to support these mesh sizes.

Reference: C. Ollivier-Gooch, Mesh Size Naming Conventions, www.gmgworkshop.com/resources

Exascale Lessons: Surface Meshing

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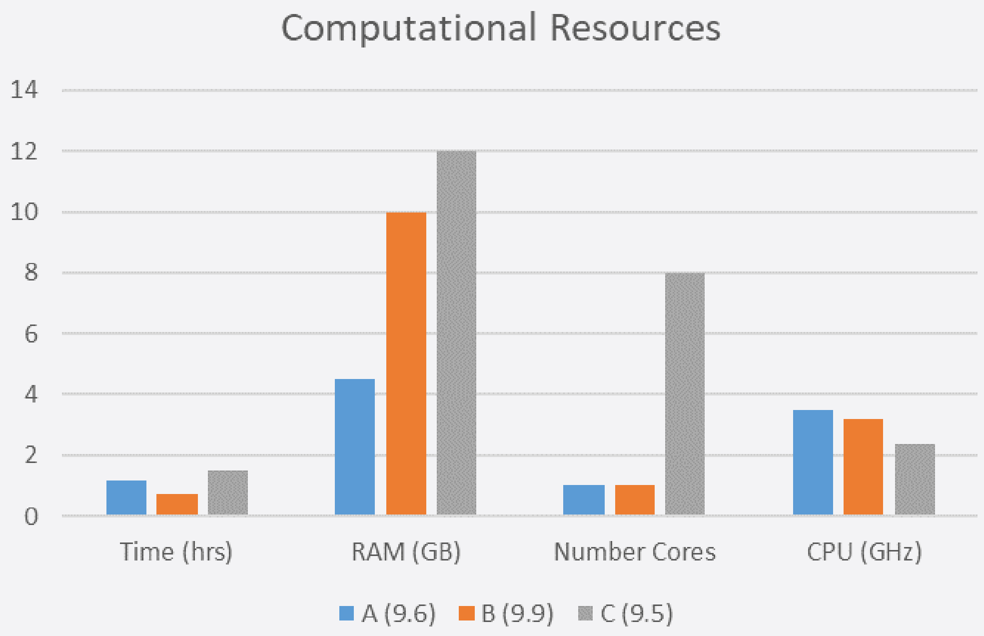
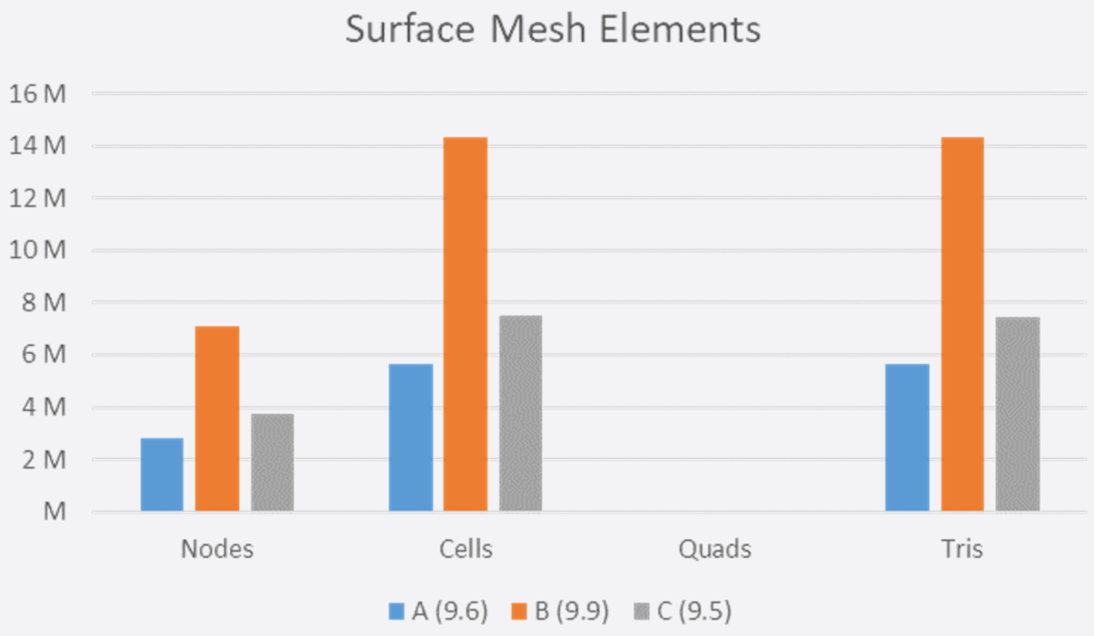
- Class 10.5 mesh attempted by 4 participants.
- Primarily triangular surface meshes
- One participant had small percentage of unstructured quads

- Time: 1-2 hours*
- Peak RAM: ~4-12 GB*
- Total node count: ~3-7 million*
- Total cell count: ~6-14 million*





* All comparisons shown are based on largest mesh successfully generated and exported. One participant (D) used an OCTREE volume approach and could not provide surface meshing data.

Exascale Lessons: Surface Meshing

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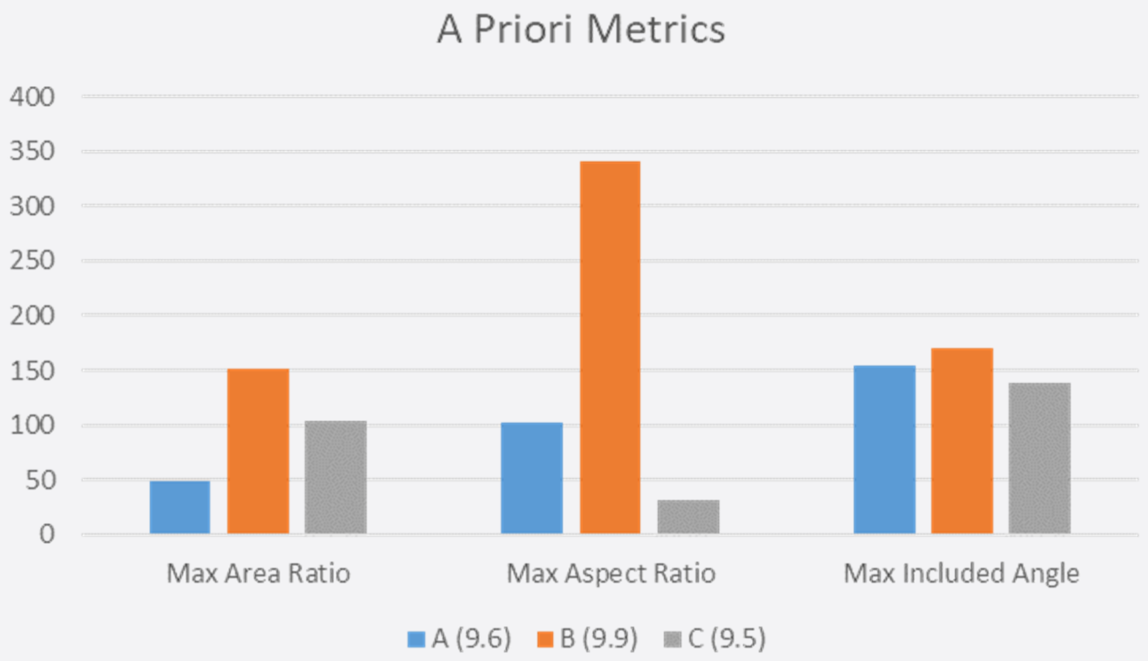
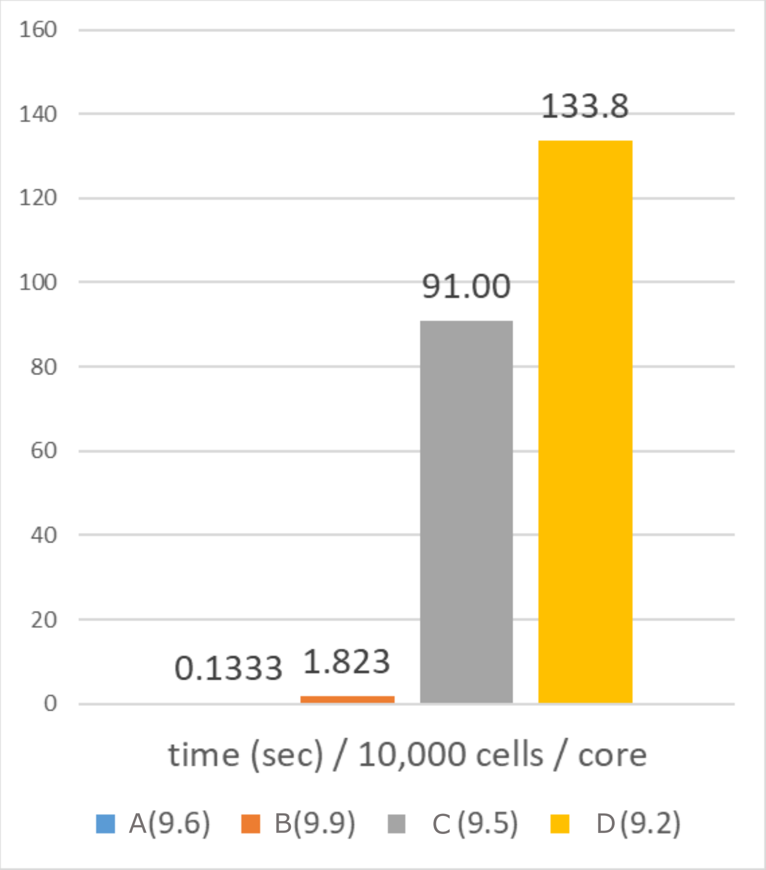
- Mesh Resolution
  - Most used a desired global sizing parameter (maximum edge length) to set overall resolution of surface mesh.
  - Two participants iterated on additional sizing parameters to refine meshes based on curvature.
- *A Priori* Mesh Metrics*
  - Significant variance was seen in all a priori metrics except the maximum included angle.
  - Only one participant had the capability to report the distance between geometry and mesh (average: 4.5e-5, max: 0.0486).

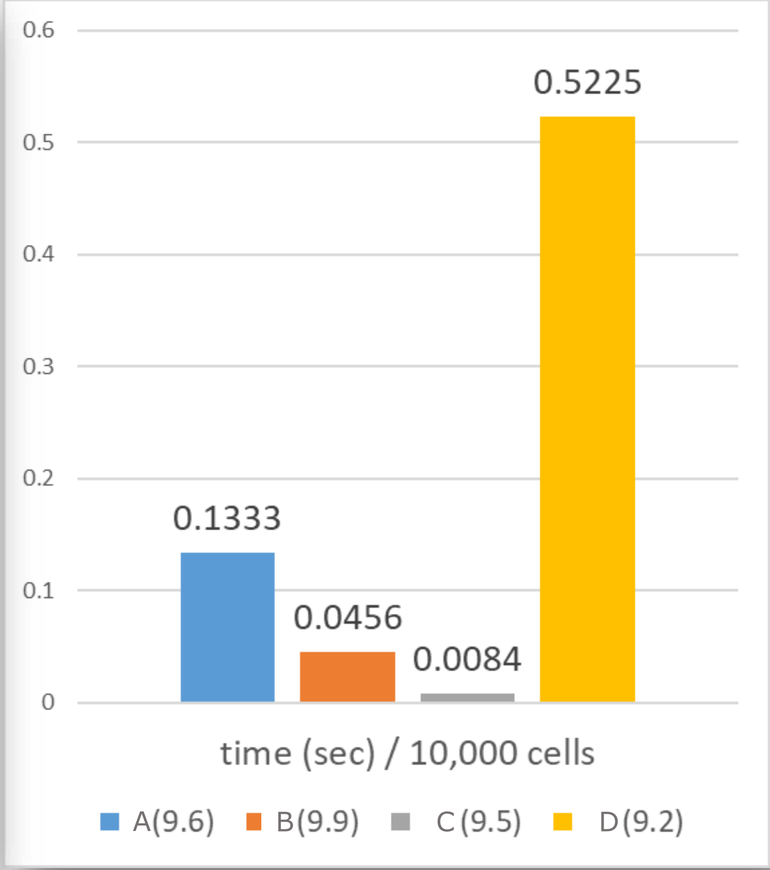


* All comparisons shown are based on largest mesh successfully generated and exported. One participant (D) used an OCTREE volume approach and could not provide surface meshing data.

Exascale Lessons: Volume Meshing

- Time:
  - ~1-28 hours
- Number of Cores:
  - 1-10,800
- Peak RAM:
  - 213-34,800 GB
- Mesh Types:
  - Octree
  - Polygonal (Voronoi)
  - Prism Tet
  - Tet Voxel





Exascale Lessons: Volume Meshing

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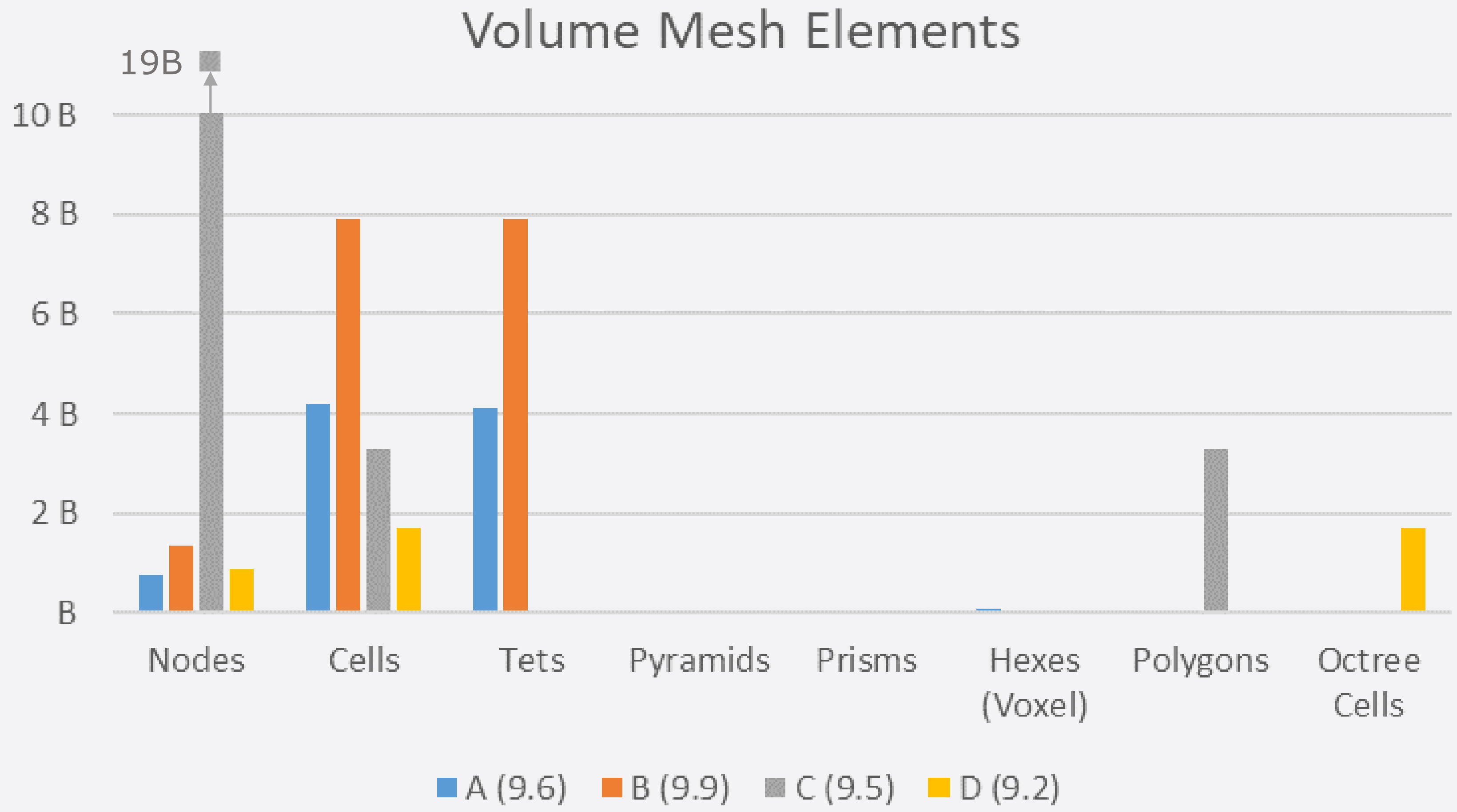

- Participant A reported 78 Million Voxel Cells and 4 Million pyramids
- Participant B reported: 2.0 Billion wedges, 1.9 Billion tets – 7.9 Billion equivalent tets

Exascale Lessons: Volume Meshing

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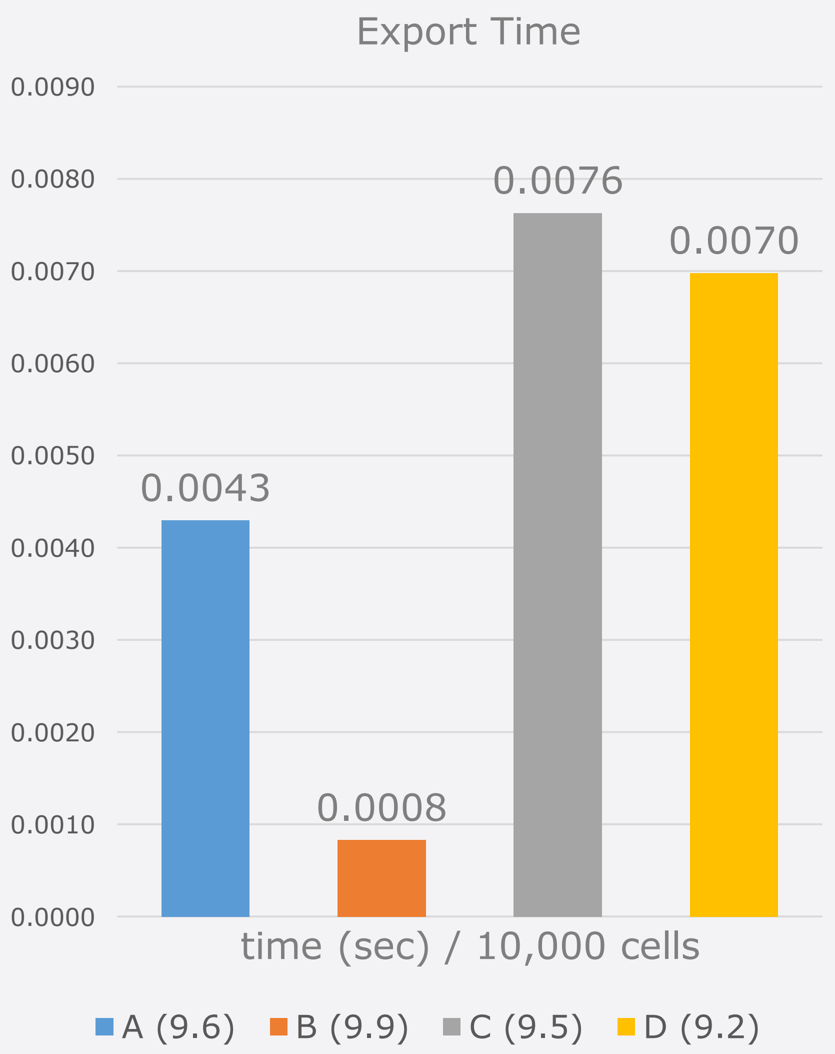
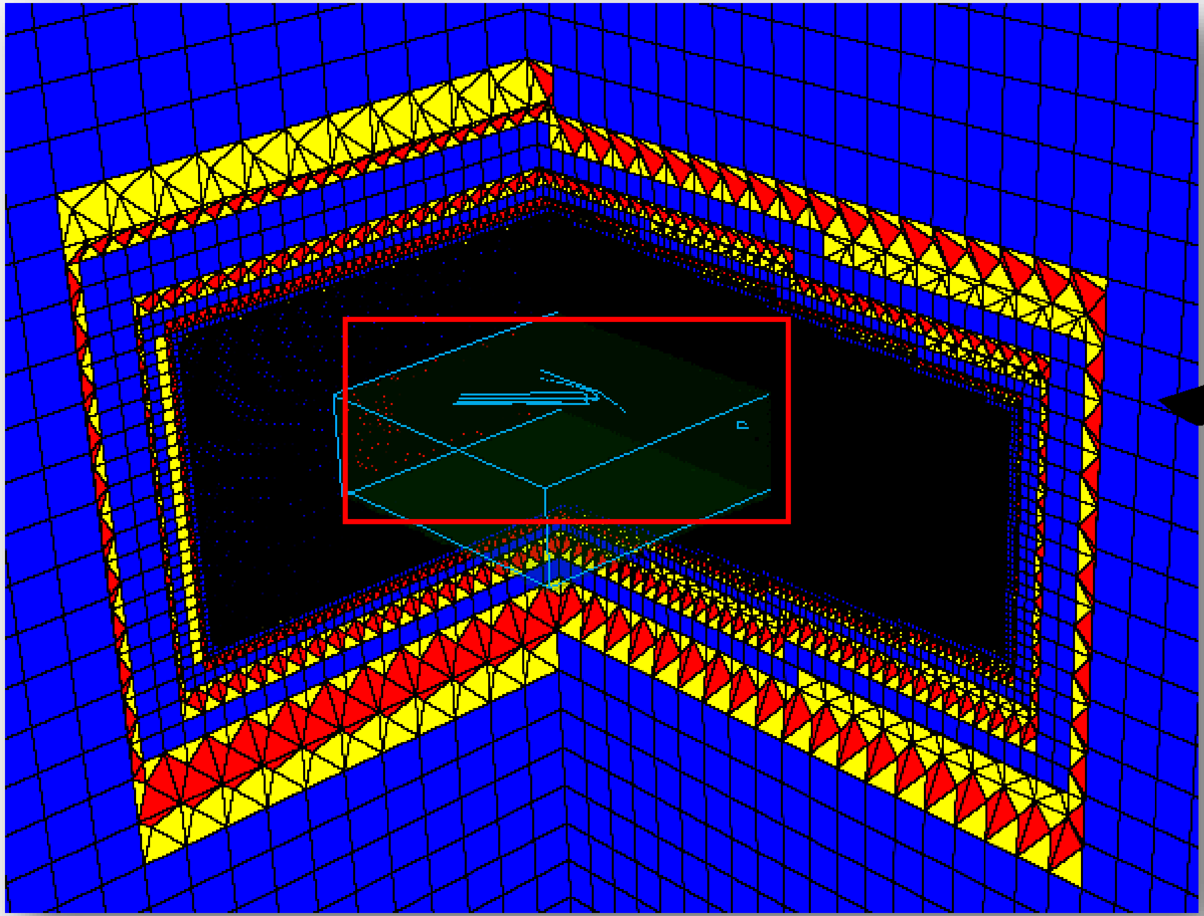
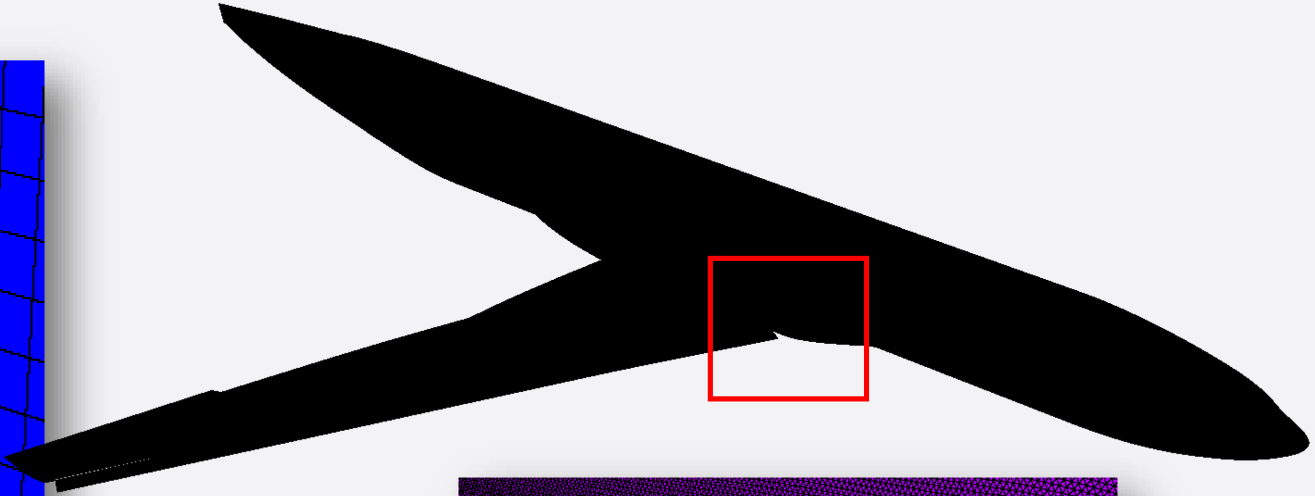
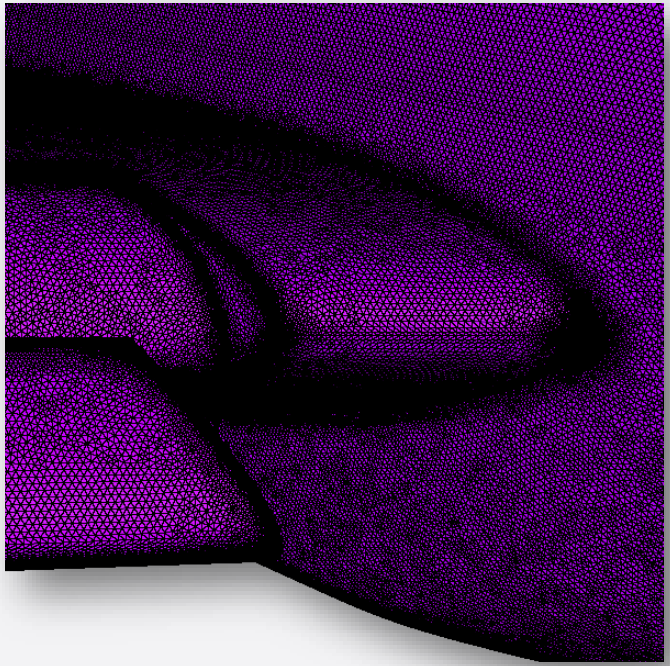
- Sparse *a priori* volume mesh quality metric reporting
  - Participants confirmed that exascale meshes were **valid**.
  - Ability to determine a priori volumetric quality was a challenge due to **RAM requirements**.
  - Some participants reported that focus on a prior metrics was **secondary** to achieving largest mesh possible.
- Mesh export, size, and transfer were challenges.
  - One participant created class 10.5 mesh but **could not export**.
  - Some export processes were serial, others were parallel. Number of cores used for export were not reported.
  - Only two participants exported to CGNS file format. Others exported to their native file format.
  - Reports of other formats **lacking exascale support**.
  - Exascale mesh files **could not be transferred** electronically due to size (81 GB – 10 TB).



A Picture is Worth a Thousand Words...







GMGW-2 Exascale Lesson Summary

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- Toolchains and hardware had enough resources to support exascale surface meshes.
- Multiple bottlenecks were evident for exascale volume meshes:
  - Integer support
  - Insufficient RAM to generate, evaluate, and export
  - Visualization
  - Limited file format support
  - Large file transmission/mesh-solver interoperability issues

Exascale and GMGW-3

- Mesh Family Goals:
  - Consistent sizing/spacing refinement in the surface and volume mesh from one level to the next.
  - Scaling and sizing guidelines for mesh family size to align with predictions for where we need to be according to CFD Vision 2030 study.

2020 Estimated mesh family sizes (GMGW-3)

Mesh Level	AA	A	B	C	D	E	F	G	H
Mesh Size (Total Cell Count)	10M	31.6M	100M	316M	1B	3.16B	10B	31.6B	100B

http://www.gmgworkshop.com

Exascale, GMGW-3, and HLPW-4

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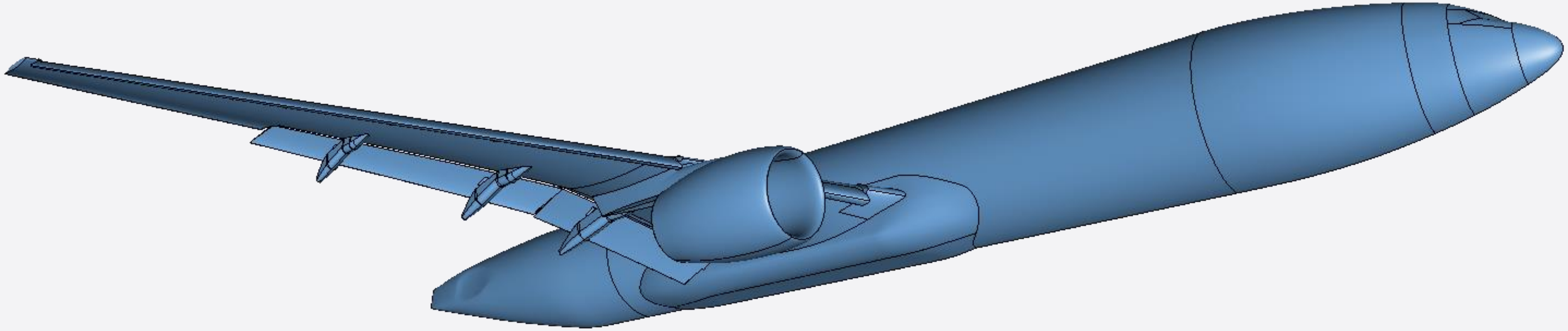
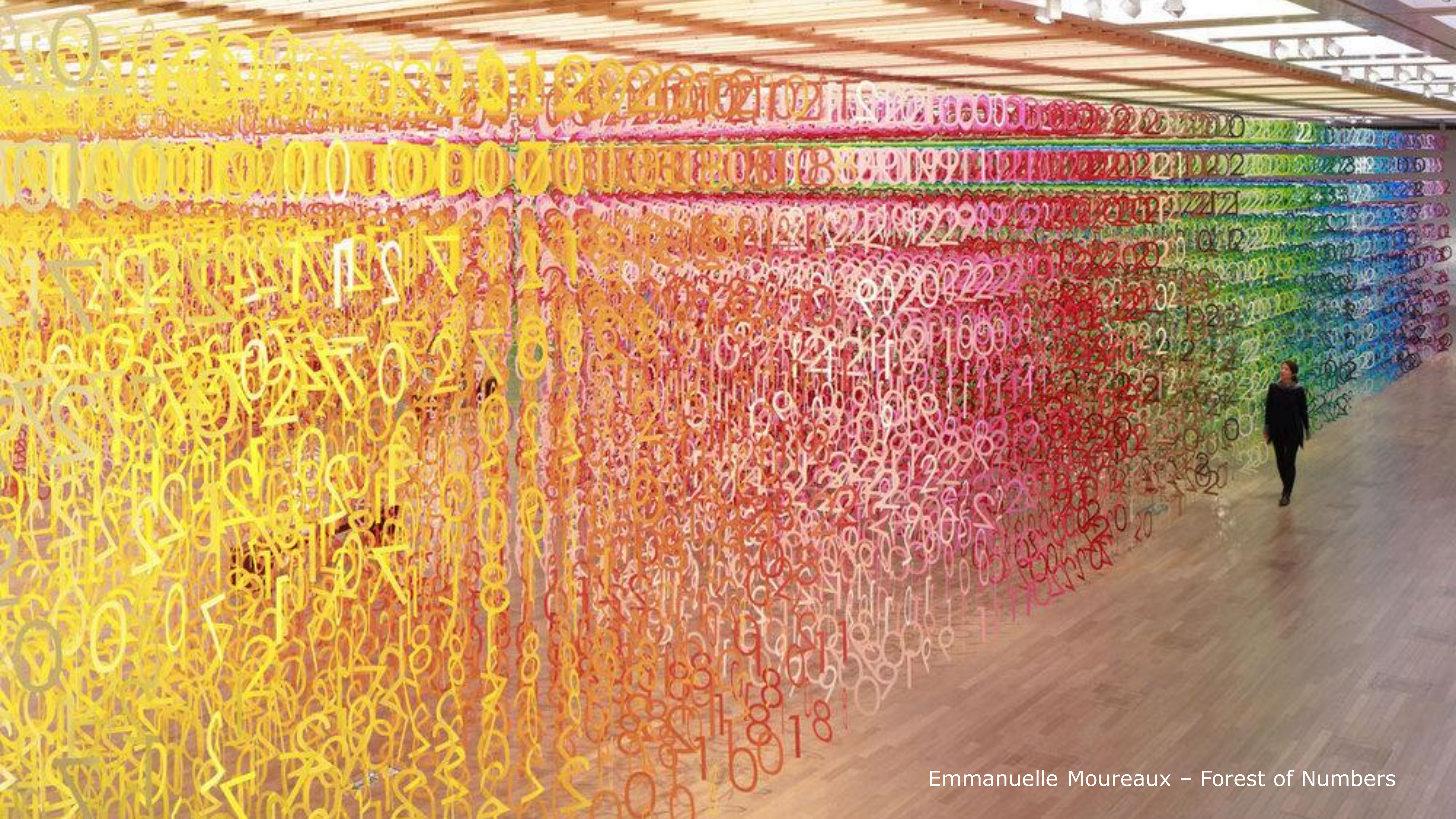
- Potential Challenges
  - Surface mesh edge lengths =< Geometric tolerances
  - Integer algorithm support to generate finest levels
  - Sufficient RAM for mesh generation and export
  - File transfer and interoperability
  - CFD solver I/O support for exascale
  - Computational resources to run solvers on exascale meshes





Emmanuelle Moureaux – Forest of Numbers